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# Early Abnormal Event Detection with Geometric Models

Third European Conference on Plant & Process Safety

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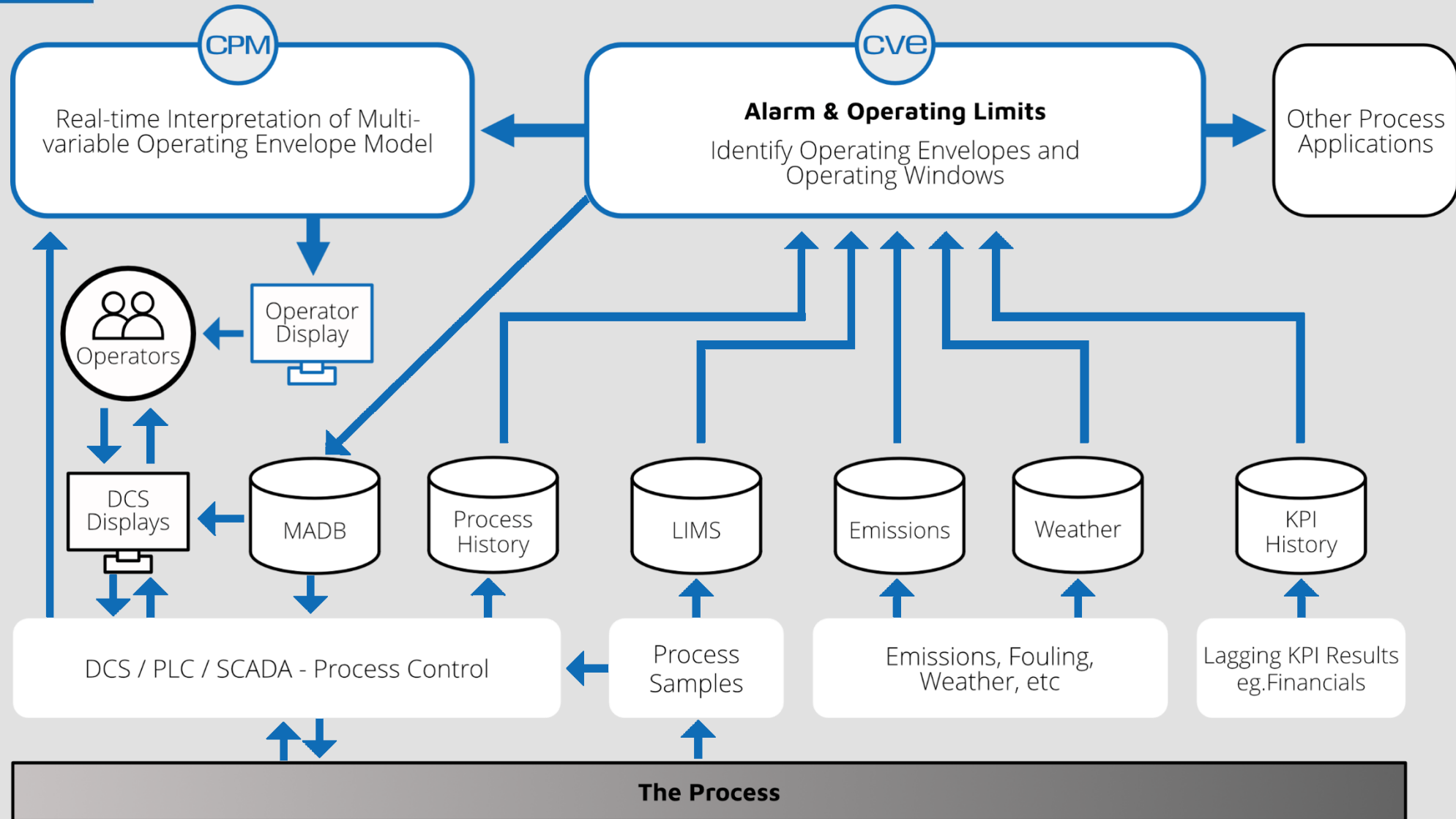


“The method successfully identified a historical significant furnace event almost two and one half days before the event occurred, flagging the exact instrument that was failing. The application has identified 3 significant events during its first 8 months of operation.

“CPM has been actively notifying the console operator of any abnormal process conditions to the furnace with an on stream time of 99.9%.”



# The Geometric Process Control Framework



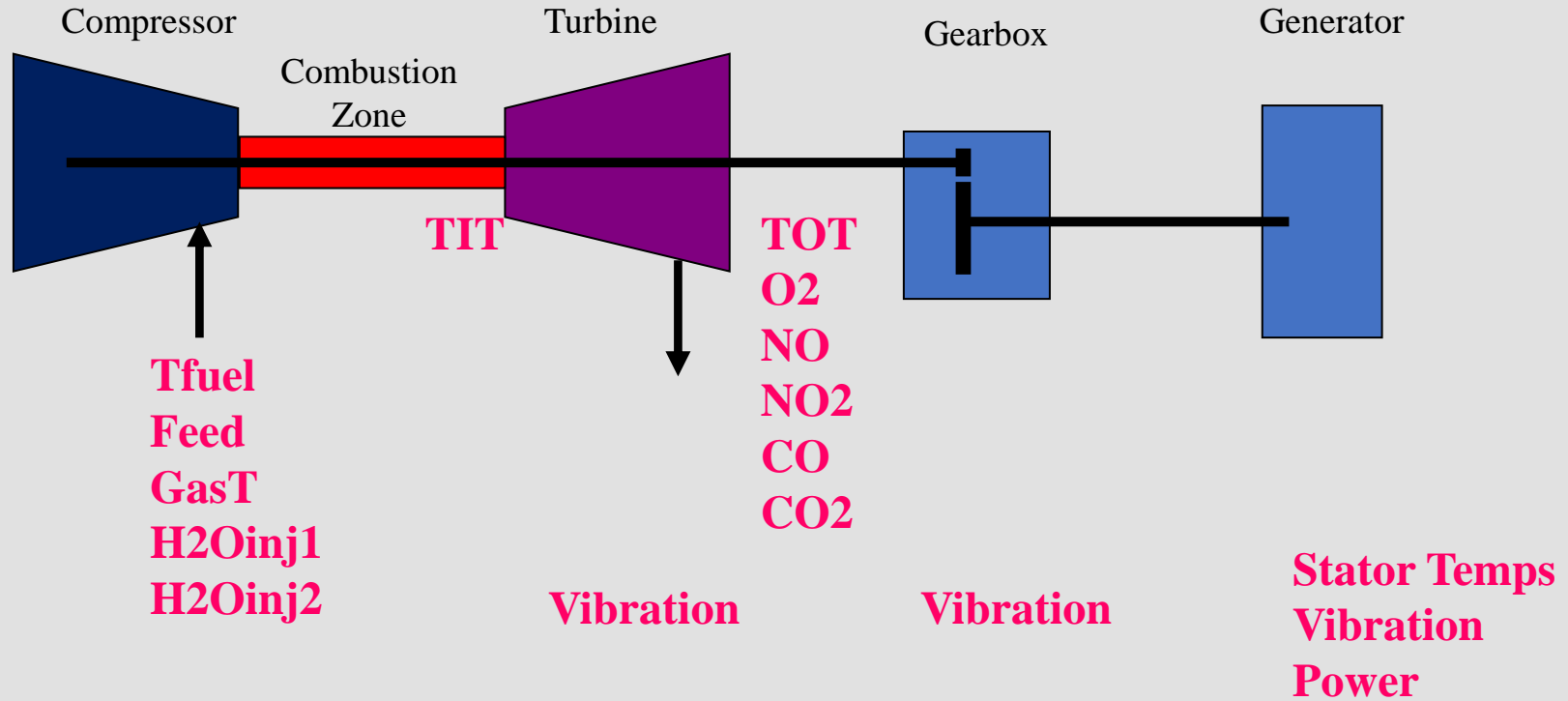


## **Geometric Modeling**

### **Building and Evaluating a Model of Fault-free Process Operation**

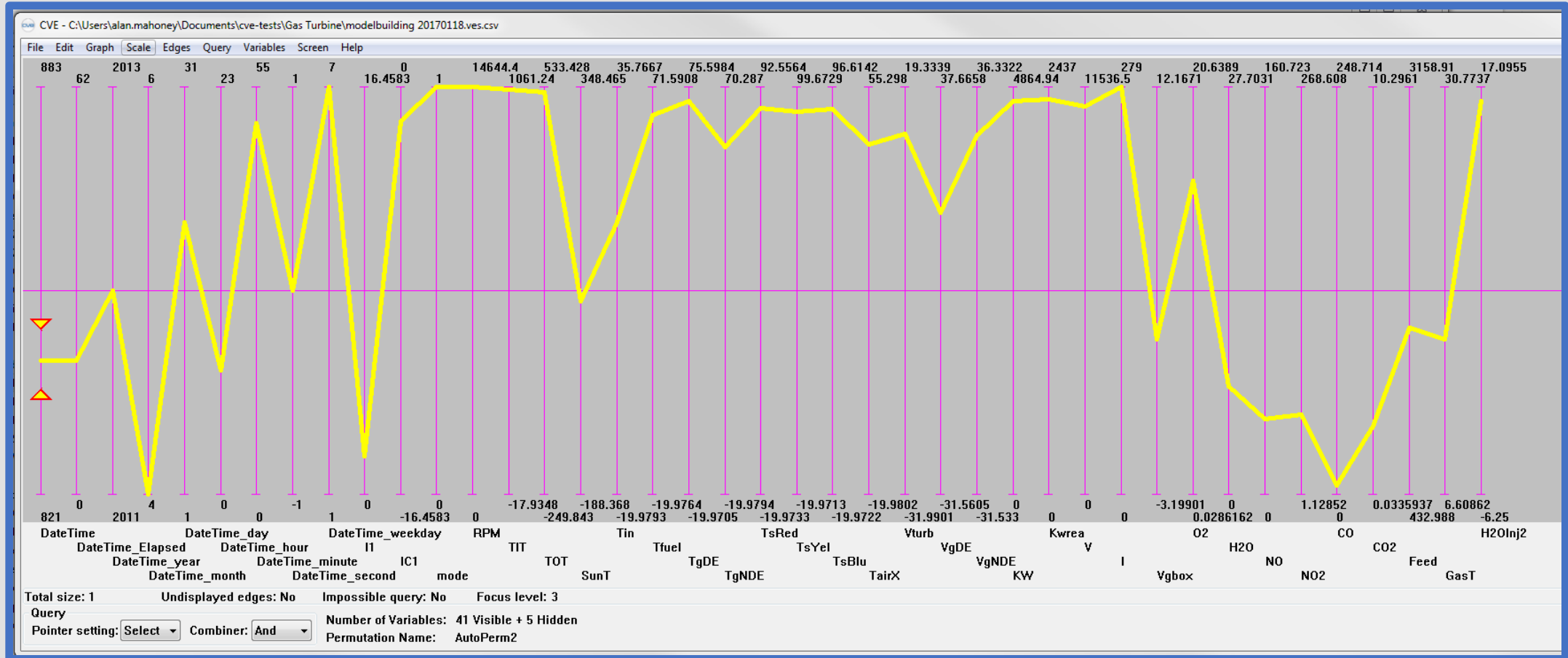
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# Demo System: Turbine and Generator



