

# Data Visualization for Large-Scale, Industrial Model Predictive Controllers



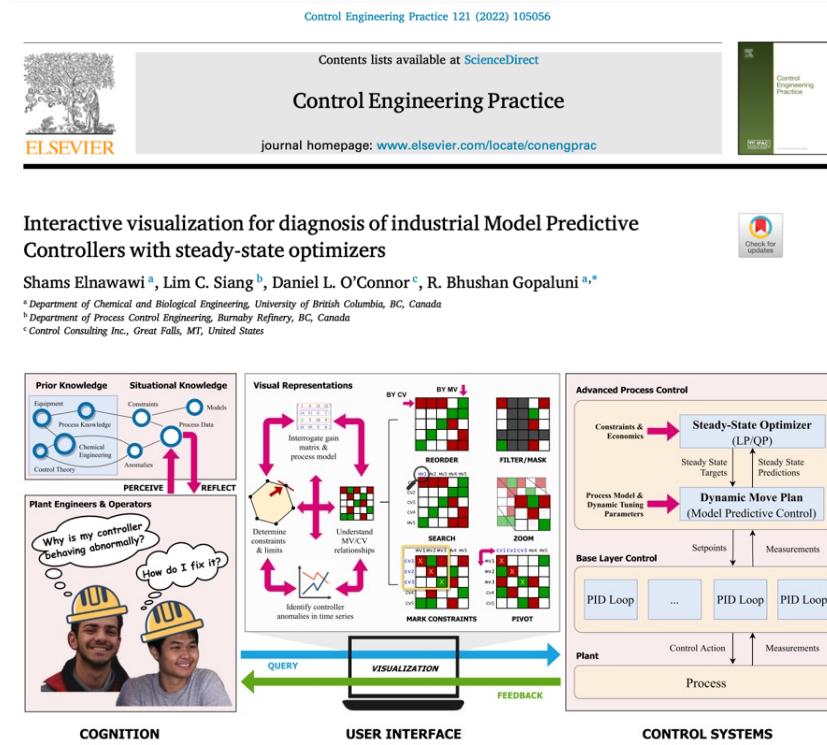
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FOPAM 2023, UC Davis, July 30, 2023

# Visualization tools for multivariable controllers

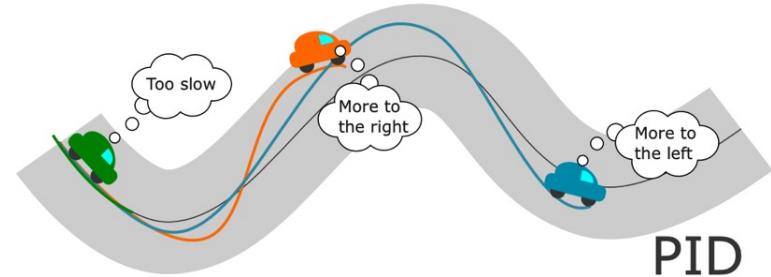
## Overview:

- Large, multivariable controllers can be difficult to understand and troubleshoot.
- Existing tools in industry rely on awkward, static, tabular views. Can we do better?
- Yes! In a 2022 CEP paper, we show that interactive heatmaps can help.



# I work on Model Predictive Controllers (MPCs)

- All controllers force a system to follow a desired behavior by adjusting actuators (valves, pumps, steering wheel etc.)
- PID control uses just the current and past states of the system to adjust the actuator. No predictive ability.

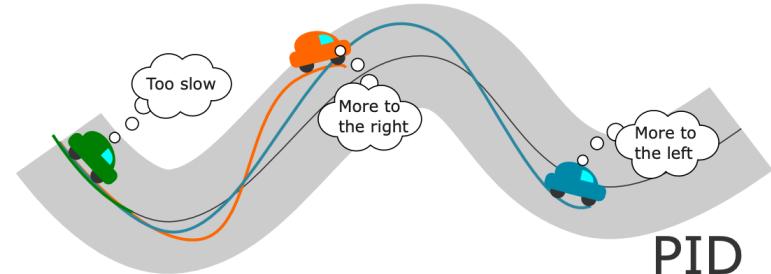


(a) The PID knows only what has happened and adjusts the controller based on the measured error.

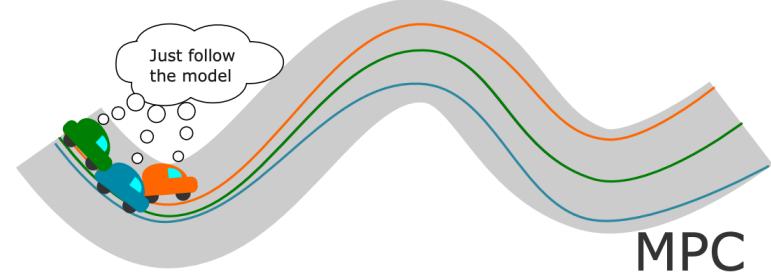
Hoekstra et al. *Critical Care* (2009) and Lindberg, *MSc Thesis, Chalmers* (2014)

# Model Predictive Controllers (MPCs)

- All controllers force a system to follow a desired behavior by adjusting actuators (valves, pumps, steering wheel etc.)
- PID control uses just the current and past states of the system to adjust the actuator. No predictive ability.
- MPC tries to **predict future states** using current and past states, and a model of the system.
- Good models -> Good MPC controller



(a) The PID knows only what has happened and adjusts the controller based on the measured error.



(b) The MPC follows its model and the present measured value. If the model is good (green car, in the middle) it follows the setpoint well, but a small error in the model can lead the system astray (orange and blue car, on the sides).

Hoekstra et al. *Critical Care* (2009) and Lindberg, *MSc Thesis, Chalmers* (2014)





## The model: steady-state gain matrix in MPCs

*The model describes relationships between MVs and CVs. At steady-state: the model is a gain matrix*

MV: manipulated variable

CV: controlled variable

$$G = \begin{bmatrix} \text{MV1} & \text{MV2} \\ -0.1942 & -0.0029 \\ 0.1843 & -0.0288 \end{bmatrix} \begin{matrix} \text{CV1} \\ \text{CV2} \end{matrix}$$

**Example:**

If MV1 goes up by 1 unit, then:

- CV1 goes down by -0.1942
- CV2 goes up by 0.1843

**Steady-state Gain Matrix**

## Problems with industrial MPC controllers

***“MPC math is simple and elegant; MPC engineering is not.”***

<https://www.emersonautomationexperts.com/papers/MPC-Unsustainable-benefits.pdf>



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### Problem 1 (Model):

Large MPC gain matrices are complex and hard to visualize!

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### Problem 1 (Model):

Large MPC gain matrices are complex and hard to visualize!

### Problem 2 (Real-time Monitoring):

Multivariable MPC time series are complex and hard to visualize!

## Problem 1: Large model gain matrices are complex



$$G = \begin{bmatrix} \text{MV1} & \text{MV2} \\ -0.1942 & -0.0029 \\ 0.1843 & -0.0288 \end{bmatrix} \begin{bmatrix} \text{CV1} \\ \text{CV2} \end{bmatrix}$$

**vs.**

Toy Model: 2x2

## Problem 1: Large model gain matrices are complex

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	
1	\$2TAR	\$2TAR	\$2AII22	\$19B1F	10R.CD	\$2F1212	263.CD	\$2F161B1	\$2AIR	1CALC	\$2PBR	\$2DPR	\$2TKS	\$2TKS	\$2PDR20B	\$2PR	\$2S121	\$2PBR	\$2FC23	\$MDUT	\$Y	\$HCNC	\$HCNC0	\$2LIGO	\$2LIGO	\$2LIGO	\$2FC23	\$2PC11	\$MF_L	\$2PDR24	\$2PDR250	\$2PDR251F	\$2PDR252	\$2COT		
2	\$2FC126.SP	1	0	-0.91	-21.5	-4.14	0	0	-0.01528	0	0	-0.28	13.8	10.21	0.11482	2.357	4.718	2.927	29.44	25.99	-7.44	-17.4	-6.01	-28.9	-6.36	2.134	10.08	2474	2561	0.04944	0.11597	0.16946	0.14293	-0.36	0	
3	\$2TC1153.P	0	1	-0.02	-0.58	-0.15	0	0.614	0	0	-0.04	-0.02	4.036	0.3	0.0144	0.101	0.838	0.027	0.335	2.935	0	0	0	0	0	0.356	0.078	0.018	0.118	66.39	31.5	0.00179	0.0042	0.00613	0.00517	0
4	\$2FC124.SP	0	0	4.176	145	72.5	60.07	5.394	0.936071	0	1	0	0	-63.2	-29	-1.392	0	0	0.027	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	\$2FC171.CO	0	0	0.072	2.5	1.25	0	0.093	0	-0.02	1.801	0	0	-1.09	-0.5	-0.024	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
6	\$2FC128.SP	0	0	-0.03	-11	-1.108	0	-0.01775	0	0.237	0	0	-1.41	-0.00337	-0.00337	-0.00337	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
7	\$2HC102	0	0	0	0	0	0	0	0.156	0	0	0	0	-0.02	0	2.412	0	0.04846	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	\$2FC121.SP	0	0	-0.03	-0.67	0	0	0.407	0	0	0	0	-0.181	-1.81	0.01862	0.847	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
9	\$2HC166.CO	0	0	-0.03	-0.61	0	0	0.373	0	0	0	0	-0.166	-1.66	0.02808	0.777	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
10	60FR183.P.WVL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
11	\$2PC111A.SP	0	0	0	0	-7.58	0.763	0	-0.01224	0	1.638	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
12	\$2TC104.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
13	\$2FC127.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
14	\$2FC114.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
15	\$2FC114S.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
16	\$2FC119.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
17	\$2FC135.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
18	\$2FC132.CO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
19	\$2FC130.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
20	\$2FC1130.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21	\$2HC174.CCT4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
22	\$2FC154.CCT4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
23	\$2FC133.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
24	\$2FC133.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
25	\$2FC106.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
26	\$2FC137.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
27	\$2PC113.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.211	0	-2.55	-2.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
28	\$2FC136.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
29	\$2PC114A.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
30	\$2FC137.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
31	\$2FC138.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
32	\$2TC107.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.03	-0.03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	\$2FC1119	0	0	0	0	-0.002	-0.01	-1.53E-05	0	0.6E-04	-0.024	0.02	0	0.002	0.007	0.003	0.033	0.026	0	0	0	0	0	0.001	0.01	0	0	4.94E-05	7.64E-05	0.00017	6.39E-05	0				
34	\$2TR252	0	0	0	0	0	0.208	0	0	0.401	0	0	0	0	0	0	0	0.0402	0.363	0	0	0	0	0	0.141	0	0	0.0008	0	0	0	0	0	0		
35	\$3FC128	0	0	3E-04	0.006	0	0	0	0	0	0	0	-5.73E-05	2E-04	0	0	0	0.002	6E-04	0.003	6E-04	-0	-0.44	-0.33	0	0	2.11E-05	-2.09E-05	0	0	0	0	0			

$$G = \begin{bmatrix} -0.1942 & -0.0029 \\ 0.1843 & -0.0288 \end{bmatrix} \begin{matrix} \text{CV1} \\ \text{CV2} \end{matrix} \quad \text{VS.}$$

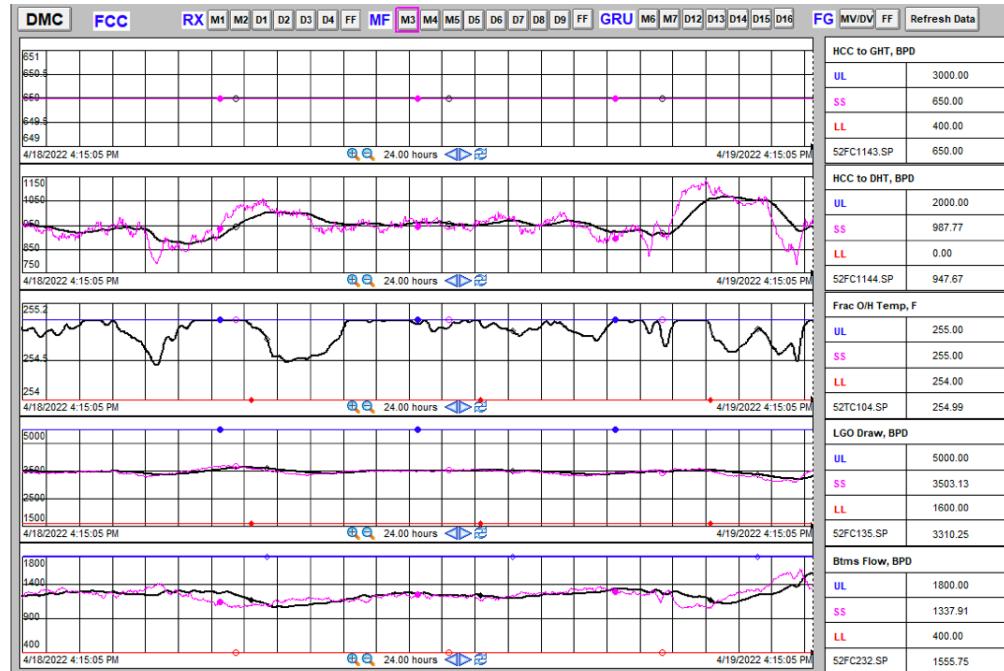
## Toy Model: 2x2

## Actual Controllers: 44x64

- **Why it's bad:** Tedious to navigate, filter and identify relationships.  
e.g. *If MV1 goes up... what happens to the CVs?*
  - **It gets worse:** Not even the full 44x64 matrix... could also be much bigger elsewhere
  - **The question:** Can we do better than static tables? How?

