

# Wafer Profile Indicator

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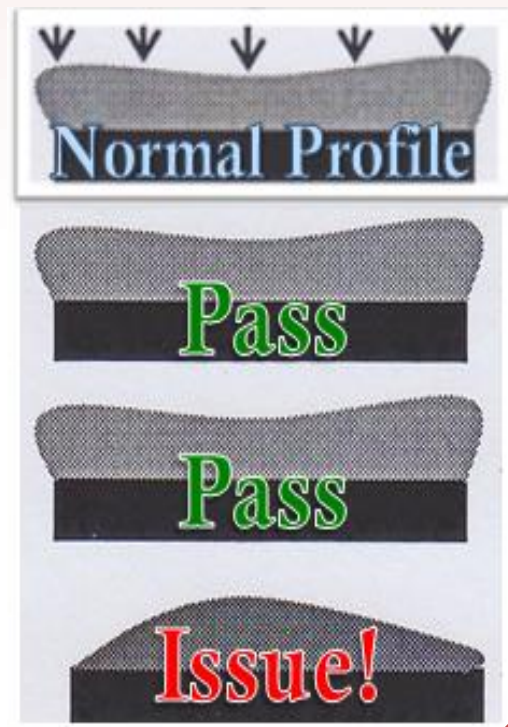
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## Problem Definition

Current process monitoring tools :

X-bar chart & Sigma Chart

- Detect abnormalities in the mean and the variance of a particular layer of the sample wafer in-line
- Unable to detect abnormalities in the profile of the layer in-line.
- Abnormalities only discovered near the end of the manufacturing process



## Objectives

Improve performance of the process by introducing a profile indicator that

- Detects wafers with profile issue in-line
- Utilizes the readily available data
- Minimizes "false-alarm"

