

# Toward Zero Defect: Automotive Fab Best Practices for Assessing “Best Performing Tools”



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# Agenda

1. Introduction
2. Process Tool Capability
3. Process Tool Defectivity
4. Summary and Recommendations

# KLA: Quality Partner for the ICs that Power the Future of Automotive

## Automotive Commitment and Expertise

Ann Arbor, MI



- R&D Center
- Automotive and AI

Commentary



- Process Watch
- Semiconductor Engineering
- ECN, Elektronik, ...

Workshops



- Auto fabs
- Tier 1s
- OEMS

<http://www.kla.com/automotive>

## Quality Control Solutions for Automotive ICs



Continuous Improvement

- Surfscan® Series



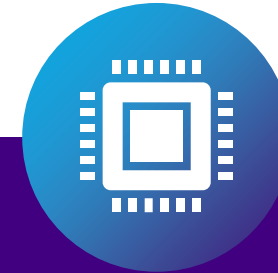
Zero Defect Screening

- 8 Series
- Certified and Relunched



Advanced Design Node

- 39xx and 29xx Series
- eDR7xxx™ Series



Packaged IC Quality

- ICOS™ Series



Power Device Reliability

- Candela® CS920

# The Appeal of a “Best Performing Tool” Program

Imagine a fab with two tools at every process step

Tool A has 99.99% yield at each step

Tool B has 99.7% yield at each step

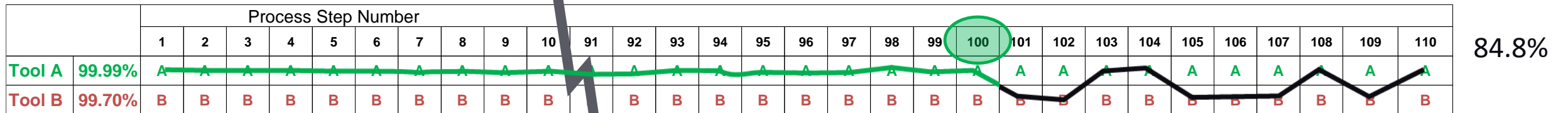
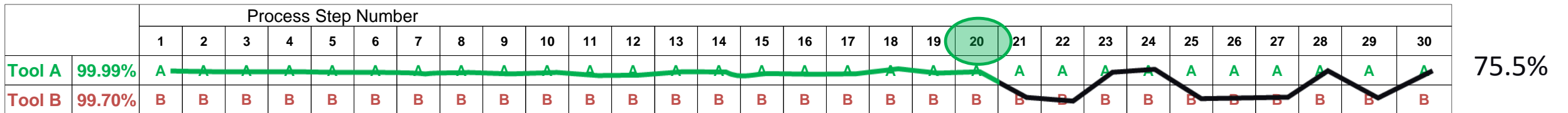
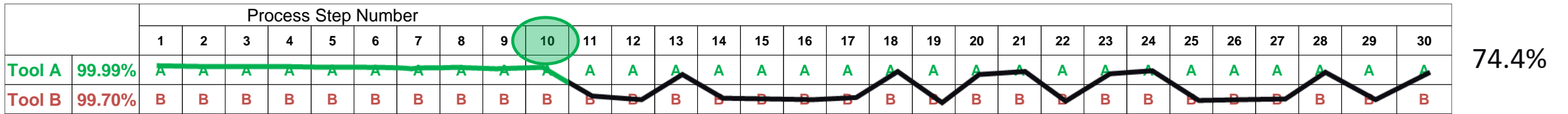
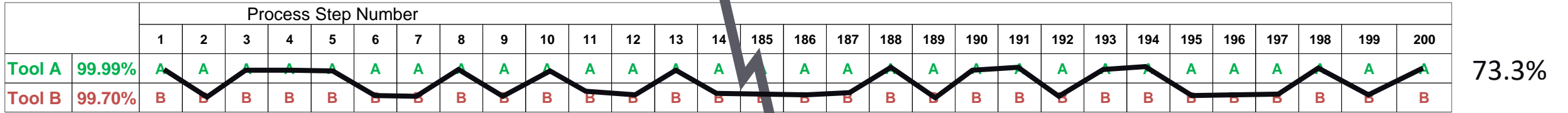
		Process Step Number																													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200
Tool A	99.99%	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Tool B	99.70%	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B

Can choose between A or B at all 200 steps

# Impact on Final Yield

— Best Performing Tool Path  
— Random Path

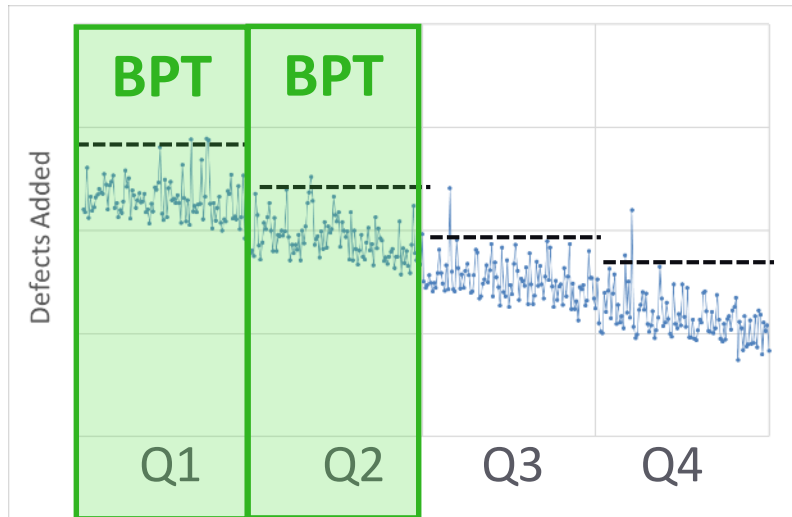
Final Yield



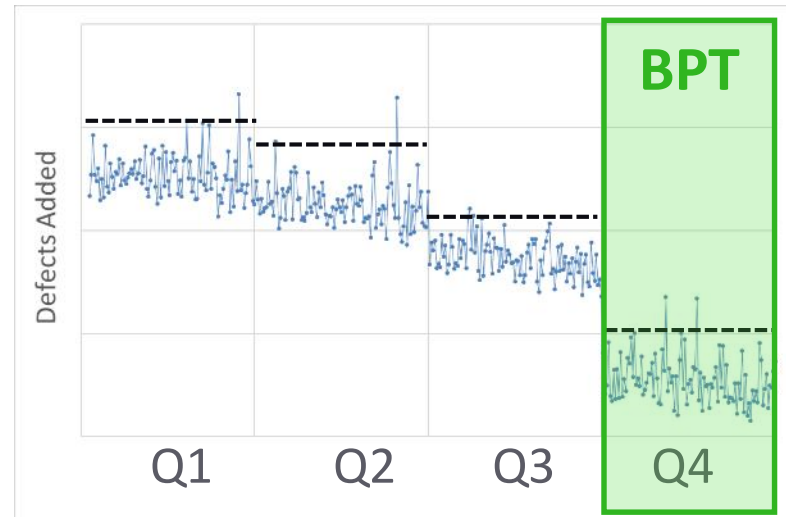
This is the "Best Performing Tool" Effect

# Always Start with a Fab-wide Yield Improvement Program

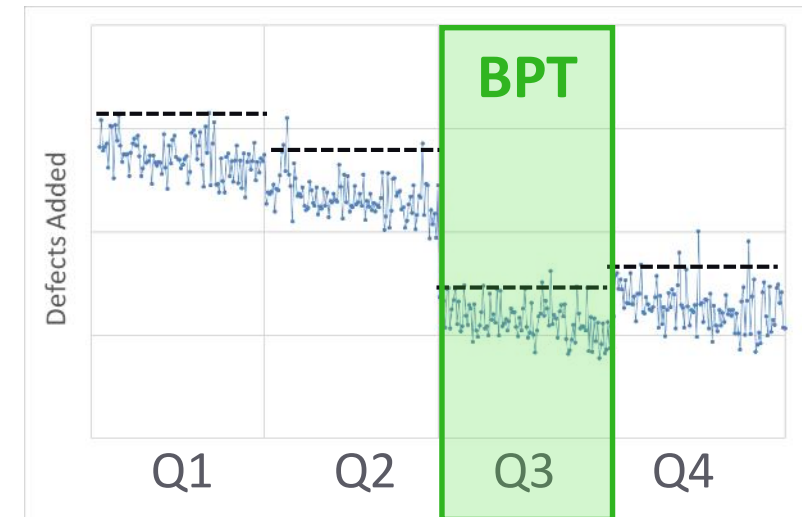
Tool 1



Tool 2



Tool 3



- Fab wide yield improvement is a long process (measured in quarters)
- The Best Tool frequently changes as the fab improves
- The goal is find the best tool wherever you are on that journey

The data needed to identify Best Performing Tools (BPT) flows naturally out of a comprehensive continuous improvement program

# What is the Criteria for “Best Performing Tool”

## 1. Tools with High Step-Yield

- Tool commonality analysis: de-convolve final wafer yield to the tool level
- Time lag: tells you how the tool performed 1-3 months ago

## 2. Tools that are Available

- Cycle time and queue time can be driving factors if there is only a single tool that is allowed for a given step.
- Best tool → Best available tool

