Learning from the Past to Prepare for the Future

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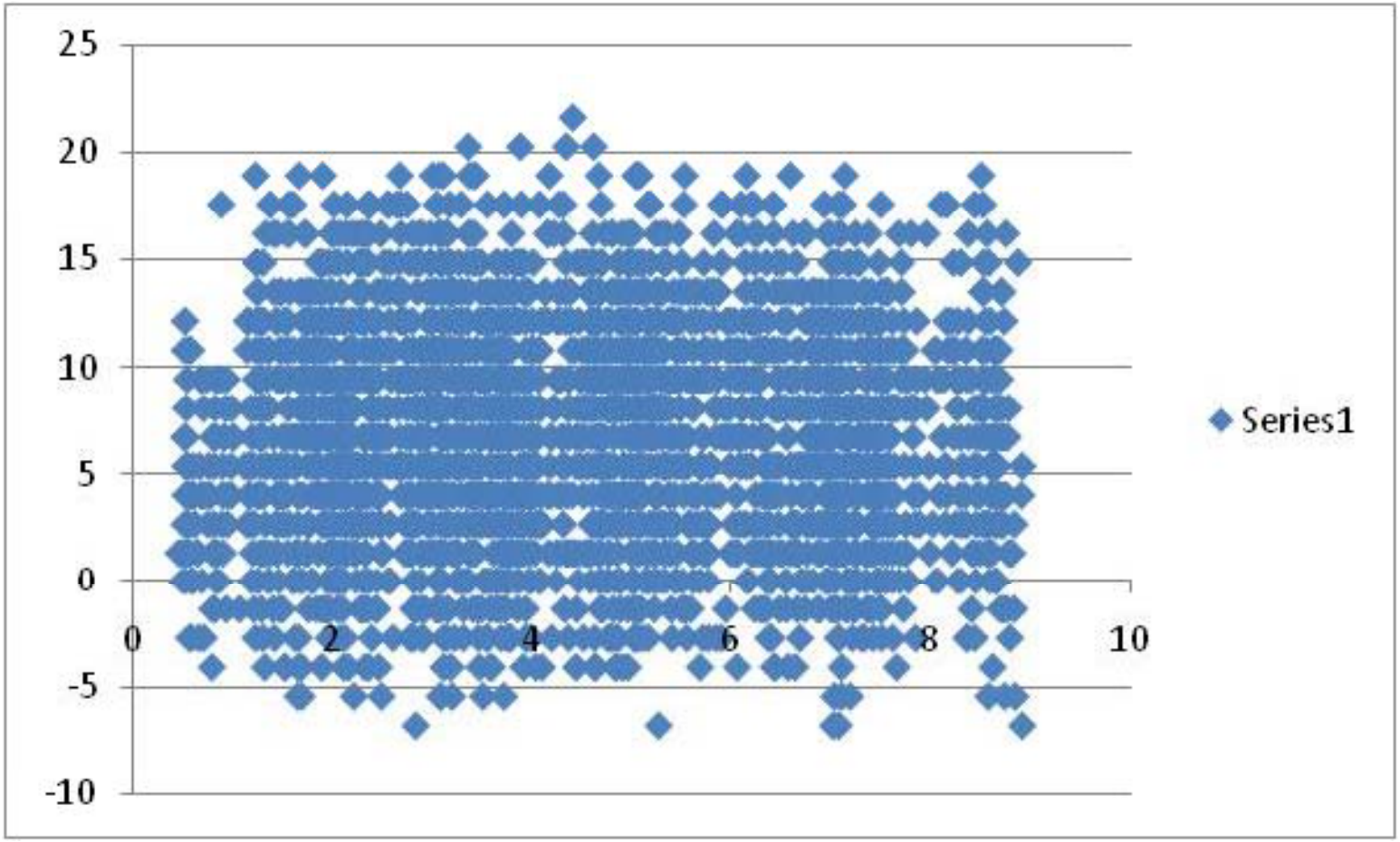
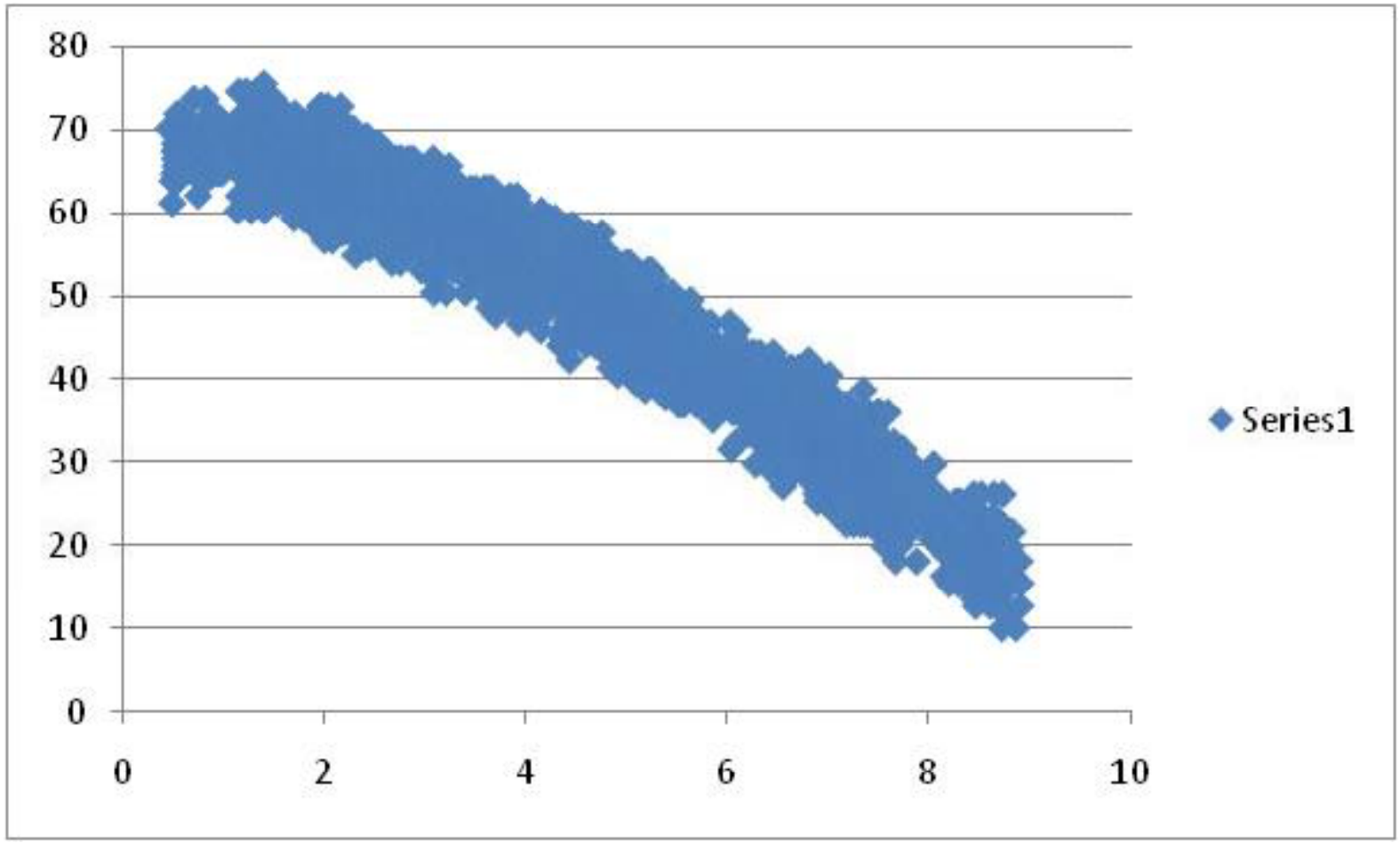
Motivation