## Approach

Wafer Profile Indicator

Define Problem & Objectives

Understand Wafer Fabrication

- Logistic Regression
- Support Vectors Machine

Generate Models

Conclusion

Implement the profile indicator

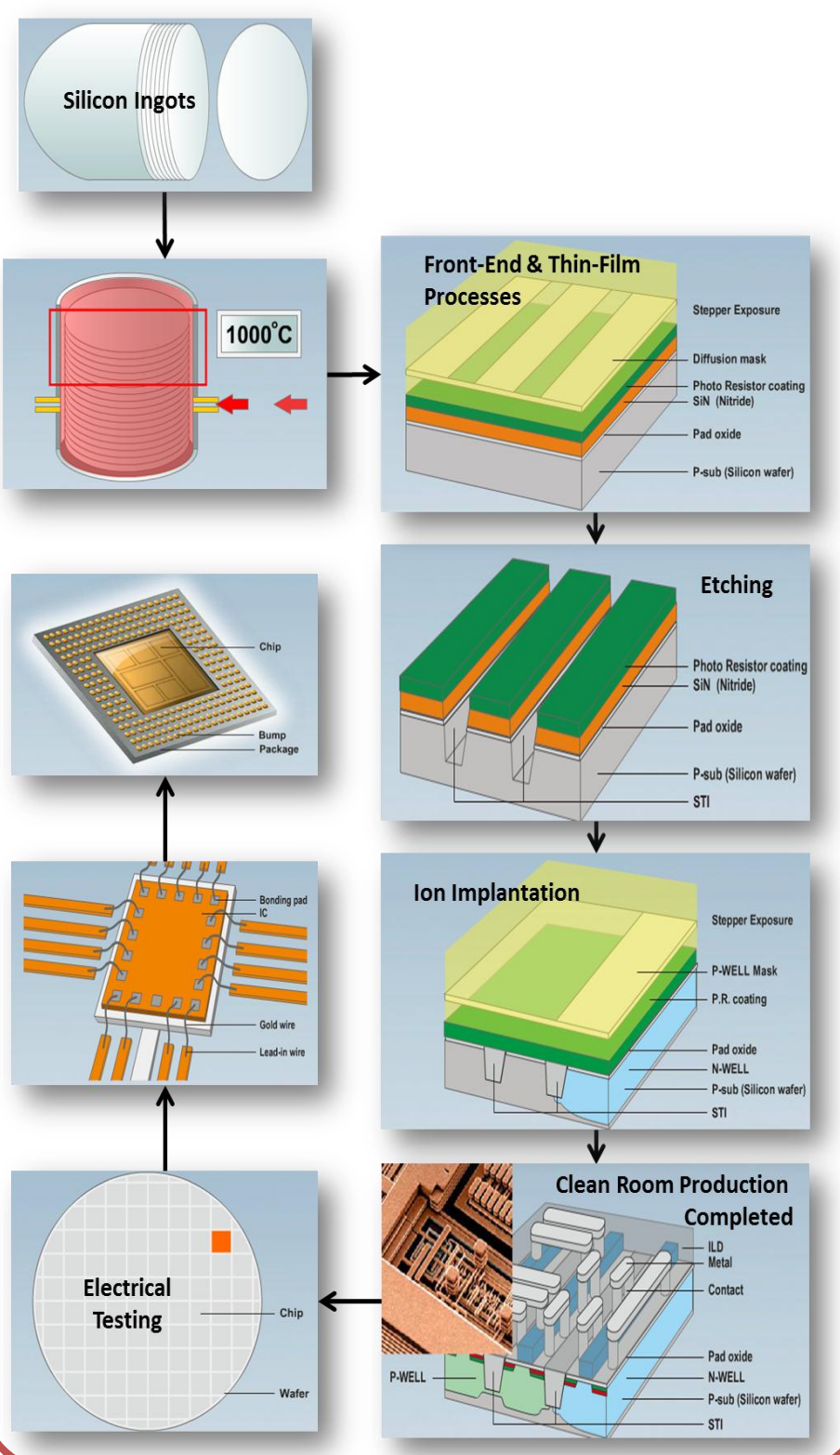
Validate Models

- Executable software
- R Programming

Stratified Cross Validation

## Process Flow

Wafer fabrication process takes 6 to 8 weeks. Wafers with profile issues are only detected late during the electrical test.



## Methodology

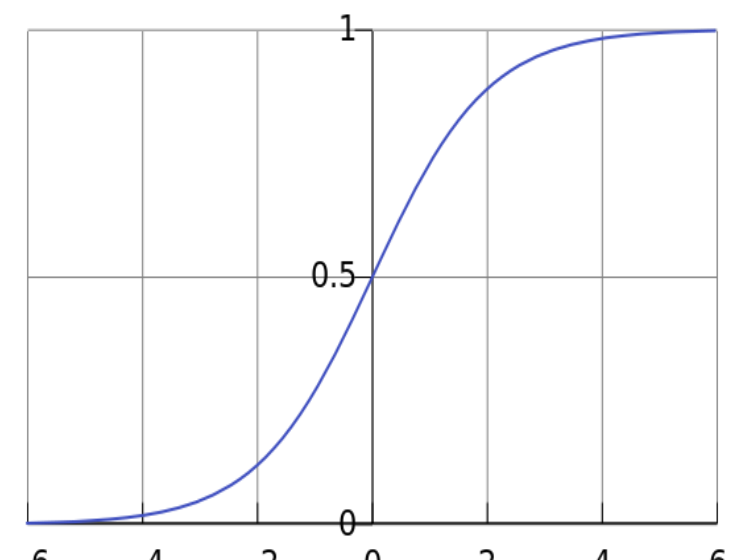
### Logistics Regression (LR)

LR is a predictive statistical model that aims to construct a parametric curve which best fits the observations. LR transforms the dependent variable, i.e. the probability of a wafer having issue, to its logit function (Logit function is the inverse of the sigmoidal logistic function). A suitable threshold can be drawn, above which an "issue detected" alarm will be triggered.