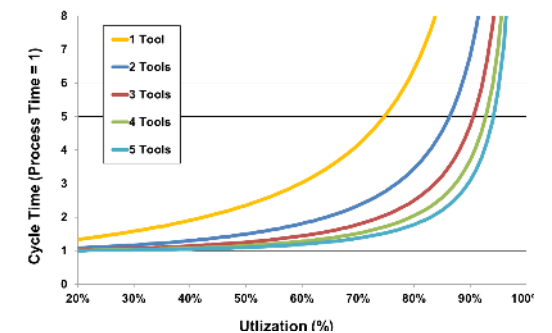
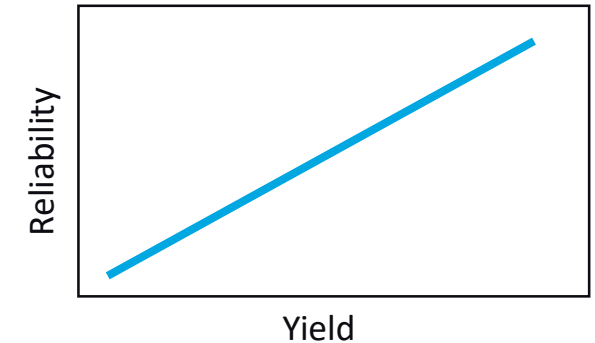
## 3. Process Tool Capability

- Process window >> total variability
- Measurement system capability

## 4. Process Tool Defectivity

- Fewer added defects (all types)
- Sufficient inspection sensitivity and sampling

Focus of this Paper



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1. Introduction

2. Process Tool Capability

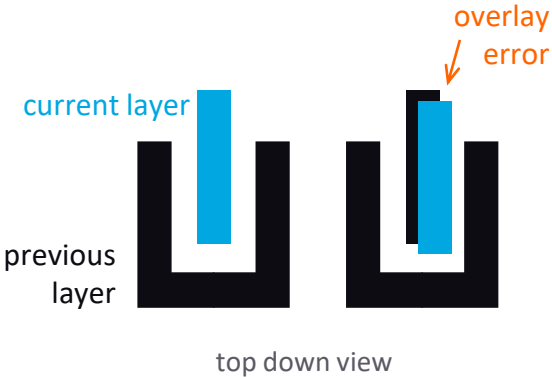
3. Process Tool Defectivity

4. Summary and Recommendations

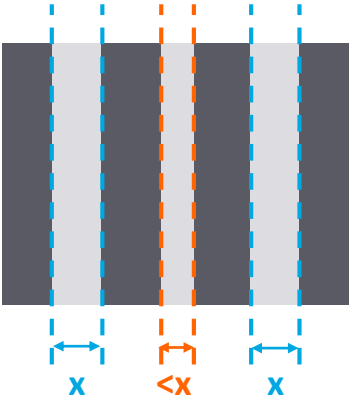


# Common Process Control Measurements

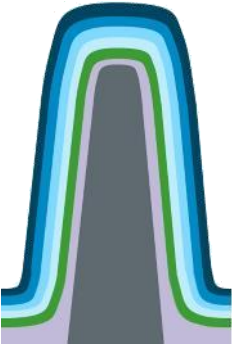
## On Product Overlay



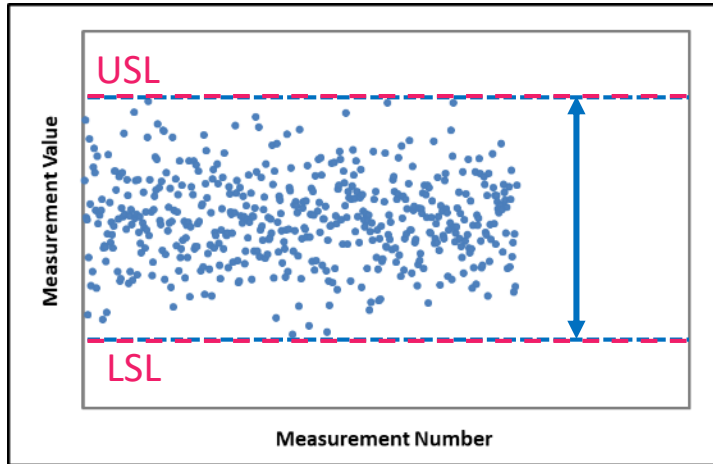
## Critical Dimension Uniformity



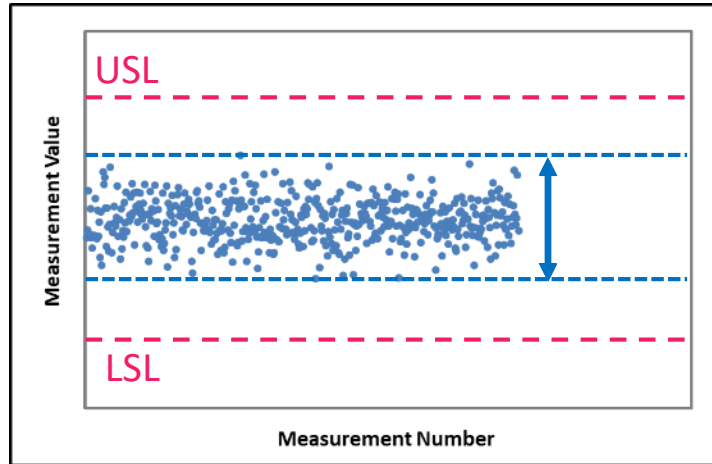
## Film Uniformity



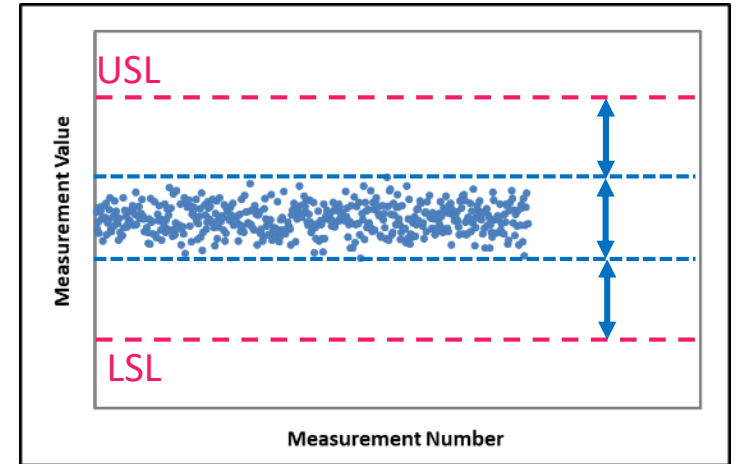
# Understanding $C_p$ (Process Capability Index)



$C_p = 1.0$



$C_p = 2.0$



$C_p = 3.0$

$C_p$  is a measure of how well the natural process variation fits within the spec limits

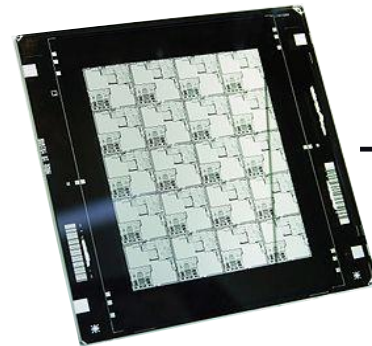
$$C_p = \frac{(USL - LSL)}{6\sigma}$$

USL = Upper Spec Limit  
LSL = Lower Spec Limit  
 $\sigma$  = Standard Deviation of the Process

# Challenge of Assessing $C_p$ for a Process Tool: Litho Example

## Reticle (Mask):

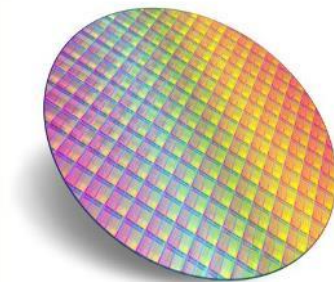
- 1 field
- 1-100 die (or more)
- 10 Billion transistors