- Power systems generate tremendous amounts of information
- In power system operation we usually have very similar operating conditions
- Data mining can be very useful for such situations
- Our approach often leverages knowledge of the underlying system model
- Data confidentiality is a significant concern

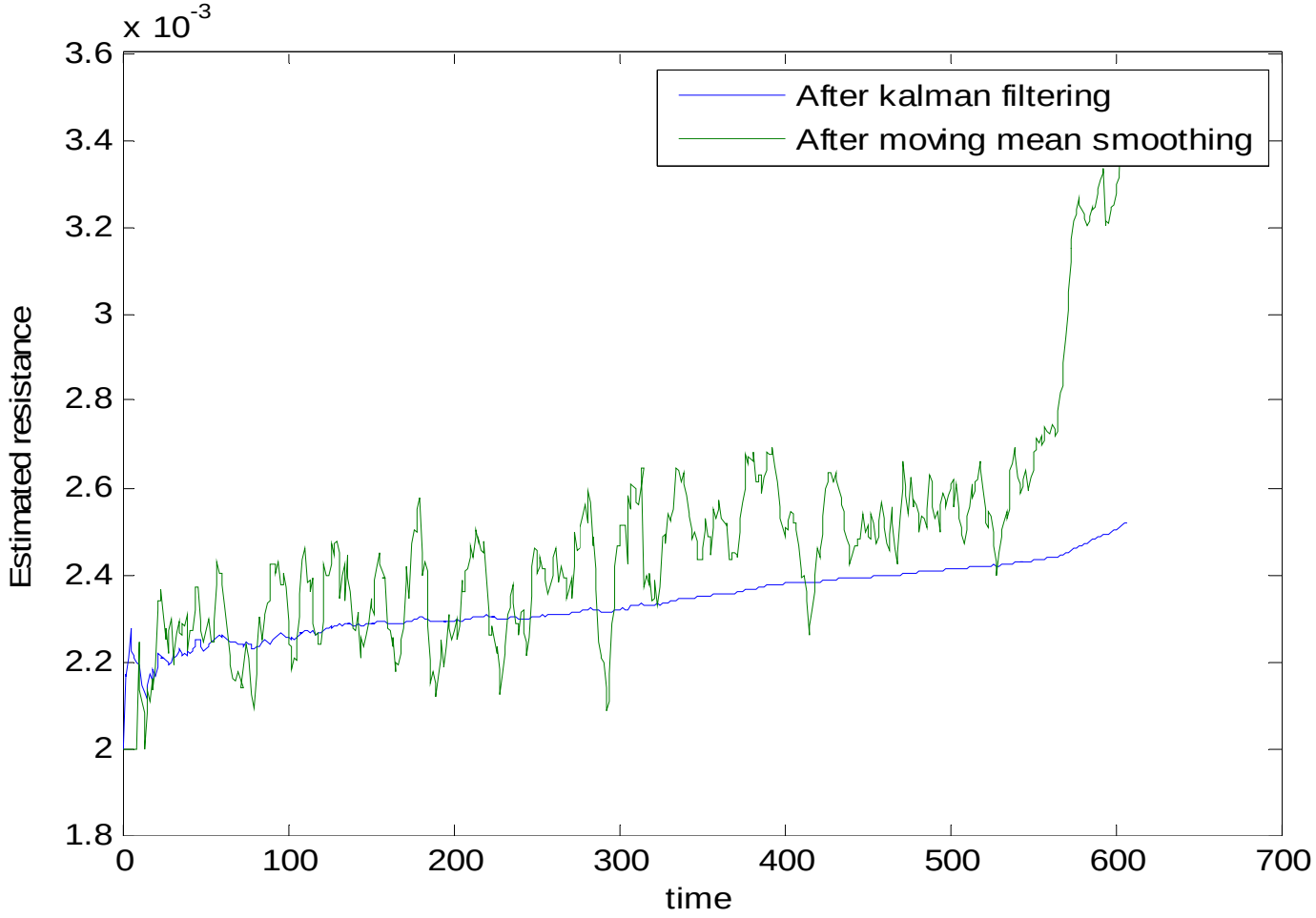
Making Sense of SCADA Data



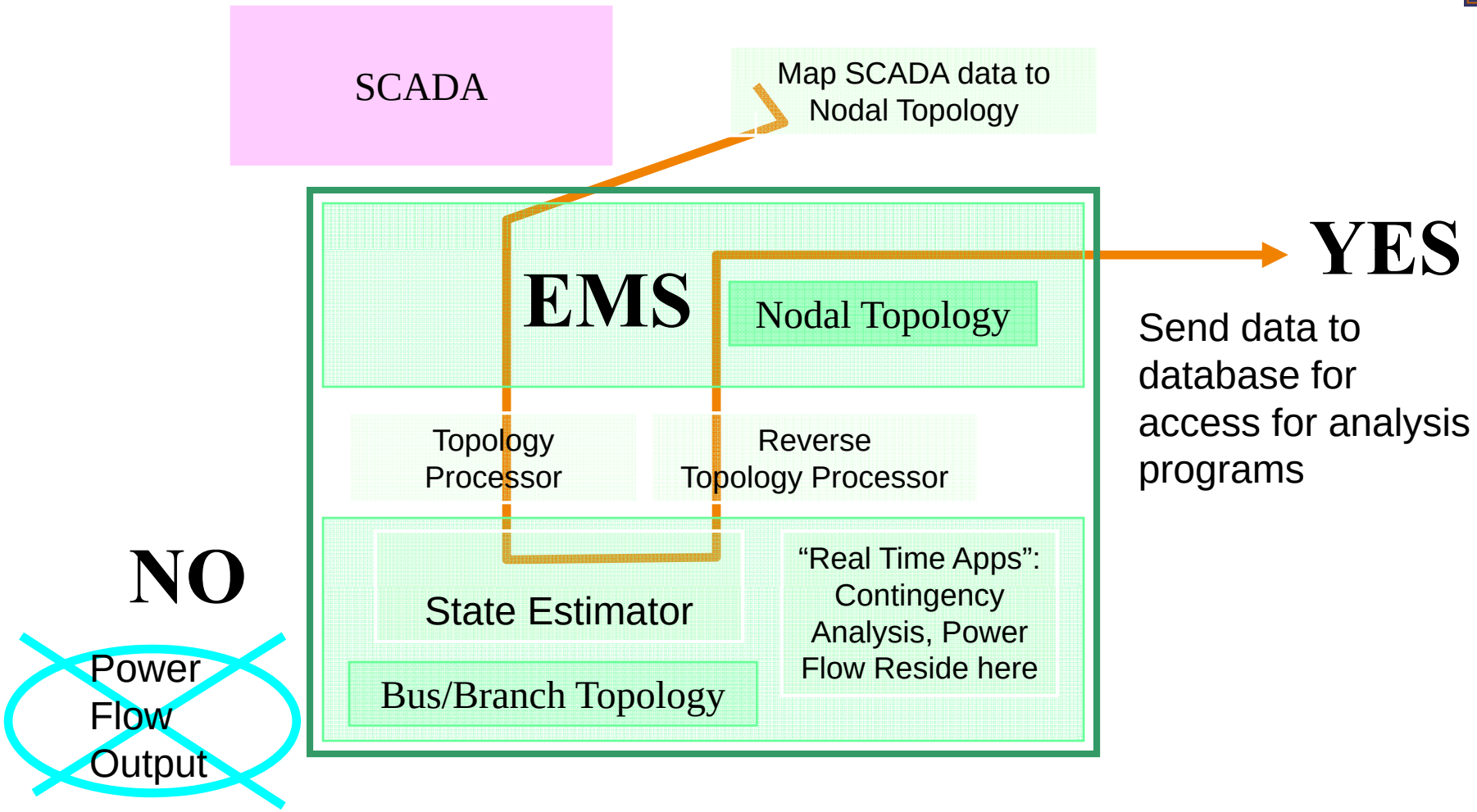
Making Sense of SCADA Data