## Problem 2: Classical MPC time series trends are complex

- 4 lines for each MPC variable
  - Upper Limit
  - Lower Limit
  - Measurement
  - SS Target
- Variables can be constrained (at limits) or unconstrained.
- Too many variables! Typically spread out across multiple pages due to limited screen space



*UI limitations: Can't easily put variables of interest on the same page, need to click on different pages*

## Fault diagnosis for MPCs is tedious, here's why:



**OPERATOR CALLS: WHY DID MPC  
DROP OUR PRODUCTION RATE??!**  
I don't know... let's find out!



# Fault diagnosis for MPCs is tedious

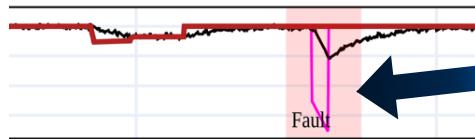


1. What was this MV controlling? Which CVs is it connected to?

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	
1	S2TAR	S2TAR	S2AII2	S1BF1	108.CO	S2D12	262.CO	S2FC151B1	S2AR	ICALC	S2POR	S2TMR	S2TMR	S2POR208	S2F1R2	S2S121	S2P1R2	S2FC23		
2	126	1153	0	-0.91	-21.5	-4.14	0	0	-0.01528	0	0	0	-0.28	13.8	10.21	0.11482	2.357	7.418	2.927	29.44
3	S2FC126.SP	1	0	-0.02	-0.58	-0.15	0	0.614	0	0	-0.04	-0.02	0.436	0.3	0.0148	0.101	0.838	0.257	3.325	
4	S2TC115.3.P	0	1	0.476	145	72.5	60.07	5.394	0.936071	1	0	0	0	63.2	-29	-1.392	0	0	0	0
5	S2FC124.SP	0	0.072	2.5	1.25	0	0.093	0	-0.02	1.901	0	0	-1.09	-0.5	-0.024	0	0	0	0	
6	S2PD108.SP	0	0	0	0	-11	1.106	6.937	-0.01775	0	2.375	-0.81	1.04	0	0	0.07633	0	0	0	
7	S2HC102	0	0	0	0	0	0.166	0	0	0	0	0.02	0	2.412	0	0.04848	0	0	0	
8	S2FC101.SP	0	0	-0.03	-0.67	0	0	0.407	0	0	0	0	-1.86	-1.86	0.0166	0.84	0	0	0	
9	S2HC106.CO	0	0	-0.03	0.61	0	0	0.373	0	0	0	0	-1.66	-1.66	0.02908	0.777	0	0	0	
10	609FL151.R.PWV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
11	S2PC111.A.SP	0	0	0	0	-7.58	0.763	0	-0.01224	0	1.638	0	0	0	0	0	0	0	0	
12	S2TC104.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
13	S2FC1127.5.P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
14	S2FC1144.5.P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
15	S2FC1143.5.P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
16	S2FC119.5.P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
17	S2FC135.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
18	S2FC137.CO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
19	S2FC130.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
20	S2FC1130.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21	S2HC174.CCT4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
22	S2FC154.CCT4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
23	S2FC1232.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
24	S2FC133.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.03	
25	S2FC106.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19.79	
26	S2FC137.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.04	
27	S2PC113.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.211	0	-2.55		
28	S2FC136.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
29	S2FC1139.5.P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
30	S2FC137.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
31	S2FC138.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
32	S2TC107.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
33	S2FI1159	0	0	-0	-0.002	-0.01	-1.53E-05	0	0	6E-04	-0	0.024	0.02	0	0.002	0.007	0.003	0.033		
34	S2TR252	0	0	0	0	0.208	0	0	0.401	0	0	0	0	0	0	0	0	0.402		
35	S2FC128	0	0	3E-04	0.006	0	0	0	0	0	0	0	0	-5.73E-05	2E-04	0	0	0		



# Fault diagnosis for MPCs is tedious



**OPERATOR CALLS: WHY DID MPC DROP OUR PRODUCTION RATE??!**

I don't know... let's find out!

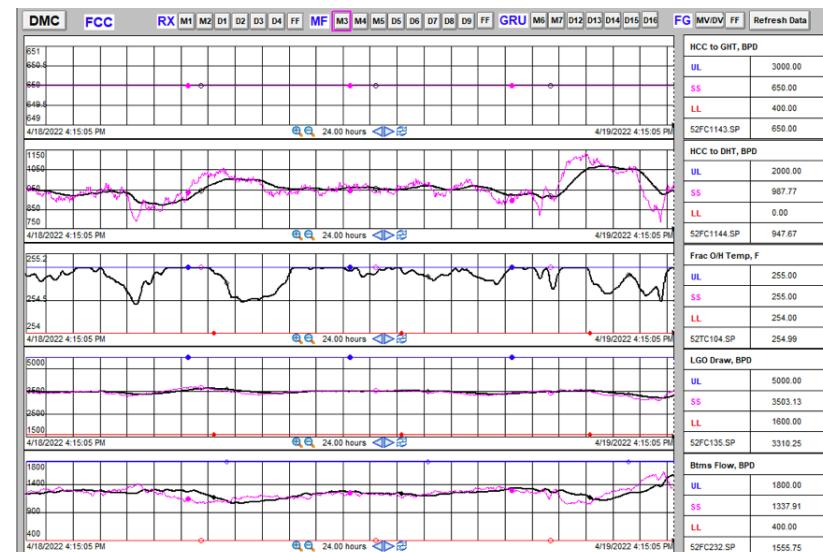


1. What was this MV controlling? Which CVs is it connected to?

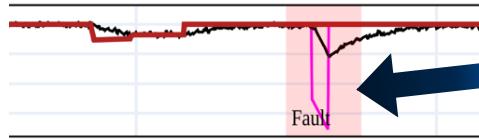


2. Look at CV1...

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	SZTAR	SZTAR	SZTAR	91BF1	108.CO	SZT112	262.CO	SZFC151B1	SZAR	ICALC	SZPOR	SZT3X	SZT3X	SZPOR208	SZFR2	SZB121	SZPR2	SZFC23	126
2	SZFC126.SP	1153	0.91	-21.5	-4.14	0	0	-0.01528	0	0	0	-0.28	13.8	10.21	0.11482	2.357	7.418	2.927	29.44
3	SZTC115.3.SP	0	1	-0.02	-0.58	-0.15	0	0.614	0	0	-0.04	-0.02	0.436	0.3	0.0148	0.101	0.838	0.257	3.325
4	SZFC124.SP	0	4.176	145	72.5	60.07	5.394	0.936071	1	0	0	63.2	-29	-1.392	0	0	0	0	0
5	SZFC171.CO	0	0.072	2.5	1.25	0	0.093	0	-0.02	1.901	0	-1.09	-0.5	-0.024	0	0	0	0	0
6	SZPD108.SP	0	0	0	-11	1.106	6.937	-0.01775	0	2.375	-0.81	1.04	0	0	0.07633	0	0	0	0
7	SZHC102	0	0	0	0	0	0.166	0	0	0	-0.02	0	2.412	0	0.08486	0	0	0	0
8	SZHC104.SP	0	0	-0.03	-0.67	0	0	0.407	0	0	-1.86	-1.8	0.0166	0.84	0	0	0	0	0
9	SZHC106.SP	0	0	-0.03	-0.61	0	0	0.373	0	0	0	-1.66	-1.66	0.02908	0.777	0	0	0	0
10	600R1518.PWV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	SZPC111A.SP	0	0	0	0	-7.58	0.763	0	-0.01224	1.638	0	0	0	0	0	0	0	0	0
12	SZTC104.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	SZFC1127.5P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	SZFC1144.5P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	SZFC1143.5P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	SZFC1129.5P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	SZFC135.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	SZFC137.CO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	SZFC130.CO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	SZFC1130.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	SZHC174.CCT4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	SZFC154.CCT4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	SZFC232.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	SZFC133.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.03	0	0
25	SZFC106.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19.79	0
26	SZFC137.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.04	0
27	SZPC113.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0.211	0	-2.55	0	0
28	SZFC136.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	SZFC135.5P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	SZFC137.5P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	SZFC138.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	SZTC107.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	SZFI159	0	0	-0	-0.002	-0.01	-1.53E-05	0	0	6E-04	-0	0.024	0.02	0	0.002	0.007	0.003	0.033	0
34	SZTR252	0	0	0	0	0.208	0	0	0	0.401	0	0	0	0	0	0	0	0.402	0
35	SZFC128	0	0	3E-04	0.006	0	0	-0	0	0	0	0	-5.73E-05	2E-04	0	0	0	0	0



# Fault diagnosis for MPCs is tedious



## OPERATOR CALLS: WHY DID MPC DROP OUR PRODUCTION RATE??!

I don't know... let's find out!

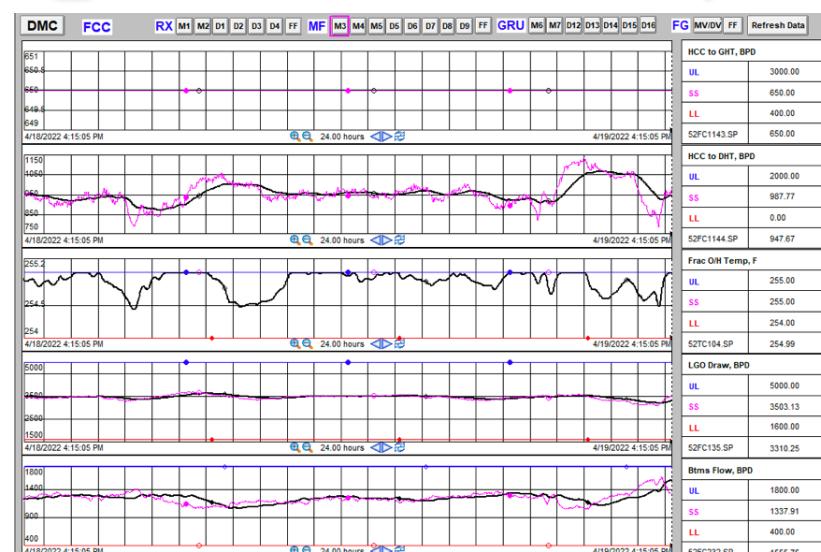
1. What was this MV controlling? Which CVs is it connected to?

2. Look at CV1...

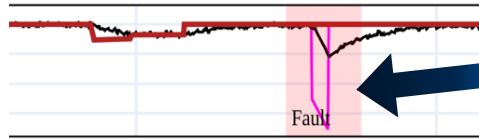
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																	
1	SZTAR	SZTAR	SZTAR	91BF1	108.CO	SZT12	262.CO	SZFC151B1	SZM1R	ICALC	SZPOR	SZT3X	SZT3X	SZPOR2B	SZP1R2	SZB121	SZP1R2	SZF23	126																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																	
2	SZFC126.SP	1153	0	-0.91	-21.5	-4.14	0	0	-0.01528	0	0	0	0	-0.28	13.8	10.21	0.11482	2.357	7.418	2.927	29.44																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
3	SZTC115.3.P	0	1	-0.02	-0.58	-0.15	0	0.614	0	0	0	-0.04	-0.02	0.436	0.3	0.0148	0.101	0.838	0.257	3.325	4	SZFC124.3.P	0	0	0.476	145	72.5	60.07	5.394	0.936071	1	0	0	0	63.2	-29	-1.392	0	0	0	0	0	5	SZFC171.CO	0	0.072	2.5	1.25	0	0.093	0	-0.02	1.901	0	0	-1.09	-0.5	-0.024	0	0	0	0	0	0	6	SZPD108.SP	0	0	0	0	-11	1.106	6.937	-0.01775	0	2.375	-0.81	1.04	0	0	0.07633	0	0	0	0	0	7	SZHC102	0	0	0	0	0	0.166	0	0	0	-0.02	0	2.412	0	0.08486	0	0	0	0	0	0	8	SZHC104.SP	0	0	-0.03	-0.67	0	0	0.407	0	0	0	1.86	-1.8	0.0166	0.84	0	0	0	0	0	0	9	SZHC106.SP	0	0	-0.03	-0.67	0	0	0.407	0	0	0	1.86	-1.8	0.0166	0.84	0	0	0	0	0	0	10	600FL151.B.PWV	0	0	0	0	0	0	0.373	0	0	0	0	0	-1.66	-1.66	0.02908	0.777	0	0	0	0	11	SZPC111.A.SP	0	0	0	0	-7.58	0.763	0	-0.01224	1.638	0	0	0	0	0	0	0	0	0	0	0	12	SZTC104.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	SZFC112.75.P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	SZFC114.45.P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	SZFC114.3.P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	SZFC112.95.P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	SZFC135.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	SZFC137.CO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19	SZFC130.CO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	SZFC1130.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21	SZHC174.CCT4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	SZFC154.CCT4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	SZFC232.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	SZFC133.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	SZFC106.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19.79	0	0	26	SZFC137.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.04	0	27	SZPC113.P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.211	0	0	0	-0.255	0	28	SZFC136.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	29	SZFC137.CO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	SZFC137.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31	SZFC138.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	SZTC107.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33	SZPF1159	0	0	-0	-0.002	-0.01	-1.53E-05	0	0	6E-04	-0	0.024	0.02	0	0.002	0.007	0.003	0.033	0	0	0.402	34	SZTR252	0	0	0	0	0.208	0	0	0.401	0	0	0	0	0	0	0	0	0	0	0	0	35	SZFC128	0	0	3E-04	0.006	0	0	0	0	0	0	0	0	0	-5.73E-05	2E-04	0	0	0	0	0
4	SZFC124.3.P	0	0	0.476	145	72.5	60.07	5.394	0.936071	1	0	0	0	63.2	-29	-1.392	0	0	0	0	0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
5	SZFC171.CO	0	0.072	2.5	1.25	0	0.093	0	-0.02	1.901	0	0	-1.09	-0.5	-0.024	0	0	0	0	0	0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
6	SZPD108.SP	0	0	0	0	-11	1.106	6.937	-0.01775	0	2.375	-0.81	1.04	0	0	0.07633	0	0	0	0	0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
7	SZHC102	0	0	0	0	0	0.166	0	0	0	-0.02	0	2.412	0	0.08486	0	0	0	0	0	0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
8	SZHC104.SP	0	0	-0.03	-0.67	0	0	0.407	0	0	0	1.86	-1.8	0.0166	0.84	0	0	0	0	0	0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
9	SZHC106.SP	0	0	-0.03	-0.67	0	0	0.407	0	0	0	1.86	-1.8	0.0166	0.84	0	0	0	0	0	0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
10	600FL151.B.PWV	0	0	0	0	0	0	0.373	0	0	0	0	0	-1.66	-1.66	0.02908	0.777	0	0	0	0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
11	SZPC111.A.SP	0	0	0	0	-7.58	0.763	0	-0.01224	1.638	0	0	0	0	0	0	0	0	0	0	0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
12	SZTC104.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
13	SZFC112.75.P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
14	SZFC114.45.P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
15	SZFC114.3.P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
16	SZFC112.95.P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
17	SZFC135.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
18	SZFC137.CO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
19	SZFC130.CO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
20	SZFC1130.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
21	SZHC174.CCT4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
22	SZFC154.CCT4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
23	SZFC232.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
24	SZFC133.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
25	SZFC106.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19.79	0	0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
26	SZFC137.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.04	0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
27	SZPC113.P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.211	0	0	0	-0.255	0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
28	SZFC136.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
29	SZFC137.CO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
30	SZFC137.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
31	SZFC138.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
32	SZTC107.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
33	SZPF1159	0	0	-0	-0.002	-0.01	-1.53E-05	0	0	6E-04	-0	0.024	0.02	0	0.002	0.007	0.003	0.033	0	0	0.402																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
34	SZTR252	0	0	0	0	0.208	0	0	0.401	0	0	0	0	0	0	0	0	0	0	0	0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
35	SZFC128	0	0	3E-04	0.006	0	0	0	0	0	0	0	0	0	-5.73E-05	2E-04	0	0	0	0	0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															

2. Look at CV1...

- Is the measurement reading correctly?
- Is the variable constrained?
- Are the limits clamped?