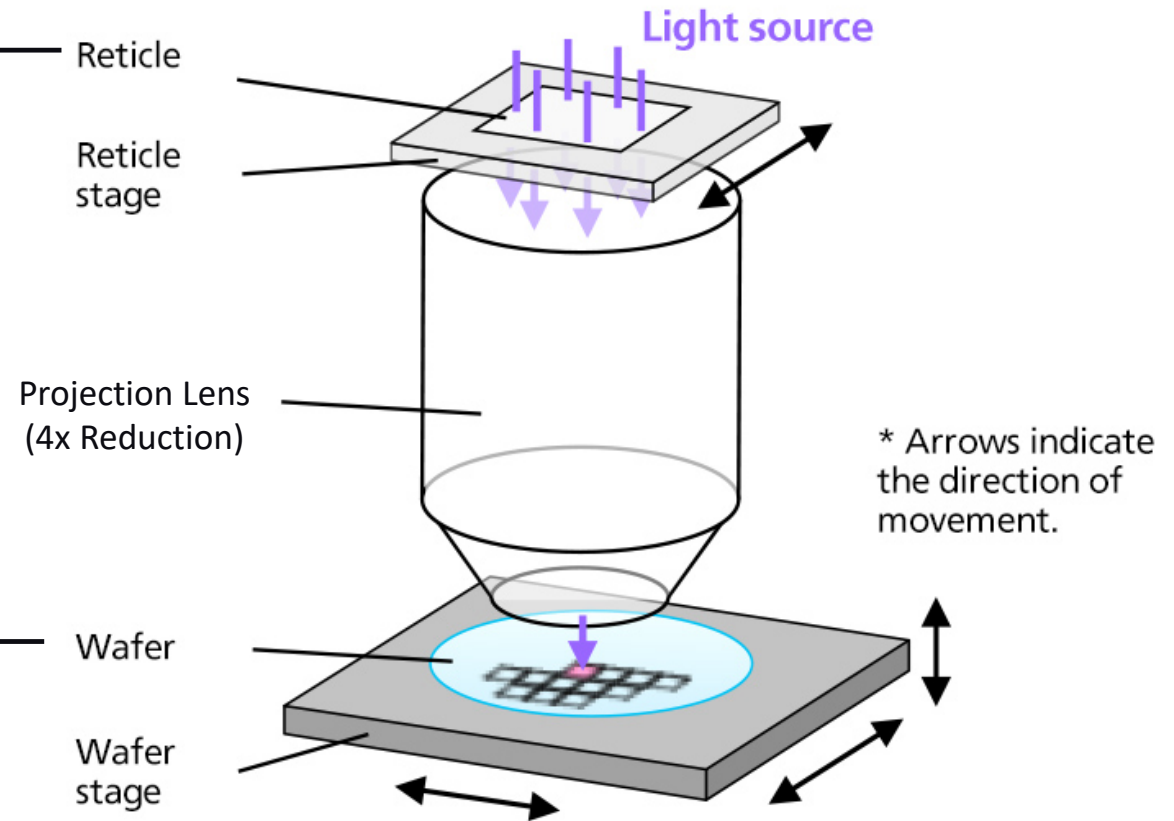
Reticle  
Reticle stage

## Wafer

- 100 fields
- 1000 die (or more)
- Trillion transistors



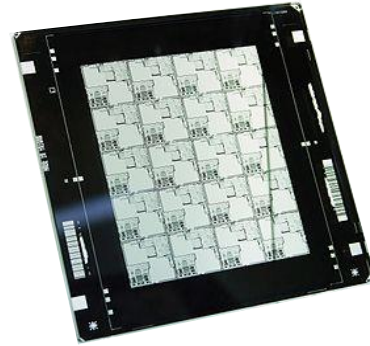
Wafer  
Wafer stage



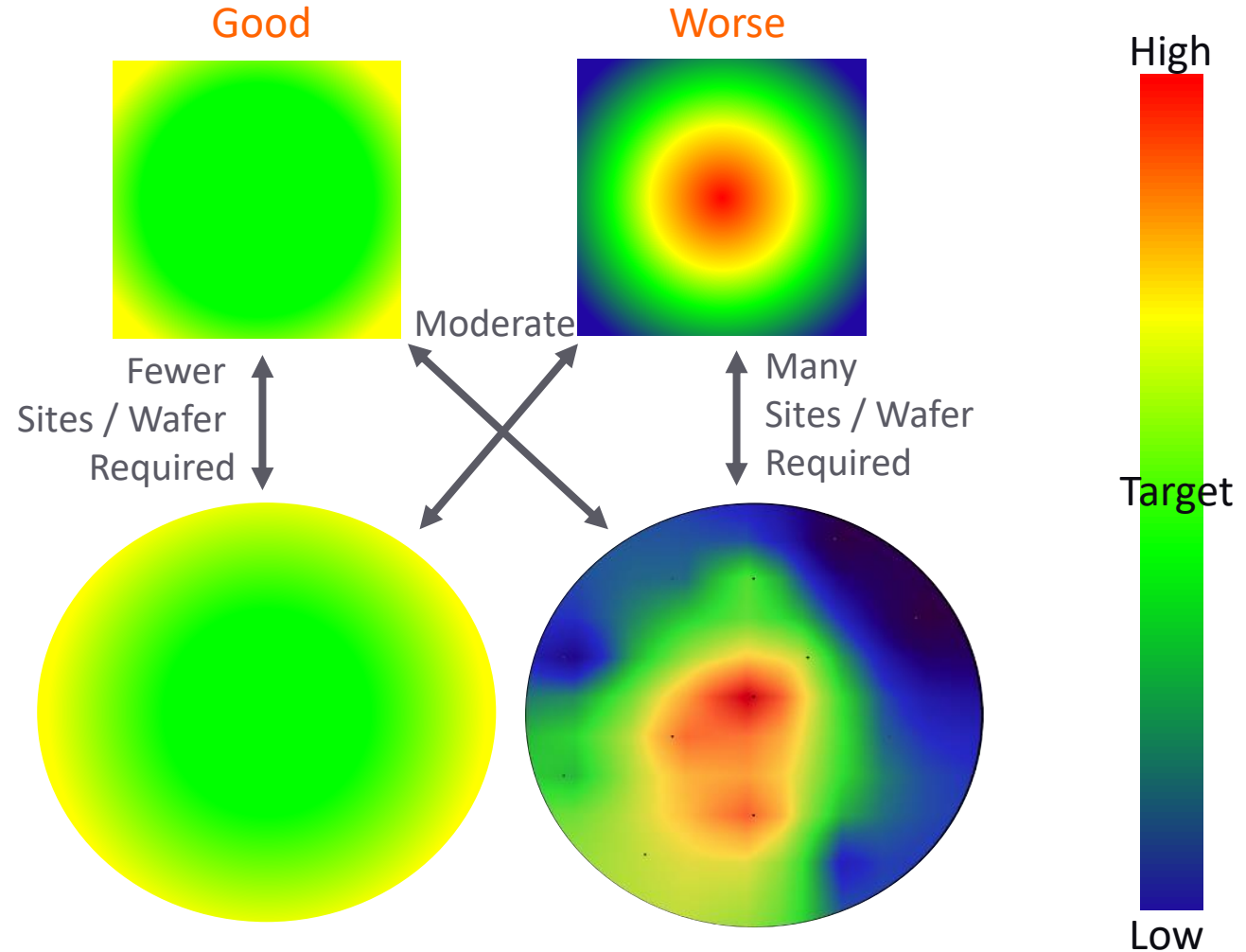
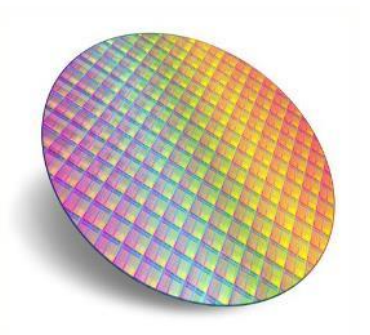
Most fabs measure 5 to 50 locations

# Complex Sources of Variability

ACLV: *Field*  
Across ~~Chip~~ Line Variation



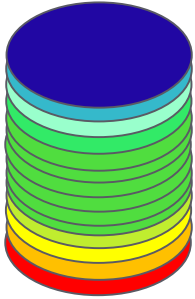
Cross Wafer Line Variation



Site Sampling Plan Must Reflect The Combined Variability

# Sources of Variability II

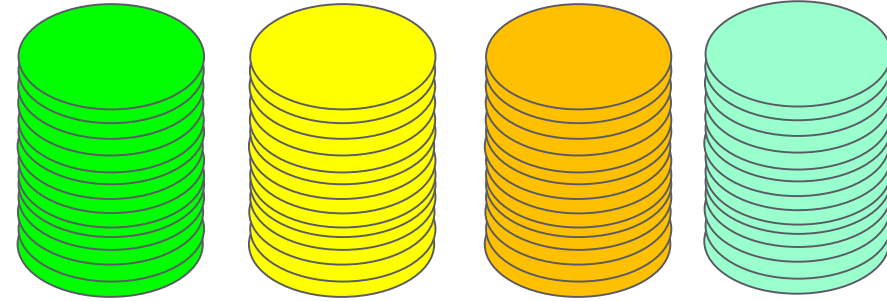
## Wafer-to-Wafer Variability



Wafer-to-wafer Variability within a lot

- First wafer effect
- Last wafer effect
- Every nth wafer
- Rogue wafer
- Random
- Tool Maintenance

