JMP GRR Project: GRR study on process and metrology tools

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APPLIED MATERIALS®
make possible

2024 JMP China DS-03 PSE GRR

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- Master Degree in Materials Science from Xi'an Jiaotong University.
- 5 years in packaging tool R&D, 2 years in CVD and 5 years in defect inspection and review experience.
- Focus on GRR Analysis using JMP platform

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- Master's Degree in Materials Science and Engineering from Northwestern University
- Responsible for rapid thermal process and epitaxial Si process
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- Master Degree in Materials Science from Fudan University
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AGENDA

1: GRR Study on OPWI Capture Rate Monitoring

2: GRR Study on Rs Measurement Tool

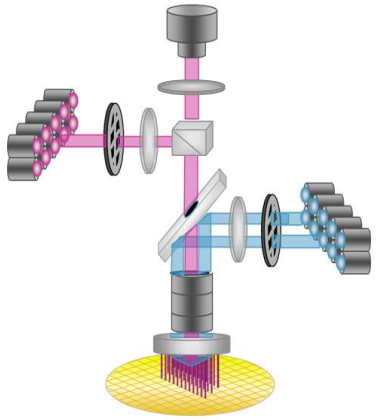
3: GRR Study on Meas. Q.Time on SiO_2 THK.

1. Optical Wafer Inspection: UVision8® Introduction

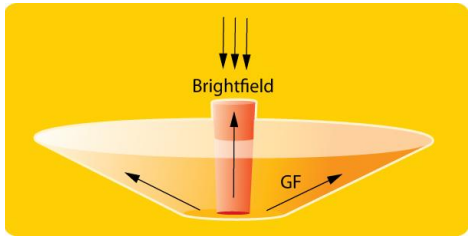
Innovation

- **Detection**
  - Sensitivity thru high illumination **266nm DUV laser**
  - **Full polarization control** in illumination & collection
  - Simultaneous **Brightfield & Grayfield** detection
  - High sensitivity & high TPT mode
- **Filtering:**
  - Multi dimension attribute engine

Optics Path



Bright & Gray Filed



Value

- **BF & GF Inspection**
  - For full application space
- **Application In Fab**
  - R&D → Ramp → HVM

UV8® is an Optical Solution for Defect Inspection in R&D and HVM in ICAPS.

1: Proposals Introduction

- **Motivation:**
  - UV8® sensitivity and stability (Capture rate-CR) need to be monitoring during PM interval to guarantee tool performance.

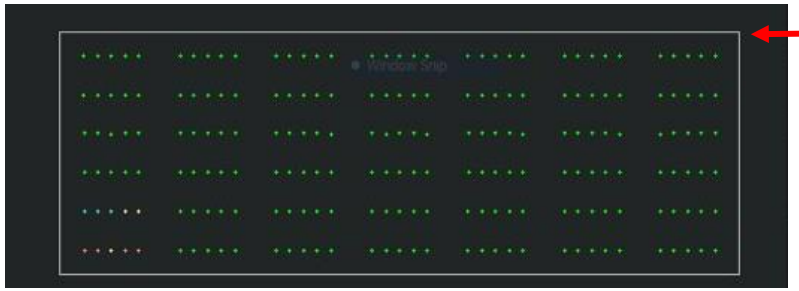
- **Sampling plan**
  - **Parts:** 1 part with 3 dies, totally 9 parts ,sample in wafer center.
  - **Repetition:** 10 repetition in each part.
  - **Reproducibility:** Test time- 1d,3d, 7d, 15d and 30d.