# Fault diagnosis for MPCs is tedious



## OPERATOR CALLS: WHY DID MPC DROP OUR PRODUCTION RATE??!

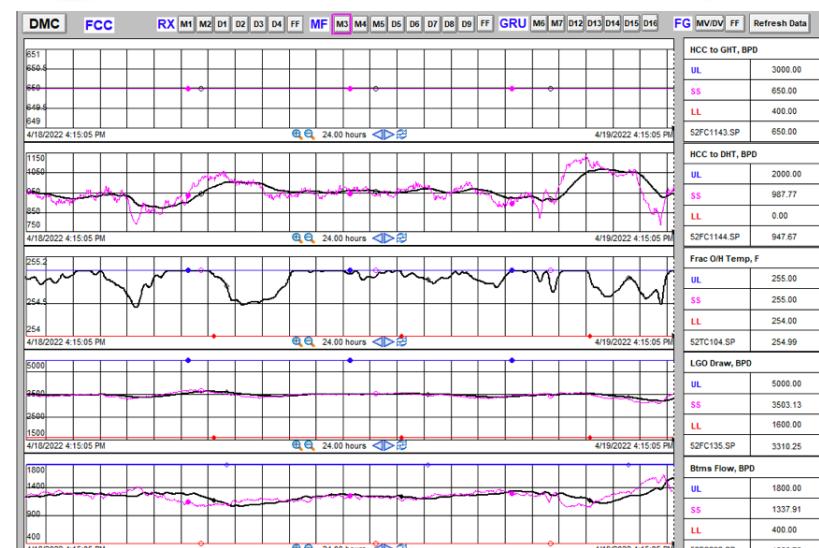
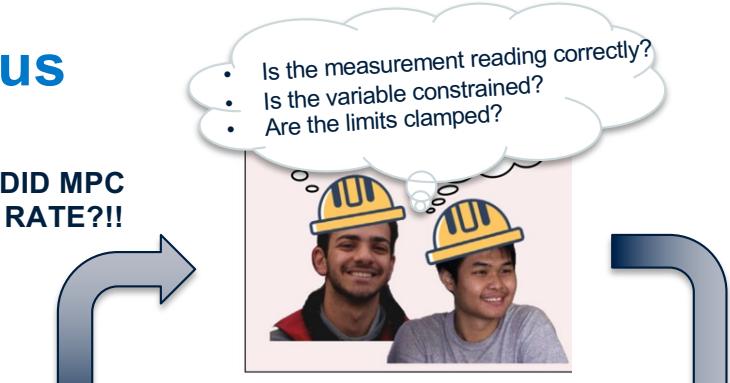
I don't know... let's find out!

1. What was this MV controlling? Which CVs is it connected to?

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	
1	SZTAR	SZTAR	SZTAR	91BF1	108.CO	SZT112	262.CO	SZFC151B1	SZM1R	ICALC	SZPOR	SZT3K1	SZT3K1	SZPOR2B	SZP1R2	SZB121	SZP1R2	SZF231	126	
2	SZFC126.SP	1153	0	-0.91	-21.5	-4.14	0	0	-0.01528	0	0	0	-0.28	13.8	10.21	0.11482	2.357	7.418	2.927	29.44
3	SZTC115.3.P	0	1	-0.02	-0.58	-0.15	0	0.614	0	0	-0.04	-0.02	0.436	0.3	0.0142	0.101	0.838	0.257	3.325	
4	SZFC124.3.P	0	0	4.176	145	72.5	60.07	5.394	0.936071	1	0	0	-63.2	-29	-1.392	0	0	0	0	
5	SZFC171.CO	0	0.072	2.5	1.25	0	0.093	0	-0.02	1.901	0	-0.109	-0.5	-0.024	0	0	0	0	0	
6	SZPD108.SP	0	0	0	0	-11	1.106	6.937	-0.01775	0	2.375	-0.81	1.04	0	0	0.07633	0	0	0	
7	SZHC102	0	0	0	0	0	0.166	0	0	0	-0.02	0	2.412	0	0.04846	0	0	0	0	
8	SZFC125.SP	0	0	-0.03	-0.67	0	0	0.4707	0	0	0	-1.84	-1.66	0.0166	0.84	0	0	0	0	
9	SZFC126.SP	0	0	-0.03	0.61	0	0	0.373	0	0	0	-1.66	-1.66	0.02908	0.777	0	0	0	0	
10	600FL151.B.PWV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
11	SZPC111.A.SP	0	0	0	0	-7.58	0.763	0	-0.01224	1.638	0	0	0	0	0	0	0	0	0	
12	SZTC104.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
13	SZFC1127.5.P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
14	SZFC1144.5.P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
15	SZFC1143.5.P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
16	SZFC1129.5.P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
17	SZFC135.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
18	SZFC1127.CO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
19	SZFC130.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
20	SZFC1130.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21	SZHC174.CCT4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
22	SZFC154.CCT4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
23	SZFC232.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
24	SZFC113.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03	
25	SZFC106.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19.79	
26	SZFC1137.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.04	
27	SZPC113.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0.211	0	0	0	-2.55	
28	SZFC1136.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
29	SZFC1139.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
30	SZFC1137.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
31	SZFC1138.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
32	SZTC107.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
33	SZPF1159	0	0	-0	0	-0.002	-0.01	-1.53E-05	0	0.6E-04	-0	0.024	0.02	0	0.002	0.007	0.003	0.033	0	
34	SZTR252	0	0	0	0	0.208	0	0	0.401	0	0	0	0	0	0	0	0	0	0.402	
35	SZFC128	0	0	3E-04	0.006	0	0	0	0	0	0	0	0	-5.73E-05	2E-04	0	0	0	0	

2. Look at CV1...

5. Which other MVs are controlling CV1?



# Fault diagnosis for MPCs is tedious



## OPERATOR CALLS: WHY DID MPC DROP OUR PRODUCTION RATE??!

I don't know... let's find out!

1. What was this MV controlling? Which CVs is it connected to?

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	SZTAR	SZTAR	SZTAR	S1BF1	108.CO	S2D12	262.CO	S2FC151B1	S2M1R	ICALC	S2P0R	S2P0R	S2T3X	S2T3X	S2P0R208	S2P0R2	S2H21	S2P0R2	S2P23
2	S2FC126.SP	1153	0	-0.91	-21.5	-4.14	0	0	-0.01528	0	0	-0.28	13.8	10.21	0.11482	2.357	7.418	2.927	29.44
3	S2TC115.3.P	0	1	-0.02	-0.58	-0.15	0	0.614	0	0	-0.04	-0.02	0.436	0.3	0.0142	0.101	0.838	0.257	3.325
4	S2FC124.SP	0	4.176	145	72.5	60.07	5.394	0.936071	1	0	0	-63.2	-29	-1.392	0	0	0	0	0
5	S2FC171.CO	0	0.072	2.5	1.25	0	0.093	0	-0.02	1.901	0	-1.09	-0.5	-0.024	0	0	0	0	0
6	S2PD108.SP	0	0	0	-11	1.10	6.937	-0.01775	0	2.375	-0.81	1.04	0	0	0.07633	0	0	0	0
7	S2HC102	0	0	0	0	0	0.166	0	0	0	-0.02	0	2.412	0	0.04846	0	0	0	0
8	S2HC104.SP	0	0	-0.03	-0.67	0	0	0.407	0	0	0	-1.84	-1.66	-0.0166	0.84	0	0	0	0
9	S2HC106.SP	0	0	-0.03	-0.61	0	0	0.373	0	0	0	-1.66	-1.66	-0.02908	0.777	0	0	0	0
10	600R151.B.PWV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	S2PC111.A.SP	0	0	0	0	-7.58	0.763	0	-0.01224	1.638	0	0	0	0	0	0	0	0	0
12	S2TC104.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	S2FC1127.5.P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	S2FC1144.5.P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	S2FC1143.5.P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	S2FC1129.5.P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	S2FC135.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	S2FC1127.CO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	S2FC130.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	S2FC1130.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	S2HC174.CCT4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	S2FC154.CCT4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	S2FC232.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	S2FC1133.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	S2FC106.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19.79	0
26	S2FC1137.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.04
27	S2PC113.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.211	0	0	-2.55
28	S2FC1136.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	S2FC1139.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	S2FC1137.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	S2FC1138.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	S2TC107.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	S2FI1159	0	0	-0	-0.002	-0.01	-1.53E-05	0	0	6E-04	-0	0.024	0.02	0	0.002	0.007	0.003	0.033	0
34	S2TR252	0	0	0	0	0.208	0	0	0	0.401	0	0	0	0	0	0	0	0.402	0
35	S2FC128	0	0	3E-04	0.006	0	0	0	0	0	0	0	0	0	-5.73E-05	2E-04	0	0	0

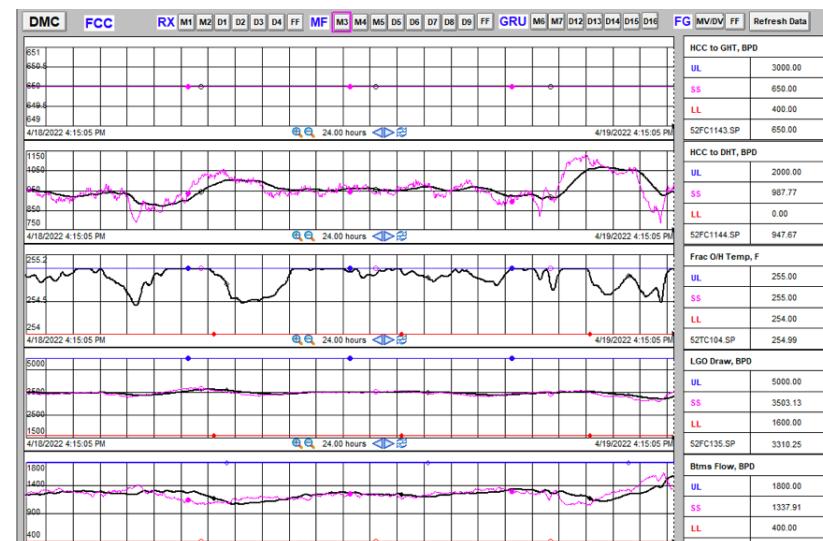
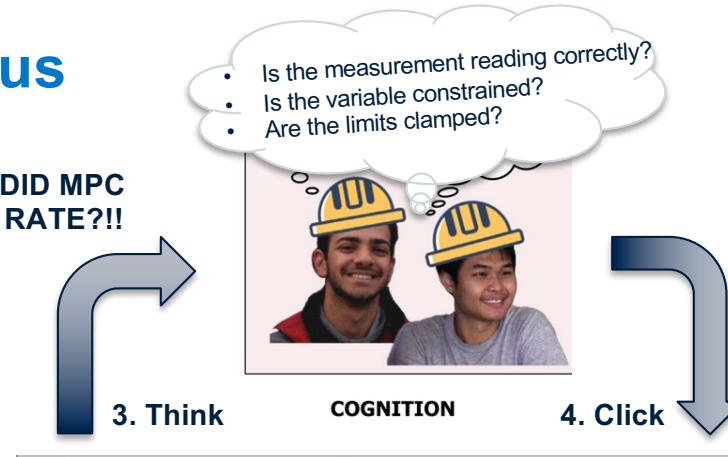
2. Look at CV1...

5. Which other MVs are controlling CV1?

- Look at MV2...

- Repeat until root cause is found...

1. What was this MV controlling? Which CVs is it connected to?



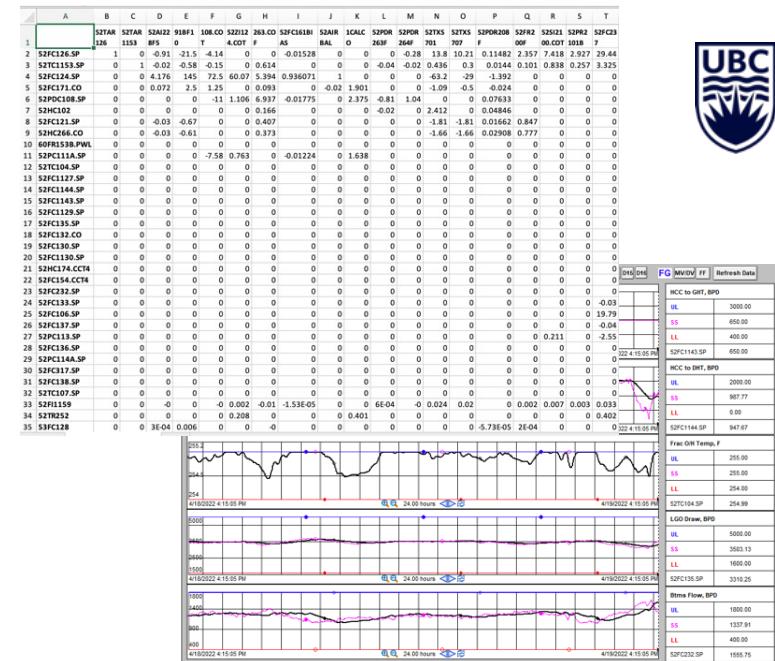
# MPC diagnosis issues

Troubleshooting MPC problems takes hours/days

- Root cause of faults usually not obvious
- Need to trend the right variables on the same page, but we have 100+ variables, which ones are the ‘right’ ones to trend? Can’t trend all at the same time.

Strong reliance on process knowledge

- Time series trends don’t mean much to less experienced engineers:
  - just squiggly lines with no context (*speaking from personal experience*)
  - new engineers wouldn’t know if a MV/CV should be typically constrained/unconstrained



## Seems like a gap! Took initiative to find visualization solutions

### My thoughts:

- I just want very simple improvements :
  - the ability to easily plot time series on the same page
  - an easy way to navigate through the model.



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### My thoughts:

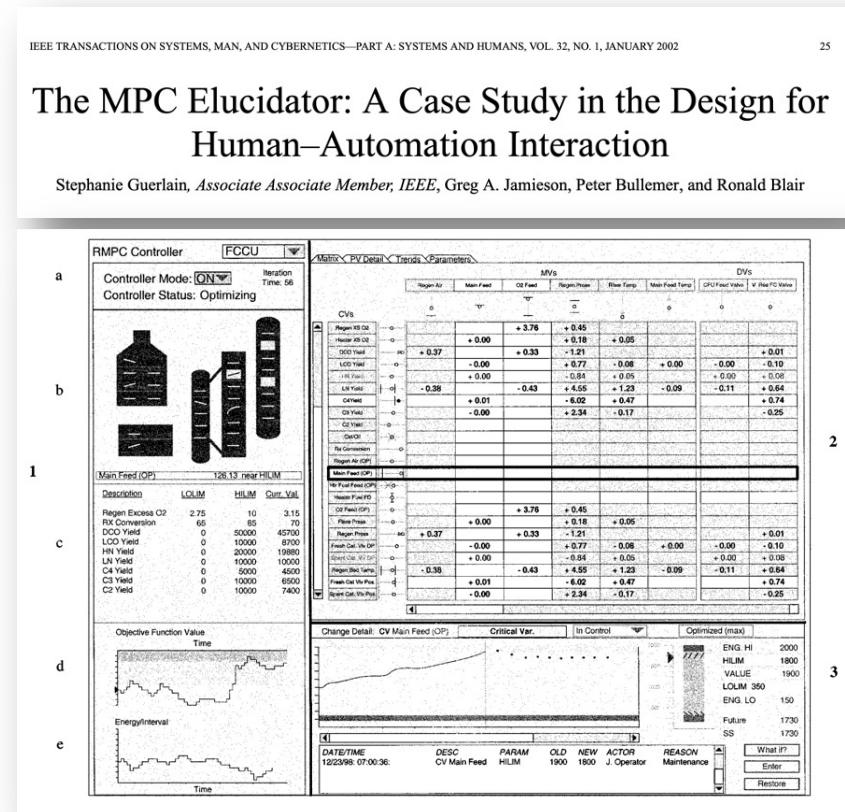
- I just want very simple improvements :
  - the ability to easily plot time series on the same page
  - an easy way to navigate through the model.
- APC has been around in refining since 1980s and matured in the 1990s.
  - Surely someone out there must have a better solution by now?