## Lot-to-Lot Variability



Lot-to-Lot Variability within the line

- Fab temperature
- Humidity
- Vibration
- Rogue Lot
- Random
- Tool maintenance

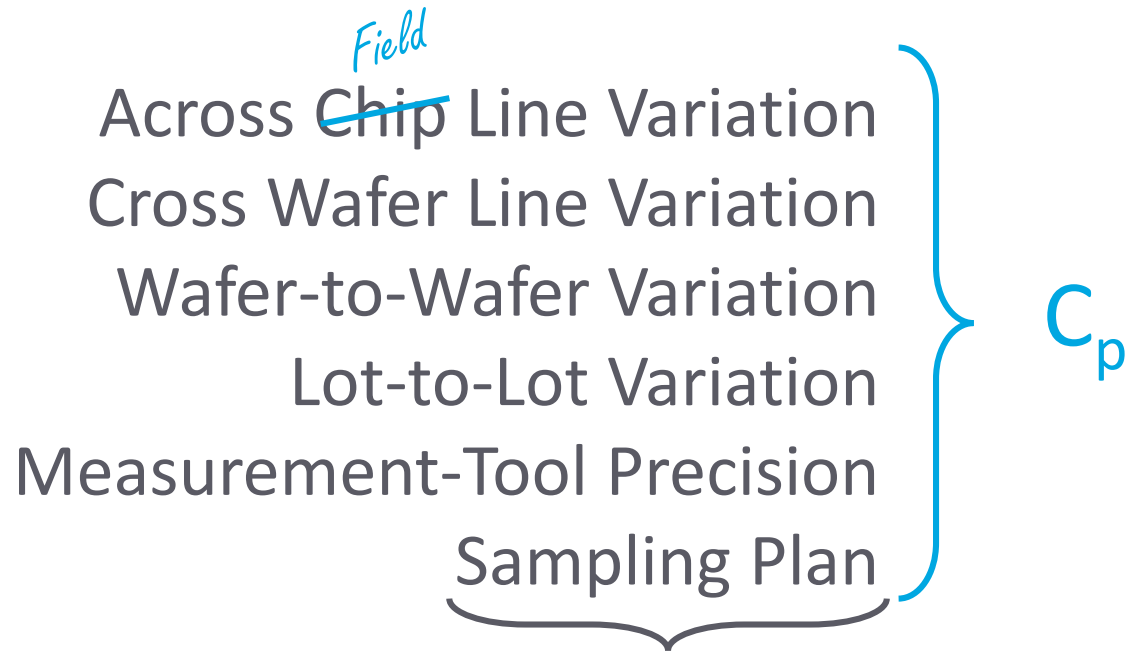
High

Target

Low

Wafer and Lot Sampling Plan Must Reflect The Combined Variability

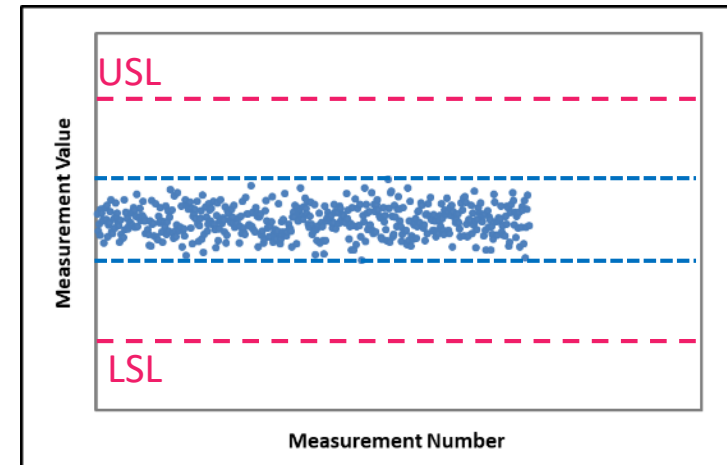
# Finding the Best Performing Tool: $C_p$



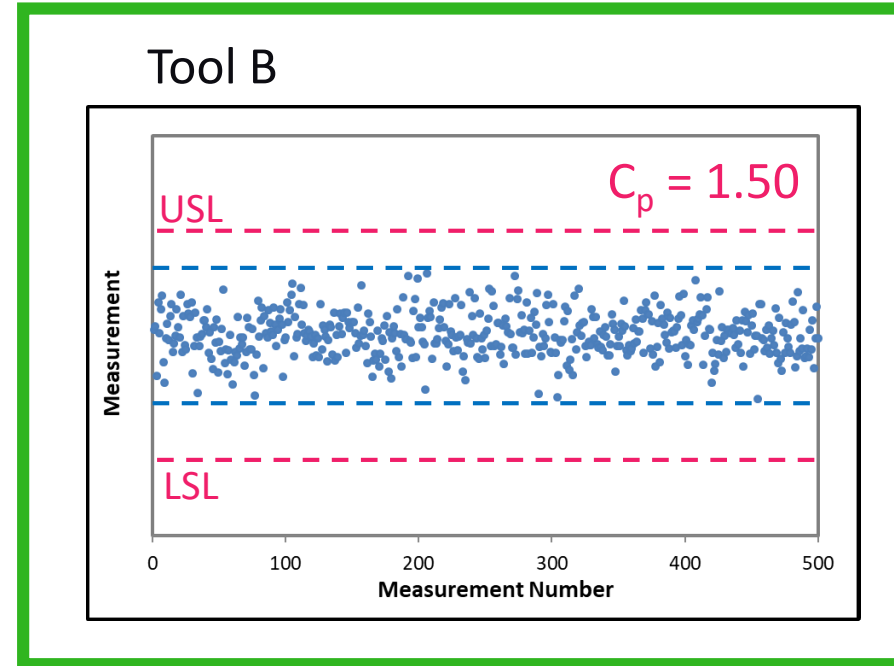
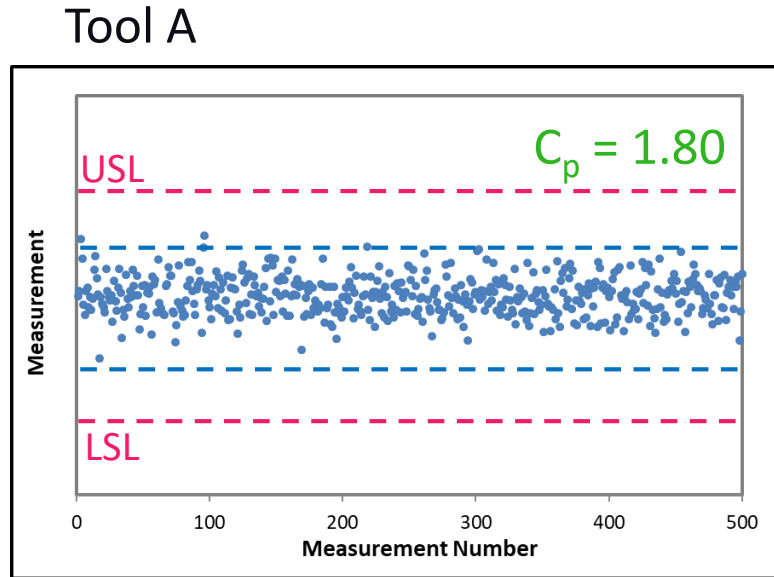
(Sites per Field, Fields per Wafer, Wafers per Lot, % of Lots)

- The sampling plan must capture the sum of all sources of variation
- The sampling plan must calculate the correct average for the lot
- The more variable a component is, the more measurements should be done at that level

*Is this the best performing tool?*



# Tool With Best $C_p$



18 Sites / Wafer; 2 Wafers / Lot

Both with this sample size, Tool B has a higher  $C_p$

# Summary Table

## Sources of Variation in The Measurement

## Applicable Tool Set

Measurement	ACLV (X-Field)	X-Wafer	Waf-2- Waf	Lot-2- Lot	Sample Plan	Litho	Etch	Films	CMP
Critical Dimension	X	X	X	X	X	X	X		
Film Thickness		X	X	X	X			X	X
Overlay	X	X	X	X	X	X			

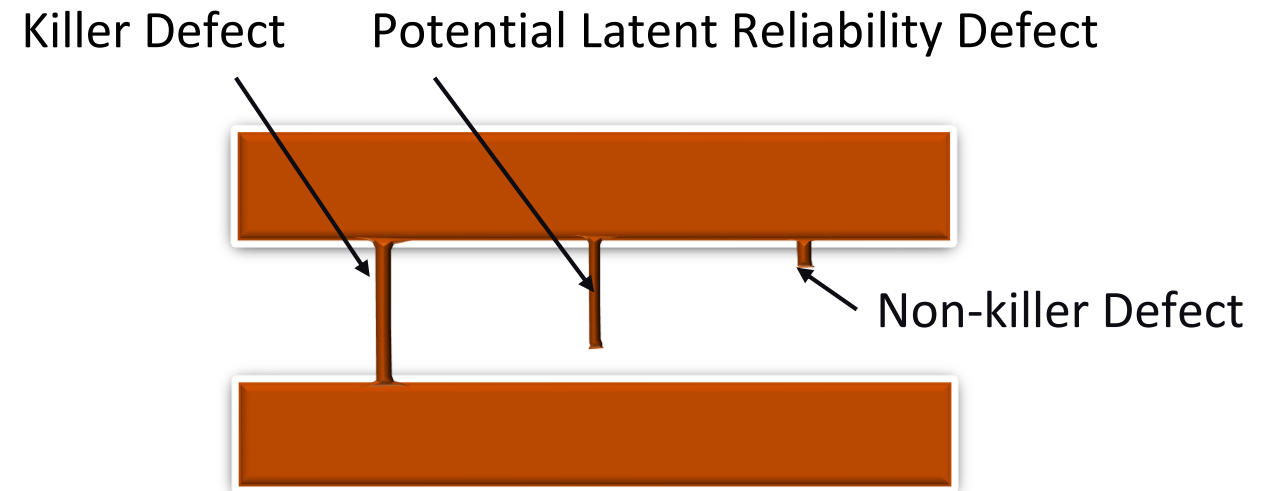
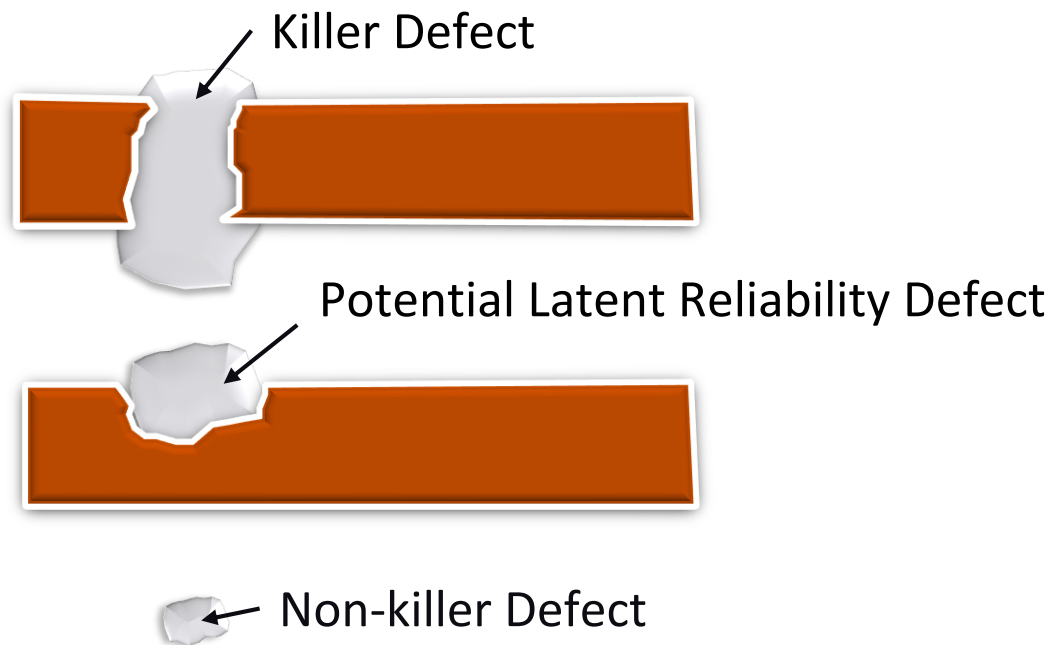