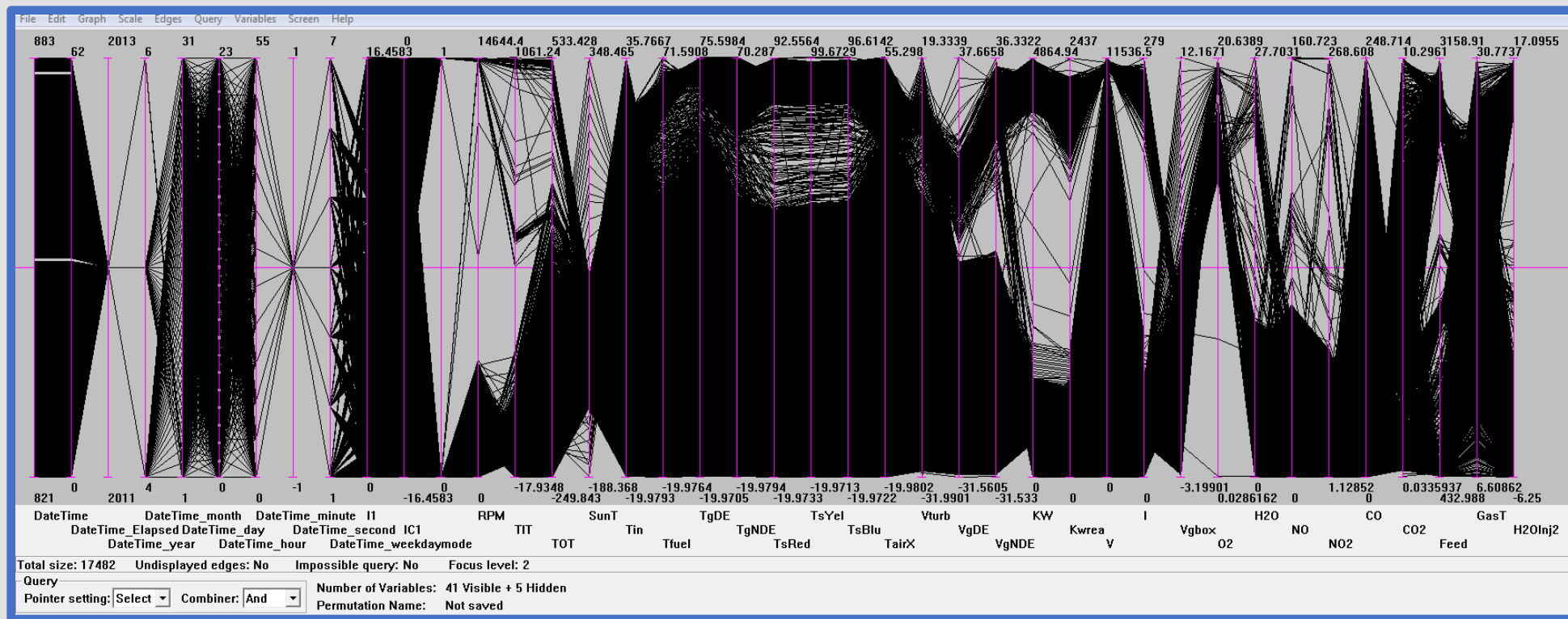


	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1		Speed	TIT	TOT	Sunwheel	Combust	Gas Fuel T	Comp Gas	Gen DE br	Gen NDE l	Red stator	Yellow sta	Blue stator	Gen exit a	Turbine vi	Gen DE vil	Gen NDE v	Turbine p	Gen react	Gen volta	Gen curre	Temp sset	Power set	Gearbox v	Exhaus
2		EUIWFSS.	EUIWFSS.	EUIWFSS.	EUIWFSS.	EUIWFSS.	EUIWFSS.	EUIWFSS.	EUIWFSS.	EUIWFSS.	EUIWFSS.	EUIWFSS.	EUIWFSS.	EUIWFSS.	EUIWFSS.	EUIWFSS.	EUIWFSS.	EUIWFSS.	EUIWFSS.	EUIWFSS.	EUIWFSS.	EUIWFSS.	EUIWFSS.	EUIWFSS.	EUIWFSS.
3	DateTime	RPM	TIT	TOT	SunT	Tin	Tfuel	Tcomp	TgDE	TgNDE	TsRed	TsVel	TsBlu	TairX	Vturb	VgDE	VgNDE	KW	Kwrea	V	I	TSP	KWSP	Vgbox	O2
4	01/04/2012 00:00	14567.75	1053.407	514.9902	24.00312	14.69922	66.83145	0	71.30195	55.91924	84.08183	89.81506	87.1	42.44119	15.00244	16.99829	30.99976	4700.125	2159	11394.4	261	100	5589.883	2.399902	
5	01/04/2012 00:05	14564.62	1053.317	514.9902	24.00312	14.98047	68.0735	0	71.30195	55.84933	83.95514	90.1355	86.95206	42.40195	14.93341	15.93099	31.06879	4689.19	2170.278	11404.14	259	100	5589.883	2.221951	19.958
6	01/04/2012 00:10	14572.71	1053.226	514.9902	24.00312	15.03281	66.95279	0	71.12763	55.80273	83.82407	89.69279	86.80413	42.40195	14.16829	16.16414	31.11098	4679.393	2158.75	11413.88	259	100	5589.883	2.293132	20.041
7	01/04/2012 00:15	14580.79	1053.135	514.9902	24.00312	15.40078	66.47232	0	71.00312	55.80273	83.69301	89.39765	86.6562	42.40195	14.16829	16.16414	32.66805	4688.349	2151.25	11423.62	258.9722	100	5589.883	2.394341	20.093
8	01/04/2012 00:20	14588.87	1053.044	514.9143	24.00312	15.45078	67.36462	0	71.00312	55.80273	83.56194	89.39765	86.30437	42.40195	14.66878	16.66463	31.66707	4674.223	2152.083	11433.35	258.1389	100	5589.883	2.372097	19.885
9	01/04/2012 00:25	14596.95	1052.908	514.8329	24.00312	15.15279	67.57195	0	71.00312	55.80273	83.50078	89.39765	86.34172	42.40195	14.55756	16.46444	31.04146	4681.9	2199.444	11399.15	260.8333	100	5589.883	2.40808	19.916
10	01/04/2012 00:30	14605.03	1052.681	514.7515	24.00312	15.00882	66.53442	0	71.00312	55.80273	83.52845	89.47591	86.37907	42.40195	14.78	16.18798	31.41683	4689.19	2166.167	11366.6	261.3667	100	5589.883	2.417894	20.097
11	01/04/2012 00:35	14606.56	1052.454	514.6702	24.00312	15.06641	66.51011	0	71.00312	55.80273	83.73597	89.58264	86.41643	42.36282	14.89122	16.08073	31.66707	4683.863	2187.333	11366.6	262.5833	100	5589.883	2.427707	19.958
12	01/04/2012 00:40	14602.49	1052.227	514.5887	24.00312	14.74922	68.0677	0	71.00312	55.80273	83.94349	89.68936	86.45378	42.30946	14.13493	16.00138	32.4178	4699.284	2191.417	11366.6	262.8889	100	5589.883	2.437521	19.975
13	01/04/2012 00:45	14607.12	1052	514.5074	24.00312	14.86172	66.83126	0	71.00312	55.80273	83.95428	89.69648	86.49113	42.2561	14.33512	17.41537	31.66707	4691.713	2188.667	11366.6	262.4445	100	5589.883	2.447334	19.986
14	01/04/2012 00:50	14619.13	1052.029	514.426	24.00312	14.71172	65.59129	0	71.00312	55.80273	83.89355	89.69648	86.52849	42.20273	14.33512	16.58122	31.66707	4697.321	2189.542	11366.6	261.2143	100	5589.883	2.457148	20.008
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16	01/04/2012 01:00	14621.59	1052.195	514.2632	24.00312	14.66048	67.51975	0	71.00312	55.80273	83.77207	89.69648	86.55215	42.09037	14.83561	17.60494	32.33439	4690.873	2190.5	11369.82	262.3889	100	5589.883	2.476775	19.966
17	01/04/2012 01:05	14610.66	1052.279	514.1819	24.00312	14.5332	65.01845	0	71.00312	55.77645	83.71133	89.69648	86.56958	41.99471	14.58537	16.66463	32.66805	4700.941	2183	11371.67	263	100	5589.883	2.486588	19.777
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19	01/04/2012 01:15	14592.28	1052.445	514.0191	24.00312	14.375	67.9761	0	70.96583	55.61873	83.58986	89.69648	86.42017	41.8034	14.33512	16.54171	32.91829	4718.333	2193.278	11375.38	261.3333	100	5589.883	2.414361	19.833
20	01/04/2012 01:20	14591.65	1052.528	514.0896	24.00312	14.2125	66.2356	0	70.92107	55.53988	83.52912	89.69648	86.34546	41.70774	14.83561	16.27829	32.91829	4703.44	2184.111	11377.24	262.6042	100	5589.883	2.447727	19.975
21	01/04/2012 01:25	14591.01	1052.612	514.171	24.00312	14.19763	65.0083	0	70.87633	55.46102	83.50078	89.69648	86.27769	41.61208	14.33512	16.01488	32.4178	4712.277	2178.5	11379.09	262	100	5589.883	2.481093	19.895
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32	01/04/2012 02:20	14587.89	1052.984	515.1459	24.00312	13.81911	65.53236	0	70.56733	55.06387	83.37627	89.04123	86.06302	41.14856	14.26098	17.33195	31.8339	4719.174	2173.333	11329.7	263	100	5589.883	2.416585	20.06
33	01/04/2012 02:25	14589.76	1052.984	515.3127	24.00312	13.76911	67.28382	0	70.54243	55.03766	83.18298	89.08084	86.06769	41.12903	14.66878	16.83146	32.83488	4718.333	2181.8	11334.28	263	100	5589.883	2.483317	19.958
34	01/04/2012 02:30	14591.64	1052.984	515.4796	24.00312	13.71911	67.67263	0	70.51752	55.01145	83.1474	89.03934	86.021	41.1095	14.78	16.33097	31.63927	4714.548	2192.667	11338.85	263	100	5589.883	2.400737	19.888
35	01/04/2012 02:35	14591.05	1052.984	515.6464	24.00312	13.69773	66.16432	0	70.49844	54.99921	83.11182	88.99783	85.9743	41.10039	14.33512	16.83146	32.91829	4721.342	2208	11343.42	263	100	5589.883	2.425761	20.097
36	01/04/2012 02:40	14588.38	1052.984	515.8132	24.00312	13.60611	66.48813	0	70.49844	54.99921	83.07626	88.95633	85.92761	41.10039	14.33512	16.72024	32.16756	4723.38	2189.741	11348	263	100	5589.883	2.450785	19.861
37	01/04/2012 02:45	14585.7	1052.984	515.9801	24.00312	13.51449	68.10117	0	70.49844	54.99921	83.04068	88.91483	85.88092	41.10039	14.54366	16.66463	32.16756	4736.591	2183.63	11352.57	263	100	5589.883	2.47581	20.041
38	01/04/2012 02:50	14583.02	1052.832	516.1469	24.00312	13.66719	67.61238	0	70.49844	54.98538	83.0051	88.8996	85.83423	41.10039	14.66878	16.33097	32.72366	4733.276	2177.519	11357.15	263	100	5589.883	2.478317	19.916
39	01/04/2012 02:55	14580.34	1052.378	51																					