# Existing Visualization Tools

## Simple Solutions:

- We want very simple improvements :
  - the ability to easily plot time series on the same page
  - an easy way to navigate through the model.
- APC has been around in refining since 1980s and matured in the 1990s.
  - Surely someone out there must have a better solution by now?
- Only one solution found in literature - Honeywell Elucidator (2002).



## Idea 1: cut down visual noise in gain matrix with a heatmap

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1	S2TAR	S2TAR	S2A122	91BF1	108.CO	S2212	263.CO	S2PC161BI	S2AUR	IACLC	S2P08	S2P09	S2TAX	S2TAX	S2PDR208	S2PR2	S2S21	S2FC29	MOUT	S2LCOP	HCCK	
128	115	1	-0.91	-21.5	-4.14	0	0	-0.01528	0	0	-0.28	13.8	19.21	0.11482	2.357	7.418	2.927	29.44	25.99	7.44	17.	
2	S2FC126.SP	1	-0.02	-0.58	0	0.614	0	0	-0.04	0.02	0.436	0.3	0.0144	0.101	0.838	0.257	3.325	2.935	0			
3	S2TC113.SP	0	1	-0.176	145	72.5	60.07	5.394	0.936071	1	0	0	0	-0.432	-29	-1.392	0	0	0	0	0	
4	S2FC124.SP	0	0	0.4176	145	72.5	60.07	5.394	0.936071	0	0.072	2.5	1.25	0.093	0	-0.02	1.901	0	-1.09	-0.5	-0.024	0
5	S2FC171.CO	0	0	0.072	2.5	1.25	0	0.093	0	0.072	2.5	1.25	0	0.093	0	0.2375	-0.81	1.04	0	0.07633	0	0
6	S2PD0108.SP	0	0	0	0	-11	1.106	6.937	-0.01775	0	0.2375	-0.81	1.04	0	0	0.04846	0	0	0	0	0	0
7	S2HCO12	0	0	0	0	0	0	0.166	0	0	0	-0.02	0	2.412	0	0.04846	0	0	0	0	0	0
8	S2FC125.SP	0	0	-0.03	-0.67	0	0	0.407	0	0	0	0	-1.81	1.81	0.01662	0.97	0	0	0	0	0	0
9	S2HC264.CO	0	0	-0.03	-0.61	0	0	0.373	0	0	0	0	0	0	0	0.02268	0.777	0	0	0	0	0
10	60F81538.PW1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	S2PC111A.SP	0	0	0	0	-7.58	0.763	-0.01224	0	1.638	0	0	0	0	0	0	0	0	0	0	1.087	0
12	S2TC104.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1.27	-2.0
13	S2FC1127.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.633	2.60
14	S2FC1144.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.513
15	S2FC1151.CO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05
16	S2FC1159.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.004
17	S2FC135.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	S2FC132.CO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.203
19	S2FC139.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.13
20	S2FC1130.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.99
21	S2HC174.CCT4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	S2FC154.CCT4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	S2FC157.CO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	S2FC133.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	S2FC106.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.003
26	S2FC137.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	S2PC1113.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	S2FC136.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	S2PC114A.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	S2FC137.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	S2FC109.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	S2FC107.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	S2FC1159	0	0	0	-0.002	-0.01	-1.53E05	0	0	6E04	-0.024	0.02	0	0.002	0.007	0.003	0.031	0.026	0			
34	S2TR252	0	0	0	0	0.208	0	0	0.401	0	0	0	0	0	0	0	0	0	0	0.402	0.363	0
35	S2FC128	0	0	3E04	0.006	0	0	-0	0	0	0	0	0	0	-5.73E05	2E04	0	0	0	0	0.00	



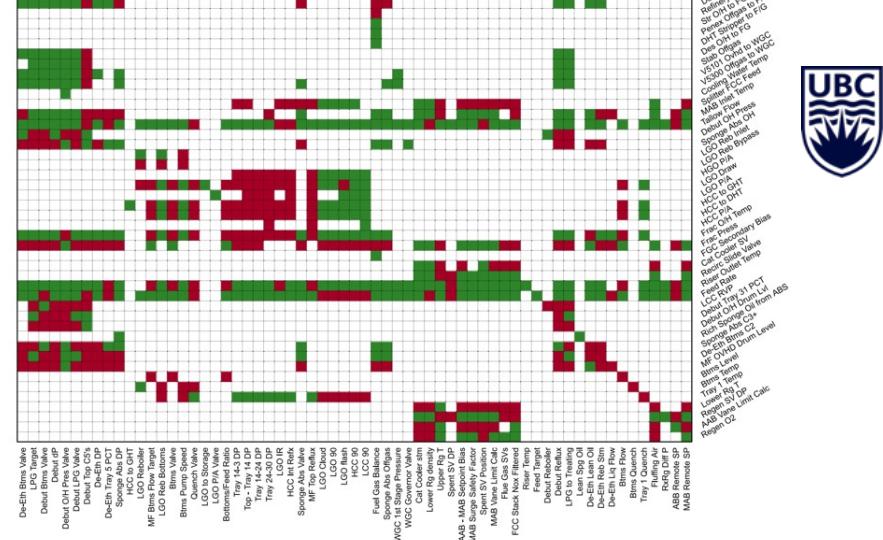
- Gain directions are more important (from a user's perspective), rather than the actual value.
- For troubleshooting purposes, we just want to know movement direction (up or down?).
- Key insight: Maybe we don't need to show the actual numbers!**

# Idea 1: cut down visual noise in gain matrix with a heatmap

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1	SZTAR	SZTAR	S2A122	91BF1	108.CO	S2212	263.CO	S2PC161B1	S2A1R	IACL	S2P08	S2P09	S2TXS	S2PDR208	S2PR2	S2S21	S2FC23	MOUT	S2LCOP	HCCG	HC	NEW	
2	S2FC126.SP	1	-0.91	-21.5	-4.14	0	0	-0.01528	0	0	-0.28	13.8	19.21	0.11482	2.357	7.418	2.927	29.44	25.99	7.44	17.		
3	S2TC113.SP	0	1	-0.02	-0.58	-0.15	0.614	0	0	-0.04	-0.02	0.436	0.3	0.0144	0.101	0.838	0.257	3.325	2.935	0			
4	S2FC124.SP	0	0	4.176	145	72.5	60.07	5.394	0.936071	1	0	0	0	-43.2	-29	-1.392	0	0	0	0	0	0	
5	S2FC171.CO	0	0	0.072	2.5	1.25	0.093	0	-0.02	1.901	0	0	-1.09	-0.5	-0.024	0	0	0	0	0	0		
6	S2PD0108.SP	0	0	0	0	0	-11	1.106	6.937	-0.01775	0	2.375	-0.81	1.04	0	0	0.07633	0	0	0	0	0	
7	S2HC102	0	0	0	0	0	0	0.166	0	0	0	-0.02	0	2.412	0	0.04846	0	0	0	0	0		
8	S2FC130.SP	0	0	-0.03	-0.67	0	0	0.407	0	0	0	0	-1.81	1.81	0.01662	0.077	0	0	0	0	0		
9	S2HC264.CO	0	0	-0.03	-0.61	0	0	0.373	0	0	0	0	0	0	0	0.02268	0.02277	0	0	0	0		
10	60F8153A.PW1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
11	S2PC111A.SP	0	0	0	0	-7.58	0.763	0	-0.01224	0	1.638	0	0	0	0	0	0	0	0	0	1.087	0	
12	S2TC104.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.638	2.60	
13	S2FC1127.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.513	
14	S2FC1144.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	
15	S2FC1151.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.004	
16	S2FC1159.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.004	
17	S2FC135.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
18	S2FC132.CO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.203	
19	S2FC139.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.13	
20	S2FC1130.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21	S2HC174.CCT4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
22	S2PC1145.CCT4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
23	S2FC130.CO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
24	S2FC133.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.03	
25	S2FC1106.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18.79	
26	S2FC1137.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.04	
27	S2FC1113.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.211	0	-2.55	-2.25	0	0	
28	S2FC1136.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
29	S2PC1144A.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
30	S2FC1145A.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
31	S2FC107.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
32	S2FC1070.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
33	S2FH1159	0	0	-0.0	-0.002	-0.01	-1.53E05	0	0	6E-04	-0.024	0.02	0	0.002	0.007	0.003	0.031	0.026	0	0	0	0	
34	S2TR252	0	0	0	0	0.208	0	0	0.401	0	0	0	0	0	0	0	0	0	0.402	0.363	0	0	
35	S2FC128	0	0	3E-04	0.006	0	0	-0	0	0	0	0	0	-5.73E05	2E04	0	0	0	0	0	0.00	0	

Encode gain values as colors to denote gain directions

+ve: green: up  
-ve: red: down



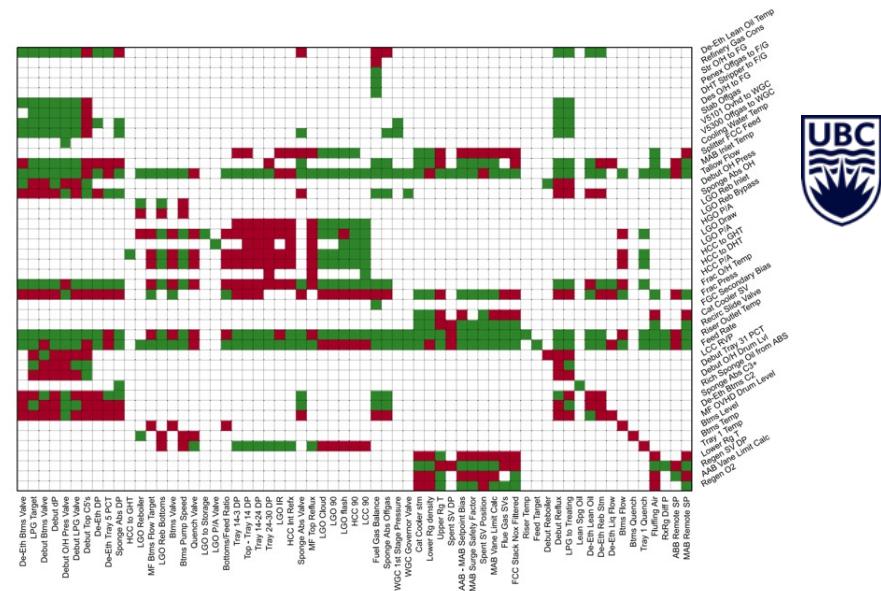
- Gain directions are more important (from a user's perspective), rather than the actual value.
- For troubleshooting purposes, we want to know movement direction (up or down?).
- Encoding directions as a heatmap helps reduce visual noise and cognitive load

## Idea 1: cut down visual noise in gain matrix with a heatmap

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	
1	\$2TAR	\$2TAR	\$2A22	91BF1	10KZ	\$2C02	263.C	\$2FC16B1	591	1CAL	\$2P0R	\$2P0R	\$2T5X	\$2T5X	\$2P0R	\$2F2R	\$2S2I	\$2PZ	\$2C23	MDUT	\$2LC2C	HC0C	
2	\$2FC126.SP		1153	8F0	1	4.03	-0.31	4.40	4.40	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	\$2FC1153.SP				0	-0.00	-0.58	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	
4	\$2FC1154.SP				0	4.176	145	71.5	60.7	5.04	6.394	6.396701	1	0	0	0	-6.32	-29	0.3	0.044	1.10	0.834	0.57
5	\$2FC171.CD				0	0.072	2.5	1.25	0.093	0	0.00	1.901	0	0	-1.09	-0.5	-0.024	0	0	0	0	0	
6	\$2PC108.SP				0	0	0	-11	1.106	6.937	-0.01775	0	2.375	-0.81	1.04	0	0	0.07633	0	0	0	0	
7	\$2HC101.CD				0	0	0	0	0	0.166	0	0	0	-0.02	0	2.412	0	0.04846	0	0	0	0	
8	\$2HC112.SP				0	-0.03	-0.67	0	0	0.407	0	0	0	0	0	-1.81	-1.81	0.1662	0.847	0	0	0	
9	\$2HC166.CO				0	-0.03	-0.61	0	0	0.373	0	0	0	0	0	-1.66	-1.66	0.2908	0.777	0	0	0	
10	\$0F1R538.PWL				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.108	0	
11	\$2FC101.SP				0	0	0	-7.58	0.763	0	-0.01224	0	1.638	0	0	0	0	0	0	0	0	0.293	
12	\$2FC104.SP				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.633	
13	\$2FC1127.SP				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.513	
14	\$2FC1144.SP				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
15	\$2FC1143.SP				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.059	
16	\$2FC1129.SP				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.004	
17	\$2FC1159.SP				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
18	\$2FC1132.CO				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.203	
19	\$2FC1130.SP				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.349	
20	\$2FC1131.SP				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21	\$2HC1174.CTCH				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
22	\$2HC1154.CTCH				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
23	\$2FC122.SP				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
24	\$2FC113.SP				0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.03	0	0	0	
25	\$2FC1106.SP				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19.79	17.47	0	
26	\$2FC1175.SP				0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.04	0	0	0	
27	\$2FC1133.SP				0	0	0	0	0	0	0	0	0	0	0	0	0	0.211	0	2.55	2.25	0	
28	\$2FC1181.SP				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
29	\$2FC1130.SP				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
30	\$2FC1131.SP				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
31	\$2FC1188.SP				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
32	\$2FC1107.SP				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
33	\$2FC1115.SP				0	0	0	0	-0.002	-0.01	-1.53E-05	0	66.04	-0	0.024	0.02	0	0.007	0.003	0.033	0.026	0	
34	\$2TR252				0	0	0	0	0.208	0	0	0	0.401	0	0	0	0	0	0	0	0.402	0.363	
35	\$2FC1128				0	0	3E-04	0.006	0	0	0	0	0	0	0	0	0	5.73E-05	2E-04	0	0	0.000	

**Encode gain values as colors to denote gain directions**

+ve: green: up  
-ve: red: down



*Better than spreadsheets, but still a static heatmap with limited capabilities.  
Need something more interactive (filtering, zooming, sorting etc.)*

# Clustergrammer - visualizing high-dimensional biological data

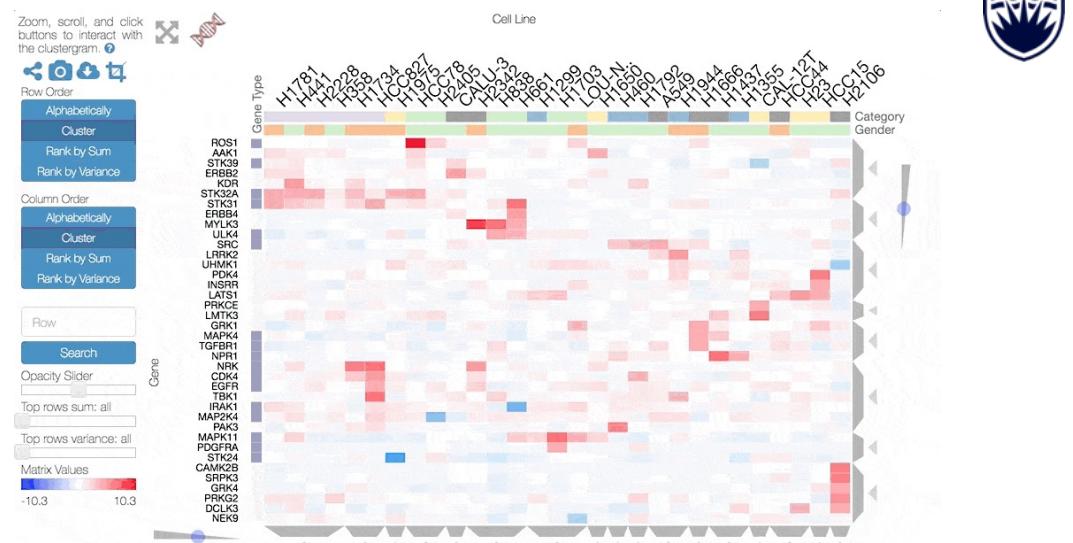
☰ README.md



npm v1.19.5 license MIT

Clustergrammer is a web-based tool for visualizing high-dimensional data (e.g. a matrix) as an interactive and shareable hierarchically clustered heatmap.