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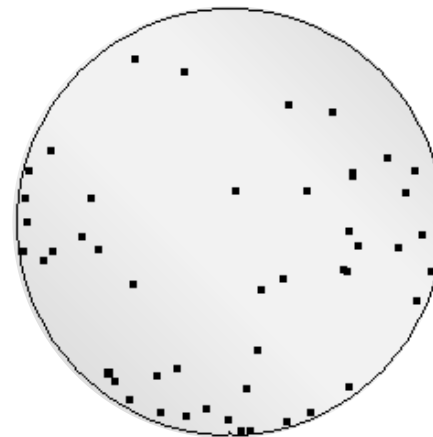
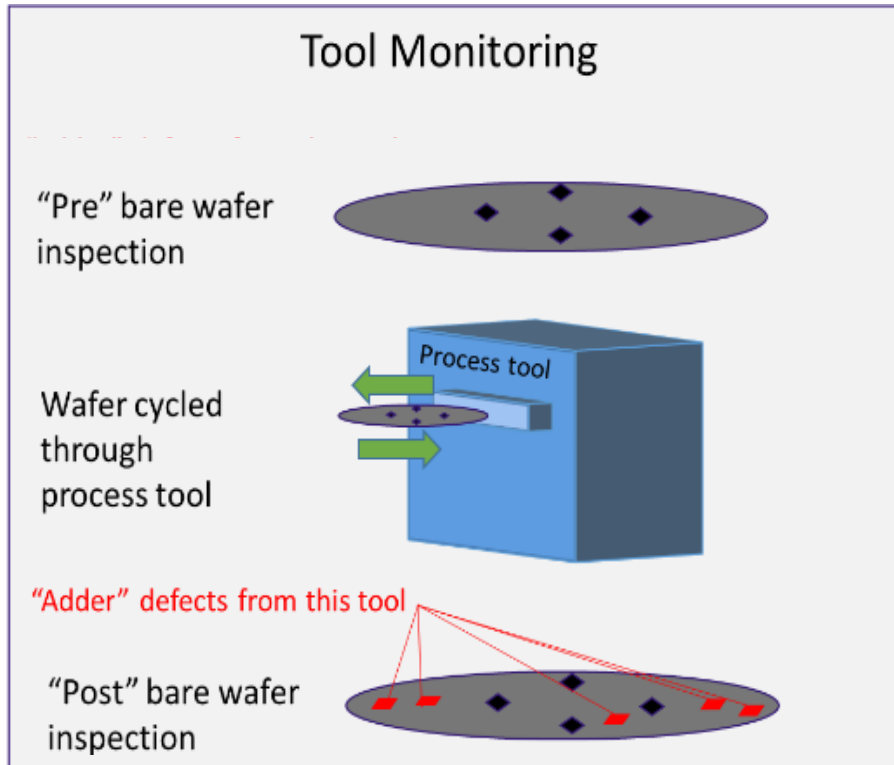
# Automotive Reliability Defects

1. Killer defects in test coverage gaps
2. Latent reliability defects which become activated after test

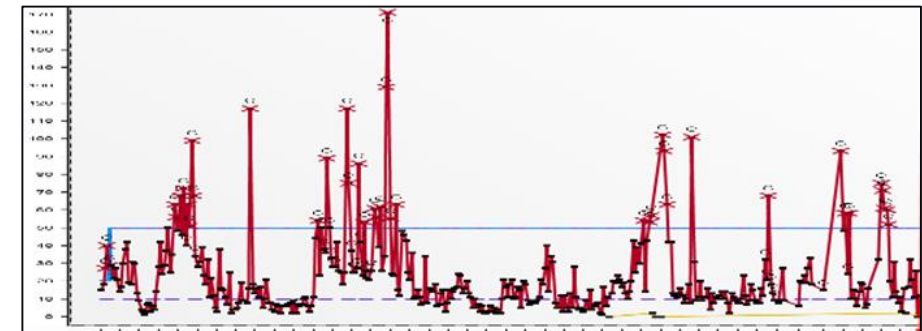


# Quantifying Defectivity

- Most mature process defectivity comes from random defects from process tools
- Monitored using blank test wafers or using production material
  - Pre / Post inspection and subtraction
  - Mechanical and process step contribution



Defect Wafer Map

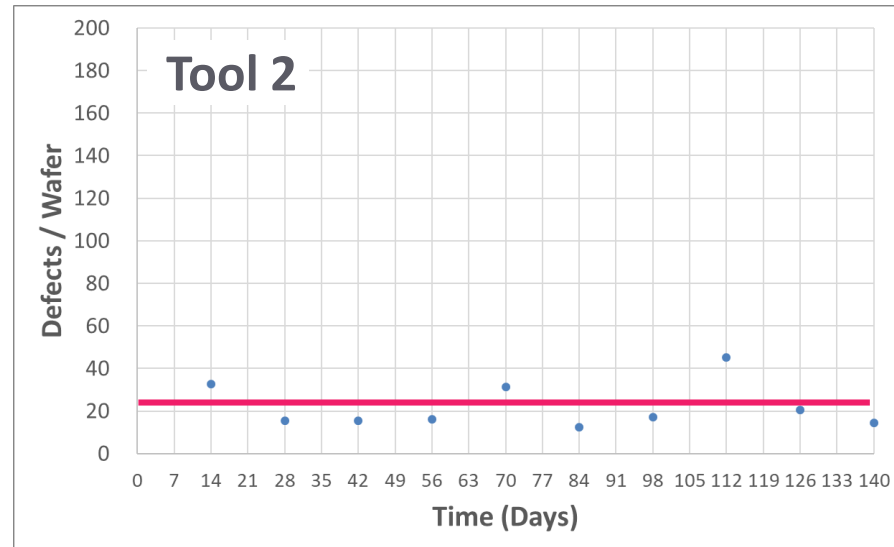
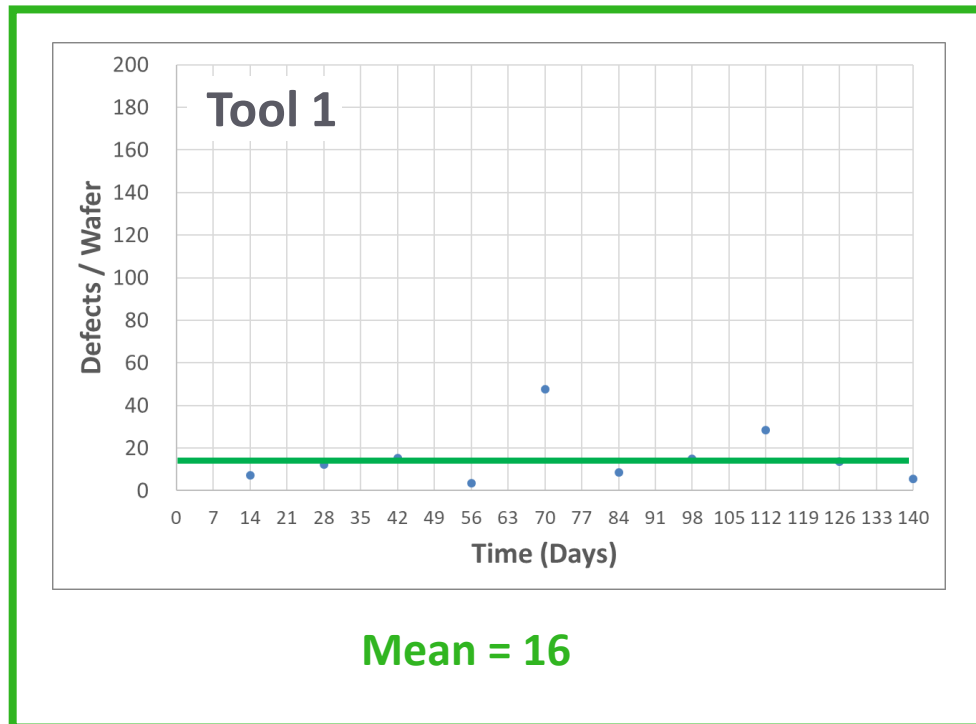