- **Rules for Fast Repeat**
  - Sequence follow queue time (1d,3d, 7d, 15d and 30d)
  - 9 parts at the same queue time
  - 10 repeats within the same Part

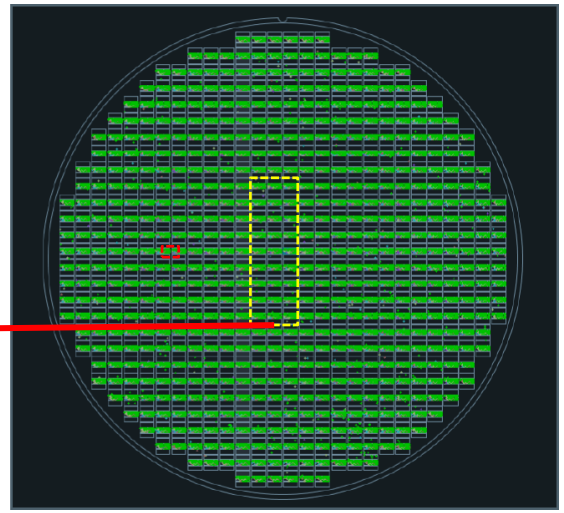
- **Criteria:**
  - P/T ratio: will be selected since Referred to spec (USL,LSL), lower request on parts selection.
  - **Spec: 630± 30ea(±4.7%)**

Defect in each part

Sensitivity Specs + Results									
Objective & Optics	Defect								
BF 100nm	sh_up	Result							
		Spec	NA	NA	NA	NA	NA	NA	NA
	sh_d	Result							
		Spec	NA	NA	NA	NA	NA	NA	NA
	op_up	Result	1						
		Spec	0.99	NA	NA	NA	NA	NA	NA
	op_d	Result	1						
		Spec	0.99	NA	NA	NA	NA	NA	NA
	Int	Result		1	1				
		Spec	NA	0.99	0.99	NA	NA	NA	NA
	Prot	Result		1	1				
		Spec	NA	0.99	0.99	NA	NA	NA	NA



Parts sample plan



1: GRR Analysis: Crossed

Crossed GRR (ANOVA with interaction)

Gauge R&R

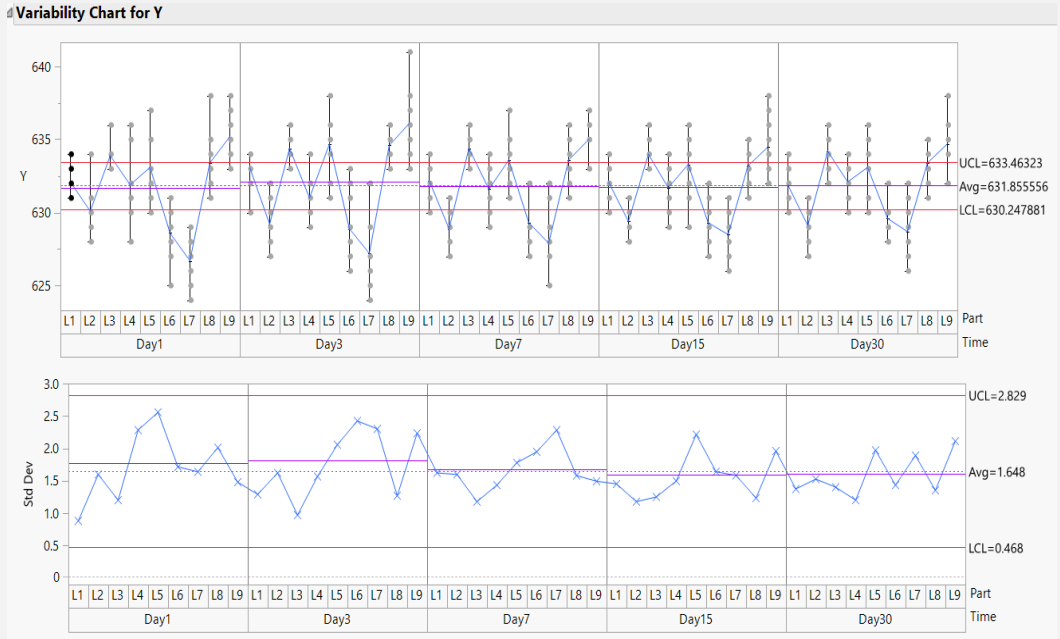
Measurement Source		Variation (6*StdDev)	% of Tolerance		which is 6*sqrt of
Repeatability	(EV)	10.072983	16.79	Equipment Variation	V(Within)
Reproducibility	(AV)	1.645274	2.74	Appraiser Variation	V(Time) + V(Time*Part)
Time		0.795957	1.33		V(Time)
Time*Part		1.439923	2.40		V(Time*Part)
Gauge R&R	(RR)	10.206464	17.01	Measurement Variation	V(Within) + V(Time) + V(Time*Part)
Part Variation	(PV)	13.655811	22.76	Part Variation	V(Part)
Total Variation	(TV)	17.048550	28.41	Total Variation	V(Within) + V(Time) + V(Time*Part) + V(Part)

