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Big Data & Machine Learning For Customer Returns

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- Proposed Solution
- Methodology
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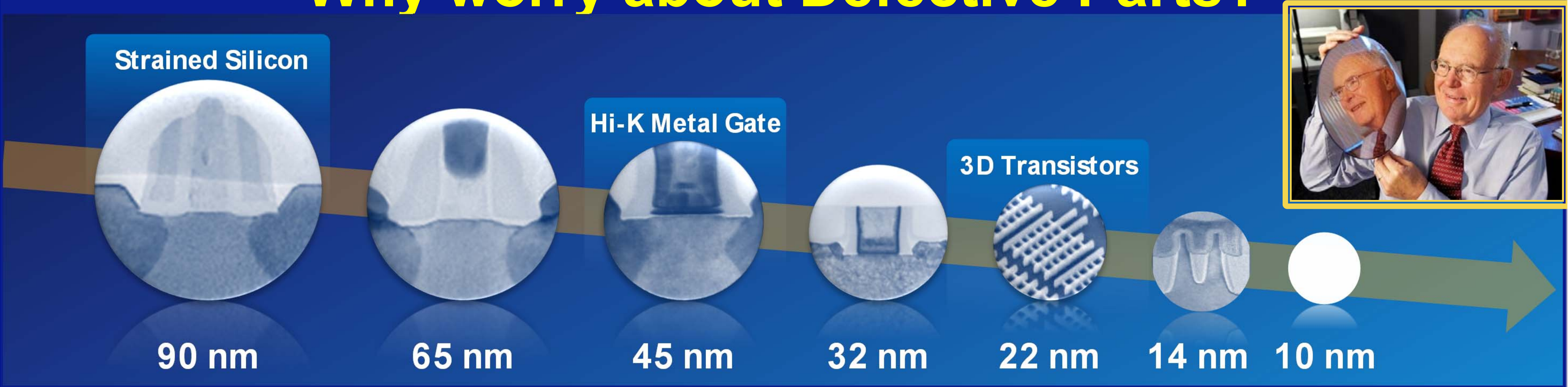
Why worry about Defective Parts?



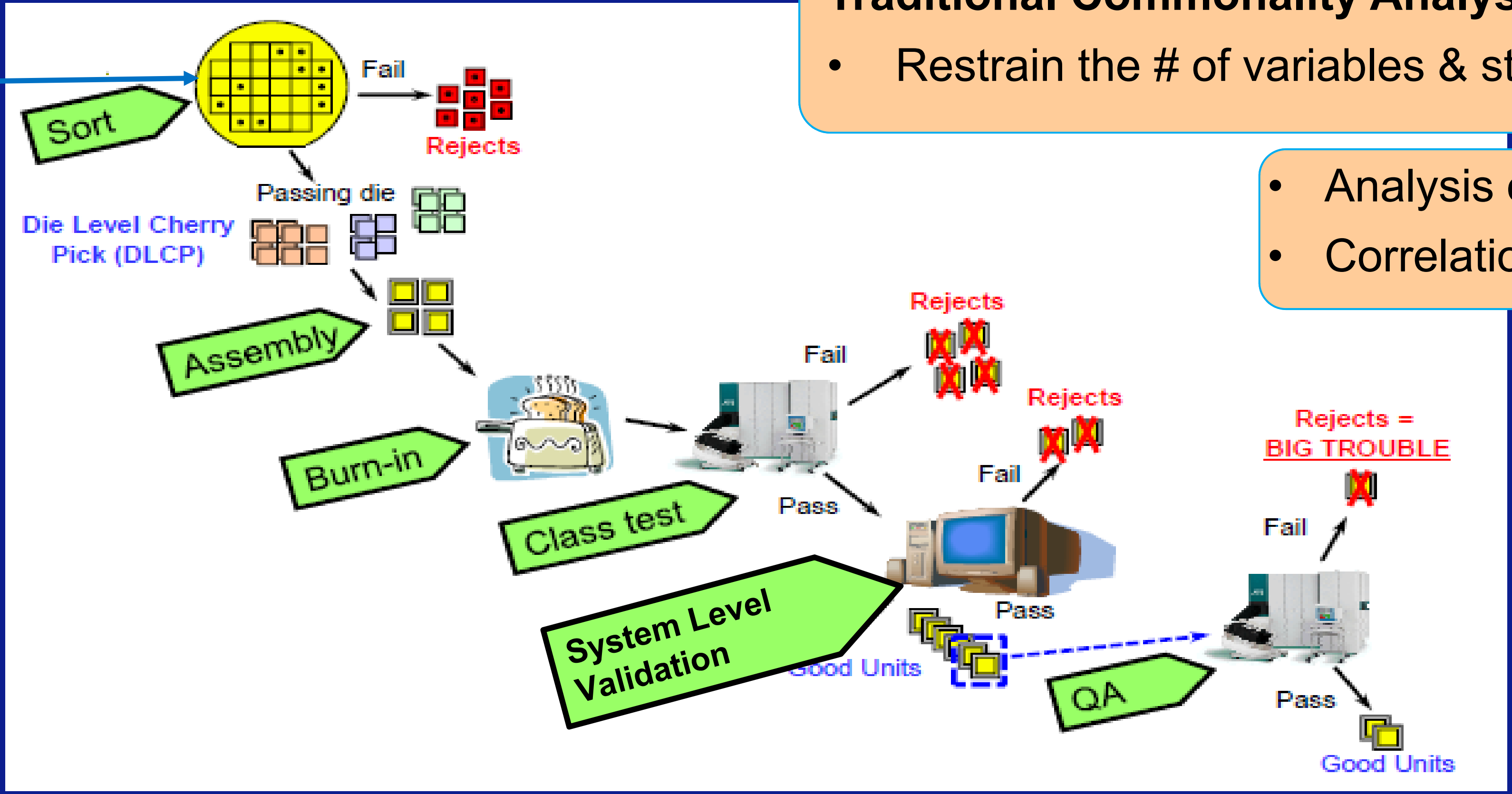
- *EXECUTING TO Moore's Law → Enabling new devices with higher functionality and complexity while controlling power, cost, and size*
- **The number of manufacturing defects are also increasing with decreasing wavelength of each semiconductor process generation**