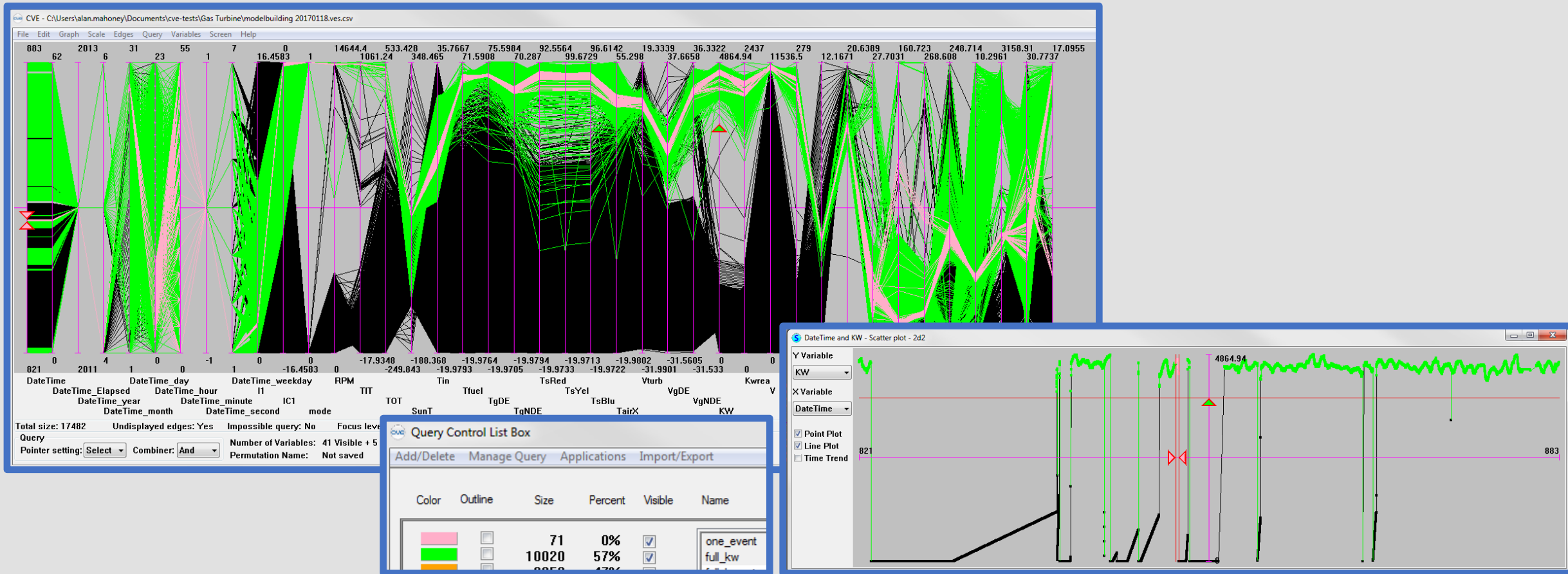


Graph with one point in time showing the entire process



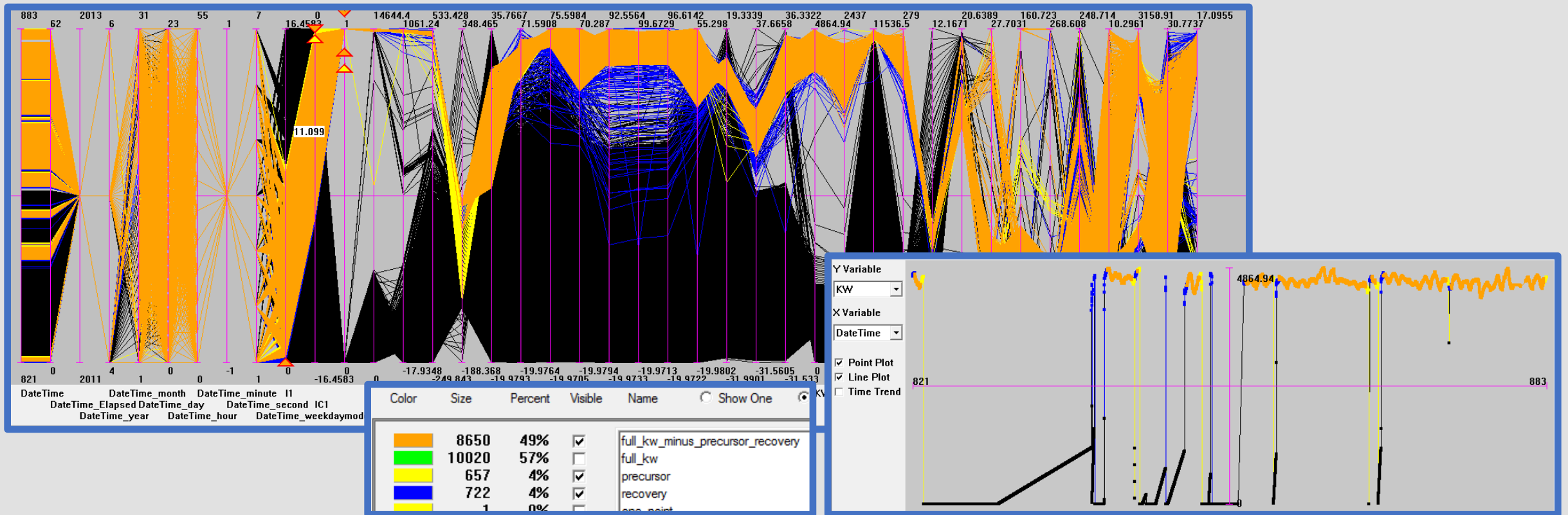


- Lots of patterns conveying process information
- Multiple modes of operation
- Process excursions



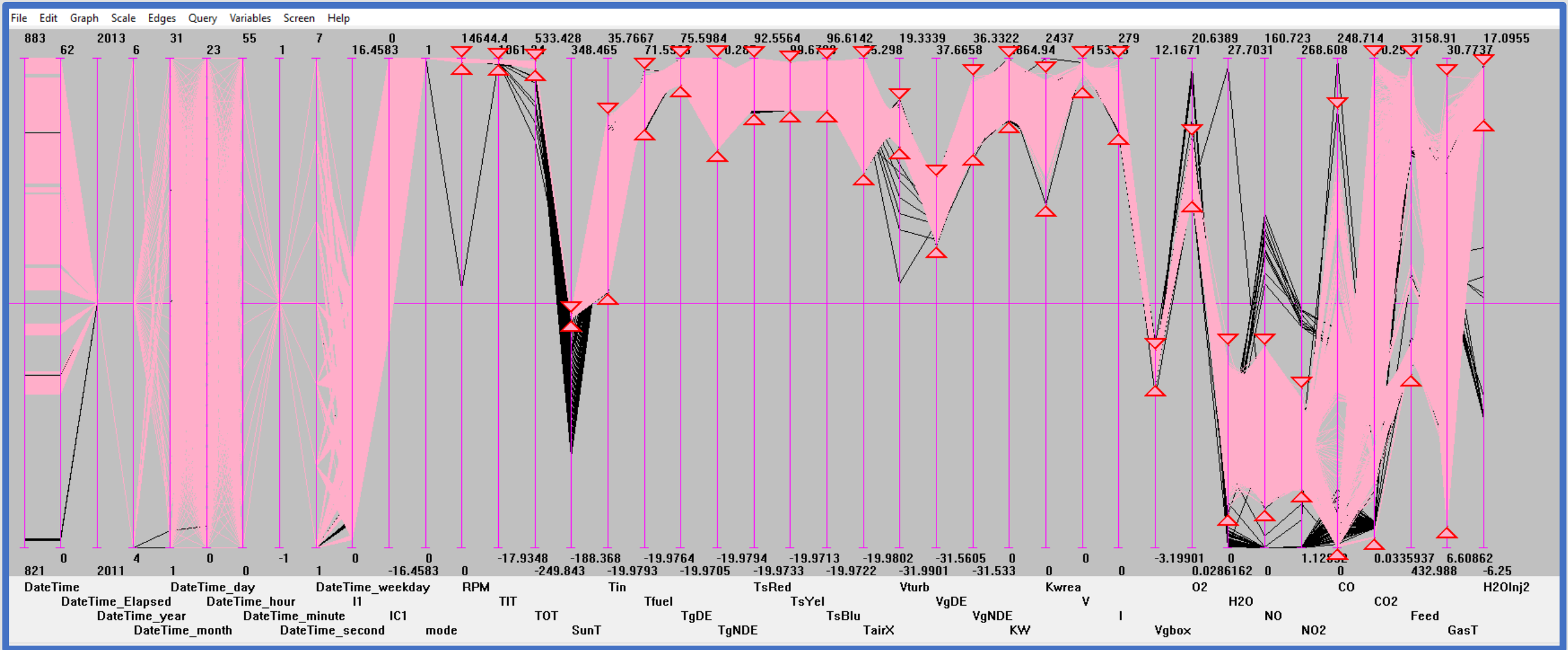
- Identify behaviour leading to one event
- Combustion conditions – NO, NO<sub>2</sub>, water injection differ from normal operation





- Remove “precursor” behaviour (yellow): leading to any event
- Remove “recovery” behaviour (blue): transients after startup
- Remove unusual transients: cluster tool
- Remaining (orange) is a normal operating envelope

# Single-Variable Limit Operating Window

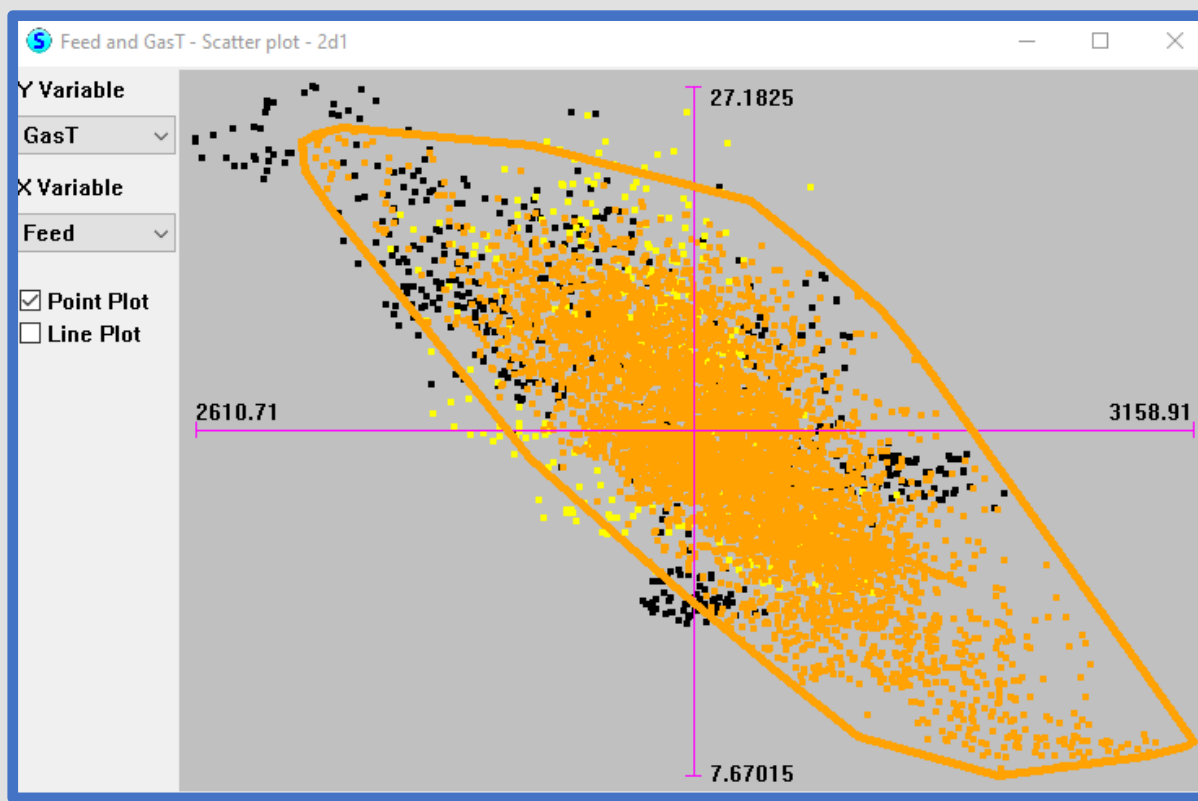


- Individual variable limits pick up most disruptions only minutes away from trip



## Could an Operating Envelope Do Better?

- If power Feed and GasT are imbalanced, yellow at bottom left/top right, could indicate precursor to a trip!
- Can't capture this with limits on single variables.



The PPCL logo is located in the top-left corner of the slide. It consists of the letters "PPCL" in a bold, white, sans-serif font, set against a solid blue rectangular background. The background of the entire slide is a low-angle, upward-looking photograph of an industrial refinery or chemical plant at night, featuring a complex network of silver pipes, blue structural beams, and yellow safety railings, illuminated by bright lights.