Summary and Gauge R&R Statistics

6	k
59.867	% Gauge R&R = 100*(RR/TV)
0.74741	Precision to Part Variation = RR/PV
1	Number of Distinct Categories = Floor(sqrt(2)*(PV/RR))
600	Lower Tolerance (LT)
660	Upper Tolerance (UT)
60	Tolerance = UT-LT
0.17011	Precision/Tolerance Ratio = RR/(UT-LT)

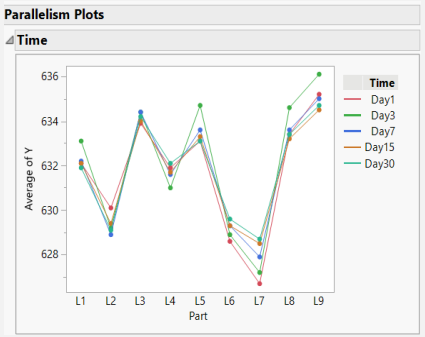
P/TV=59%
P/T=17%

Variability Chart



- **Conclusion:**
  - PT ratio is preferred to evaluate GRR performance on spec.
    - PT ratio =17%<30%, meaning acceptable measurement error, adequate GRR measurement capability.
  - P/TV Ratio is much higher than P/T ratio ,indicating the selected GRR samples selection is too tight.

- **Repeatability**
  - **>55%** points is out of Gauge variation range
  - No OOC in Std DeV chart, 6σ repeatability =9.8<60
- **Reproducibility**
  - Five curves are parallel.
  - Smaller group mean difference(0.46<spec 60)
  - Little interaction with parts*time



1: GRR Analysis: Misclassification Rate

- **Misclassification Rate**

Misclassification Probabilities

Lower Tolerance = 600, Upper Tolerance = 660, Grand Mean = 631.8556

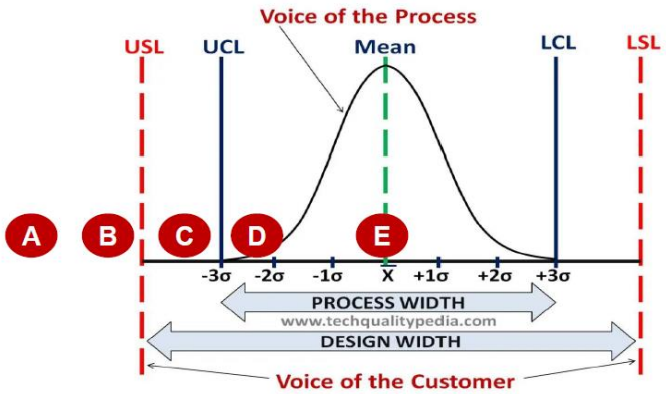
Description	Probability
P(Good part is falsely rejected)	0.00000000
P(Bad part is falsely accepted)	.
P(Part is good and is rejected)	0.00000000
P(Part is bad and is accepted)	0.00000000
P(Part is good)	1.00000000

Alpha risk: Producer Risk
Beta risk: Customer Risk

Note: The probability that a part is outside of tolerance is zero.

- **Conclusion:**
  - » All measurement targets distribution is tight and measurement value is +/- 11 compared with spec +/- 30
  - » Most measurements parts are in Type E area (target area), very tight measurement distribution causes zero Alpha and Beta risk.