Hence, understanding the characterization of the defective units is very critical to improve the quality of the products delivered to the market

Problem Statement

Fab Wafer Process

Electrical Test



Traditional Commonality Analysis methods

- Restrain the # of variables & statistical methods

- Analysis of Variance (ANOVA)
- Correlation/ Regression Analysis

Traditional Commonality Analysis

→ Leads to forced commonalities or overlooks the interactions between the processes

Methodology

Data Extraction

- Unique Proc ID → Part history recreation
- Fetch data at every step: SORT + Burn In + Class + Binning + Fusing + System Level Validation
- Trace Neighboring Parts, repeat history recreation

Data Analytics

- Use Machine Learning methods to pin-point the most critical parameters
- Supervised segmentation analysis narrows down thousands of variables to a few relevant ones

Data Visualization

- Multivariate graphical analysis finds any specific patterns

Pattern Recognition

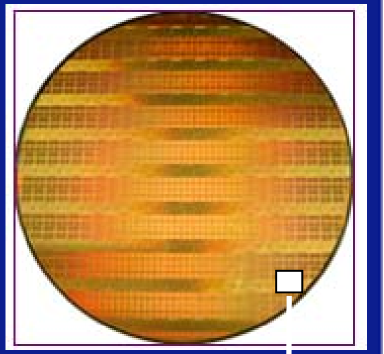
- Identify potential causal mechanisms for the defective parts

How Customer Returns Lead To BIG DATA?

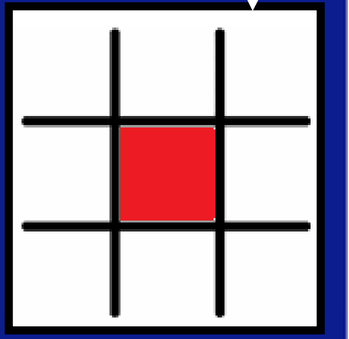
Customer Return (Unique Processor ID) → Wafer Level Sort, Package level (Burn-in, Class, Binning, Fusing, System level validation, Quality assurance and packaging)

Trace Neighboring Parts

- Same Lot
- Neighboring Lots/wafers
- Same Test program
- Same conditions at each of the manufacturing tests at the various manufacturing sites



Unique Processor ID



	Sort Wafer Test	Class Test (Package level)	System Level Validation
Variables	15K -60K	3K- 15 K	1K-3K

Examples: Parametric data (leakage, voltages, process monitors) and Attribute data (product characteristics, die position on the wafer , lot numbers, etc.)

One single part →19k to 78k of variables for only 3 of the Tests!