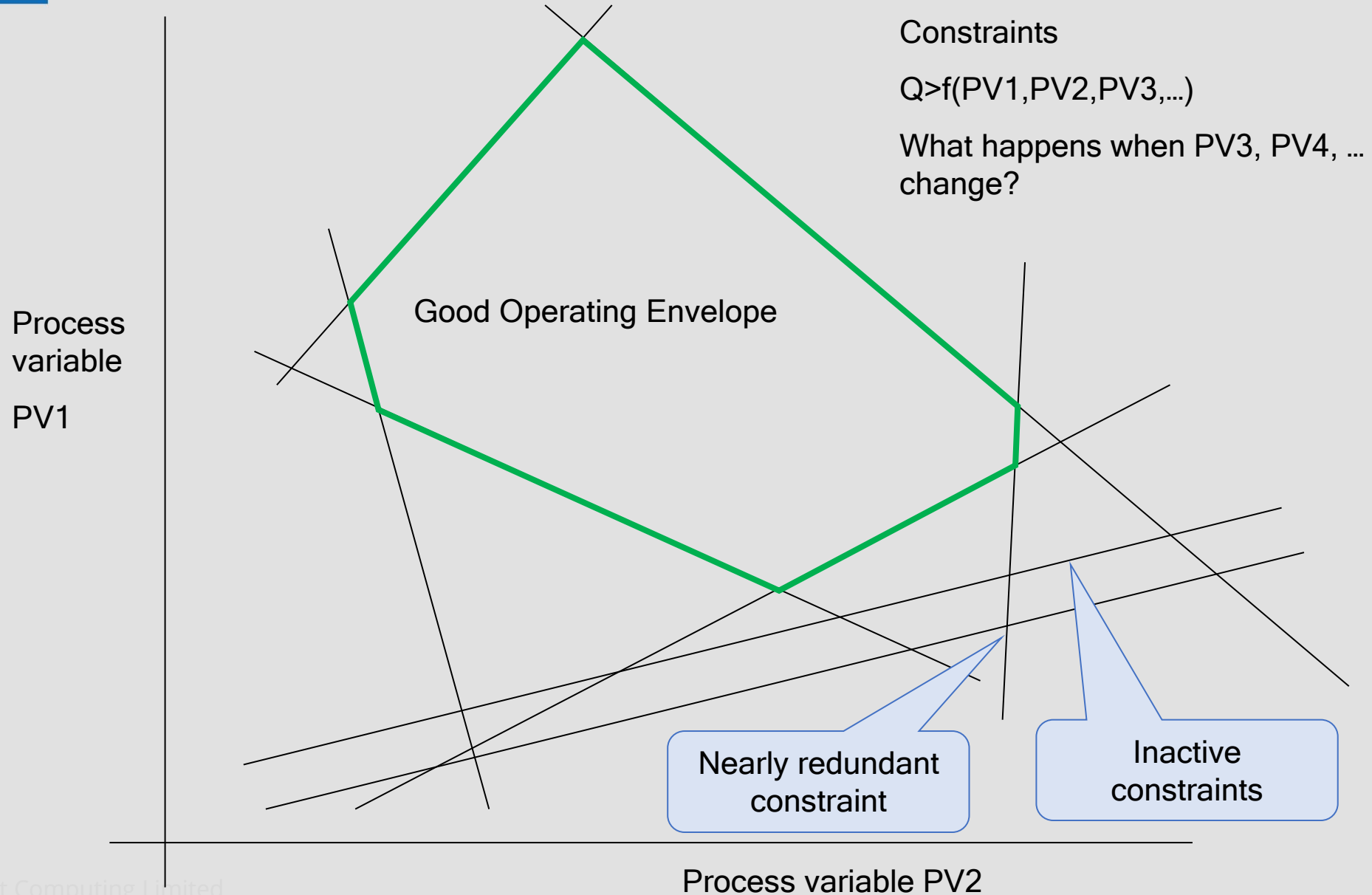
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**Real-Time Geometric Models  
for  
Early Warning**

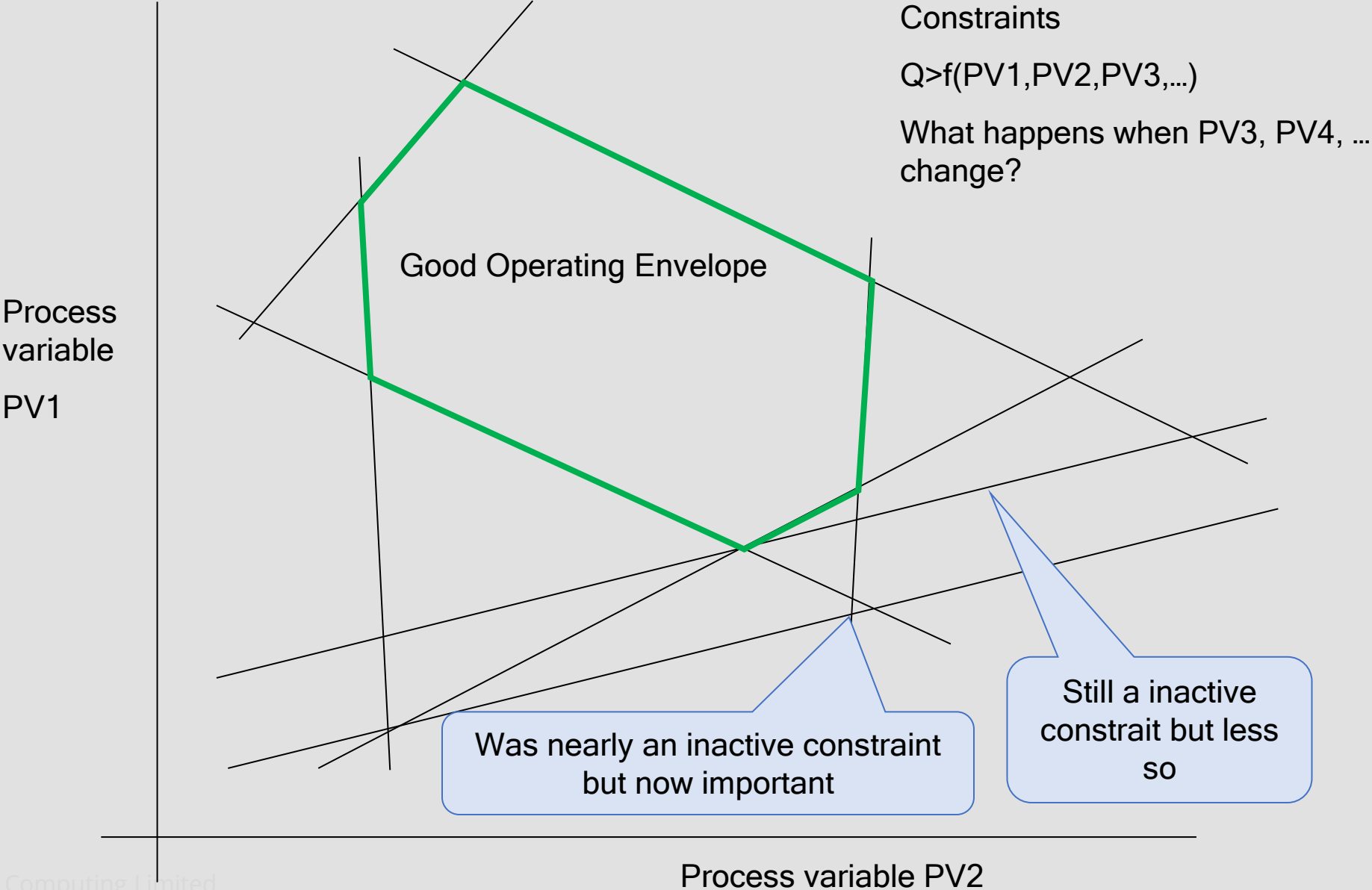
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## 2-D Schematic of Operating Envelope