Clustergrammer's front end ([Clustergrammer-JS](#)) is built using [D3.js](#) and its back-end ([Clustergrammer-PY](#)) is built using Python. Clustergrammer produces highly interactive visualizations that enable intuitive exploration of high-dimensional data and has several biology-specific features (e.g. enrichment analysis, see [Biology-Specific Features](#)) to facilitate the exploration of gene-level biological data. Click the screenshot below to view an interactive tutorial:



# Write a parser: controllers and models are plaintext files

CCF - controller configuration file

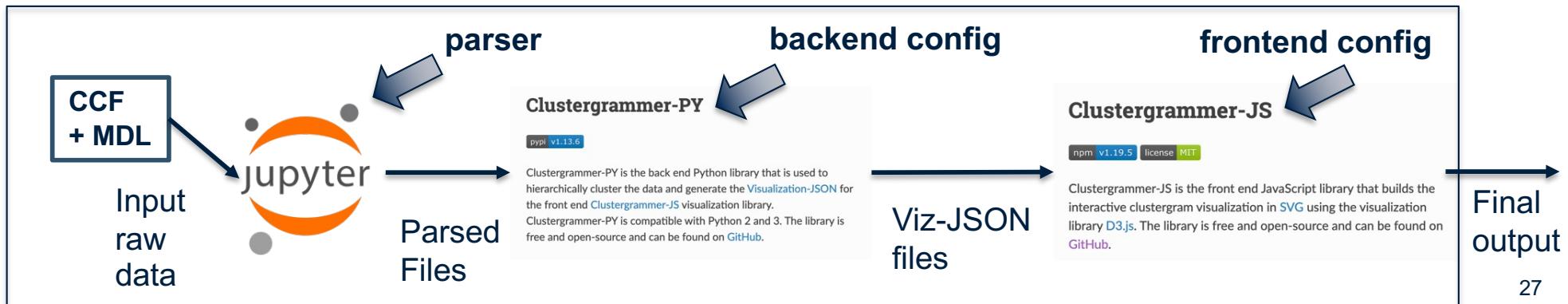
```

1675 [IND:52FC317.SP]
1676 .ATAG3~~BUILD~~CH(50)~~~52FCC~~
1677 .AWSCOD~~LOCAL~~I4~~~0~~
1678 .BARTL~~LOCAL~~R4~~~1000.~~
1679 .BARISC~~LOCAL~~I4~~~0~~
1680 .BARIU~~LOCAL~~R4~~~4000.~~
1681 .CMOV~~WRITE~~R4~~~1.45209~~"";"1.51.2.1448.12":DBVL:
1682 .CRIIND~~LOCAL~~I4~~~1~~
1683 .CSTIND~~LOCAL~~I4~~~0~~
1684 .CSTIND~~LOCAL~~I4~~~0~~
1685 .CST~~~WRITE~~R4~~~0.07~~"";"1.51.2.1441.12":DBVL:
1686 .DESCIND~~LOCAL~~CH(40)~~Debut OVHD to treating~~
1687 .DESCIND~~LOCAL~~CH(40)~~Debut OVHD to treating~~
1688 .ENGIND~~CONSTANT~~CH(12)~~DEBUT O/H LI~~
1689 .INDFLG~~LOCAL~~I4~~~0~~
1690 .INDSTA~~LOCAL~~I4~~~0~~
1691 .IREVRS~~LOCAL~~I4~~~0~~
1692 .ISFF~~CONSTANT~~I4~~~0~~
1693 .ISMET~~CONSTANT~~I4~~~0~~
1694 .LLINDM~~RDWT~~R4~~~1200.~~"";"1.31.9.421.19":DBVL:
1695 .LMVENG~~WRITE~~R4~~~800.~~"";"1.51.2.1450.12":DBVL:
1696 .LOOPST~~READ~~I4~~~1~~"";"1.31.5.574.8":CBST:
1697 .LPCRIT~~LOCAL~~I4~~~0~~
1698 .LVLIND~~LOCAL~~R4~~~0.~~
1699 .MANACT~~LOCAL~~I4~~~0~~
1700 .MAXMOV~~LOCAL~~R4~~~100.~~
1701 .MDLIND~~CONSTANT~~CH(12)~~52FC317.SP~~
1702 .MOVACC~~LOCAL~~R4~~~0.~~

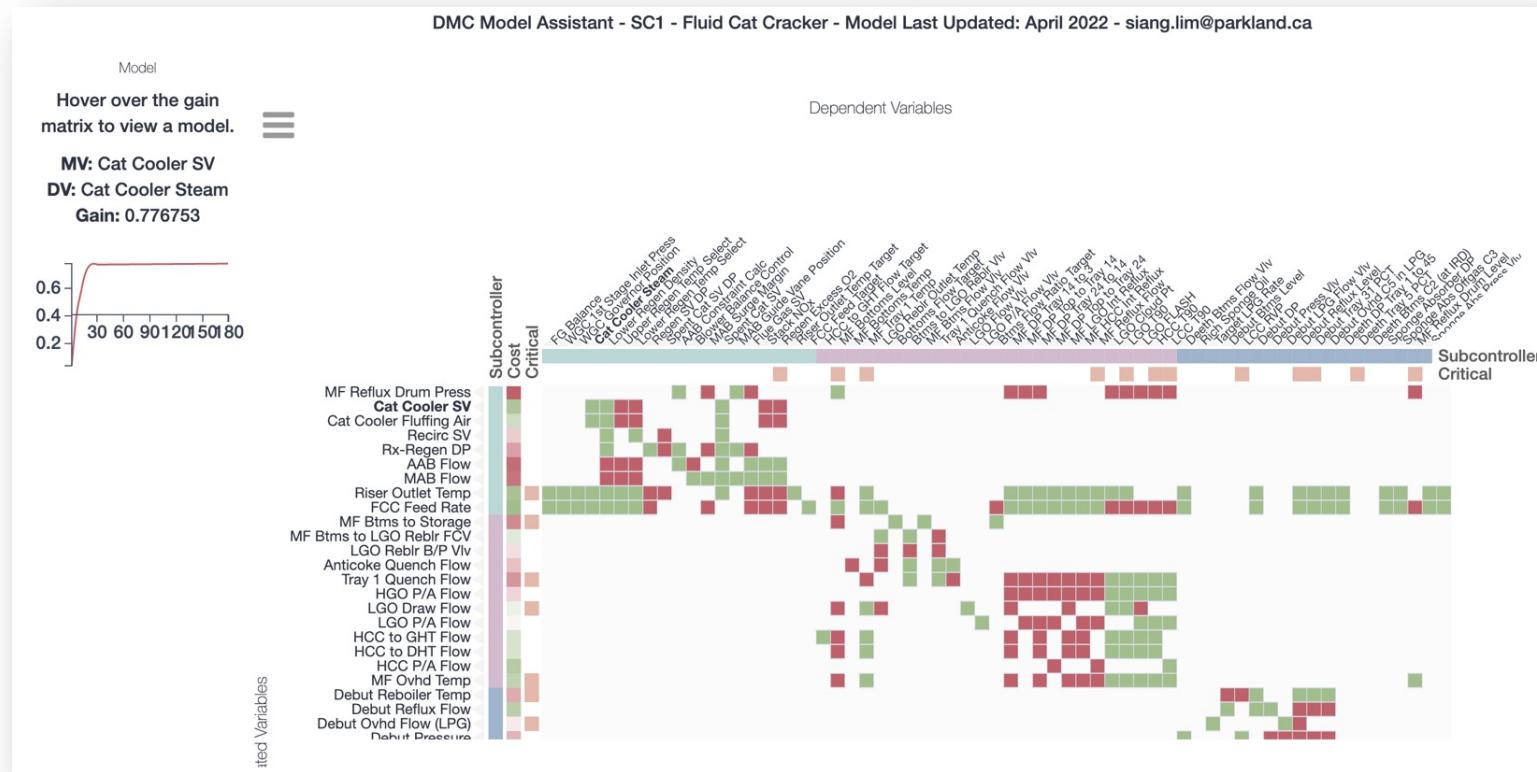
```

MDL – controller model file

95418	52FC317.sp	DEBUT O/H LI	-9.228751198254448e-004
95419		-5.742692e-005	-9.327383e-004
95420		-2.429630e-003	-3.312579e-003
95421		-7.222148e-003	-8.184575e-003
95422		-1.213147e-002	-9.108321e-003
95423		-1.726679e-002	-1.423902e-002
95424		-2.233948e-002	-2.336108e-002
95425		-2.749285e-002	-2.851865e-002
95426		-3.246340e-002	-3.342404e-002
95427		-3.728649e-002	-3.825792e-002
95428		-4.208172e-002	-4.301971e-002
95429		-4.677820e-002	-4.771912e-002
95430		-5.143350e-002	-5.235223e-002
95431		-5.604079e-002	-5.696367e-002
95432		-6.065517e-002	-6.157804e-002
95433		-6.526954e-002	-6.619242e-002
95434		-6.988392e-002	-7.080679e-002
95435		-7.449829e-002	-7.542117e-002
95436		-7.911267e-002	-8.003554e-002
95437		-8.372704e-002	-8.464992e-002
95438		-8.834142e-002	-8.926429e-002

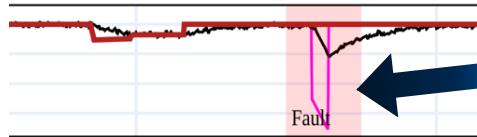


# Phase 1: Interactive MPC models with Clustergrammer



Adapted from Clustergrammer.js source code, with some custom-coded HTML5/CSS styling and D3.js charts

# Improved fault diagnosis process



WHY DID OUR MPC DROP THE PRODUCTION RATE?  
I don't know... let's find out!

This MV is connected to which CVs?

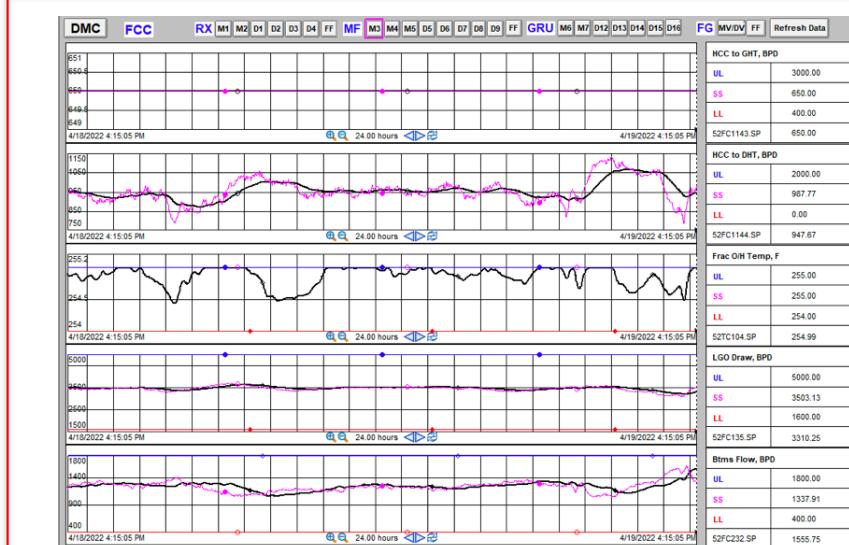
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	SZTAR	SZTAR	SZ421B1	108.CO	SZ2112	258.CO	SZFC151B1	SZAR	ICAC	SZPDR	SZPDR	SZTR5	SZTR5	SZPDR20B	SZPDR2	SZ1121	SZPR2	SZFC23	
2	SZFC126.SP	1	0	0.91	-21.5	-4.14	0	0	-0.01528	0	0	0	-0.28	13.8	10.21	0.11482	2.357	7.418	2.927 29.44
3	SZTC1153.SP	0	1	-0.02	-0.58	-0.15	0	0.614	0	0	0	-0.04	-0.02	0.436	0.3	0.0144	0.101	0.838	0.257 3.325
4	SZFC124.SP	0	0	41.76	145	72.5	60.07	5.394	0.936071	1	0	0	0	-63.2	-29	-1.392	0	0	0
5	SZFC117.LCO	0	0	0.072	2.5	1.25	0	0.093	0	-0.02	1.901	0	0	-1.09	-4.5	-0.024	0	0	0
6	SZPDC108.SP	0	0	0	0	-11	1.106	6.937	-0.01775	0	2.375	-0.81	1.607	0	0	0.07633	0	0	0
7	SZFC112.SP	0	0	0	0	0	0	0.163	0	0	0	-0.03	0	2.423	0	0.0246	0	0	0
8	SZFC113.SP	0	0	-0.03	-0.67	0	0	0.077	0	0	0	0	-1.81	-1.81	0.01662	0.847	0	0	
9	SZFC246.CO	0	0	-0.03	-0.61	0	0	0.373	0	0	0	0	-0.66	-1.81	0.01662	0.847	0	0	
10	609R153B.PWL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	SZPFC111A.SP	0	0	0	0	-7.58	0.763	0	-0.01224	0	1.638	0	0	0	0	0	0	0	0
12	SZTC110A.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	SZFC1127.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	SZFC1144.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	SZFC1145.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	SZFC1139.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	SZFC1135.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	SZFC1132.CO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	SZFC1130.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	SZFC1130.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	SZFC114.CCT4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	SZFC154.CCT4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	SZFC1146.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	SZFC1135.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03
25	SZFC1105.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19.79
26	SZFC1137.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.04
27	SZFC1135.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.211	0	-2.55	
28	SZFC136.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	SZPDC114A.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	SZFC317.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	SZFC118.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	SZFC1107.SP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	SZFC1195	0	0	0	0	0	0	-0.002	-0.01	-1.53E-05	0	0	6E-04	0	0.024	0.02	0	0.002	0.007 0.003 0.03
34	SZTC252	0	0	0	0	0	0	0.208	0	0	0	0.401	0	0	0	0	0	0	0.402
35	SZFC128	0	0	3E-04	0.006	0	0	-0	0	0	0	0	0	0	-5.73E-05	2E-04	0	0	0

Look at CV1...

Which other MVs are controlling CV1?

Look at MV2...

Repeat until root cause is found...



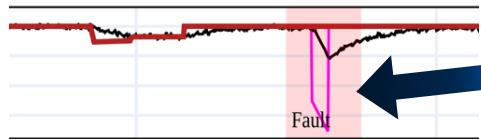
- Is the measurement reading correctly?
- Is the variable constrained?
- Are the limits clamped?