Big Data Constituents

Big Data for Semiconductor Manufacturing

Volume

Sheer Volume of data to process

Variety

Large diversity of data

- Structured (categorical and continuous)
- Semi-structured (categorical and textual)
- Non-structured data (video, audio and textual)

Data complexity

- Decoding/transformation

Different databases

Velocity

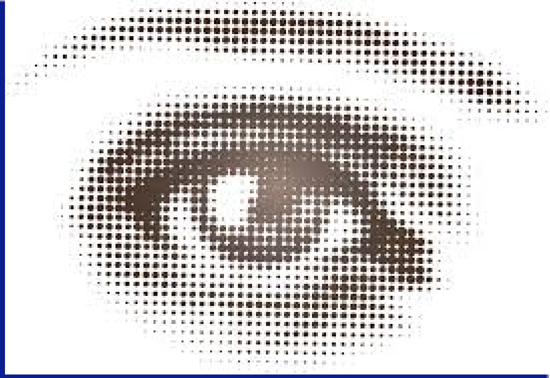
~ Real time feedback necessary

Veracity

Uncertainty in data

- Data inconsistency
- Incompleteness or missing data
- Ambiguities
- Latency
- Model approximations

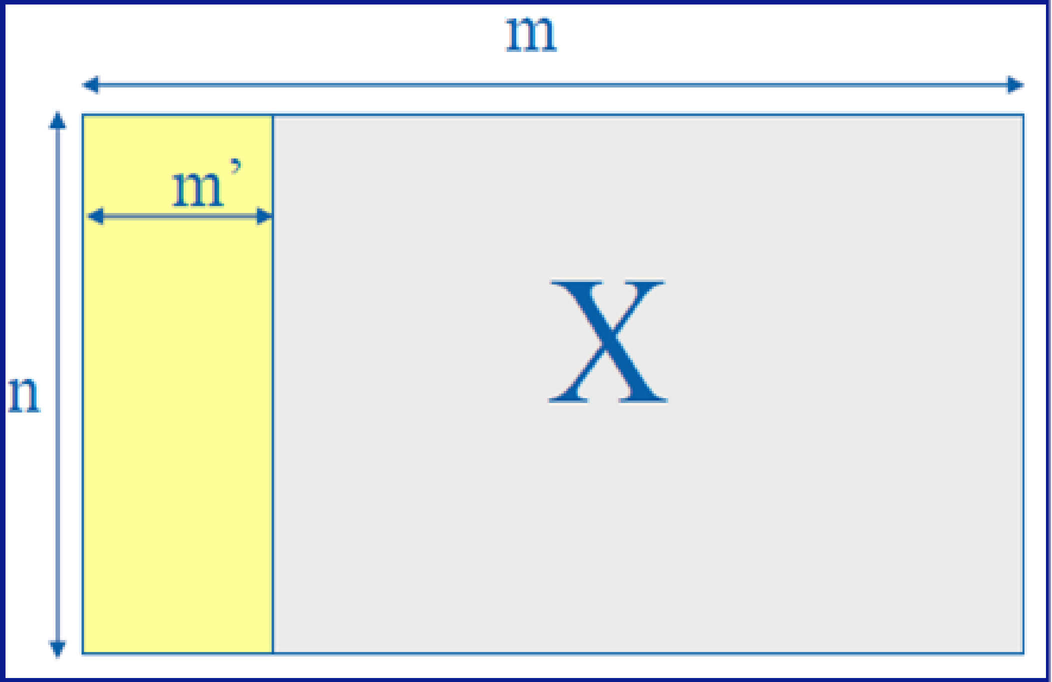
Data Mining Goals



Find hidden pattern to explain the difference between the defective and non-defective parts

Feature Selection (FS)

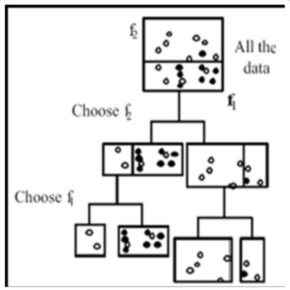
Process of selecting a subset of relevant features (predictors) to **reduce the variance and avoid over-fitting.**



Feature Selection reduces Matrix of space of *n* x *m* → *n* x *m'*

Feature Selection helps to reduce the number of variables to the meaningful ones

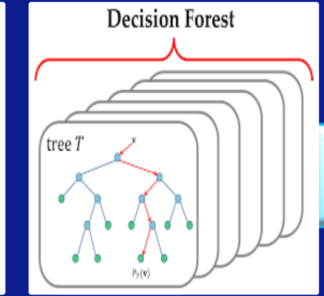
Decision Trees Algorithms

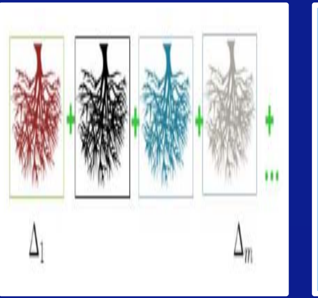


Classification And Regression Tree (CART)

Simple learning machine that partitions data to reduce variance using binary recursive partitioning algorithm

Random Forest (RF)