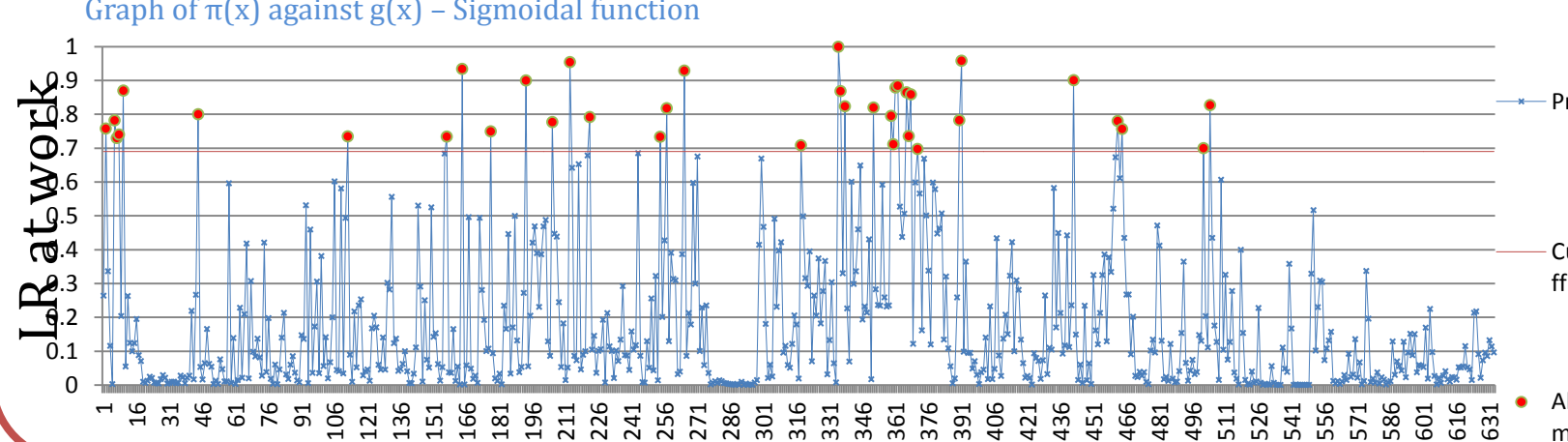
Single Variable Logit Function : Multi-variate Logit Function

$$g(x) = \ln \frac{\pi(x)}{1 - \pi(x)} = \beta_0 + \beta_1 x$$

$$g(\vec{x}) = \ln \frac{\pi(\vec{x})}{1 - \pi(\vec{x})} = \beta_0 + \vec{\beta}^T \cdot \vec{x}$$

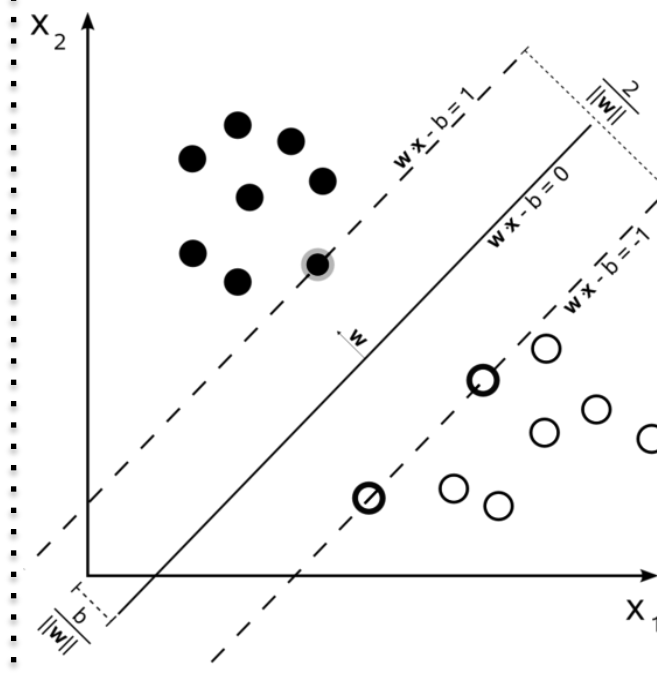


$\pi(x)$  ranges from 0 to 1 and can be interpreted as the probability of detecting an issue.  $g(x)$  takes all values and is therefore used to map to the linear product terms at the right hand side of the regression equation.