Making Sense of SCADA Data



Where Should the Data Come From



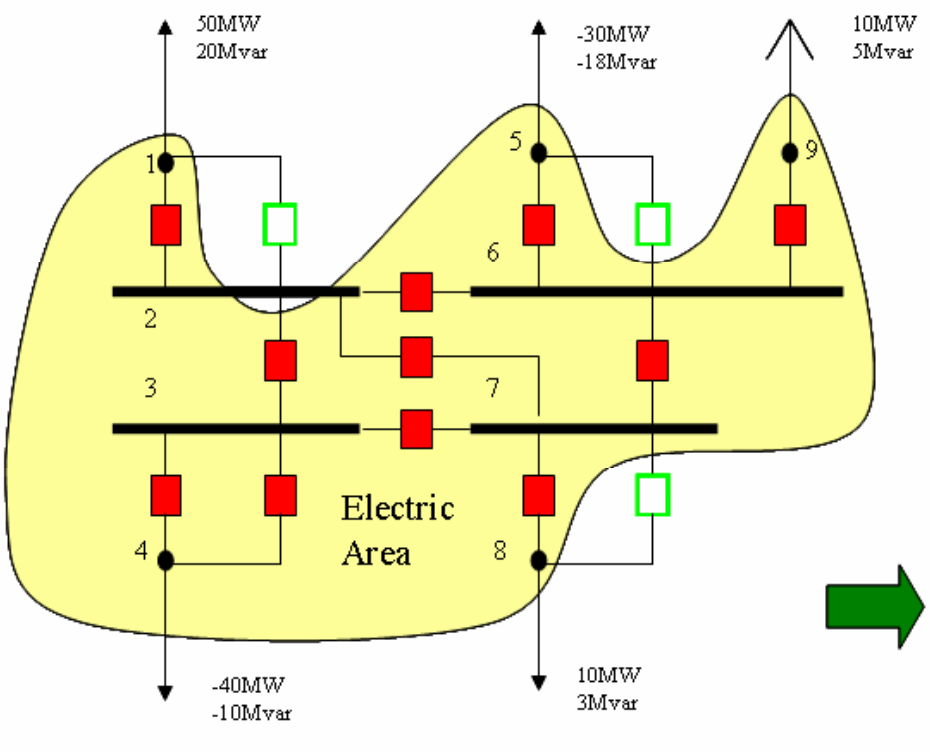
Real-Time and Planning Models

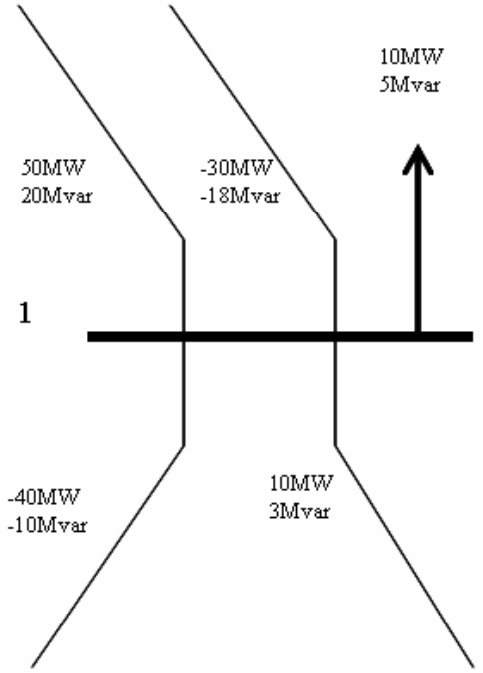
Real-Time Model

Node/breaker
Full topology

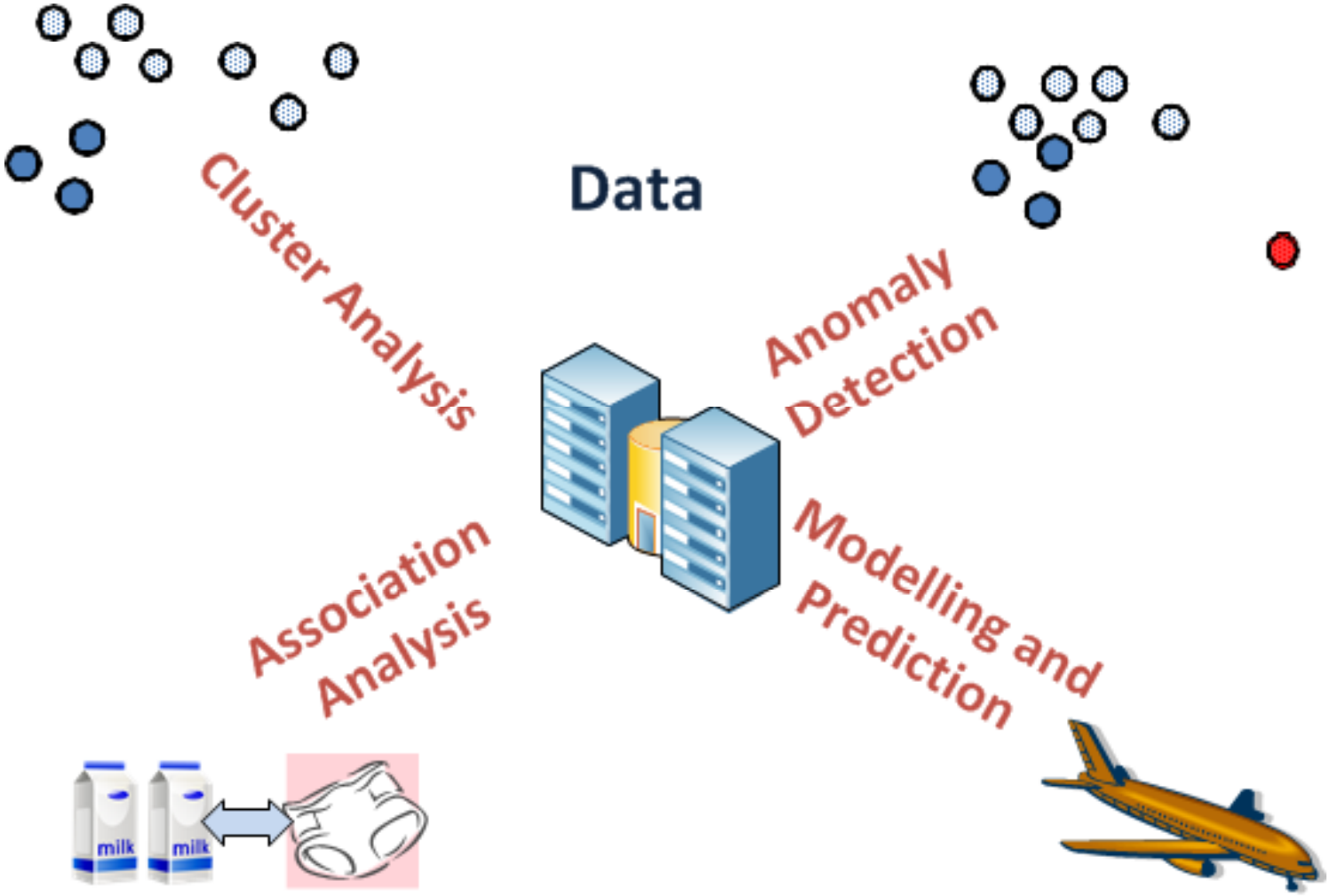
Planning Model

bus/branch
Consolidated



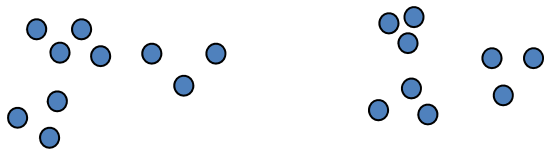


Some Broad Data Analysis Concepts



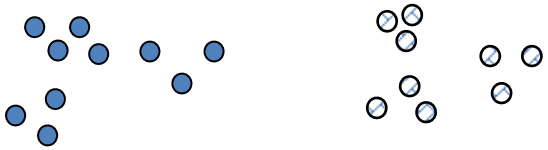