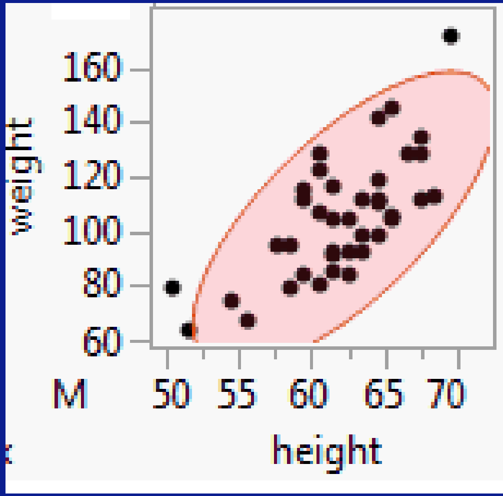
Gradient Boosting Tree (GBT)

Data Dimension	Speed
Recommended when there are more variables (x) than observations (n)	Very fast
Large number of observations (n)	Might get slow if #of variables (x) is large

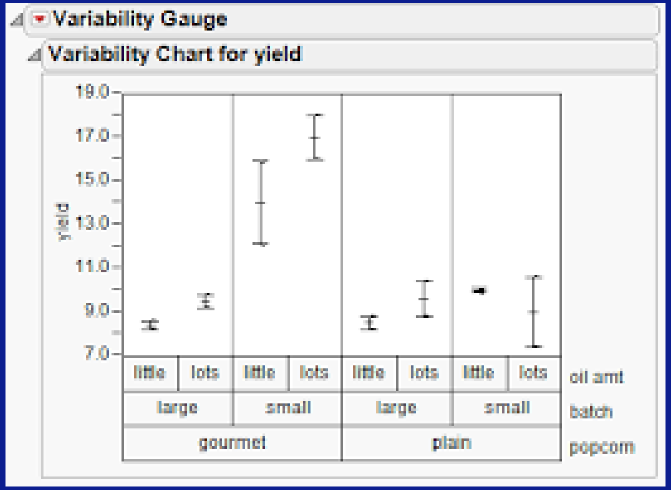
Dynamic Graphical User Interface

Dynamically explore graphically the potential variables that show the difference between defective and non-defective parts.