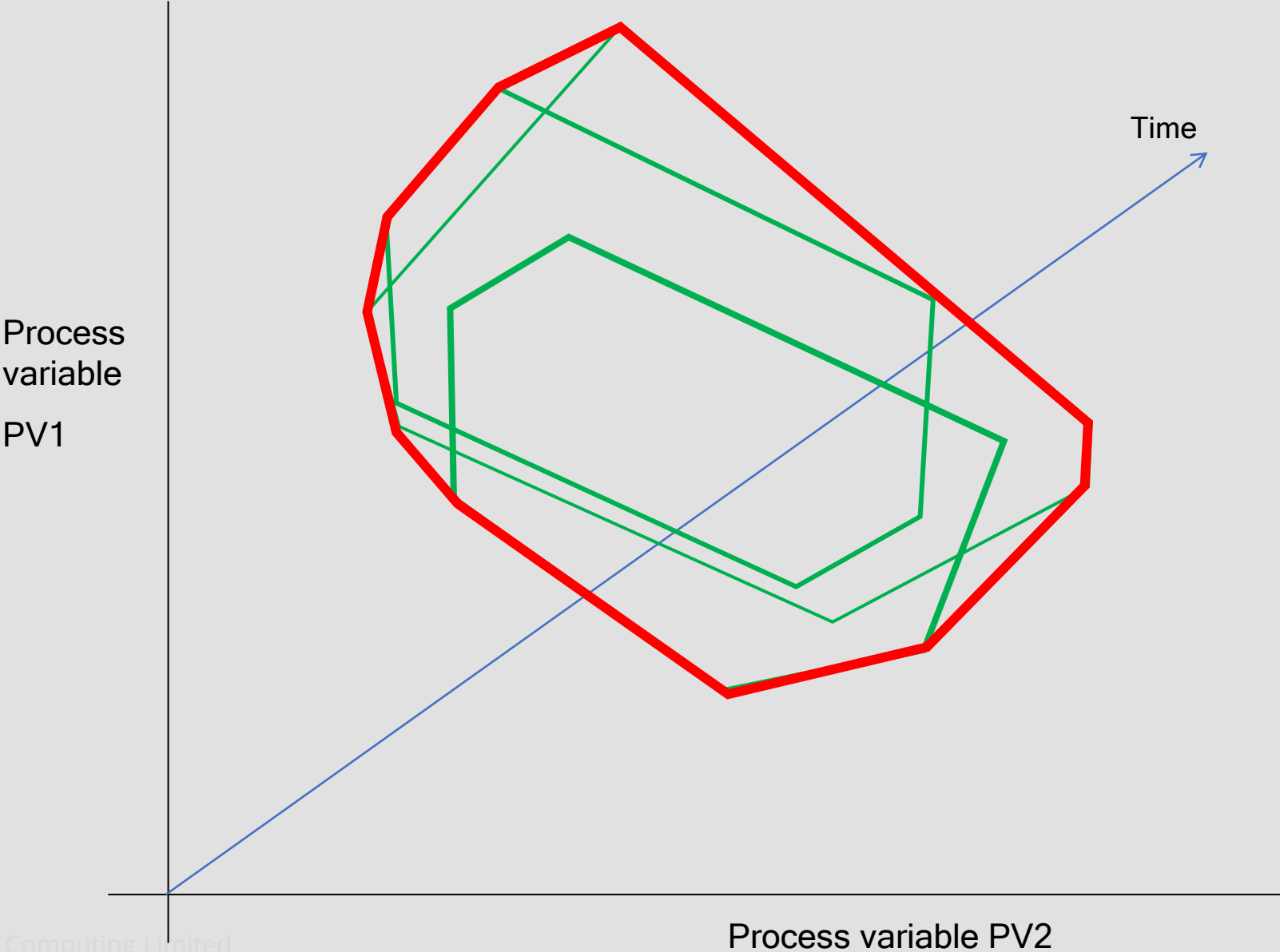


# 2-D Schematic of Operating Envelope

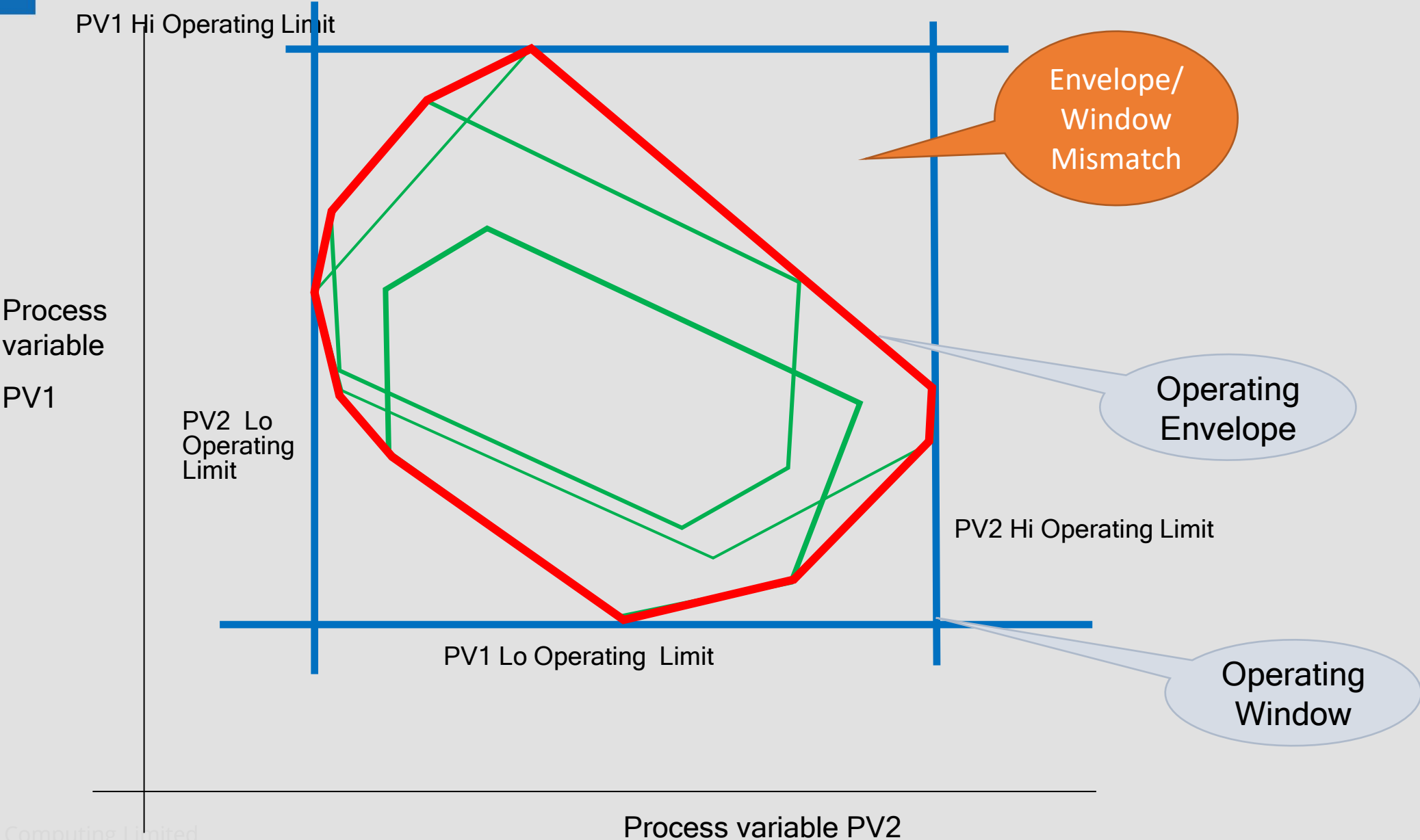




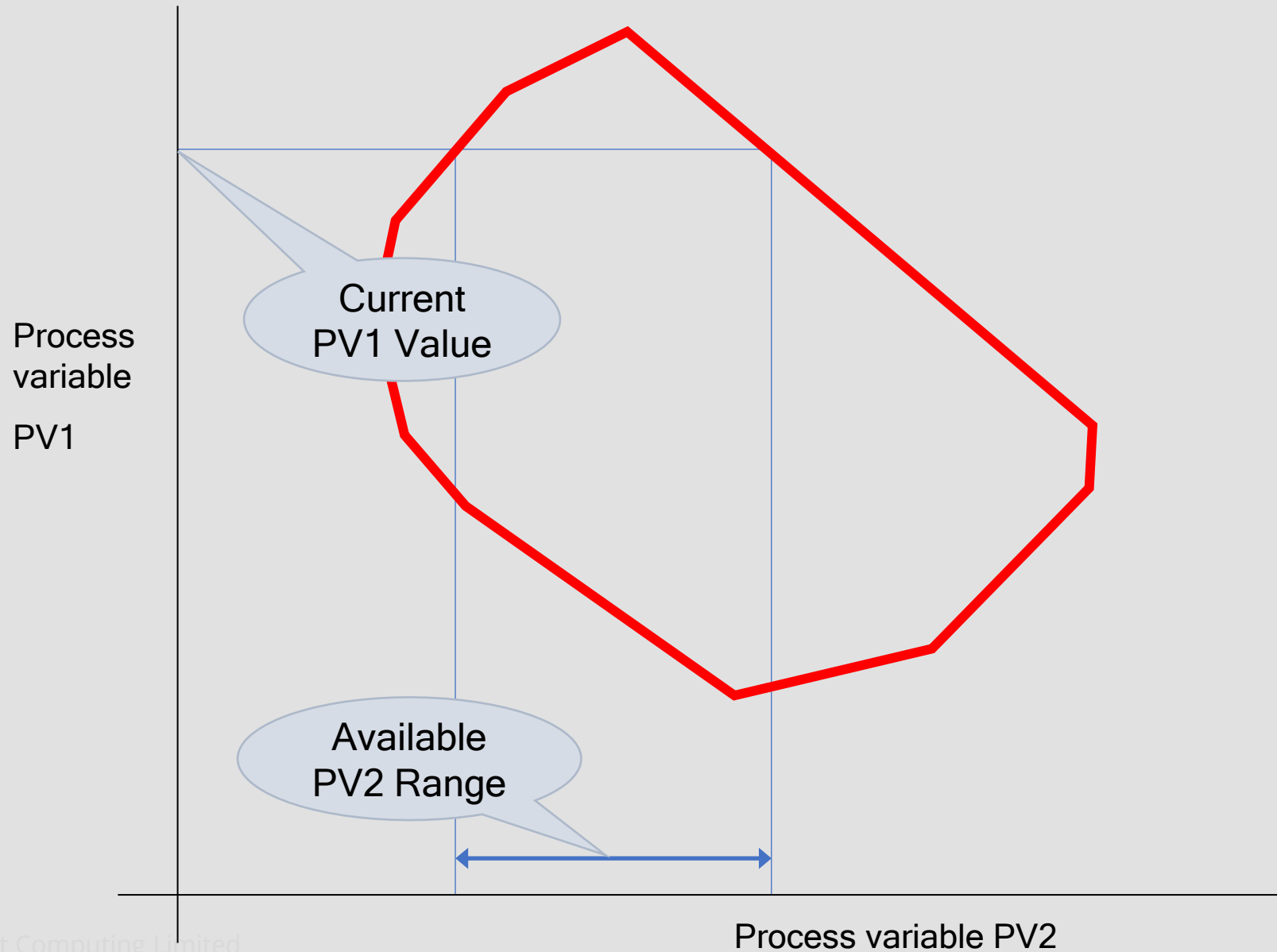
# Intersections Progress with Time



# Operating Limits - Operating Windows - Operating Envelopes

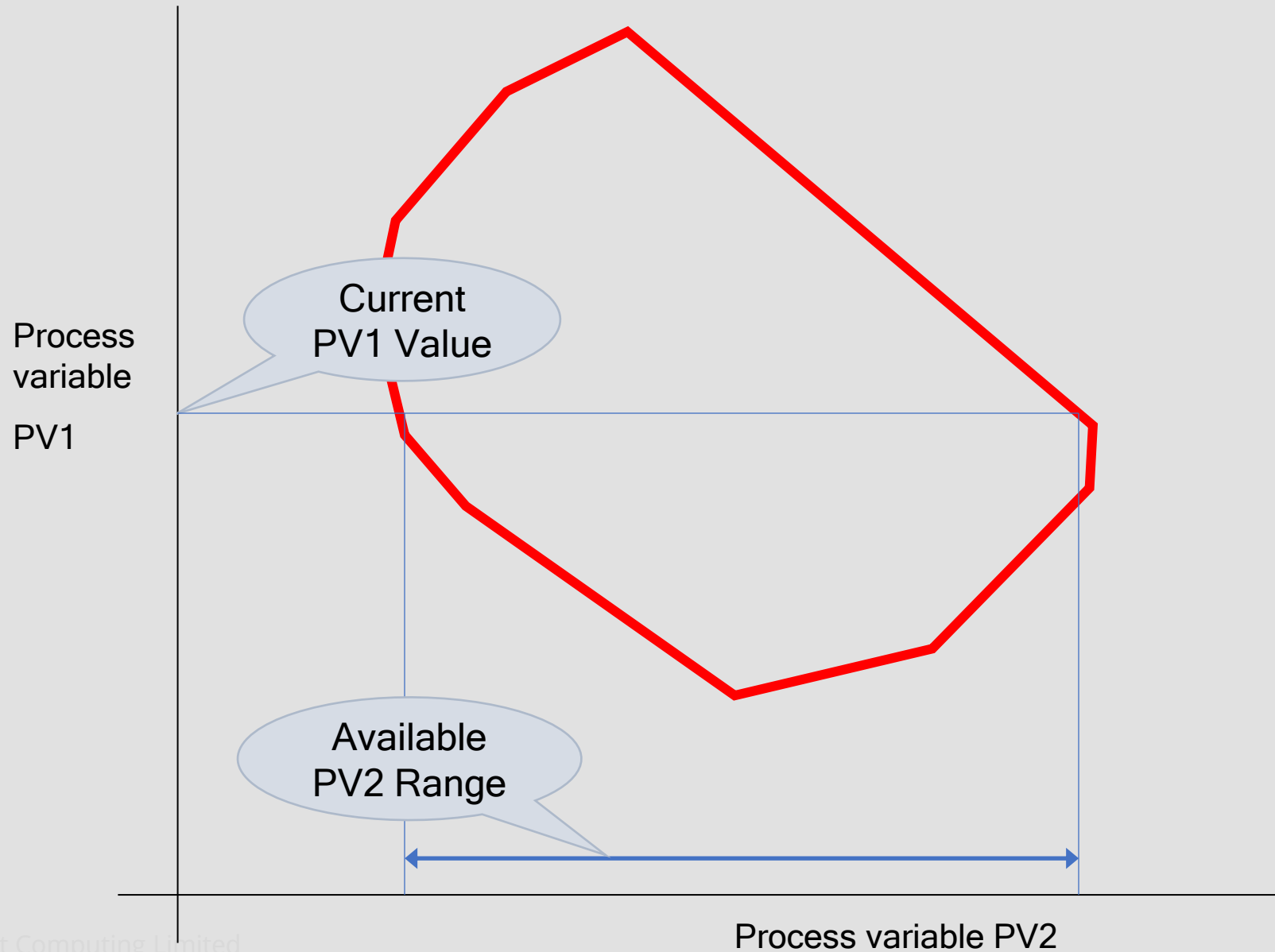


# CPM: Dynamic Ranges from Operating Envelope





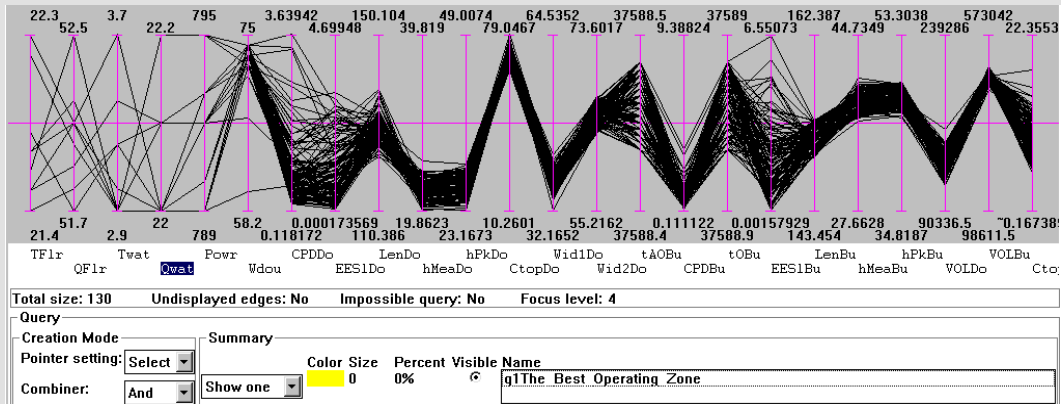
# CPM: Dynamic Ranges from Operating Envelope