Tool Defectivity SPC Chart

# Finding the Best Performing Tool: Defectivity

## Is There Enough Data?

Qual Frequency: **Every Other Week**



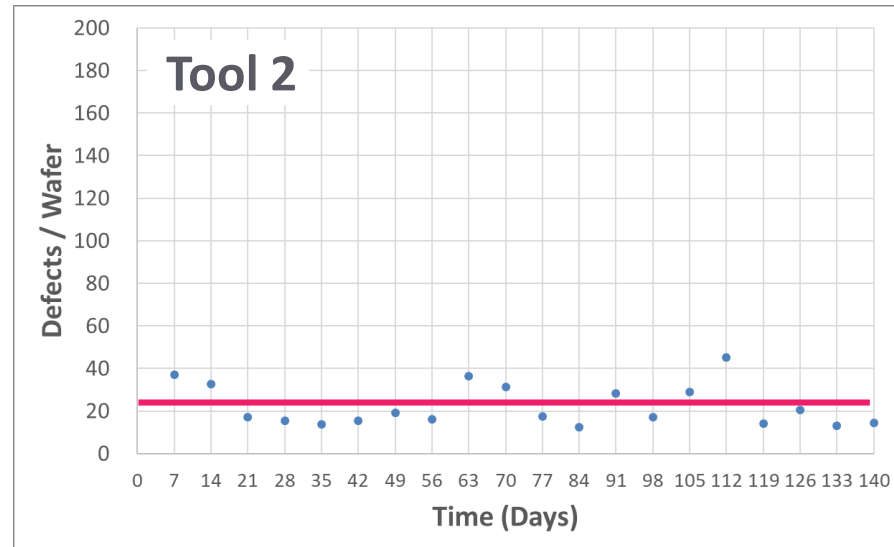
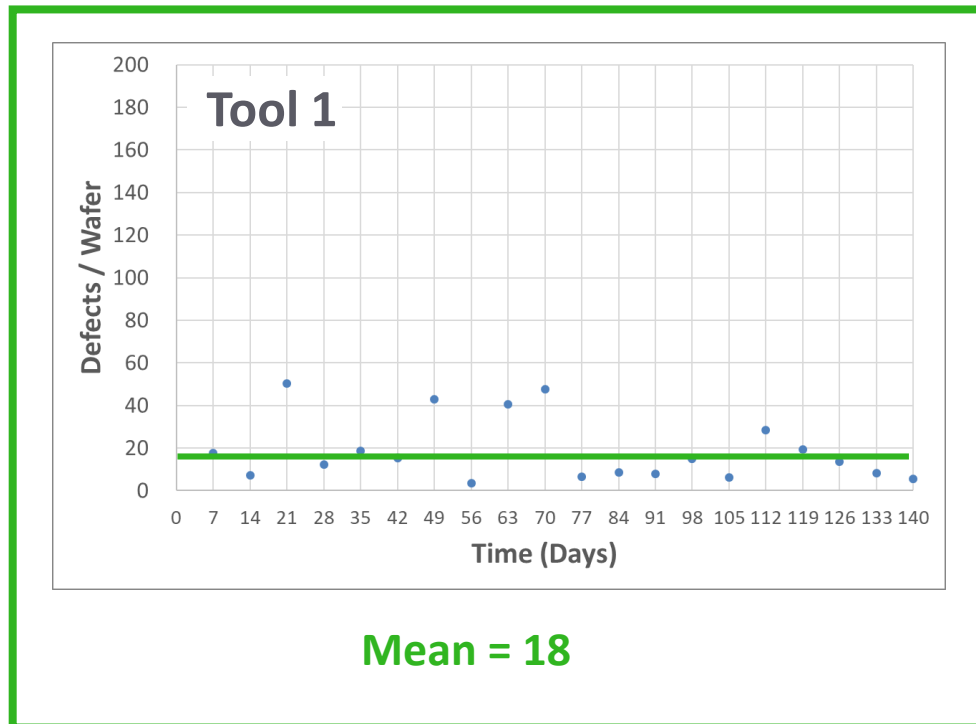
**Mean = 22**

With sparse data Tool 1 appears to be cleaner

# Finding the Best Performing Tool: Defectivity

## Is There Enough Data?

Qual Frequency: **Every Week**

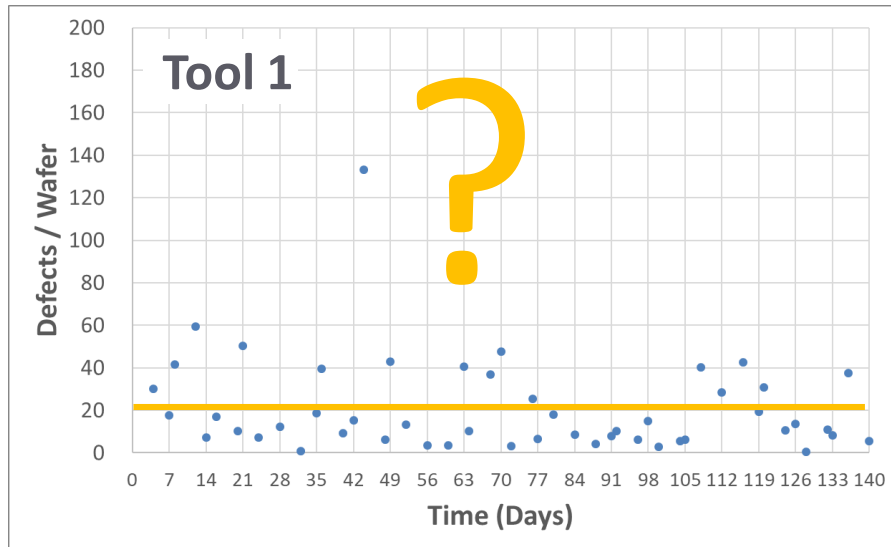


More variability but Tool 1 is still cleaner

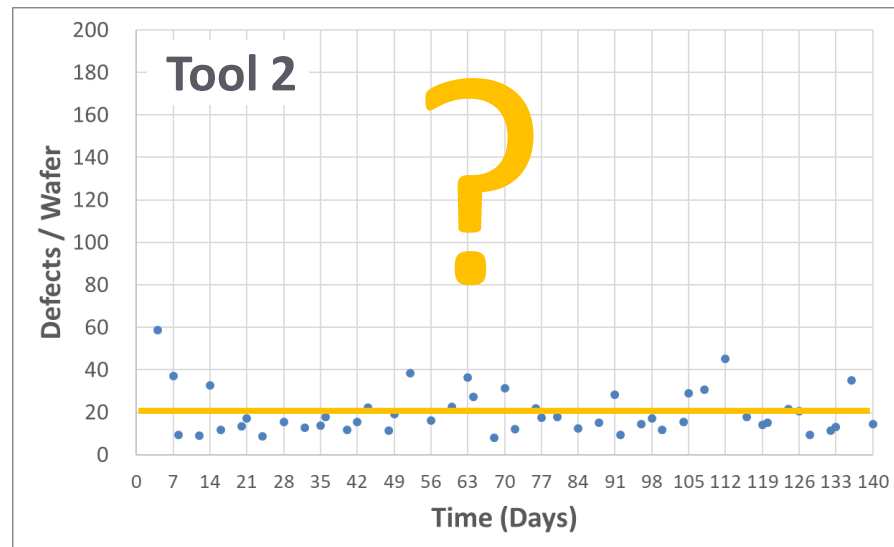
# Finding the Best Performing Tool: Defectivity

Is There Enough Data?

Qual Frequency: **Every 4 Days**



Mean = 21



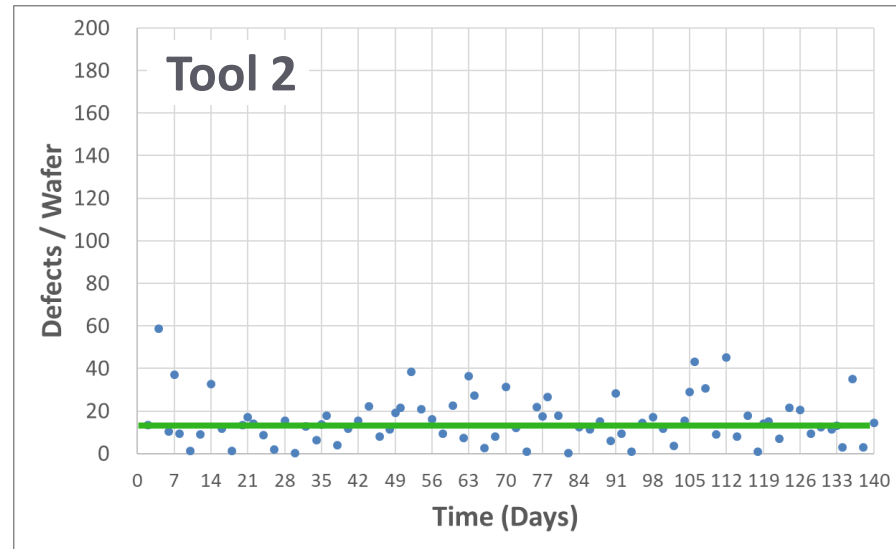
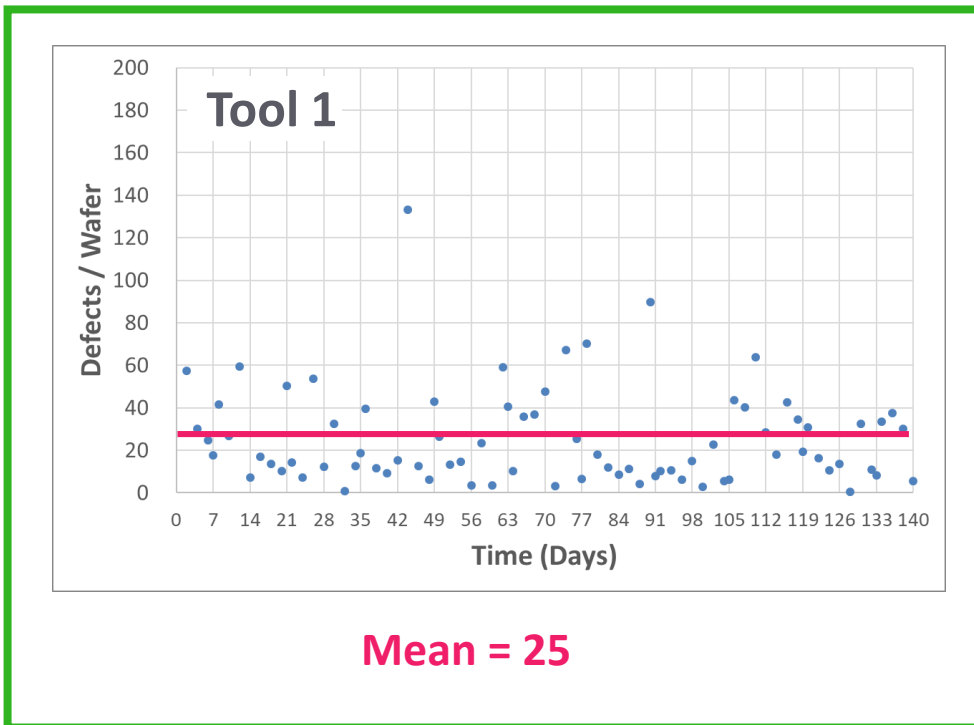
Mean = 20

Hard to tell the difference

# Finding the Best Performing Tool: Defectivity

Is There Enough Data?