Cluster Analysis

- Cluster analysis is an important tool, but determining what is a cluster can be ambiguous



All Points

Four Clusters



Two Clusters

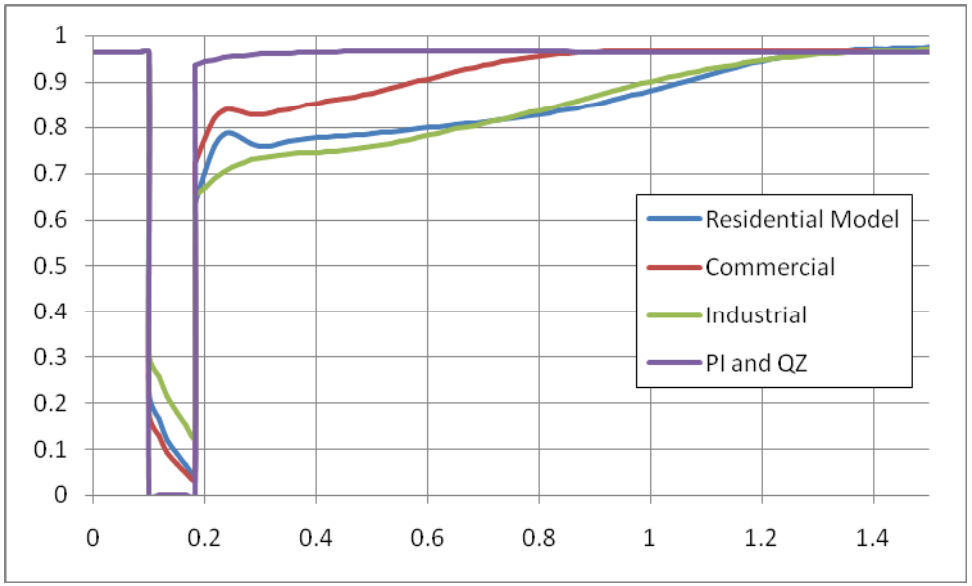
Six Clusters

Load Model Identification

- Transient stability and short-term voltage stability studies require dynamic load models
- Recent work in load modeling indicates that model parameters can vary substantially with time and location
  - Standard induction motor models do not well represent air conditioner compressor behavior
- Load model identification is facilitated by looking at voltage/frequency behavior during system faults with PMU/DFR data

Load Model Identification

- Since faults seldom occur at any particular system location, time
- But faults occur often enough that data mining techniques can be used to gradually infer more appropriate system models and parameters.