### Support Vectors Machine (SVM)

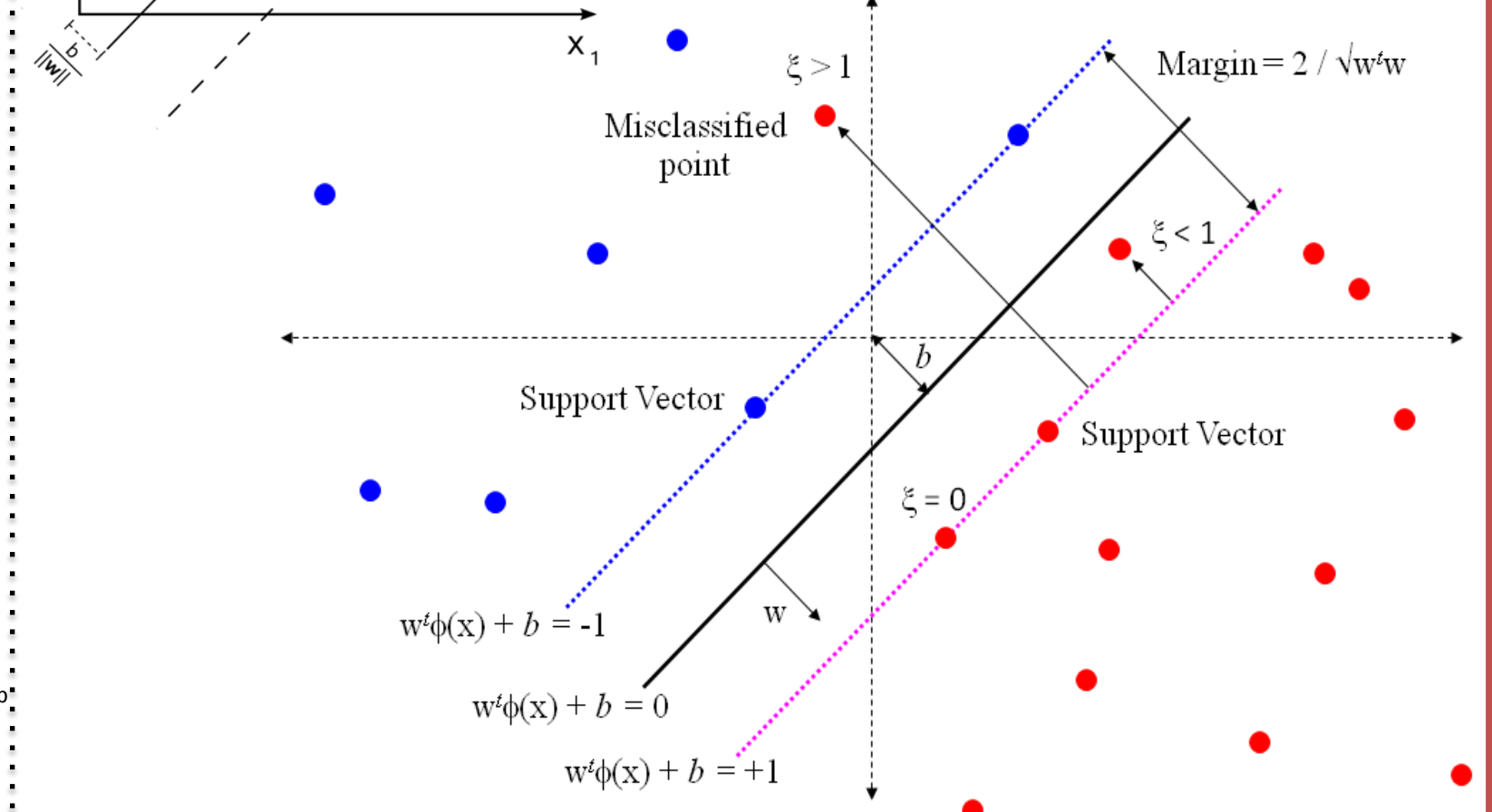
SVM classify the data by recognizing patterns and separating the defected units from the non-defect units.



A hyperplane is generated such that the distance between the hyperplane and the nearest data point on both sides is maximized.