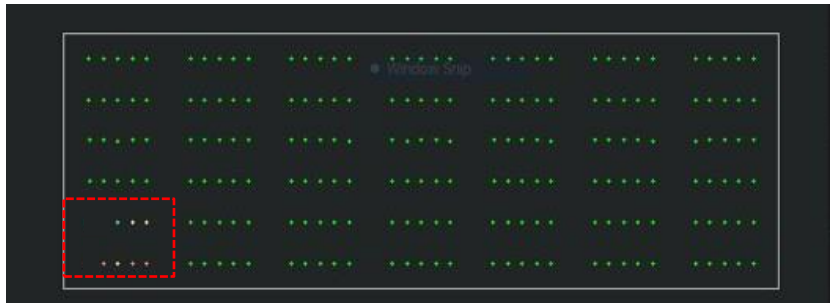
Location	Spec Limit	Control Limit	Target	Alpha Risk	Beta Risk
A	Way bwyond Spec Range	Way bwyond Control Range	Far Away from the Target	Zero	Very Low
B	Slightly outside Spec Range	Way beyond Control Range	Far Away from the Target	Low	High
C	Inside the Spec Range	Slightly outside the Control Range	Still away from the Target	High	Low
D	Inside the Spec Range	Inside the Control Range	near the Target	Low	Very Low
E	Inside the Spec Range	Inside the Control Range	At the Target	Zero	Zero



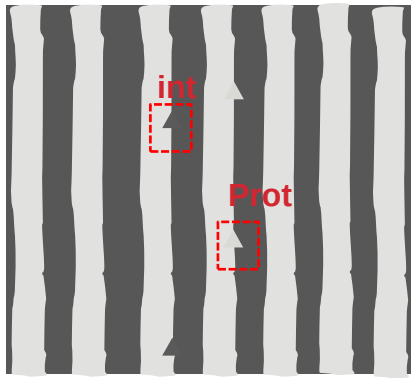
1: Missing Analysis

- **Missing analysis**
  - Missing defects are smaller size (100nm) intrusion and protrusion.
  - Detection challenges are defects SNR is lower, which easily to mix with line roughness in the background.
  - Such detection capability and stability is not enough to handle advanced tech nodes.
  - Need to enhance missing defects detection SNR in new platform(Enlight®) by using new optical design and new algorithm.

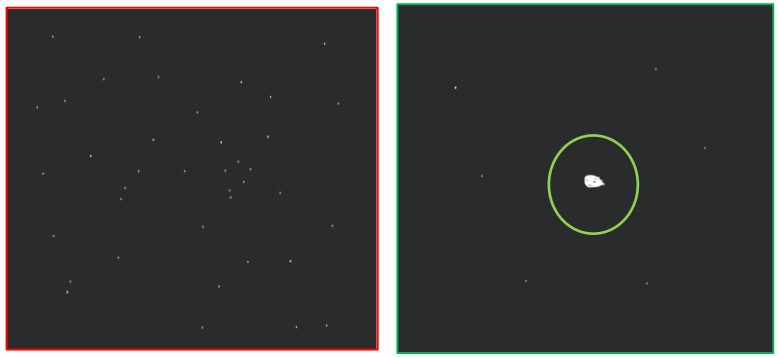
Missing defects map



Missing defect types illustration (Manual drawing)



Missing defect SNR Illustration (Manual drawing)