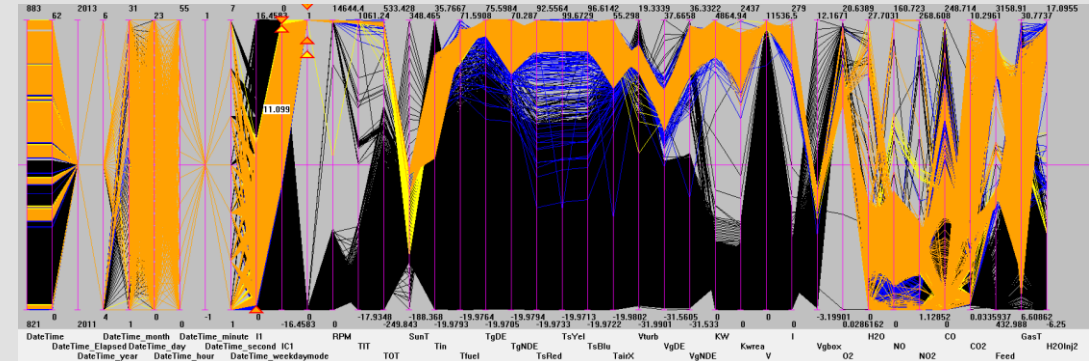
# CPM Operator Display



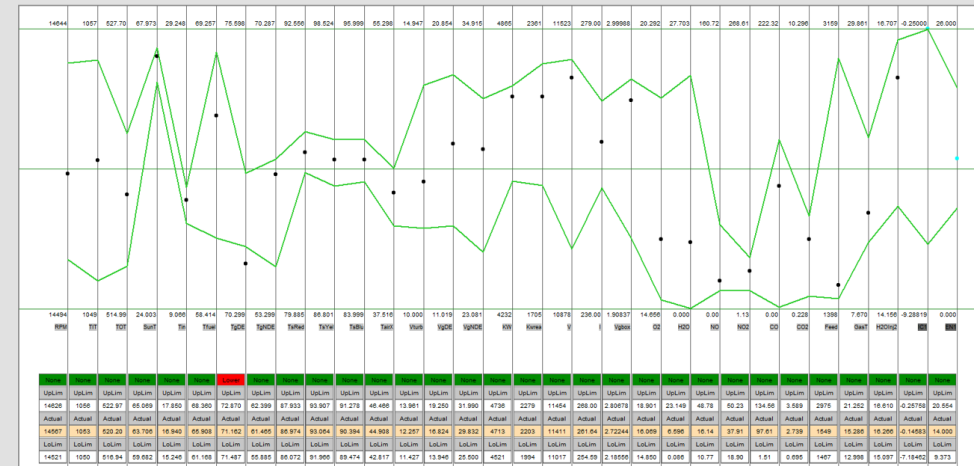
- Using Visual Explorer, decide with hindsight where the plant should have operated by applying objectives (e.g. normal operation) as a query.



- Open the file in Process Modeller. In real time, the current operation and envelope limits are shown to the operator



- 'Focus' on the selected points, remove unwanted variables and save the points. These represent best past experience to be targeted in the future.









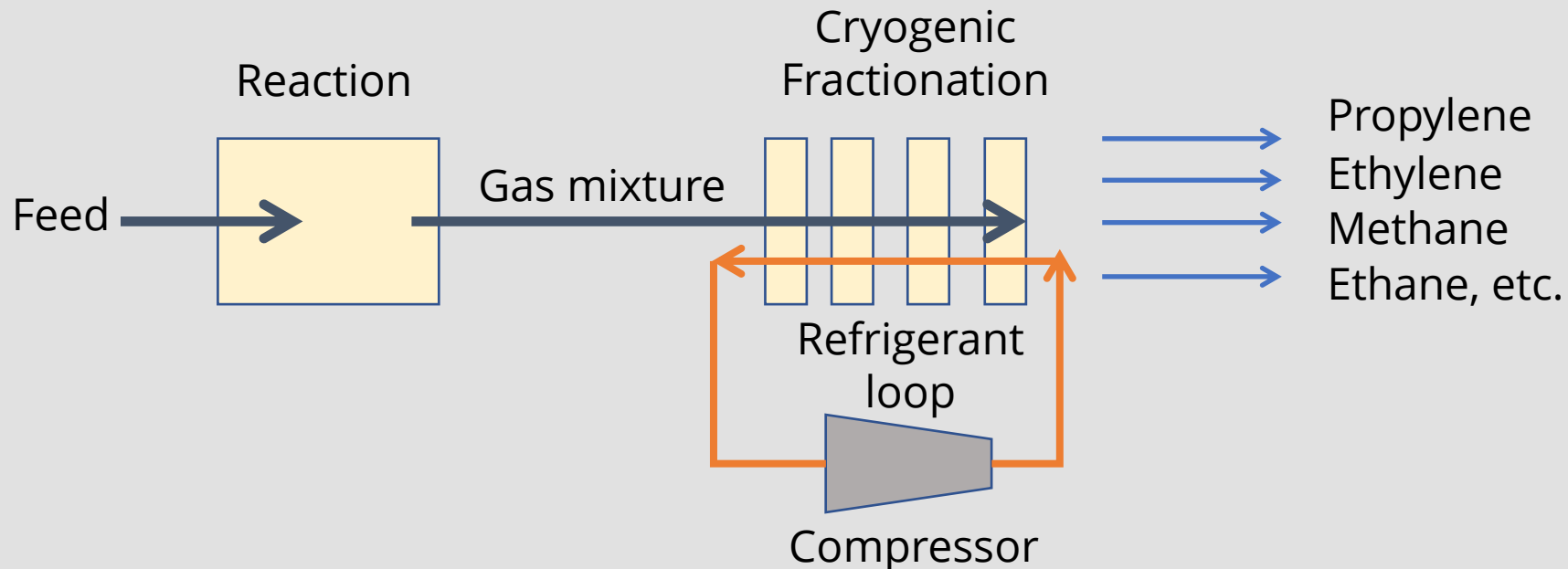
# Early Event Warning: Multi-Stage Compressor

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**Warning of impending surge event  
in an ethylene refrigeration compressor**

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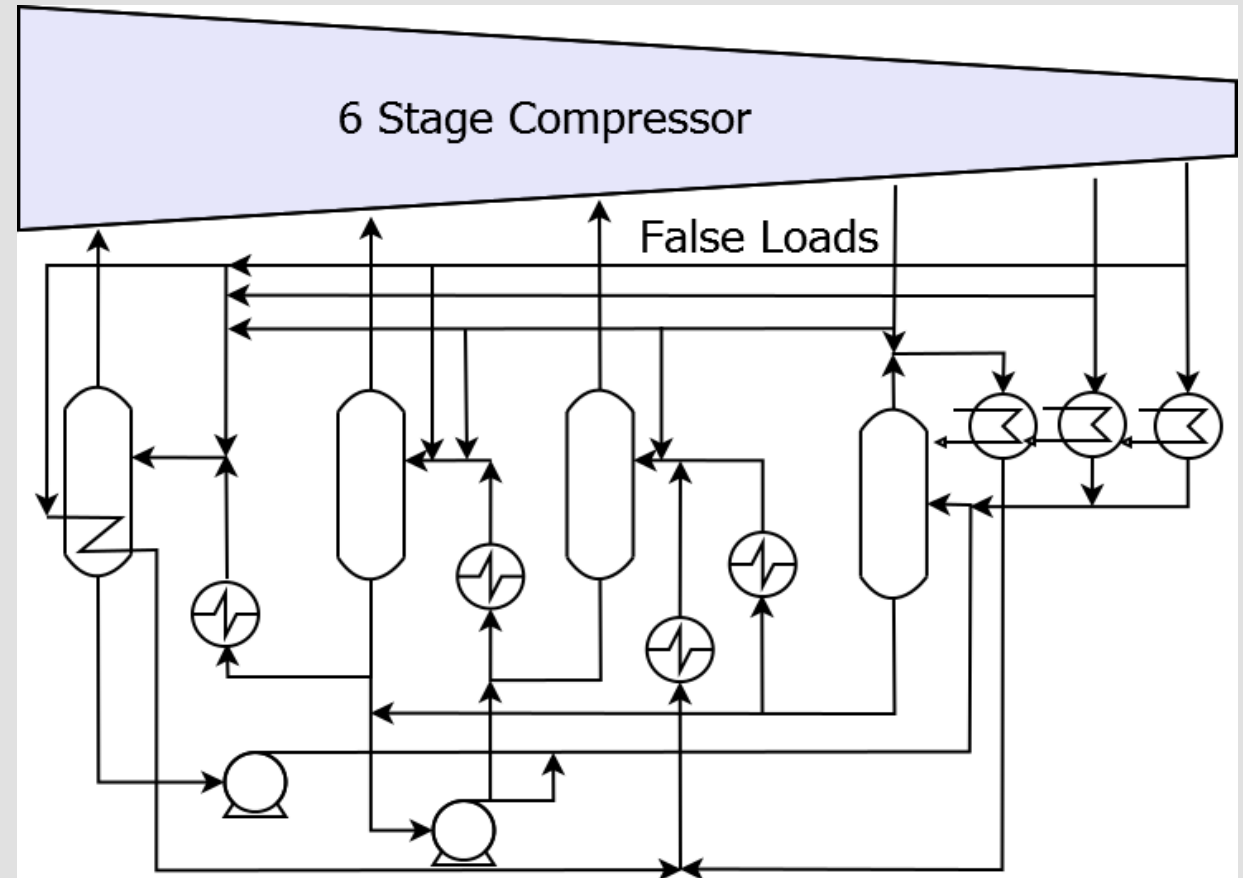
- Operation near surge offers best efficiency
- Process and external disturbances have potential to push compressor toward surge
- JT valves near compressor protect from surge but process can take hours to recover following activation
- Operators manage process demand and false load to balance these





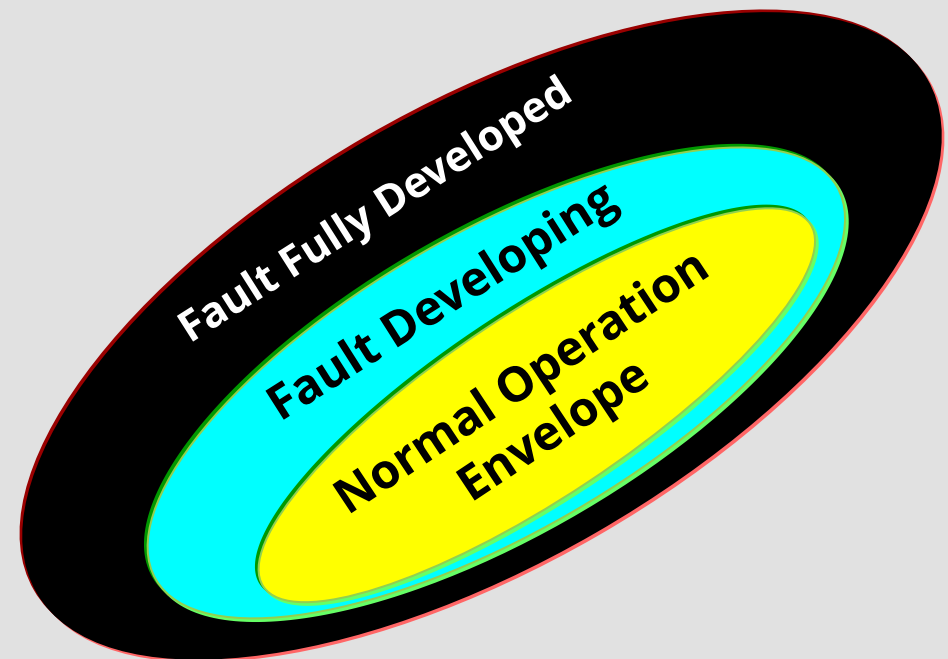
## Compressor surge

- Ethylene refrigeration system
- Long settling time because of interaction with the process
- Avoid conditions where surge is likely