COGNITION



# Improved fault diagnosis process



WHY DID OUR MPC DROP THE PRODUCTION RATE?  
I don't know... let's find out!

This MV is connected to which CVs?



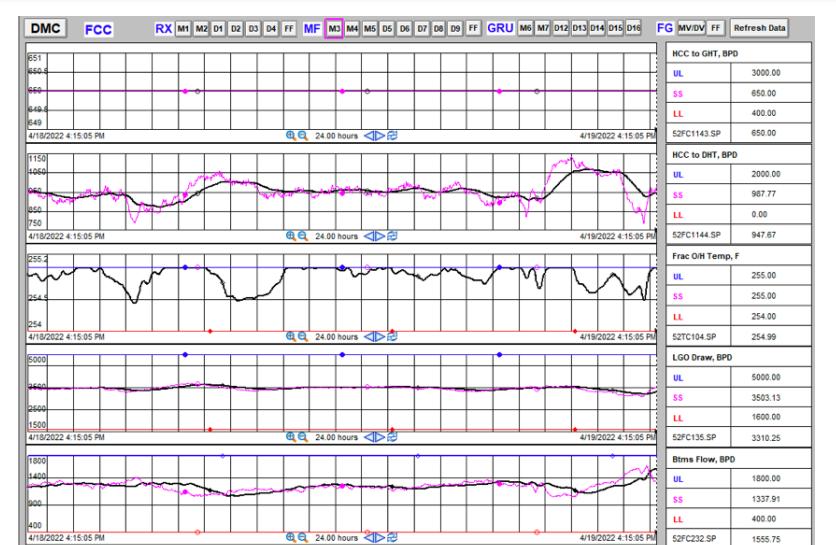
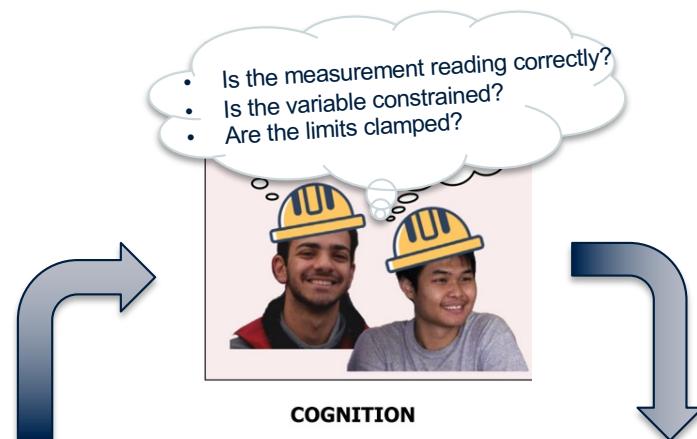
Problem 1: Solved-ish. Replaced spreadsheet with Clustergrammer

Look at CV1...

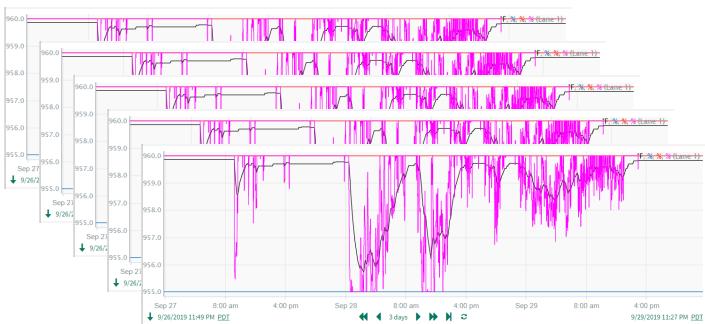
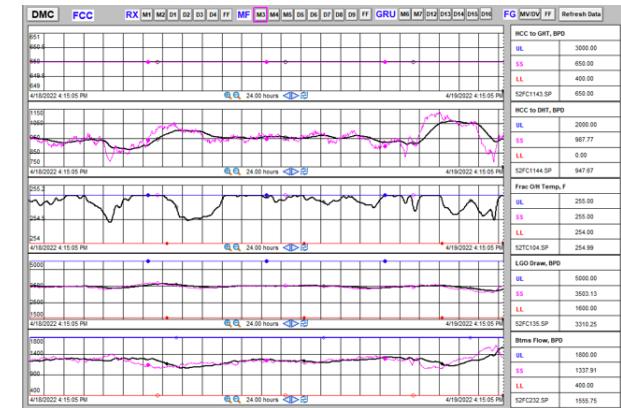
Which other MVs are controlling CV1?

Look at MV2...

Repeat until root cause is found...



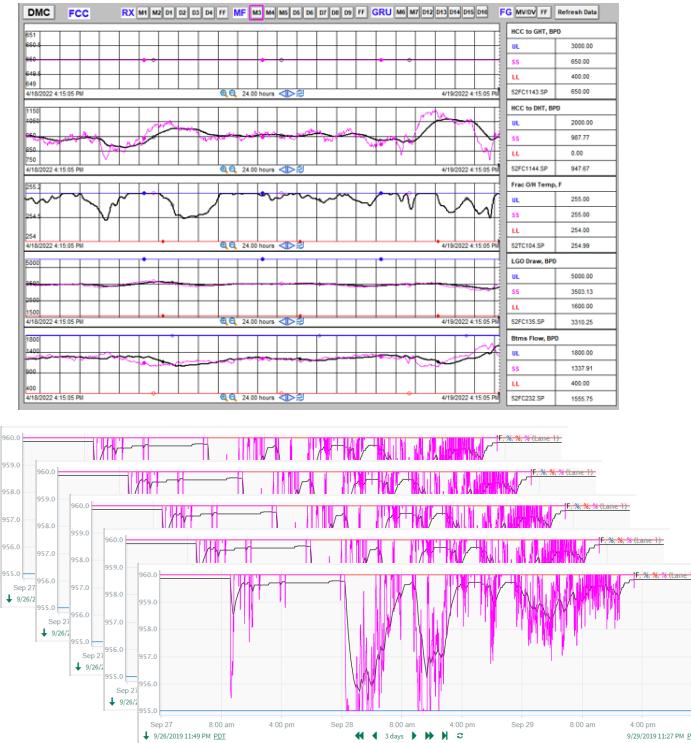
## Idea 2: reduce visual noise in time series using active constraints



**Time series data for each MPC variable spread across different pages, multiple views and trends, can we do better than this without 'squishing' the trends?**

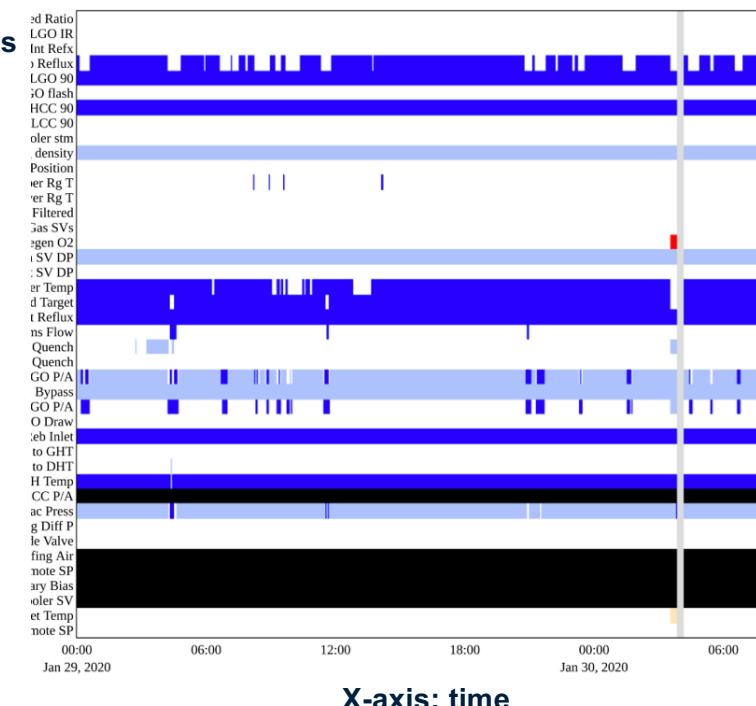


## Idea 2: reduce visual noise in time series using active constraints



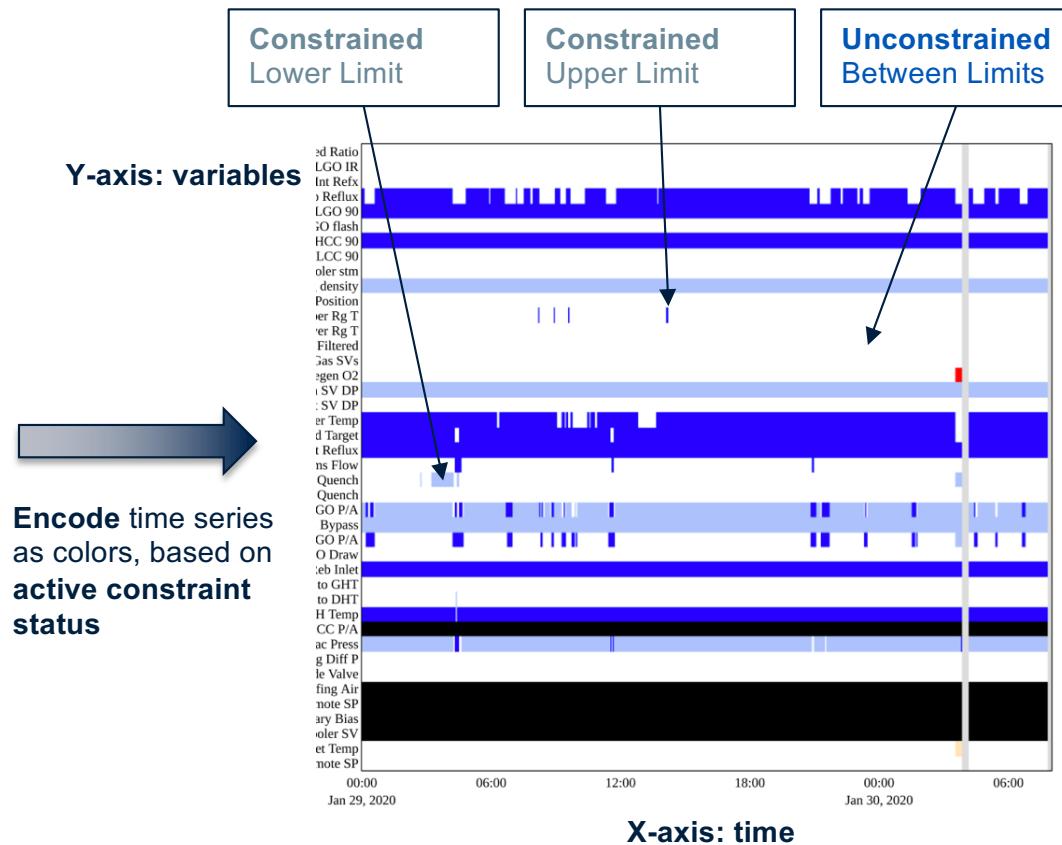
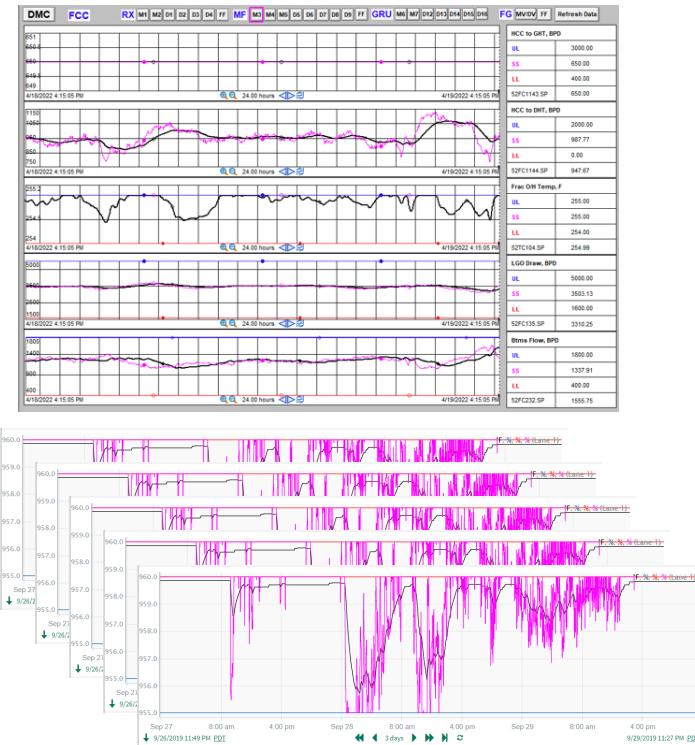
**Y-axis: variables**

**Encode time series  
as colors, based on  
active constraint  
status**



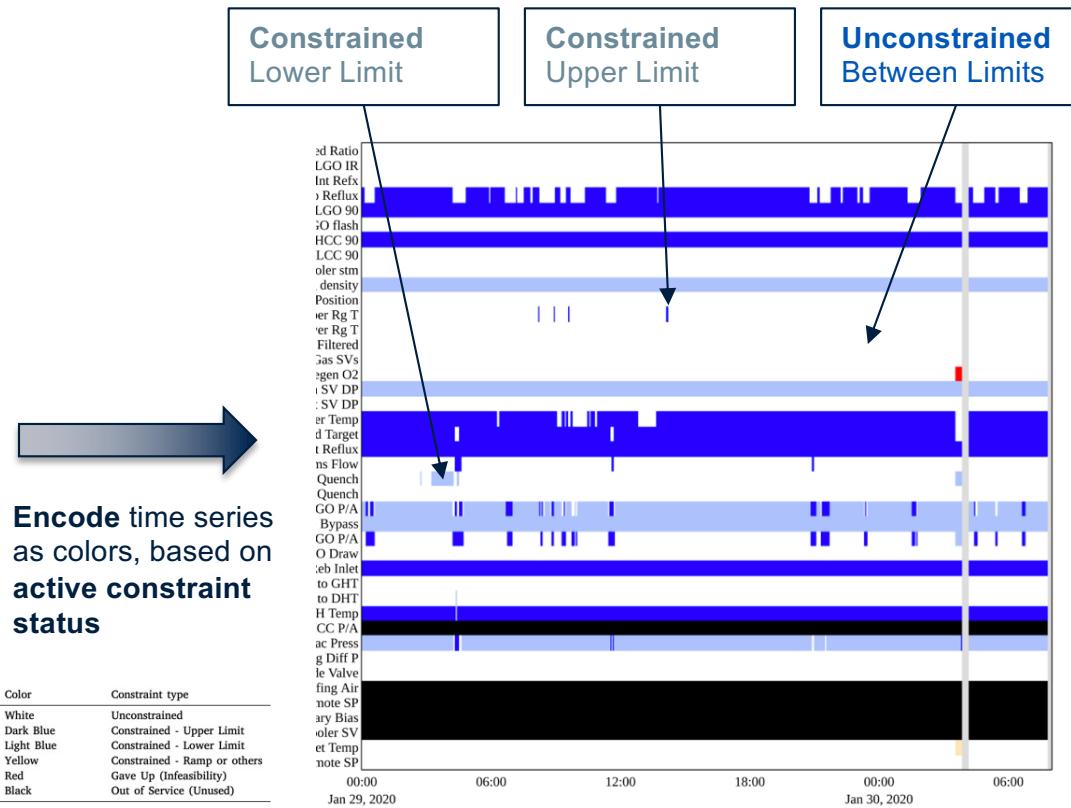
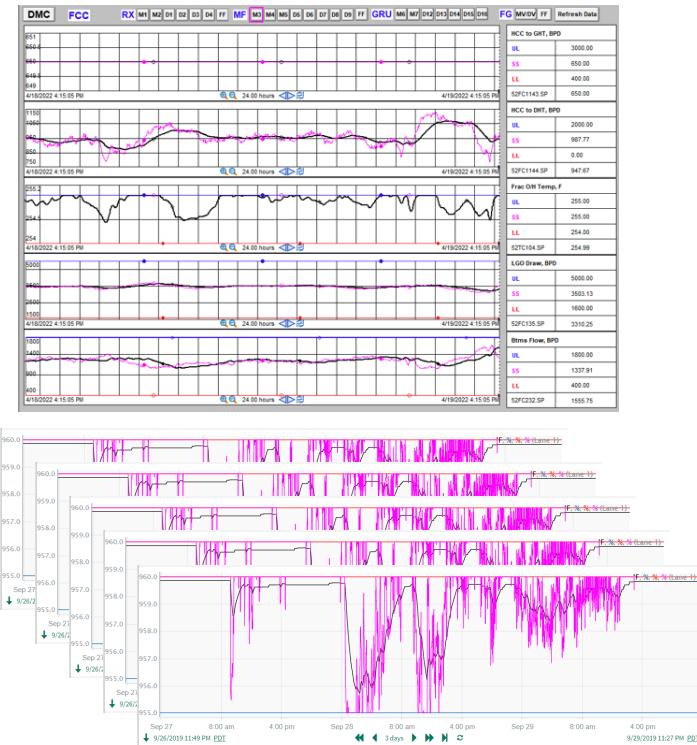
**Time series data for each MPC variable spread across different pages, multiple views and trends, can we do better than this without 'squishing' the trends?**

## Idea 2: reduce visual noise in time series using active constraints



Time series data for each MPC variable spread across different pages, multiple views and trends, can we do better than this without 'squishing' the trends?