Var Police Application

- Goal is to know whether wind farms are doing the "right thing" with respect to reactive power support
- Should be able to look at reactive power and voltage data to form an idea of what is going on in the system
  - What are the operators doing?
  - What are they using to make their decisions?
  - Are certain variables being controlled with respect to certain other variables?
  - What switching actions have occurred and why?

Market Monitoring Application

Goal

- Enhance Real Time Market Monitoring tools to detect Market Power Potential.

Approach

- Combine Economic and Engineering models to determine when market participants may have an advantageous position in the market.

Impact

- Improve the efficiency and reliability of the electric power grid.

Motivation: Dispatch Sensitivity

$$\Delta g = M \Delta y$$

M is called the Dispatch Sensitivity Matrix

Dispatch Vector

Price Perturbation Vector

Identify sets of **non-substitutable generators**: They may adjust price without affecting dispatch

$$0 = M \Delta y$$

The price perturbation vector is not unique. For *(m-1)* constraints there are *m* independent vectors that satisfy this equation. For example, a vector of all ones, meaning the price is uniformly changed a each generator.

SVD and Null Space

- For an n by m matrix **A** (where n is the number of rows), the singular value decomposition (SVD) is

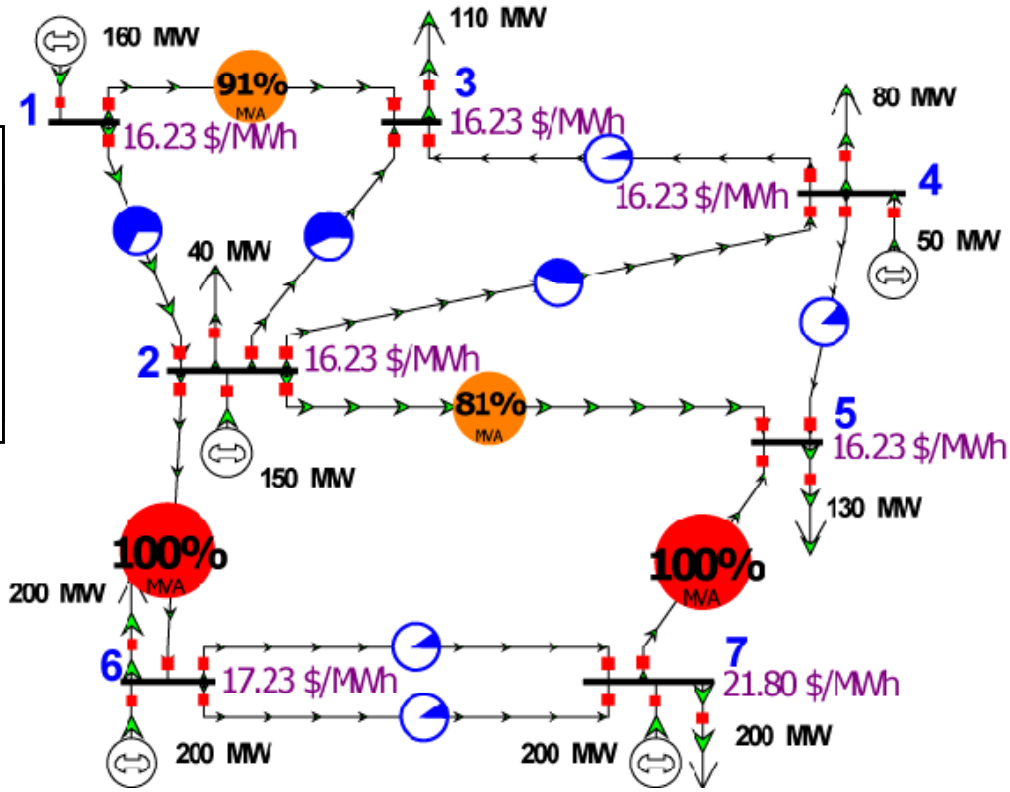
  $\mathbf{A} = \mathbf{U}\mathbf{D}\mathbf{V}^T$

  U = n by m column orthogonal matrix
  D = m by m diagonal matrix whose diagonals are the singular values
  V = m by m orthogonal matrix
- An orthogonal matrix is one were $\mathbf{V}\mathbf{V}^T = \mathbf{I}$
- The columns of **V** that correspond to the zero singular values form the orthonormal basis of the null space of **A**, which is what we need.

Example System

- The lines connecting buses (2, 6) and buses (5, 7) are constrained, resulting in higher LMPs at buses 6 and 7.

$$\mathbf{S} = \begin{array}{c} \\ \textit{Gen } 1 \\ \textit{Gen } 2 \\ \textit{Gen } 4 \\ \textit{Gen } 6 \\ \textit{Gen } 7 \end{array} \begin{array}{c} \begin{array}{c} P_{flow(2,6)} \end{array} \\ \begin{bmatrix} 0.23 \\ 0.24 \\ 0.17 \\ -0.58 \\ -0.21 \end{bmatrix} \end{array} \begin{array}{c} \begin{array}{c} P_{flow(5,7)} \end{array} \\ \begin{bmatrix} -0.06 \\ -0.05 \\ -0.11 \\ 0.14 \\ 0.50 \end{bmatrix} \end{array} \begin{bmatrix} 1.00 \\ 1.00 \\ 1.00 \\ 1.00 \\ 1.00 \end{bmatrix}$$