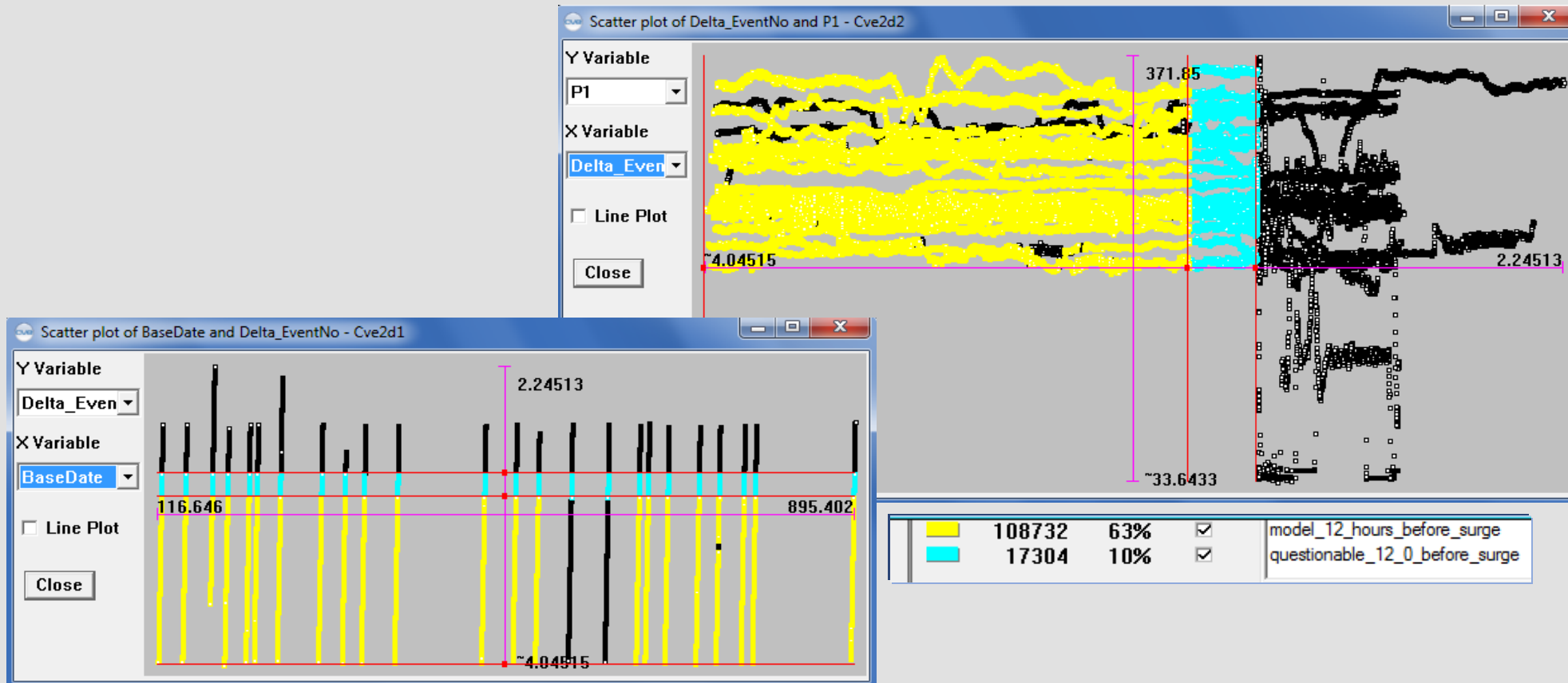


## Building the Geometric Model

- Create an envelope from past operation far from fault conditions (yellow)
- Avoid entering the fault condition black space
- Violations of the envelope in real-time increase in the turquoise space when approaching the fault condition
- Operations model, need warning times of many minutes so operator can act

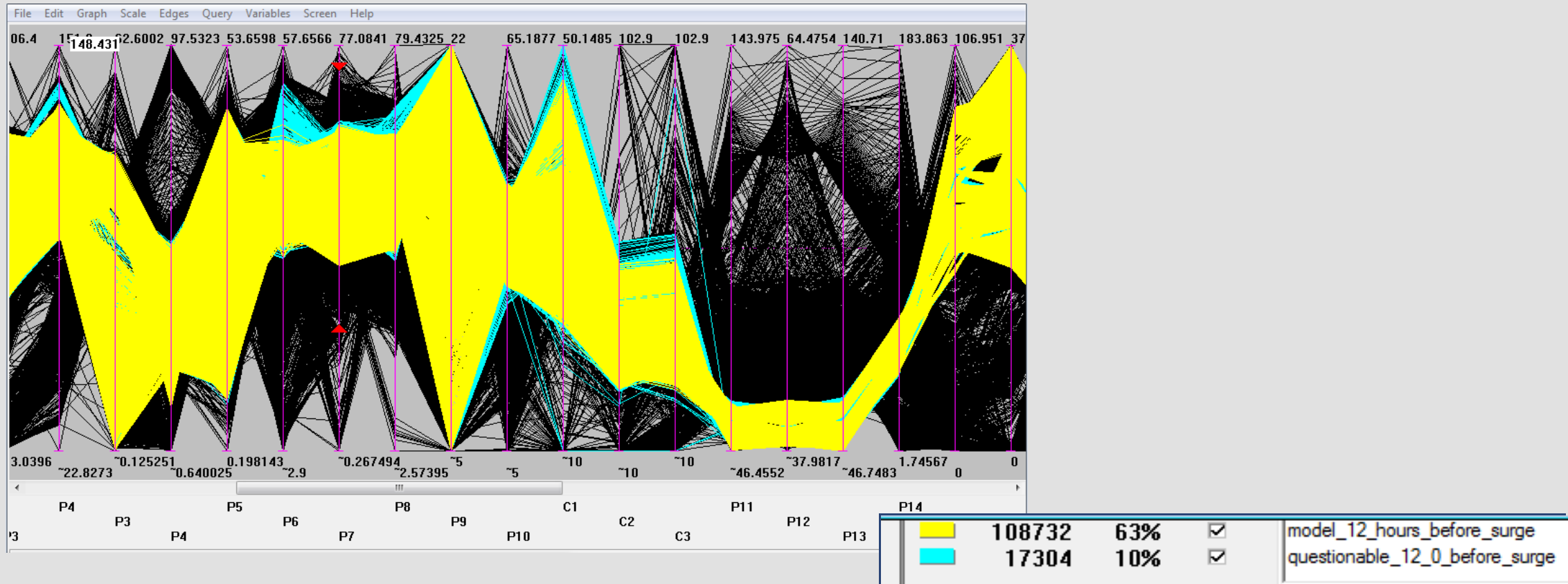


- Action of anti-surge valves is the onset of event
- Precursor period extends twelve hours before event





- Model lies within precursor data
- Single variable excursions provide little warning time





- Model run on 30 historic events
- 40% of surge events seen at least 15 minutes in advance
- 80% of surge events seen over 5 minutes in advance
- Extra time for operators to understand situation and make corrections



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# Fault Detection

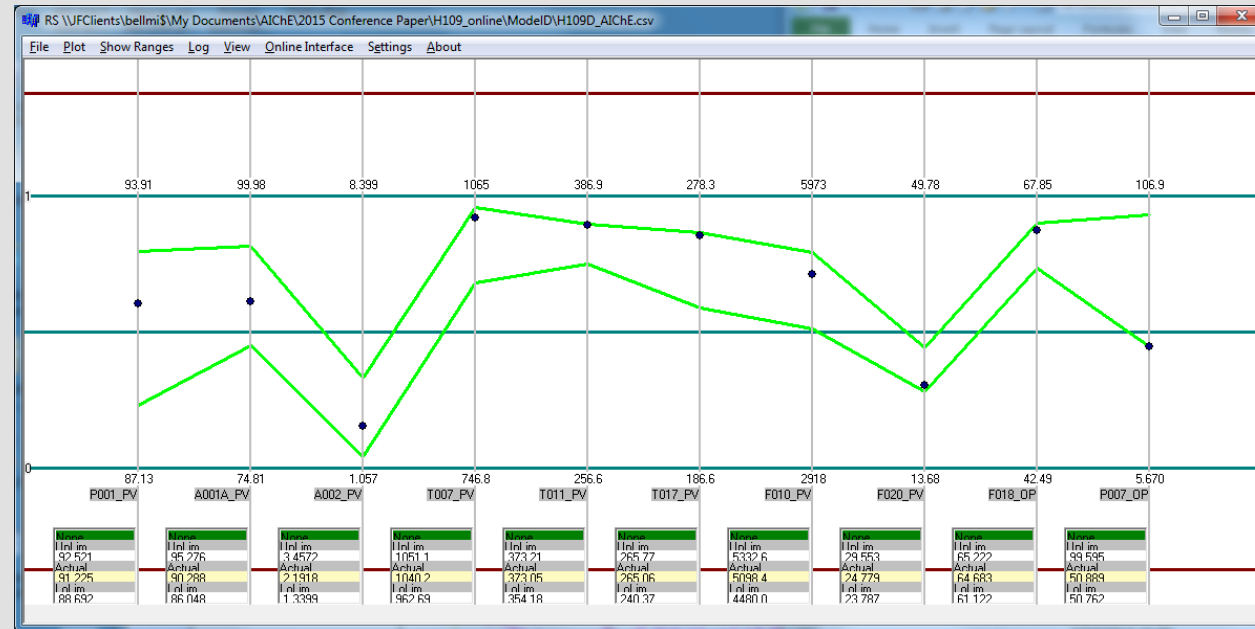
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## Ethylene Cracker Case Study

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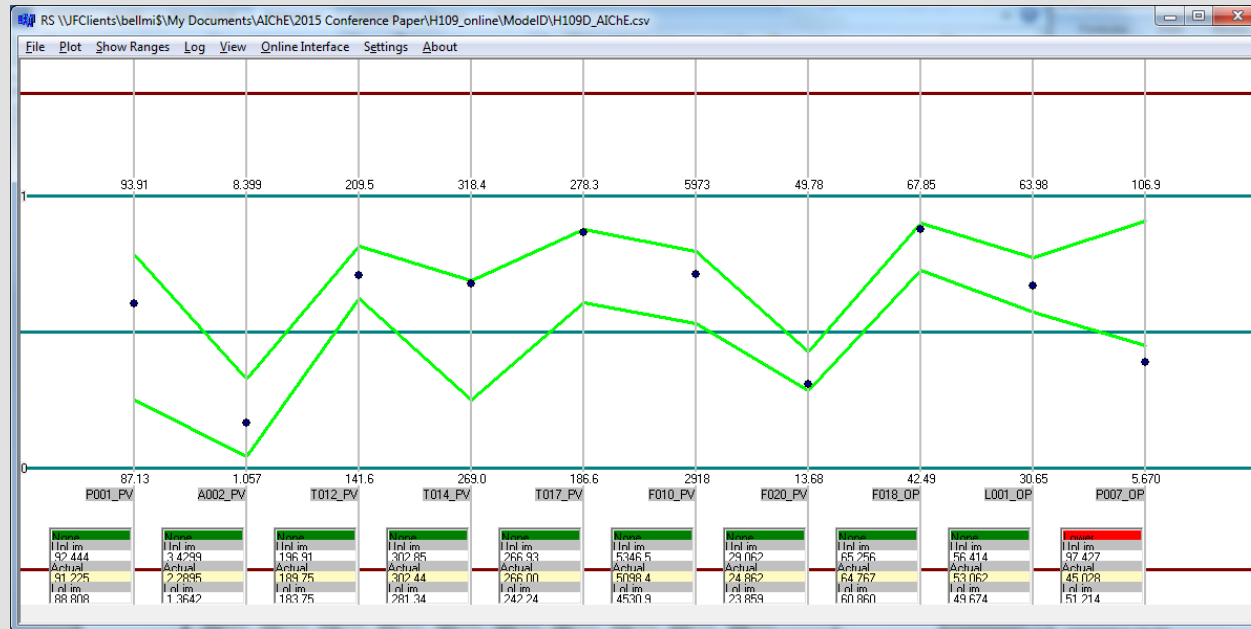


- 2 days 12 hours before event: Normal Operation



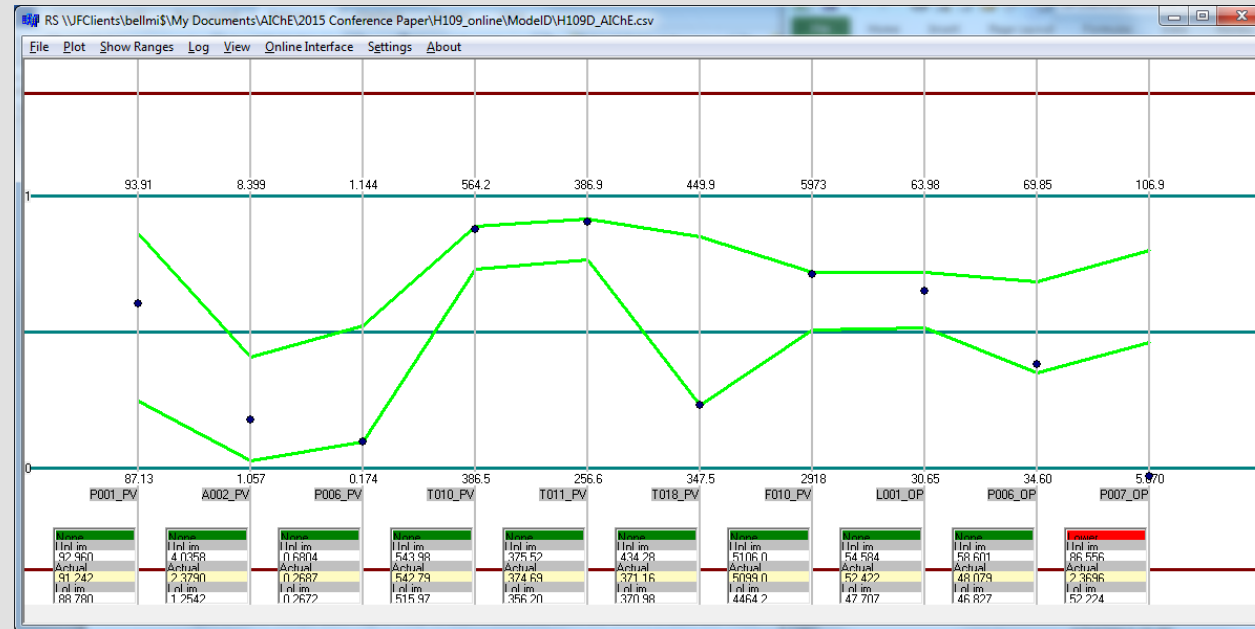
Reproduced courtesy of the author from "A Novel Approach to the Event Prediction and Mitigation Problem in an ethylene plant", Bell, M., Paper 098D, Proceedings of the AIChE Spring Conference 2015