1: New Platform: Enlight® Overview

High NA Optics

Highest available OPWI NA

Light Budget

High Power Laser
Higher QE detectors
Enhanced Optical Path

Oblique illumination

-SideView™ module

Advanced imaging

Innovative advanced computing architecture

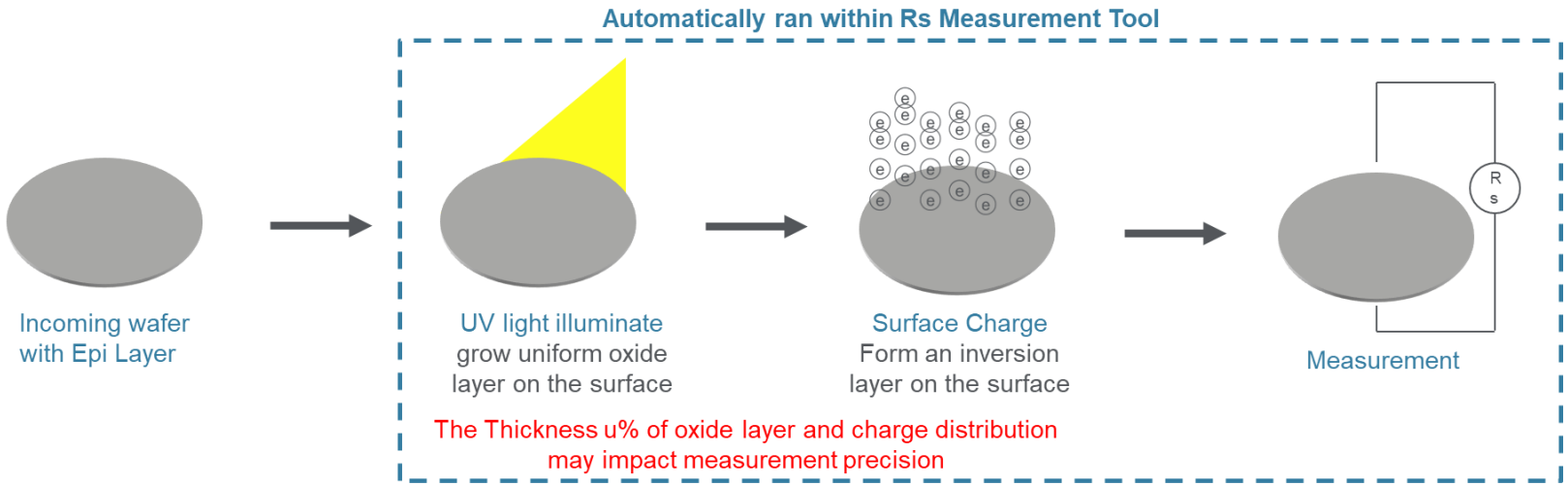
Algo improvement

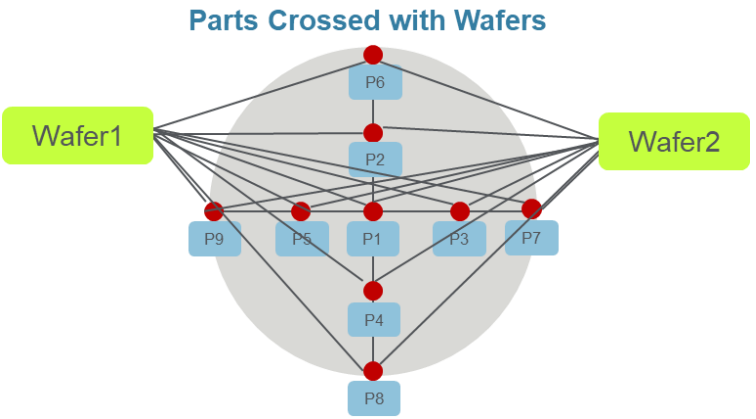
-Deep learning algo.

- **Continuous Improvement Plan**
  - For Enlight® with higher sensitivity in advanced tech-node:
    - Design new OTW wafer with smaller and challenging types defects for tool GRR performance monitoring .
    - Perform attribute GRR on defect dimension and type instead of only focusing on total defect counts to identify detection gap root cause, thus improve OPWI products performance and enhance OPWI marketing position.

2: Project Background & Problem Statement

- **Problem statement**
  - Rs or Resistivity, measured by lab QCs tool, is a key parameter of Epi films
  - The unstable measurement precision severely influences Epi process recipe tuning
- **Objective**
  - Apply JMP GRR platforms to analyze the measurement GRR capability and stability of lab QCs tool
  - Find out the most unstable measured points
- **Sampling Plan**
  - Repeatability: 4 repeats per wafer
  - Reproducibility: 2 wafers
  - Tolerance Spec: 9.8~10.2





2: GRR Performance Analysis: Main effect vs. Crossed

- **Main Effect (ANOVA without interaction)**

Gauge R&R

Measurement Source		Variation (6*StdDev)	% of Tolerance		which is 6*sqrt of
Repeatability	(EV)	0.6686637	167.17	Equipment Variation	V(Within)
Reproducibility	(AV)	0.0929991	23.25	Appraiser Variation	V(Wafer)
Wafer		0.0929991	23.25		V(Wafer)
Gauge R&R	(RR)	0.6750999	168.77	Measurement Variation	V(Within) + V(Wafer)
Part Variation	(PV)	0.7932474	198.31	Part Variation	V(Part)
Total Variation	(TV)	1.0416340	260.41	Total Variation	V(Within) + V(Wafer) + V(Part)