- Can already see suggestive patterns in the elements of **S**

Algorithm

- For the set of binding line constraints, determine the sensitivity of the line flow (or other constraint) with respect to each of the generators of interest
  - Augment with a column of all ones
  - Computationally identical to determining the tableau for an LP OPF
  - Assume there are (m-1) constraints, n generators, with n >> m
- Use a Singular Value Decomposition to obtain an orthonormal basis matrix
  - the SVD computational order is mn^2 so this step is quite quick

Algorithm

- Do cluster analysis to group generators
  - Quality Threshold (QT) - does not require a number of clusters do not need to be specified, is deterministic, but is order n^2 and requires specifying a distance threshold
  - K-means - much faster but requires user to specify number of clusters *a priori*, clusters depend on starting point
- Perform eigenvector analysis and visualize results

Small Example Solution

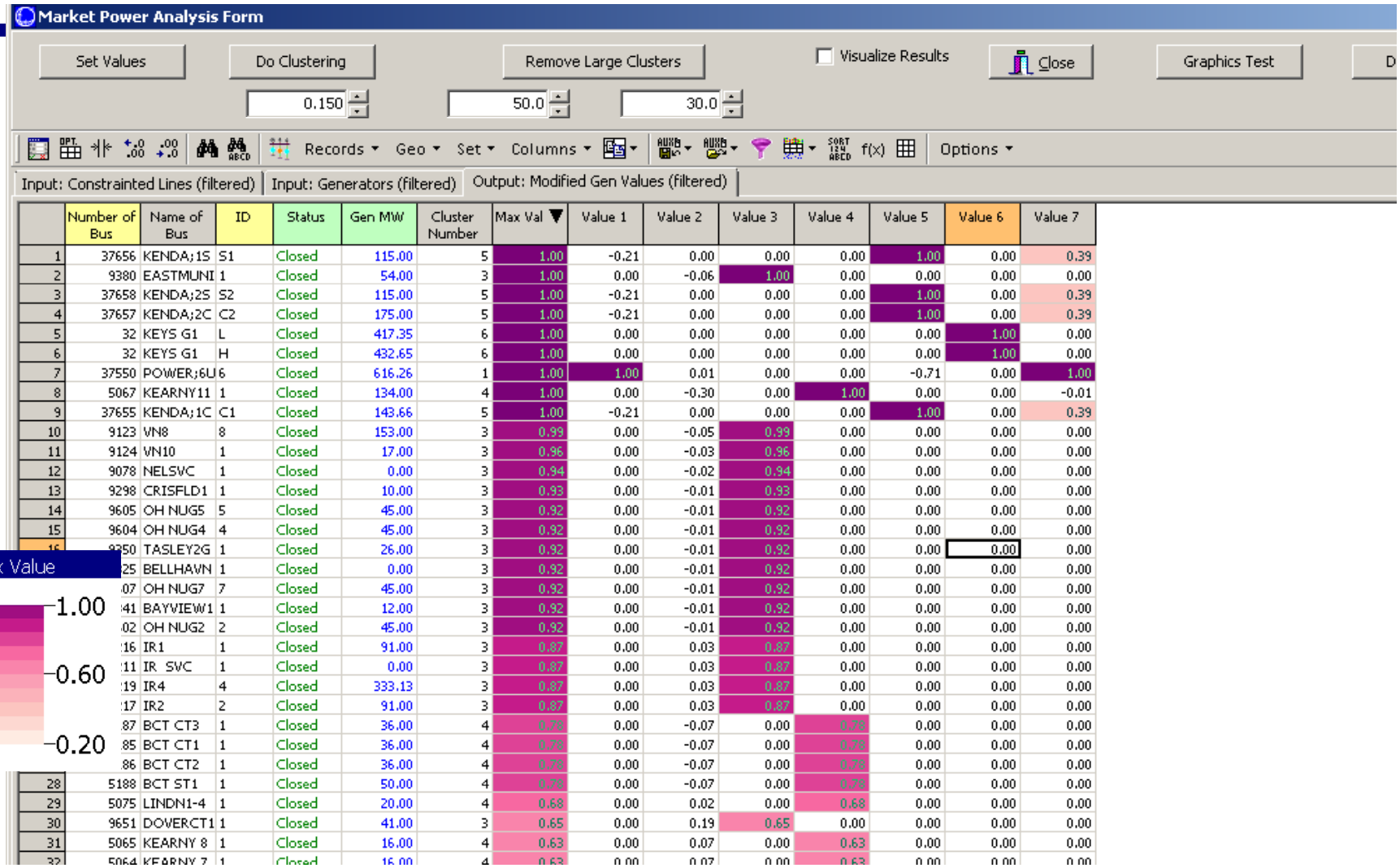
This is an eigenvalue problem with the solution that x is the eigenvector associated with the largest eigenvalue of $(B_i^T B_i - B_{-i}^T B_{-i})$. Solve this problem for each cluster.