$$\min \frac{1}{2} \|w\|^2 + C \sum_{i=1}^L \xi_i$$

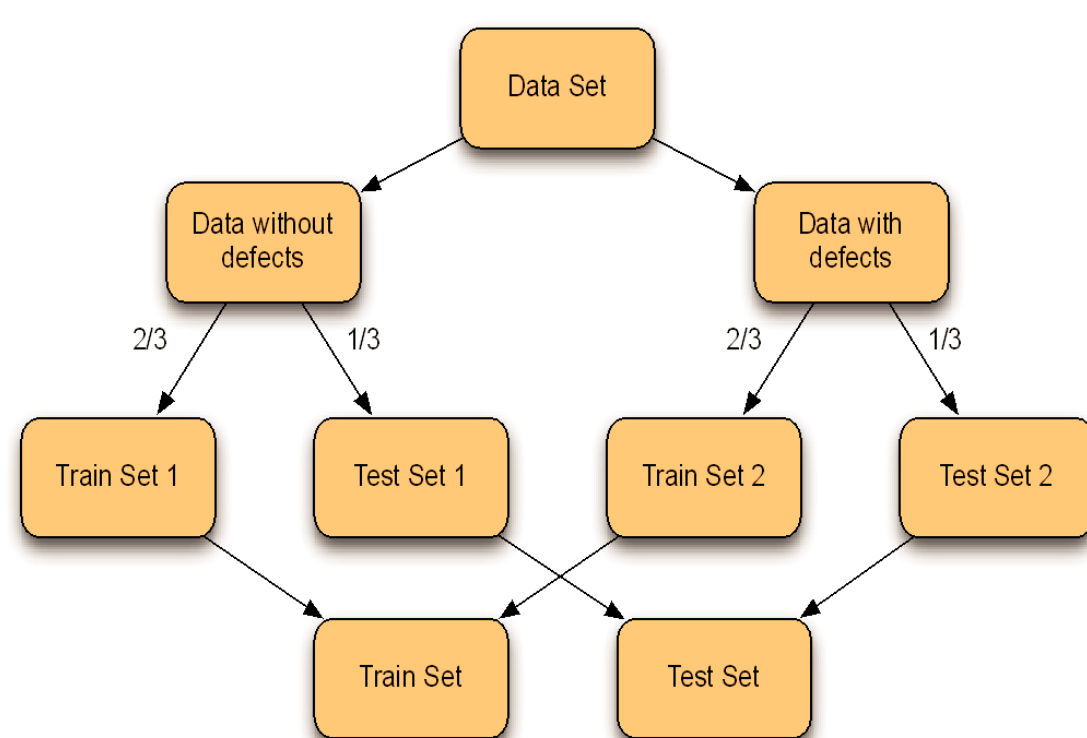
$$\text{s.t. } y_i(x_i \cdot w + b) - 1 + \xi_i \geq 0 \quad \forall_i$$



Misclassification of points is inevitable. By adjusting both the degree of model separator and the cost constraint value,  $C$ , will affect the values of alpha- and beta-errors.

## Validation

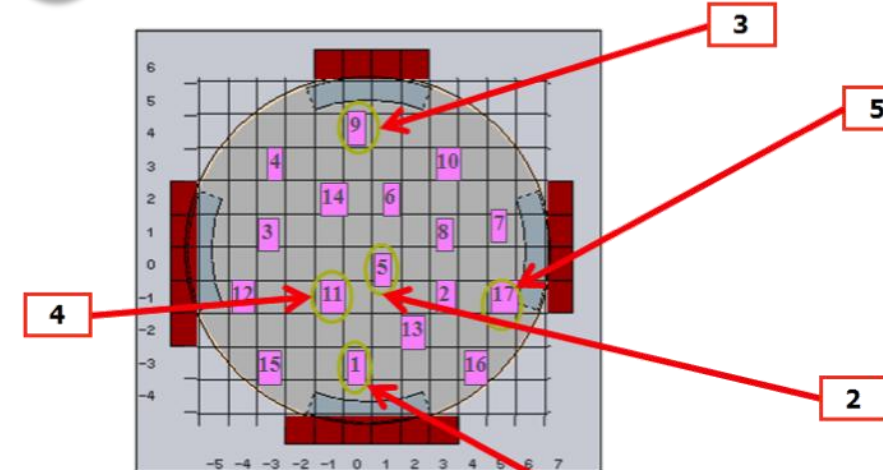
To ensure that (1) the model is able to detect the defects and (2) to achieve a low alpha-error with a reasonable beta-error, Stratified Cross-Validation is used to verify and validate the effectiveness of the model.



1. Due to the lack of faulty data points in, Stratified Sampling is applied to ensure there are sufficient defective units in the train set proportionally.
2. For both defective and non-defectives points, 2/3 of the data points are assigned to the train set, and 1/3 to the test.
3. Model generation is completed based on train set and then tested on the test set.