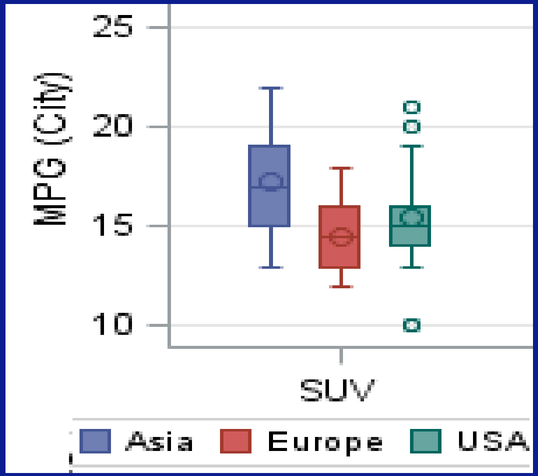
2D Scatterplots



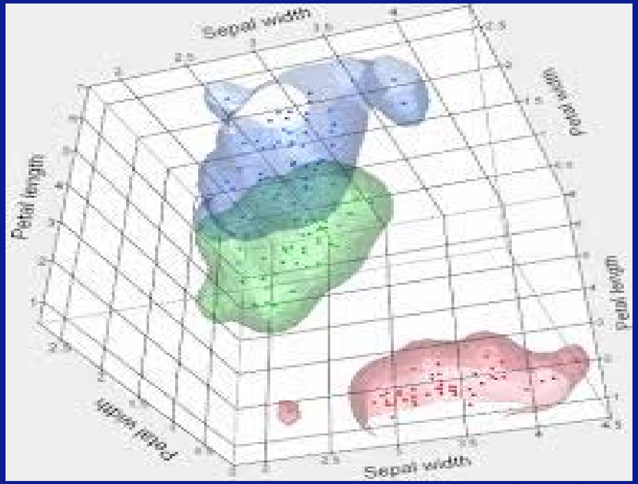
Variability Charts



Box Plots



3D Scatterplots



Case Study

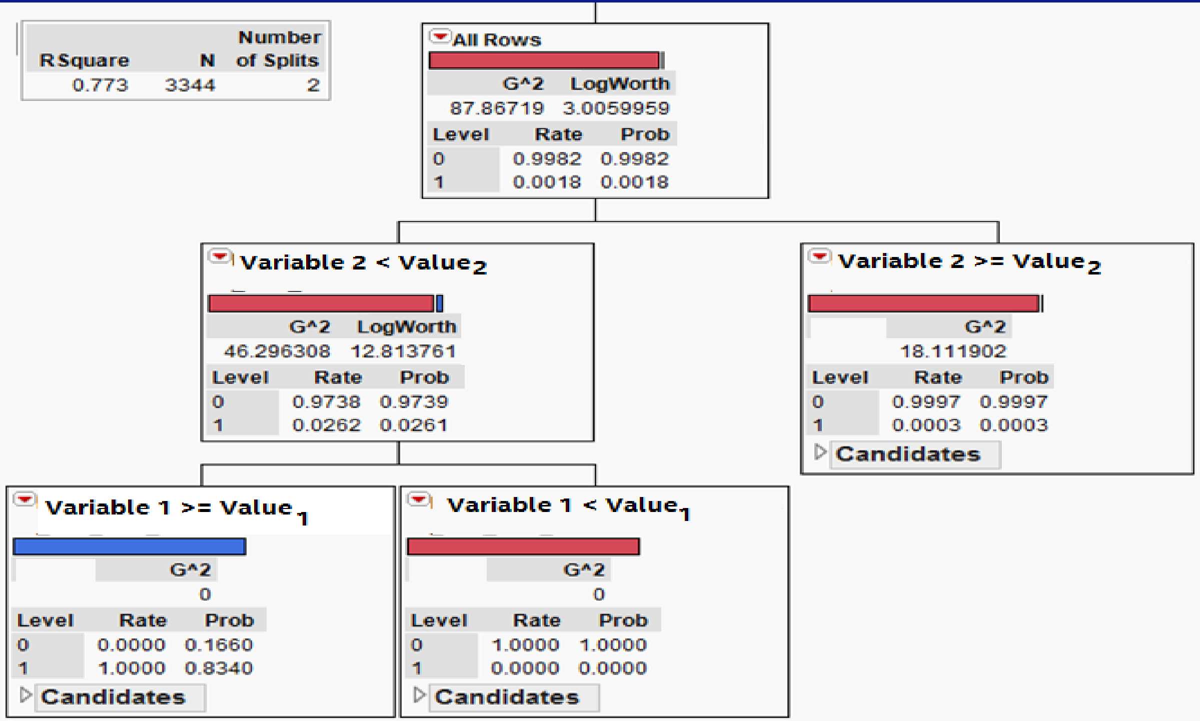
- Total of 6 defective parts were found at specific downstream operation step

Feature Selection

Feature Selection Chart using Interactive Data Exploration and Learning tool [IDEAL]

Variables	Importance
defect_flag <Response>	
Variable_1	100%
Variable_2	91.14%
Variable_3	46.76%
Variable_4	43.73%
Variable_5	37.75%
…	
Variable_10	14.17%
…	
F	negligible

Decision Tree: CART



Decision Tree Results Comparison

Relevant Variables Comparison by Decision Trees Algorithms

Algorithm	Relevant Variables
CART	Variable_2: 100% Variable_1: 24.48% Variable_10: 10.27%
GBT	Variable_4: 100% Variable_2: 76.80% Variable_1: 10.70%
RF	Variable_2: 100% Variable_1: 94.30% Variable_3: 58.80%

All 3 different decision tree algorithms show variable 1 and variable 2 as part of the Top 3 relevant variables