- 2 days 11 hours before event: first deviation detected



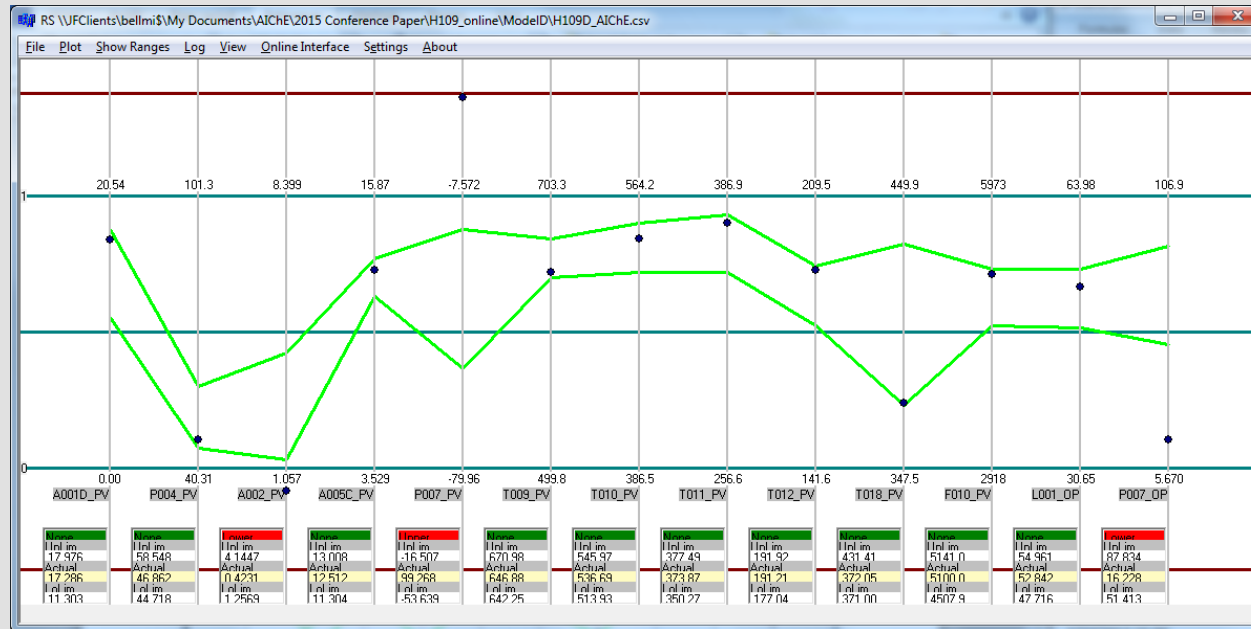
Reproduced courtesy of the author from "A Novel Approach to the Event Prediction and Mitigation Problem in an ethylene plant", Bell, M., Paper 098D, Proceedings of the AIChE Spring Conference 2015

- 1 day before event: large deviation



Reproduced courtesy of the author from “A Novel Approach to the Event Prediction and Mitigation Problem in an ethylene plant”, Bell, M., Paper 098D, Proceedings of the AIChE Spring Conference 2015

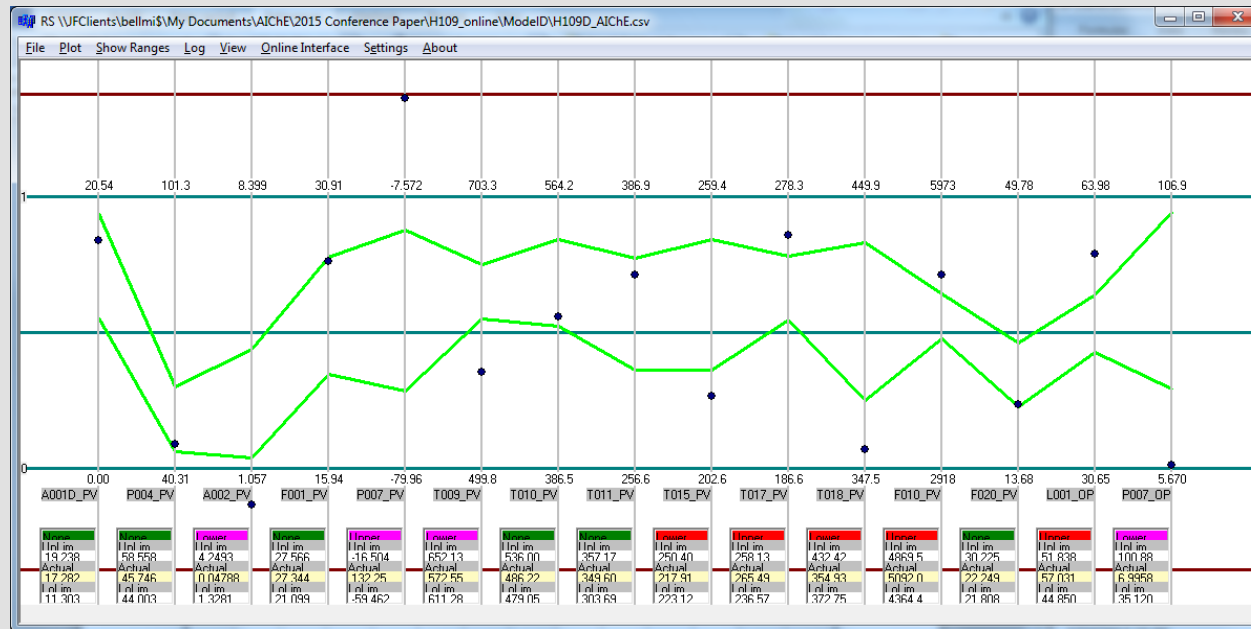
- 2 minutes before event: large deviations on three tags



Reproduced courtesy of the author from “A Novel Approach to the Event Prediction and Mitigation Problem in an ethylene plant”, Bell, M., Paper 098D, Proceedings of the AIChE Spring Conference 2015



- During event: multiple alerts as operator brings furnace down



Reproduced courtesy of the author from “A Novel Approach to the Event Prediction and Mitigation Problem in an ethylene plant”, Bell, M., Paper 098D, Proceedings of the AIChE Spring Conference 2015

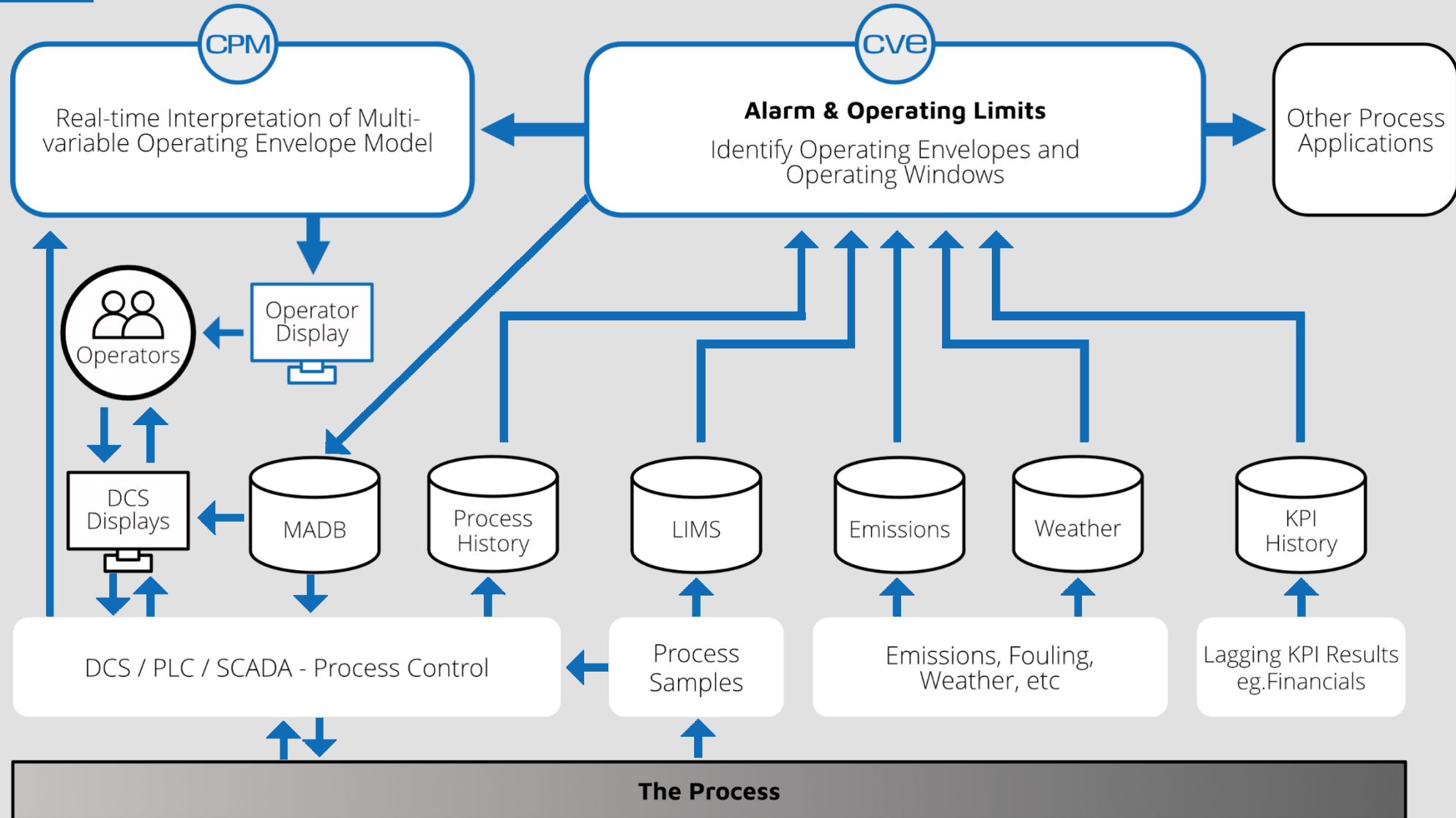
“The method successfully identified a historical significant furnace event almost two and one half days before the event occurred, flagging the exact instrument that was failing. The application has identified 3 significant events during its first 8 months of operation.

“CPM has been actively notifying the console operator of any abnormal process conditions to the furnace with an on stream time of 99.9%.”



- Affordable
  - No specialist math skills needed;
  - Models built & maintained by unit engineers in hours/days
- Extends condition monitoring to smaller equipment
  - Trip of a pump causes process disturbance that can take hours of costly settling out
  - Data to build models already present in historian
- Early indication of developing faults gives operators time to think and act
  - Better performance than PCA and PLS models
  - Indication of key variables in developing situation

# The Geometric Process Control Framework





The logo for Process Plant Computing Limited (PPCL) is displayed in white, bold, uppercase letters within a blue rectangular box. The background of the entire slide is a low-angle, upward-looking photograph of a complex industrial facility, likely a refinery or chemical plant, featuring a dense network of silver pipes, blue structural beams, and yellow safety railings, all illuminated by bright blue lights.

**PPCL**

**THANK YOU FOR YOUR TIME TODAY**

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**PPCL**