Qual Frequency: **Every 2 Days**

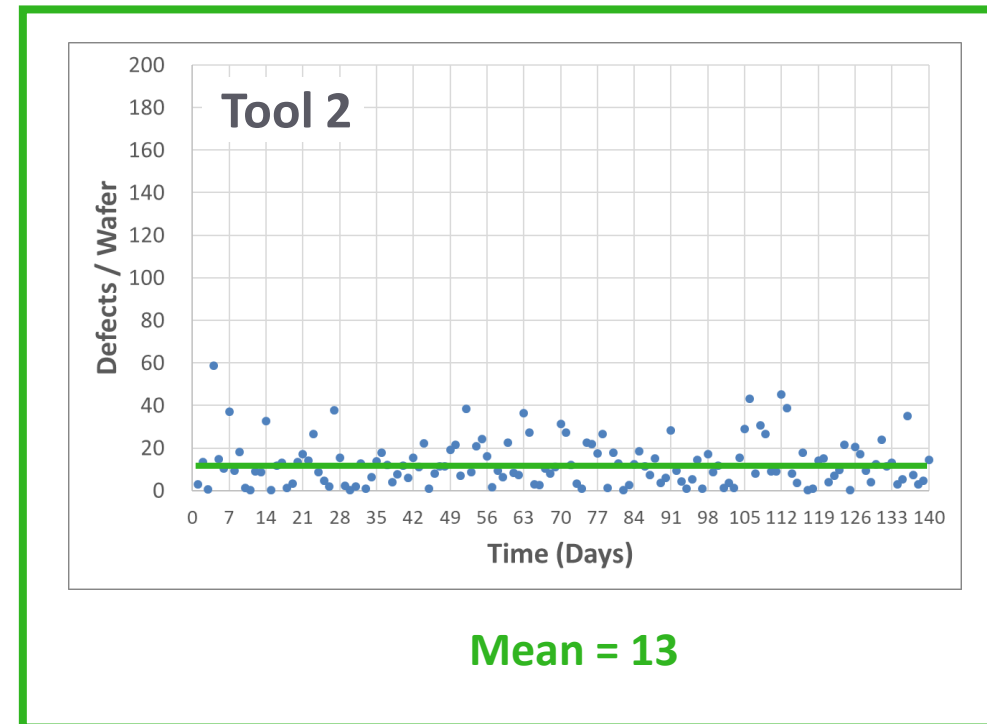
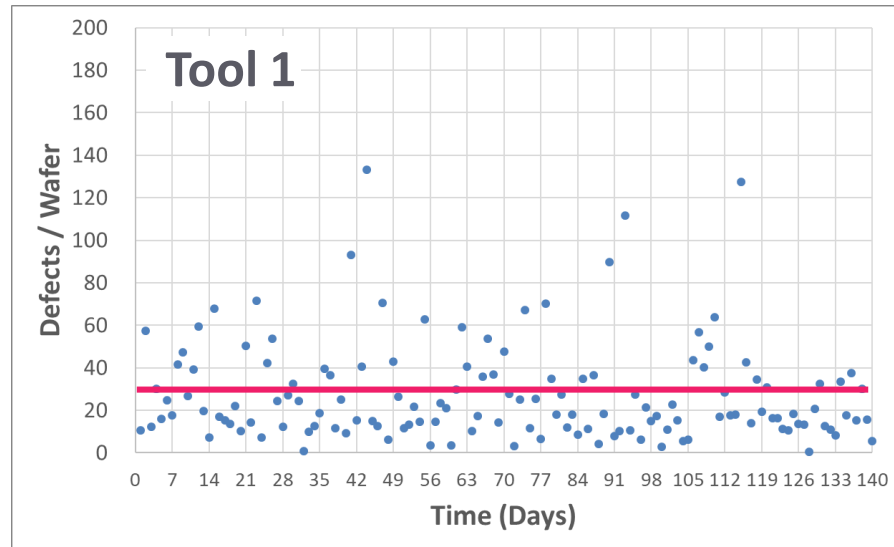


More data highlights the variability in Tool 1

# Assessing the Best Performing Tool: Defectivity

Is There Enough Data?

Qual Frequency: **Every Day**

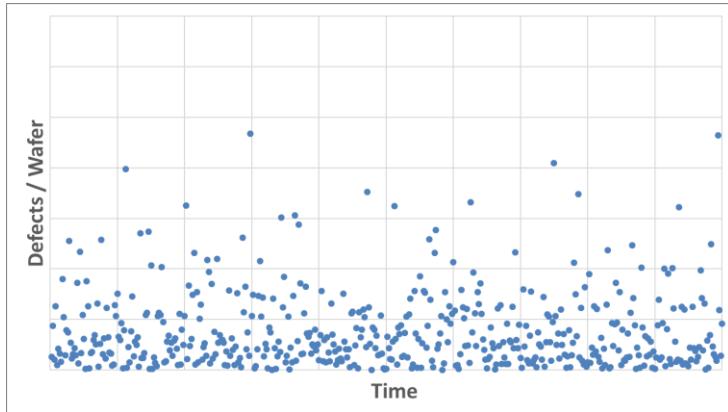


Must collect enough data to capture potential patterns

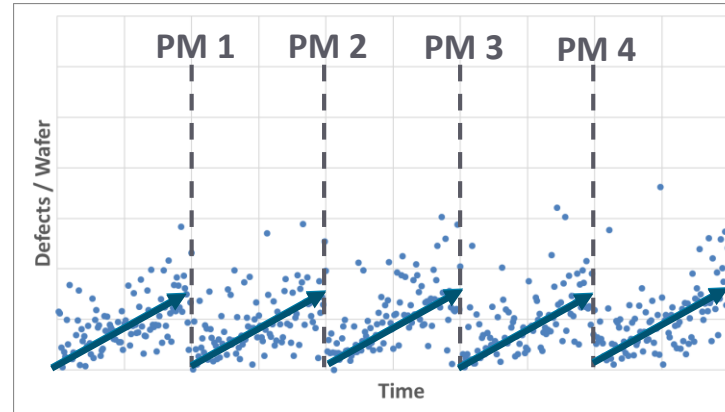


# Time-Based Defect Patterns

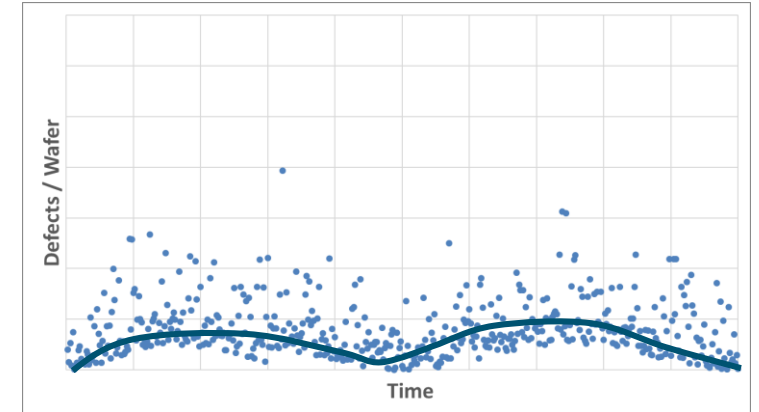
Random Defectivity



Event-Based Defectivity



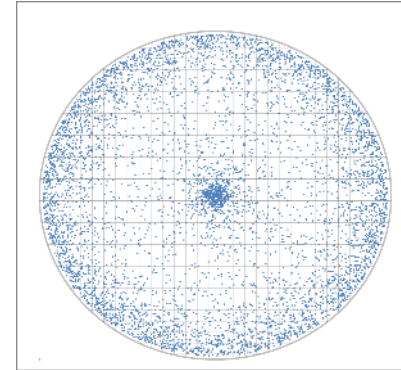
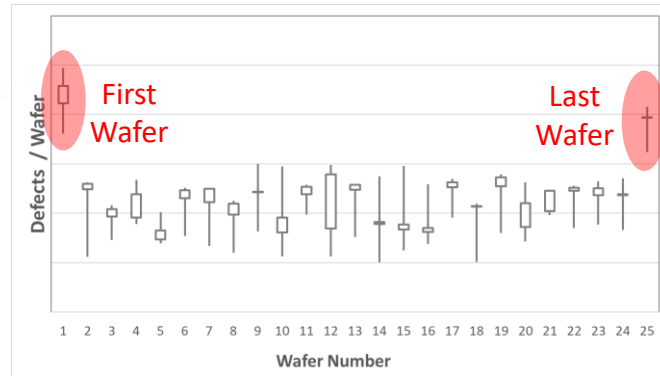
Cyclical Defectivity