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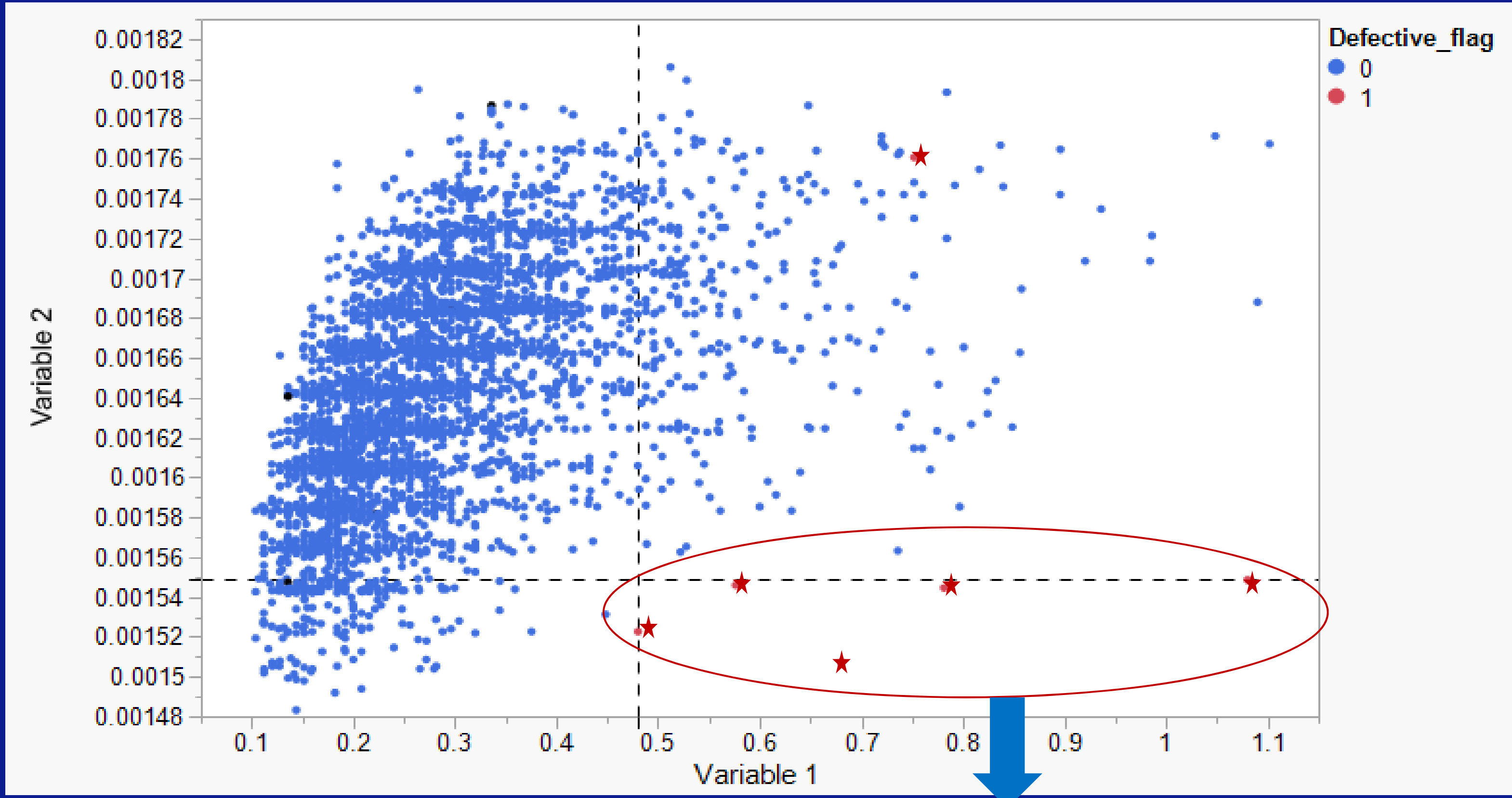