For the seven-bus example-

$$[\Delta \mathbf{y}_{CL\#1}, \Delta \mathbf{y}_{CL\#2}, \Delta \mathbf{y}_{CL\#3}] = \begin{array}{c} \\ Gen\ 1 \\ Gen\ 2 \\ Gen\ 4 \\ Gen\ 6 \\ Gen\ 7 \end{array} \begin{array}{c} \begin{array}{ccc} CL\#1 & CL\#2 & CL\#3 \end{array} \\ \begin{bmatrix} 0.04 & -0.04 & 1.00 \\ 0.07 & -0.07 & 1.00 \\ -0.11 & 0.11 & 1.00 \\ 0.02 & 1.00 & 0.00 \\ 1.00 & 0.02 & 0.00 \end{bmatrix} \end{array}$$

Examine the result. If there are large entries outside the cluster, add these to the "make-large" group, and repeat previous step.

Eastern Interconnect Example



	Number of Bus	Name of Bus	ID	Status	Gen MW	Cluster Number	Max Val	Value 1	Value 2	Value 3	Value 4	Value 5	Value 6	Value 7
1	37656	KENDA;1S	S1	Closed	115.00	5	1.00	-0.21	0.00	0.00	0.00	1.00	0.00	0.39
2	9380	EASTMUNI	1	Closed	54.00	3	1.00	0.00	-0.06	1.00	0.00	0.00	0.00	0.00
3	37658	KENDA;2S	S2	Closed	115.00	5	1.00	-0.21	0.00	0.00	0.00	1.00	0.00	0.39
4	37657	KENDA;2C	C2	Closed	175.00	5	1.00	-0.21	0.00	0.00	0.00	1.00	0.00	0.39
5	32	KEYS G1	L	Closed	417.35	6	1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
6	32	KEYS G1	H	Closed	432.65	6	1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
7	37550	POWER;6U	6	Closed	616.26	1	1.00	1.00	0.01	0.00	0.00	-0.71	0.00	1.00
8	5067	KEARNY11	1	Closed	134.00	4	1.00	0.00	-0.30	0.00	1.00	0.00	0.00	-0.01
9	37655	KENDA;1C	C1	Closed	143.66	5	1.00	-0.21	0.00	0.00	0.00	1.00	0.00	0.39
10	9123	VN8	8	Closed	153.00	3	0.99	0.00	-0.05	0.99	0.00	0.00	0.00	0.00
11	9124	VN10	1	Closed	17.00	3	0.96	0.00	-0.03	0.96	0.00	0.00	0.00	0.00
12	9078	NELSVC	1	Closed	0.00	3	0.94	0.00	-0.02	0.94	0.00	0.00	0.00	0.00
13	9298	CRISFLD1	1	Closed	10.00	3	0.93	0.00	-0.01	0.93	0.00	0.00	0.00	0.00
14	9605	OH NUG5	5	Closed	45.00	3	0.92	0.00	-0.01	0.92	0.00	0.00	0.00	0.00
15	9604	OH NUG4	4	Closed	45.00	3	0.92	0.00	-0.01	0.92	0.00	0.00	0.00	0.00
16	9250	TASLEY2G	1	Closed	26.00	3	0.92	0.00	-0.01	0.92	0.00	0.00	0.00	0.00
	25	BELLHAVN	1	Closed	0.00	3	0.92	0.00	-0.01	0.92	0.00	0.00	0.00	0.00
	07	OH NUG7	7	Closed	45.00	3	0.92	0.00	-0.01	0.92	0.00	0.00	0.00	0.00
	41	BAYVIEW1	1	Closed	12.00	3	0.92	0.00	-0.01	0.92	0.00	0.00	0.00	0.00
	02	OH NUG2	2	Closed	45.00	3	0.92	0.00	-0.01	0.92	0.00	0.00	0.00	0.00
	16	IR1	1	Closed	91.00	3	0.87	0.00	0.03	0.87	0.00	0.00	0.00	0.00
	11	IR_SVC	1	Closed	0.00	3	0.87	0.00	0.03	0.87	0.00	0.00	0.00	0.00
	19	IR4	4	Closed	333.13	3	0.87	0.00	0.03	0.87	0.00	0.00	0.00	0.00
	17	IR2	2	Closed	91.00	3	0.87	0.00	0.03	0.87	0.00	0.00	0.00	0.00
	87	BCT CT3	1	Closed	36.00	4	0.78	0.00	-0.07	0.00	0.78	0.00	0.00	0.00
	85	BCT CT1	1	Closed	36.00	4	0.78	0.00	-0.07	0.00	0.78	0.00	0.00	0.00
	86	BCT CT2	1	Closed	36.00	4	0.78	0.00	-0.07	0.00	0.78	0.00	0.00	0.00
28	5188	BCT ST1	1	Closed	50.00	4	0.78	0.00	-0.07	0.00	0.78	0.00	0.00	0.00
29	5075	LINDN1-4	1	Closed	20.00	4	0.68	0.00	0.02	0.00	0.68	0.00	0.00	0.00
30	9651	DOVERCT1	1	Closed	41.00	3	0.65	0.00	0.19	0.65	0.00	0.00	0.00	0.00
31	5065	KEARNY 8	1	Closed	16.00	4	0.63	0.00	0.07	0.00	0.63	0.00	0.00	0.00
32	5064	KEARNY 7	1	Closed	16.00	4	0.63	0.00	0.07	0.00	0.63	0.00	0.00	0.00

Questions?