## Implementation

### 1 Site Measurements



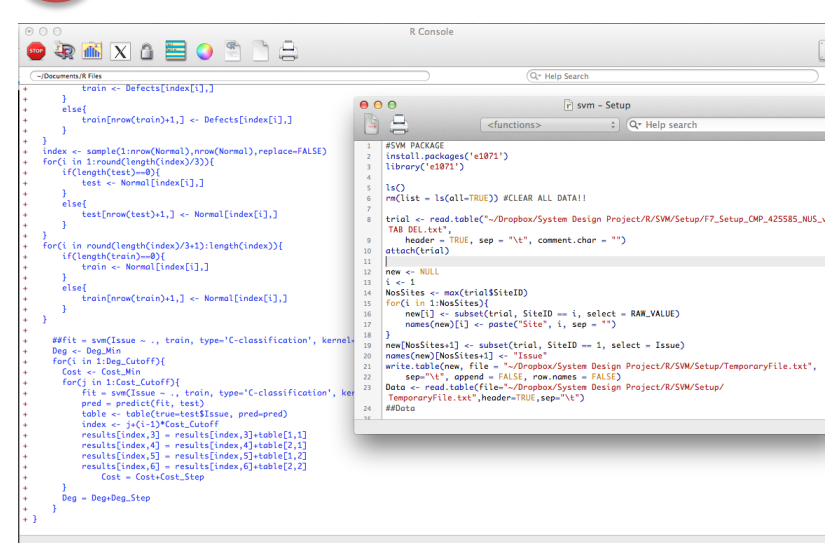
Thickness at 5 sites are measured.

### 2 Raw Data

DATE	WaferID	SiteID	Thickness	WaferID	SiteID	Thickness	Issue
18/6/2012 7:24	S-38-05	0113225	1.12	W31	1	0	-
18/6/2012 7:24	S-38-05	0113452	1.12	W31	2	1	0
18/6/2012 7:24	S-38-05	0113048	1.12	W31	3	0	4
18/6/2012 7:24	S-38-05	0112902	1.12	W31	4	-1	-1
18/6/2012 7:24	S-38-05	0113302	1.12	W31	5	5	-1
18/6/2012 7:24	S-38-05	0112825	1.12	W32	1	0	-3
18/6/2012 7:24	S-38-05	0113258	1.12	W32	2	1	0
18/6/2012 7:24	S-38-05	0113388	1.12	W32	3	0	4
18/6/2012 7:24	S-38-05	0113398	1.12	W32	4	-1	-1
18/6/2012 7:24	S-38-05	0113068	1.12	W32	5	5	-1
18/6/2012 7:24	S-38-05	0112589	1.12	W33	1	0	-3
18/6/2012 7:24	S-38-05	0112648	1.12	W33	2	1	0
18/6/2012 7:24	S-38-05	0113328	1.12	W33	3	0	4
18/6/2012 7:24	S-38-05	0113027	1.12	W33	4	-1	-1
18/6/2012 7:24	S-38-05	0115172	1.13	W33	5	5	-1
20/6/2012 17:27	S-38-05	0110663	1.13	W34	1	0	-3
20/6/2012 17:27	S-38-05	0110249	1.13	W34	2	1	0
20/6/2012 17:27	S-38-05	0110166	1.13	W34	3	0	-4
20/6/2012 17:27	S-38-05	0110208	1.13	W34	4	-1	-1
20/6/2012 17:27	S-38-05	0112223	1.13	W34	5	5	-1
20/6/2012 17:27	S-38-05	0112038	1.13	W35	1	0	-8
20/6/2012 17:27	S-38-05	0111908	1.13	W35	2	1	0
20/6/2012 17:27	S-38-05	0111228	1.13	W35	3	0	4
20/6/2012 17:27	S-38-05	0110666	1.13	W35	4	-1	-1
20/6/2012 17:27	S-38-05	0113176	1.13	W35	5	5	-1
20/6/2012 17:27	S-38-05	0110899	1.13	W36	1	0	-8
20/6/2012 17:27	S-38-05	0112782	1.13	W36	2	1	0
20/6/2012 17:27	S-38-05	0111848	1.13	W36	3	0	4

Issue wafers are highlighted in red.

### 3 Execution



Programming language R is used to code and run LR and SVM models.