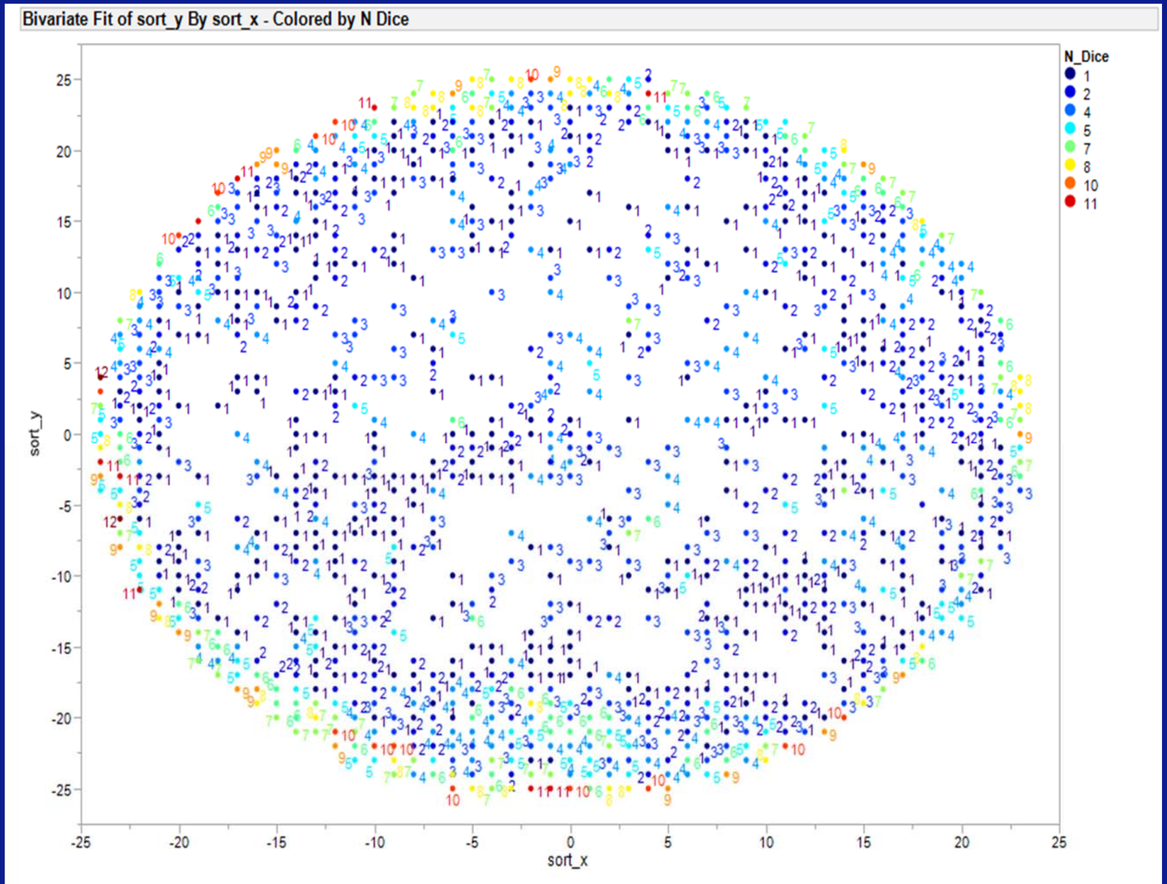
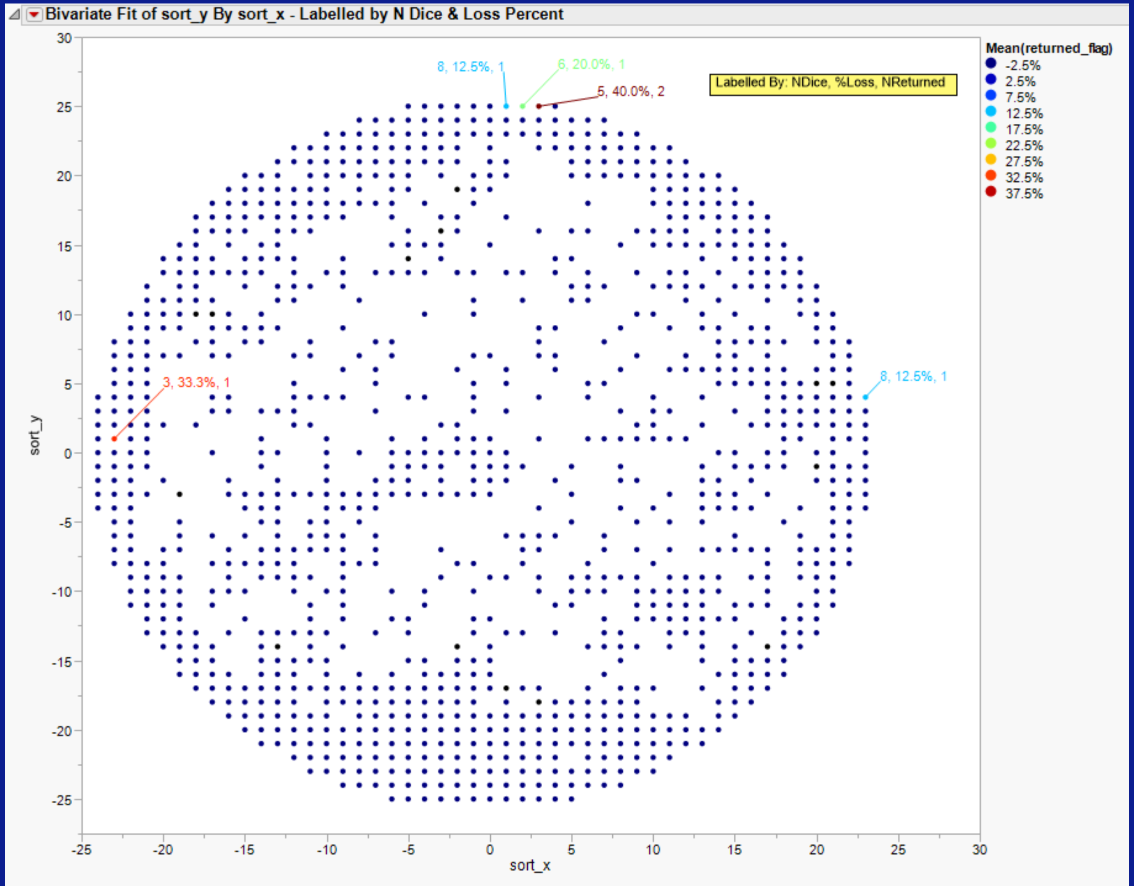
Data Visualization