Summary and Gauge R&R Statistics

6	k
64.8116	% Gauge R&R = 100*(RR/TV)
0.85106	Precision to Part Variation = RR/PV
1	Number of Distinct Categories = Floor(sqrt(2)*(PV/RR))
9.8	Lower Tolerance (LT)
10.2	Upper Tolerance (UT)
0.4	Tolerance = UT-LT
1.68775	Precision/Tolerance Ratio = RR/(UT-LT)

P/TV = 66.8%

Tolerance = 0.4

P/T = 172%

- **Crossed (ANOVA with interaction)**

Gauge R&R

Measurement Source		Variation (6*StdDev)	% of Tolerance		which is 6*sqrt of
Repeatability	(EV)	0.6496890	162.42	Equipment Variation	V(Within)
Reproducibility	(AV)	0.2274164	56.85	Appraiser Variation	V(Wafer) + V(Wafer*Part)
Wafer		0.1058743	26.47		V(Wafer)
Wafer*Part		0.2012680	50.32		V(Wafer*Part)
Gauge R&R	(RR)	0.6883415	172.09	Measurement Variation	V(Within) + V(Wafer) + V(Wafer*Part)
Part Variation	(PV)	0.7679325	191.98	Part Variation	V(Part)
Total Variation	(TV)	1.0312780	257.82	Total Variation	V(Within) + V(Wafer) + V(Wafer*Part) + V(Part)

Summary and Gauge R&R Statistics

6	k
66.7465	% Gauge R&R = 100*(RR/TV)
0.89636	Precision to Part Variation = RR/PV
1	Number of Distinct Categories = Floor(sqrt(2)*(PV/RR))
9.8	Lower Tolerance (LT)
10.2	Upper Tolerance (UT)
0.4	Tolerance = UT-LT
1.72085	Precision/Tolerance Ratio = RR/(UT-LT)

- **P/T =172%> 30%: poor GRR measurement capability, need to investigate the RC.**