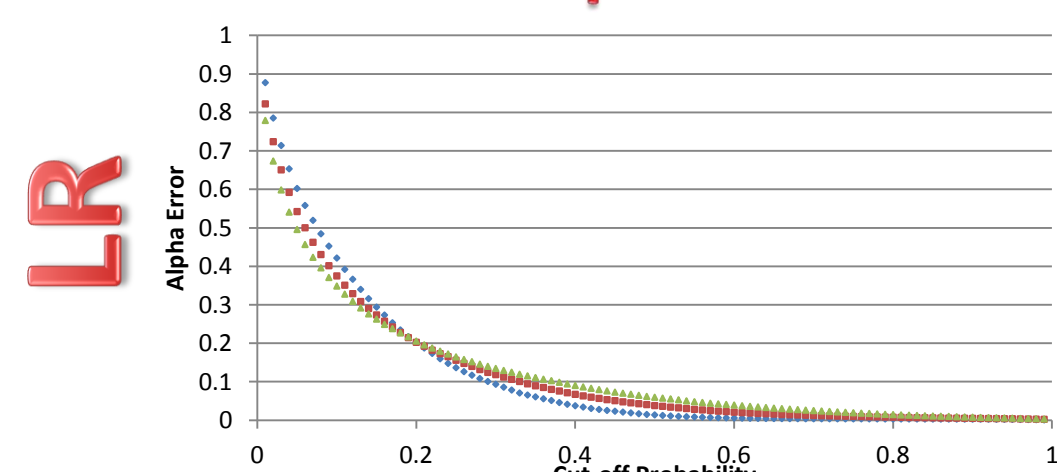
### 4 Output

Cost	Degree	alpha	beta	alpha_beta	beta_beta	false_alarm		
1.0	1	34312	2652	86	5141	0.26%	34.09%	1.68%
1.5	1	34298	2639	102	5261	0.30%	32.55%	1.90%
2.0	1	34286	2655	114	5365	0.33%	31.99%	2.12%
2.5	1	34268	2490	132	5310	0.38%	31.82%	2.43%
3.0	1	34249	2484	151	5306	0.44%	31.97%	2.77%
3.5	1	34231	2489	167	5311	0.49%	31.93%	3.02%
4.0	1	34215	2493	185	5307	0.54%	31.96%	3.37%
4.5	1	34193	2498	207	5302	0.60%	32.07%	3.74%
5.0	1	34164	2499	236	5301	0.69%	32.04%	4.26%
5.5	1	34145	2502	255	5298	0.74%	32.08%	4.59%
6.0	1	34119	2505	281	5295	0.82%	32.19%	5.04%
6.5	1	34099	2508	301	5292	0.88%	32.15%	5.38%
7.0	1	34075	2514	325	5286	0.94%	32.21%	5.79%
7.5	1	34061	2512	339	5288	0.99%	32.13%	6.02%
8.0	1	34040	2512	360	5288	1.05%	32.21%	6.37%
8.5	1	34021	2529	379	5271	1.10%	32.42%	6.71%
9.0	1	34008	2544	392	5256	1.14%	32.62%	6.94%
9.5	1	33996	2558	404	5242	1.17%	32.79%	7.16%
10.0	1	33988	2568	412	5232	1.20%	32.92%	7.30%
10.5	1	33972	2575	428	5225	1.24%	33.01%	7.57%
11.0	1	33957	2577	443	5223	1.29%	33.04%	7.82%
11.5	1	33941	2581	457	5219	1.33%	33.09%	8.05%
12.0	1	33926	2585	474	5215	1.38%	33.14%	8.33%
12.5	1	33912	2594	488	5204	1.42%	33.18%	8.57%