Lower right quadrant → Defective units fall as outliers of correlation between variable 2 and 1. Prompt feedback was sent to the manufacturing process step for corrective actions

Die Position @ Wafer Level





Defective parts were mostly distributed on wafer edges

Summary

Unique Processor ID → Data Assembly → Machine Learning Output → Dynamic GUI → Corrective Preventive Action or Monitoring Mechanism

1. Save valuable time on the investigation and deliver results faster
2. Allow the user interactivity with the data and results
3. Evaluate the problem from different angles
4. Deliver intelligence on the causal mechanisms of the defective parts
5. Impact decisions on subsequent units

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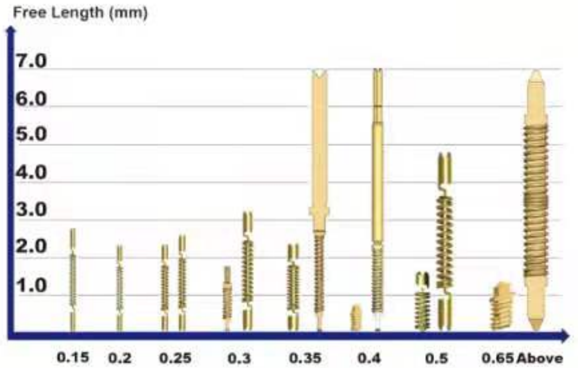
Spring probe by stamping



250 kinds of spring probe pin

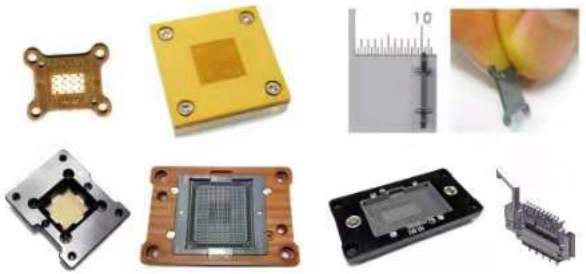
300 kinds of test socket (44,000 Pin count socket possible)

One piece spring probe

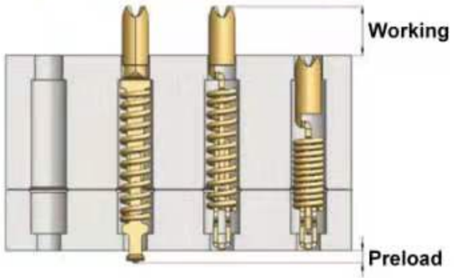
Three piece spring probe

High speed product → 0.63mm free length spring probe pin available

Finest Pitch → 0.15mm Pitch



Spring probe by stamping

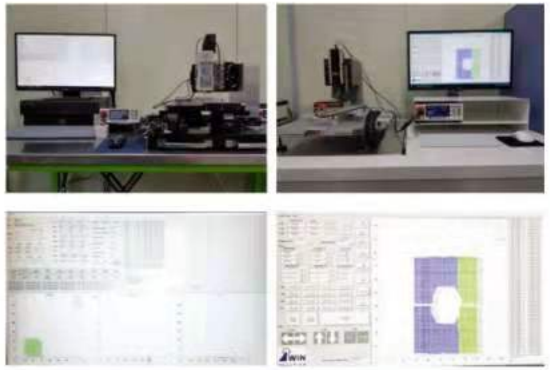


Patented

Pitch(mm)	Free Length(mm)	Current Carrying(Amps)
0.15/0.2/0.25	2.17~	0.5~
0.3	1.5~	1.5~
0.35	2.08~	1.8~
0.4	0.8~	2.5~
0.5	1.5~	3.0~
0.65	1.13~	9.0~
0.8	3.14~	3.0~

Automation

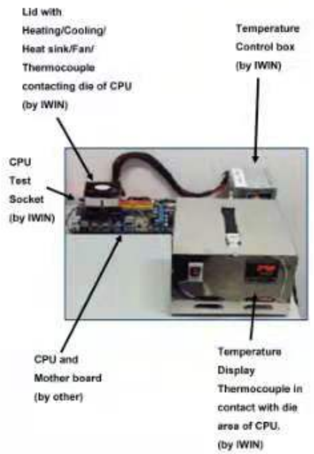
Pin assembly and Quality control



Top Figure: Socket CRES, Force, Stroke test
Bottom Figure: Data displayed

Top Figure: Socket CRES test
Bottom Figure: Data display 5,903 pins socket

Socket and Lid



Pin assembly

(Fully automated machines)

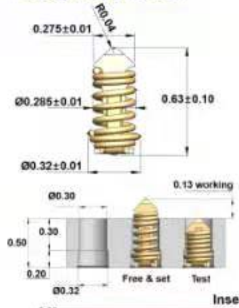
- Stamped piece parts attached to a reel fed into the assembly machine

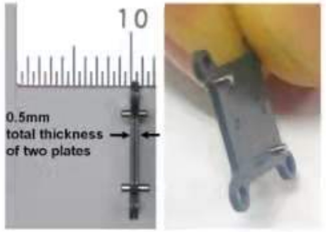
- Assembled pins can be attached to a reel, or, supply in separate for socket assembly.

Spring probe pins for High speed

Extremely short spring probes by stamping

Design approach





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