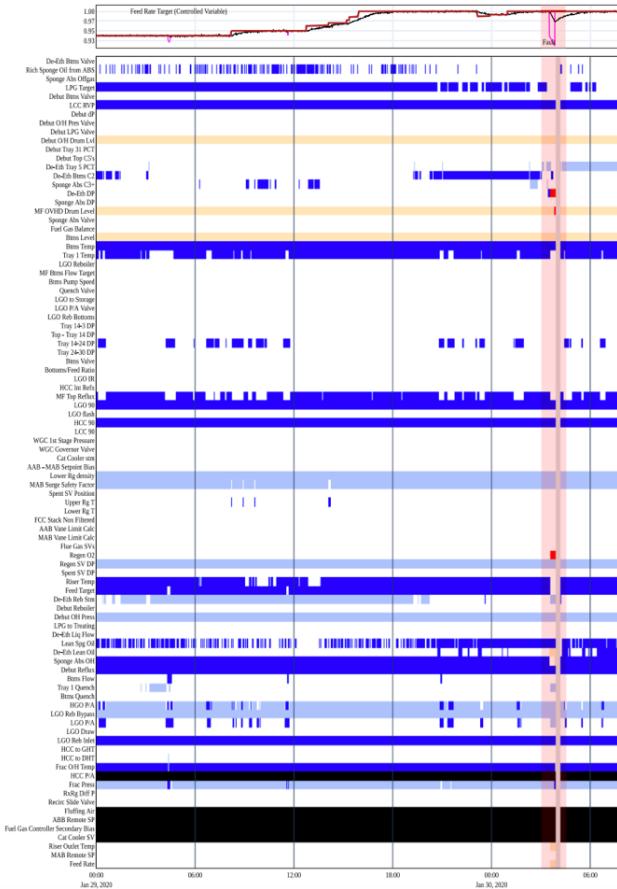
## Idea 2: reduce visual noise in time series using active constraints



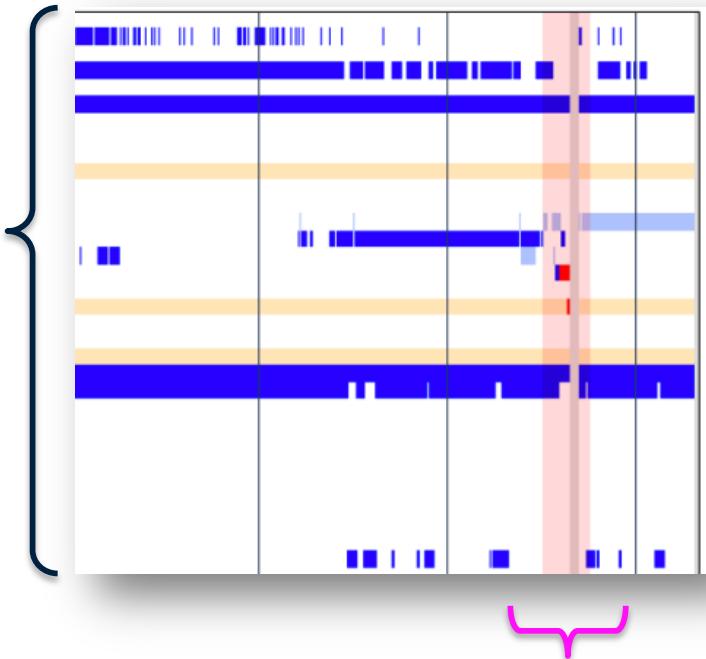
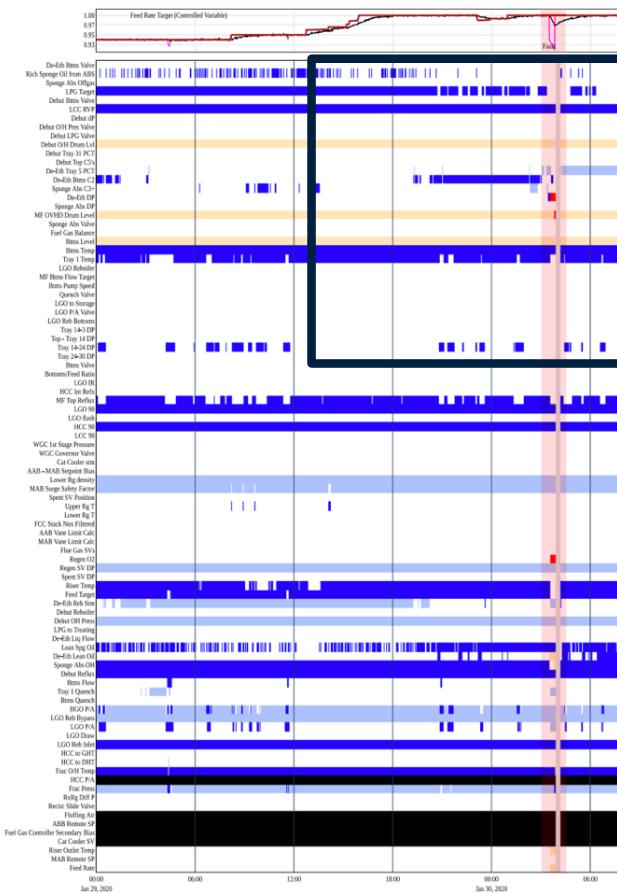
Time series data for each MPC variable spread across different pages, multiple views and trends, can we do better than this without 'squishing' the trends?

**Dynamic Constraint Map (DCM)** – compressed time series values into colors, based on active constraint status, multiple variables now visible on one single page

# Compressed time series as a Dynamic Constraint Map



## Key insight for MPC diagnosis: most variables are irrelevant!



Many MV/CVs do not undergo any constraint (color) changes.

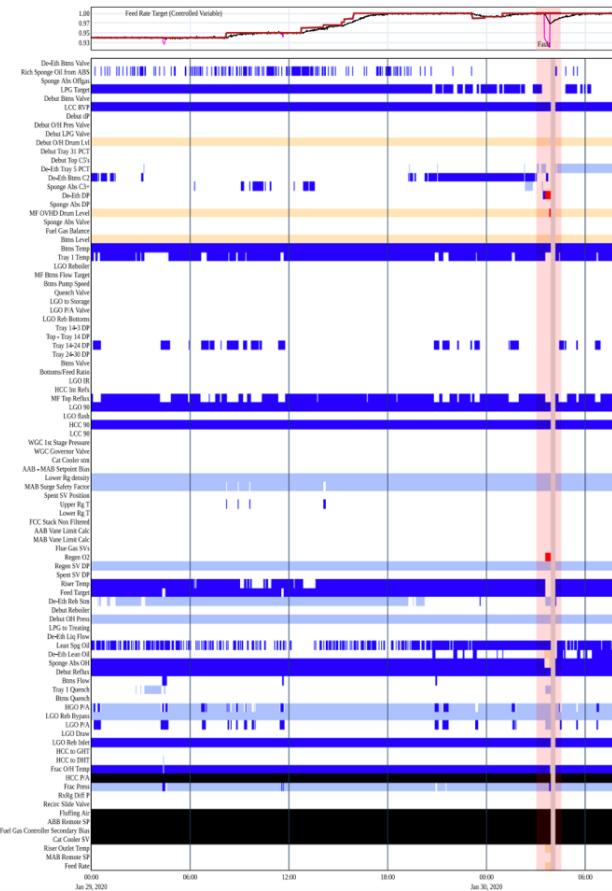
These MV/CVs would not have caused the fault.

**Key insight:**  
We can hide these!

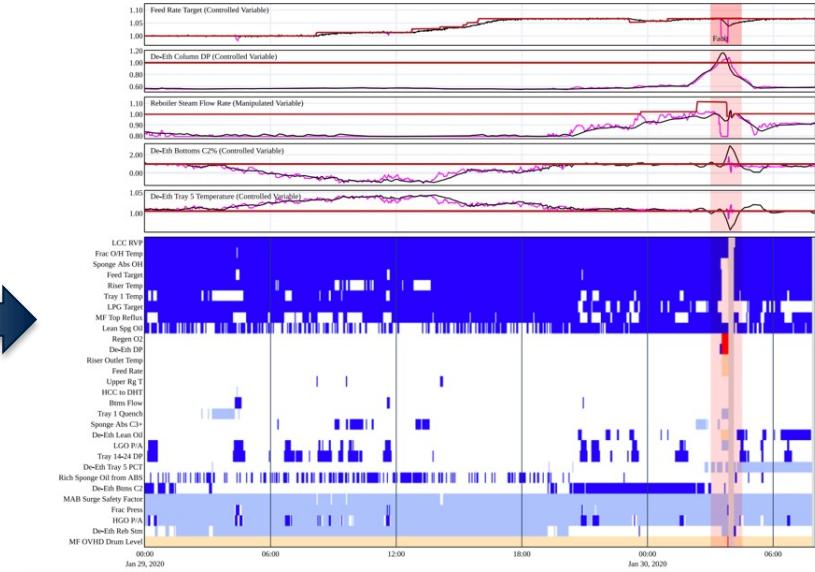


Red strip highlights time window during the fault

# Hiding irrelevant variables reduces visual noise

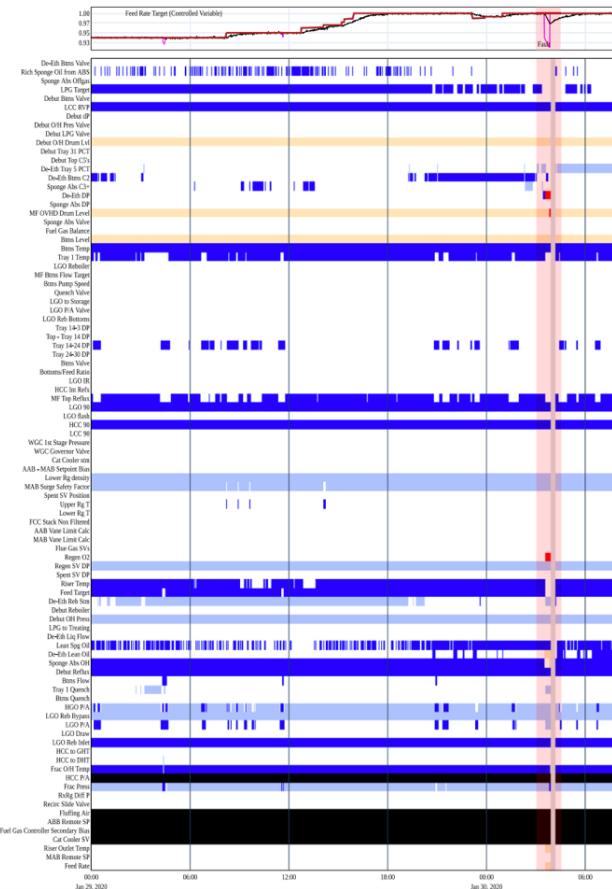


Hide irrelevant variables with no constraint changes



- Hiding irrelevant variables allow us to focus on just the ones that directly contributed to the fault.
- Don't need to dig through pages of time series trends

## Hiding irrelevant variables reduce visual noise

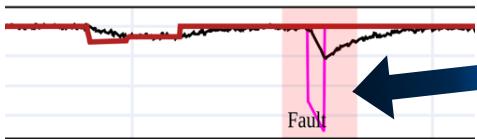


Hide irrelevant variables in the matrix too!



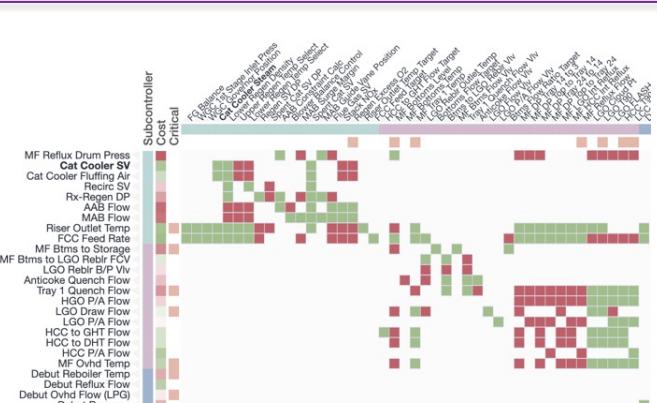
- Now we just need to check a smaller submatrix instead of digging through 100+ variables!

# Revamped fault diagnosis process



WHY DID OUR MPC DROP THE PRODUCTION RATE?  
I don't know... let's find out!

This MV is connected to which CVs?



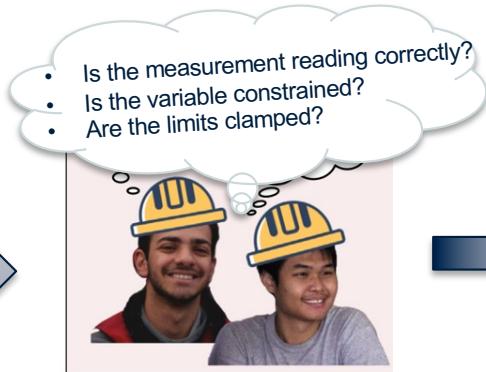
Problem 1: Solved-ish. Replaced spreadsheet with Clustergrammer

Look at CV1...