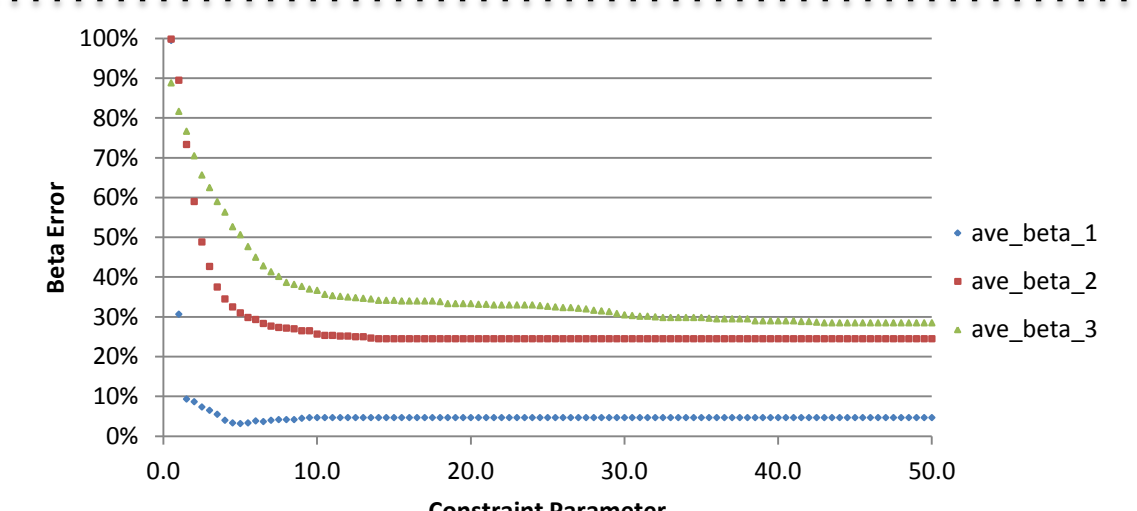
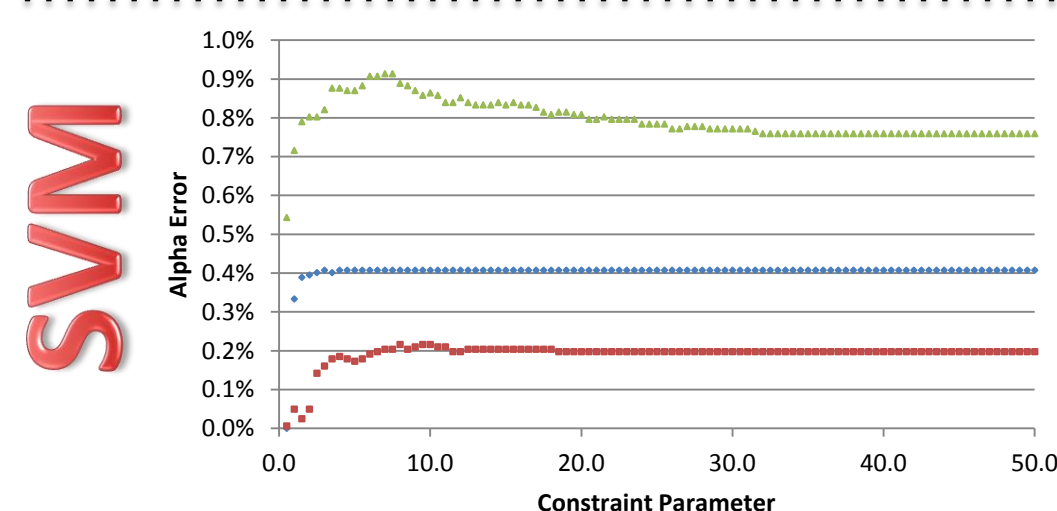
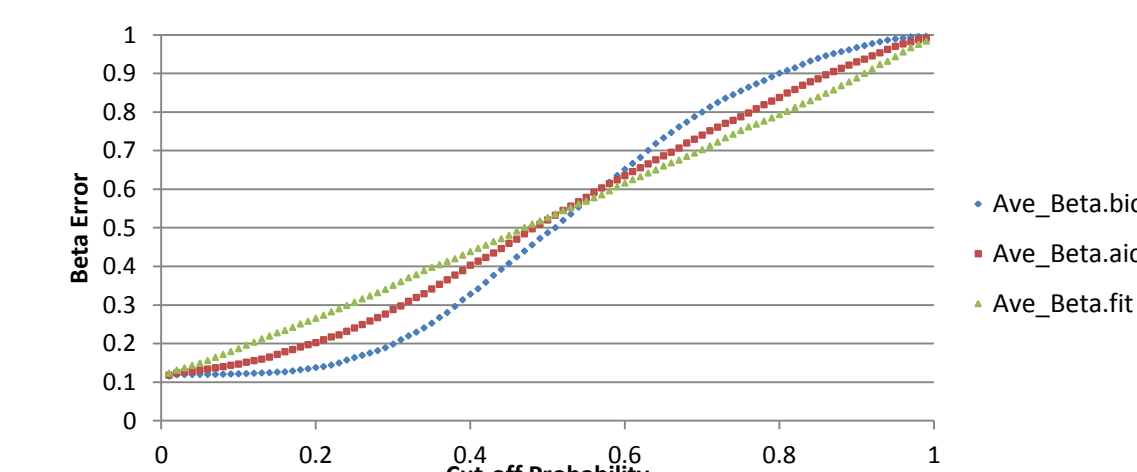
Output data are kept in .txt files for easy analysis later.

## Results

### Alpha Error



### Beta Error



Alpha error and beta error is inversely proportionate. Suitable cut-off probability (in LR) and separation parameters (in SVM) are to be selected for an acceptable error allowance.

## Conclusion

- ✓ LR and SVM methodology can be applied to processes in GlobalFoundries
  - ✓ Using existing data
  - ✓ Identify wafer profiles in line
  - ✓ Minimize alpha error
- Results show promising potential for implementation in GlobalFoundries.