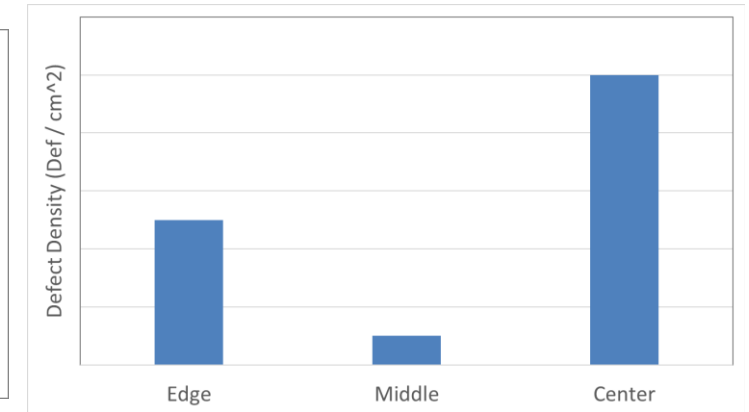
There must be enough data to identify these patterns  
(or rule them out)

# Position-Based Defect Patterns

## Within-Lot Patterns



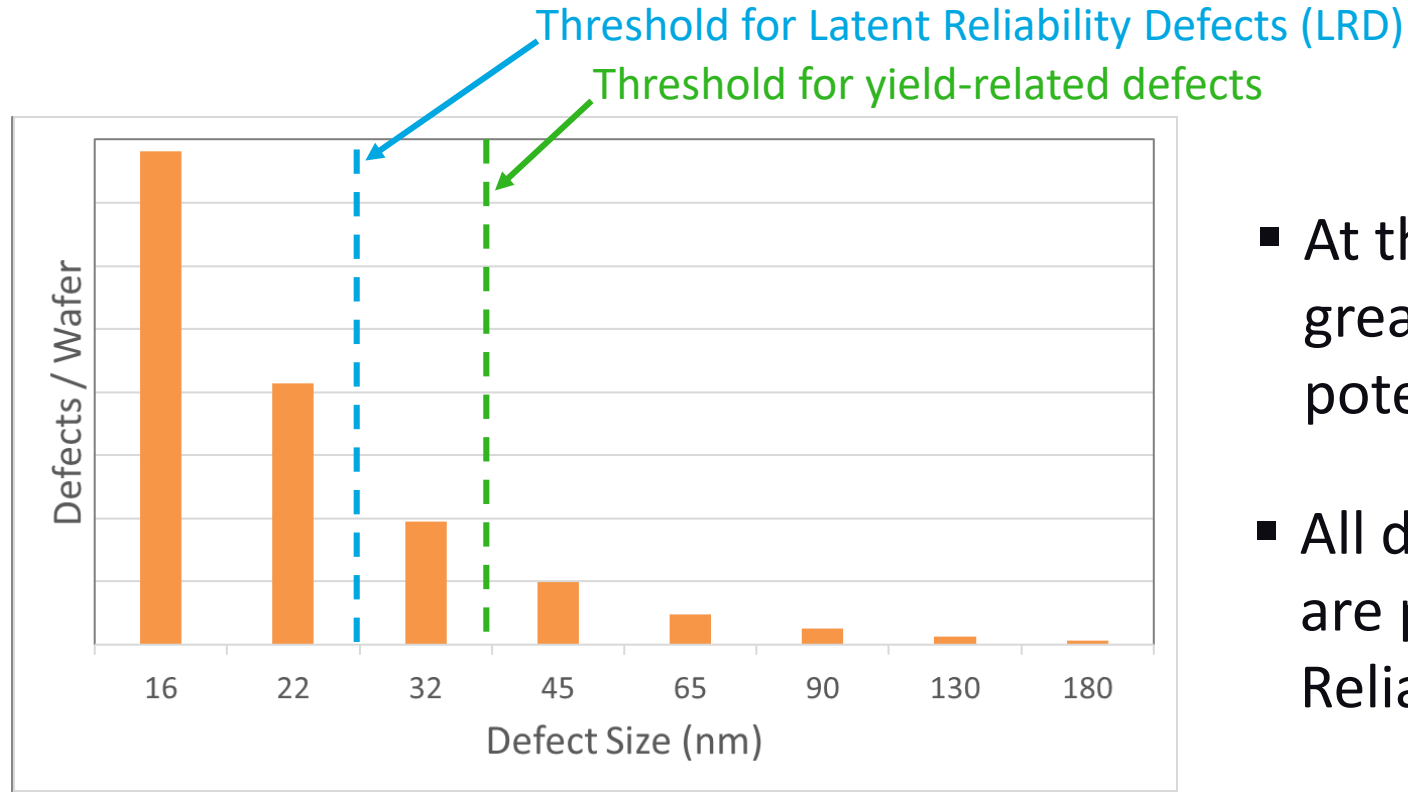
## Within-Wafer Patterns



The defect density is as important as the defect count

- Is it concentrated in select wafers?
- Is it concentrated in select regions of the wafer?

# Stapper Equation



Defect count is proportional to  $1/X^n$  where X is the defect size

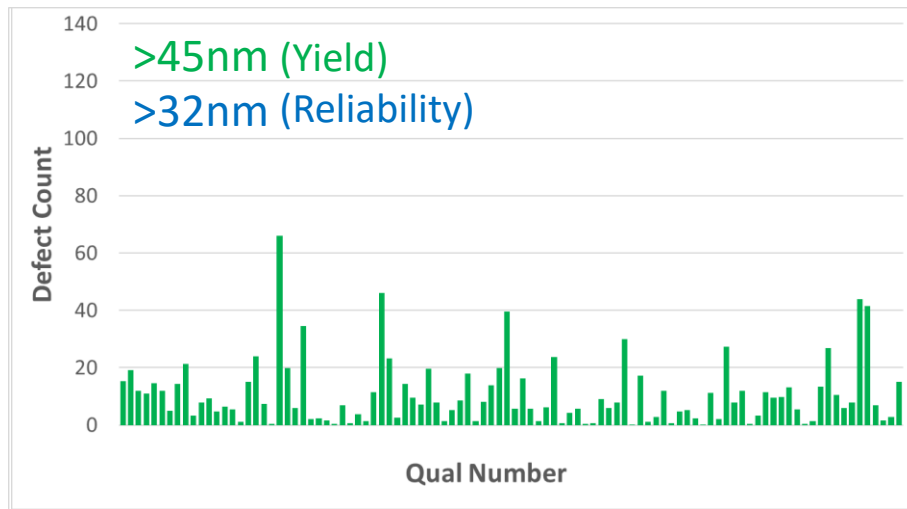
- At the 45nm DR, all defects greater than 45nm are potential killers
- All defects greater than 32nm are potential Latent Reliability Defects (LRD)

LRD's are typically a full design rule smaller than yield killers

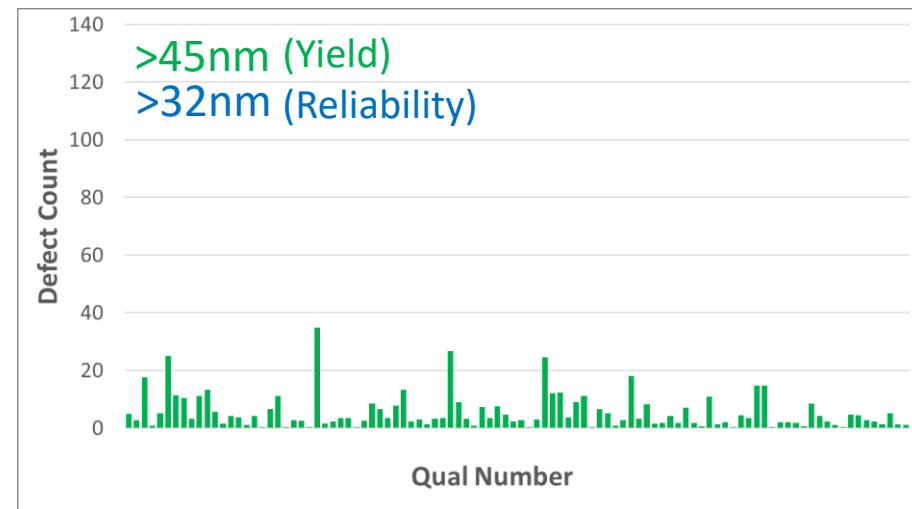
# Sensitivity

## Daily Process Tool Qual Results

Tool # 1



Tool # 2



Which tool is cleaner? It depends on the inspection sensitivity!

You need to monitor both thresholds: Yield & Reliability

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# Summary

1. The best way to reduce reliability escapes is a fab-wide commitment to reduction in defectivity and process variability. A Best Performing Tool program can be layered on top of this to find the optimum tool at that particular point in time.
2. The Best Performing Tool is generally the one(s) with:
  - Low defectivity (measured with defect inspection)
  - Low variability (measured with metrology)

# Available KLA Workshops for Auto Fabs, Tier 1s, and OEMs

- Latent Reliability Defects
- Fab-wide Baseline Defect Reduction Strategies
- Inspection and Metrology Strategy Re-Optimization with DR Shrink
- Excursion Monitoring Optimization
- Die Level Screening Methodologies (inline)
- Micro-Excursions and Yield Variation
- Improving Cycle Time
- Sampling Optimization (% lots, wafers/lot, area/wafer, sites/wafer, SEM review)
- Virtual Metrology and Fault Detection
- Precision, Accuracy, and Misclassification Risk
- Using Metrology to Expand the Process Window
- Others upon request...

For more information, please contact [Kara.Sherman@kla.com](mailto:Kara.Sherman@kla.com)

Thank You