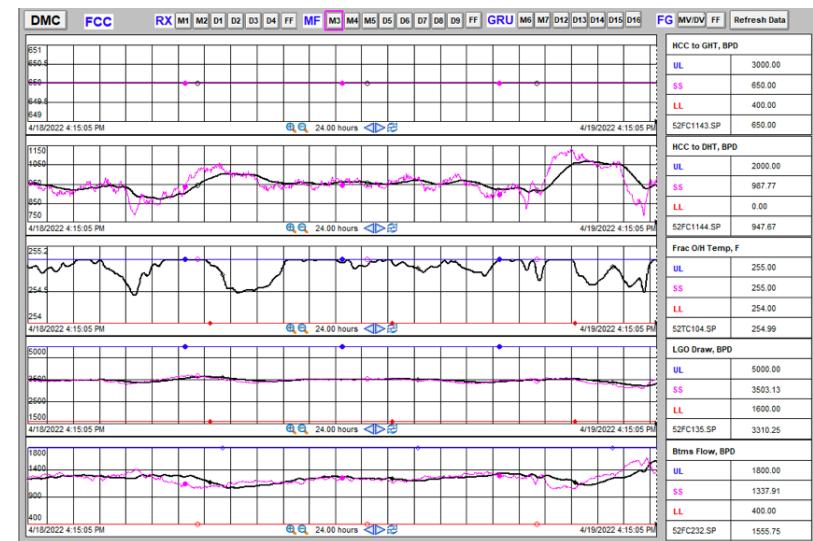
Which other MVs are controlling CV1?

Look at MV2...

Repeat until root cause is found...



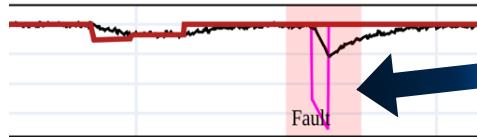
COGNITION



Problem 2: multivariable time-series trends still an issue



# Revamped fault diagnosis process

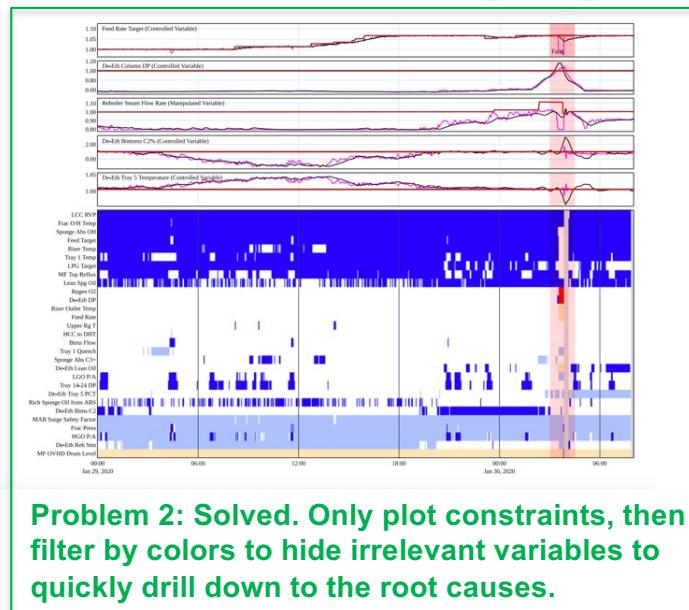


WHY DID OUR MPC DROP  
THE PRODUCTION RATE?

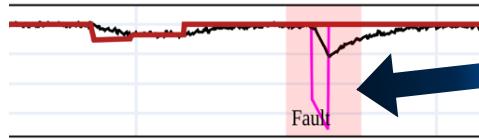
I don't know... let's find out!



Different perspective:  
What variables had  
constraint changes?  
Filter!



# Revamped fault diagnosis process

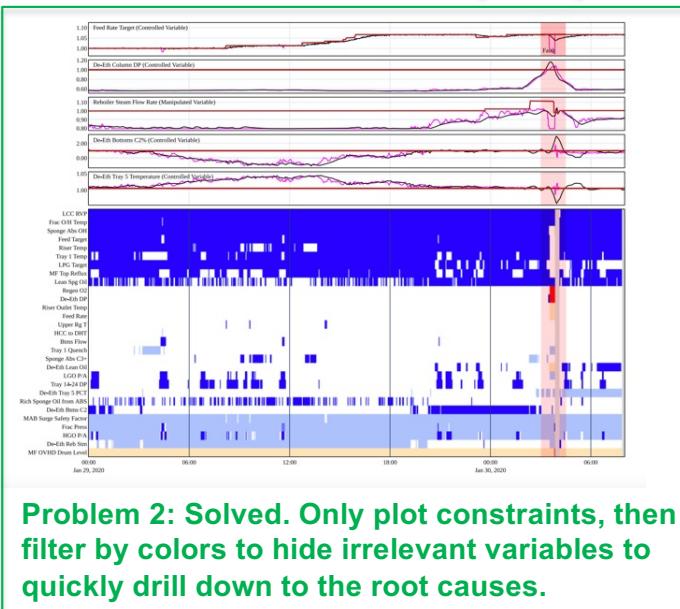


**WHY DID OUR MPC DROP THE PRODUCTION RATE?**

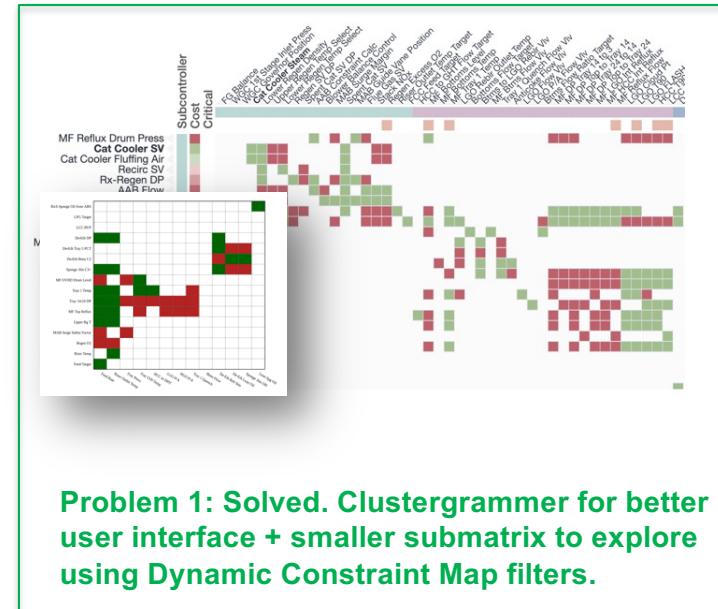
I don't know... let's find out!

↓  
This MV is connected to which CVs? X

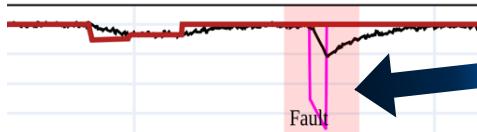
**Different perspective:**  
What variables had constraint changes?  
**Filter!**



→  
**Filter submatrix (much smaller list!)**



# Revamped fault diagnosis process



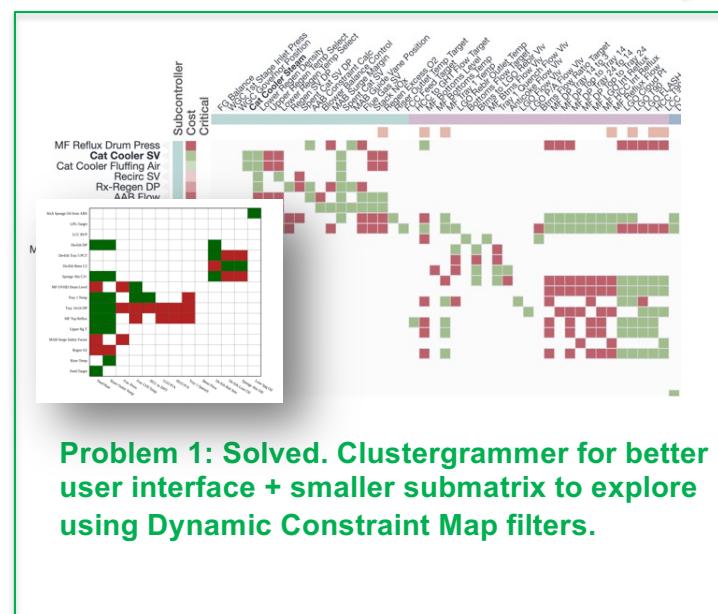
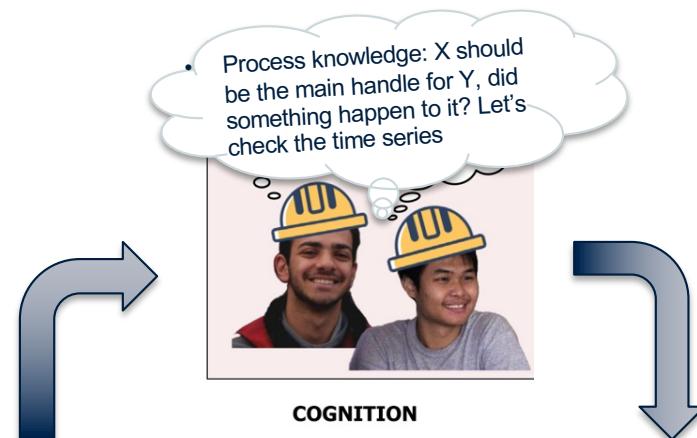
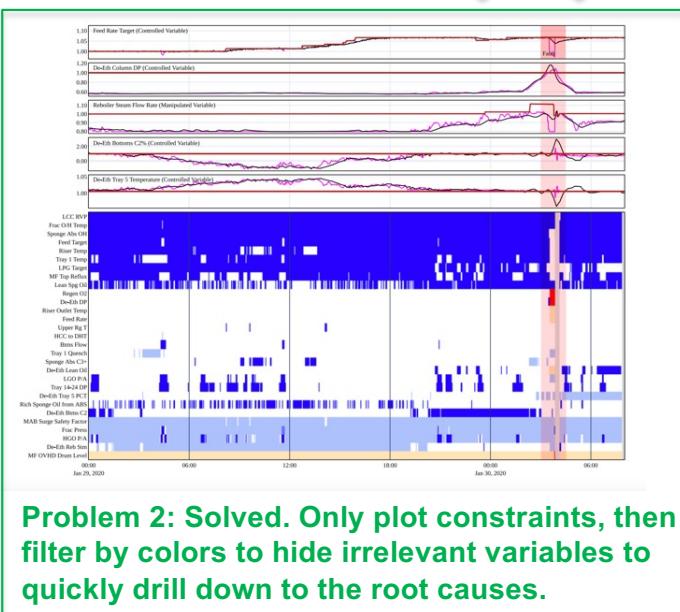
This MV is connected to which CVs?

**WHY DID OUR MPC DROP THE PRODUCTION RATE?**

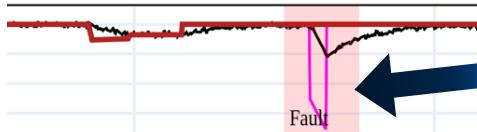
I don't know... let's find out!

**Different perspective:**  
What variables had constraint changes?  
**Filter!**

Filter submatrix  
(much smaller list!)



# Revamped fault diagnosis process

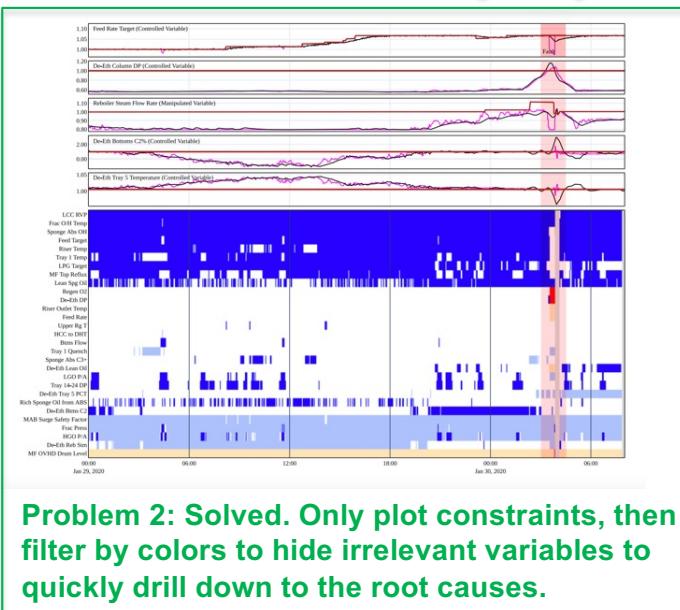


This MV is connected to which CVs?

**WHY DID OUR MPC DROP THE PRODUCTION RATE?**

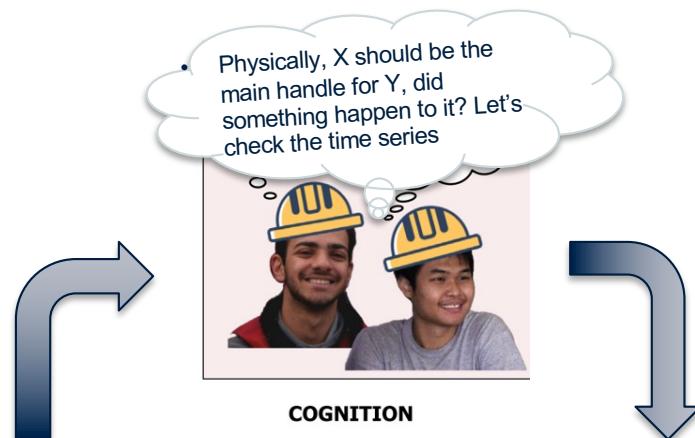
I don't know... let's find out!

**Different perspective:**  
What variables had constraint changes?  
**Filter!**

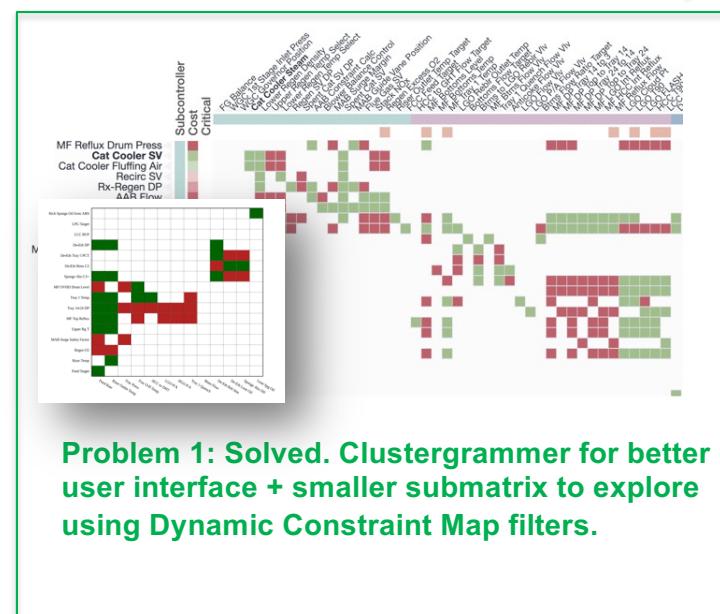


Filter submatrix  
(much smaller list!)

Check process time series for anomalies  
(much smaller list!)



**COGNITION**





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