2: GRR Root Cause Analysis

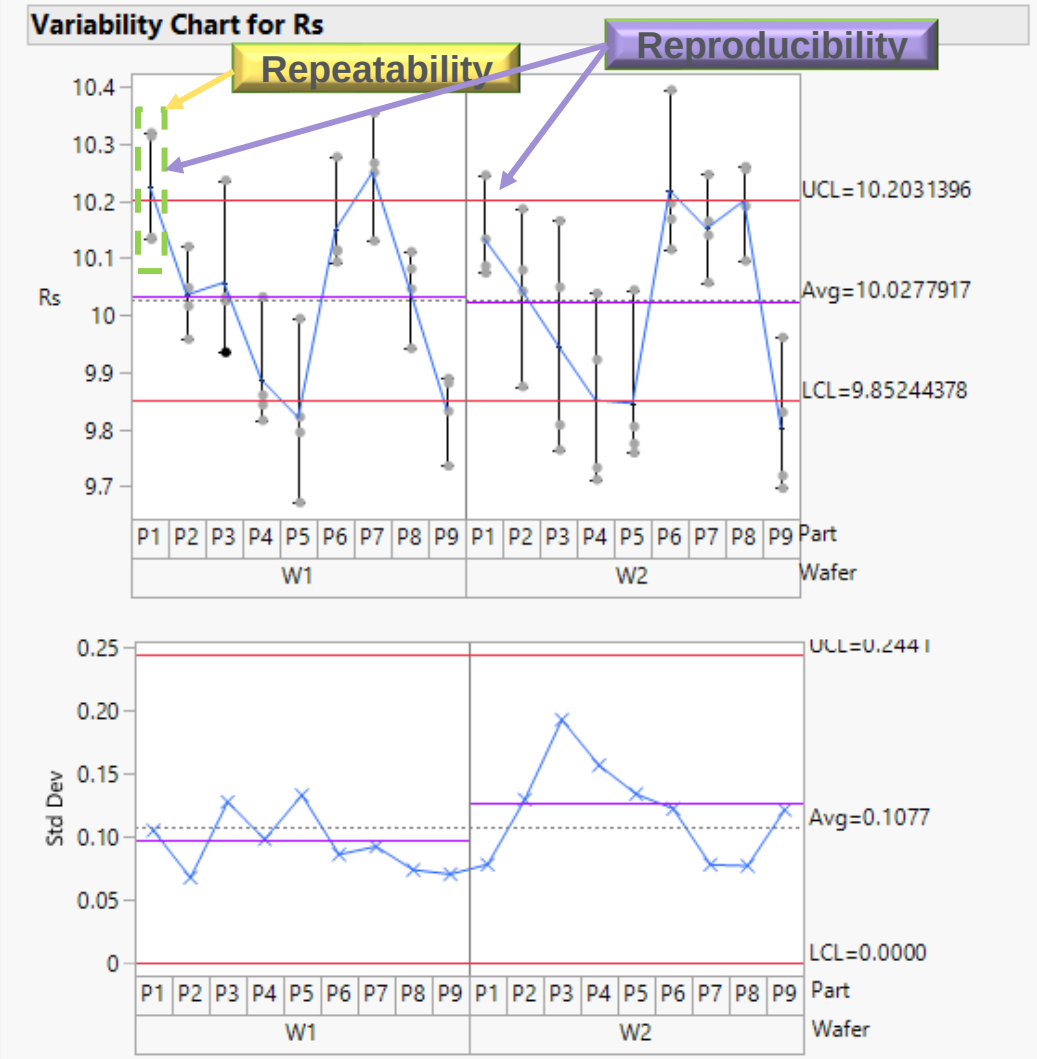
- **Objective**
  - To find out where we can improve the repeatability and reproducibility

- **Repeatability**
  - No OOC in Std DeV chart, the repeatability is stable for each part
  - But the repeatability is too bad, for 6σ=0.6, greater than tolerance(10.2-9.8=0.4)

$$P/T = \frac{6\sqrt{\sigma^2_{repeatability}+\sigma^2_{reproducibility}}}{Tolerance}$$

  - More than 50% of the points fall into the control limit in xBar Chart, indicating the control limit is too wide due to bad repeatability

- **Reproducibility**
  - Obvious reproducibility issue because the two Rs blue connecting lines of 2 wafers are not parallel with each other

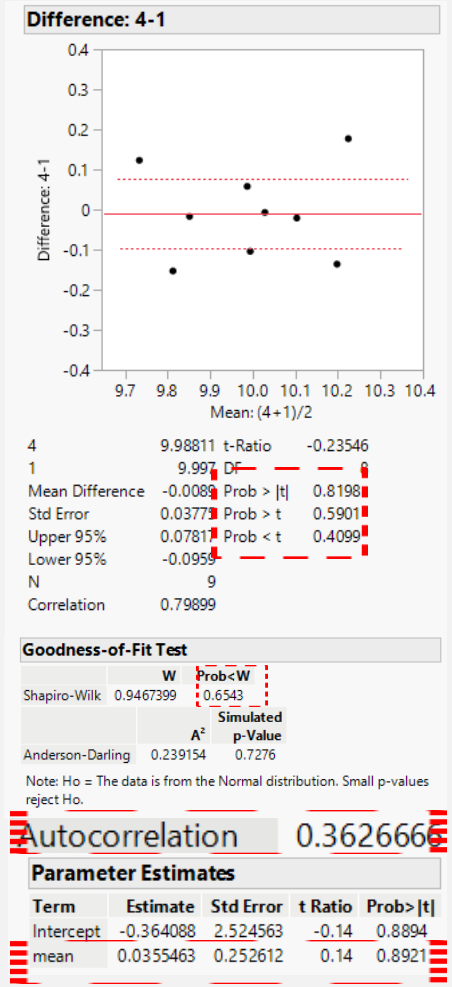


2: Degradation Risk: Replication 1 vs. Replication 4

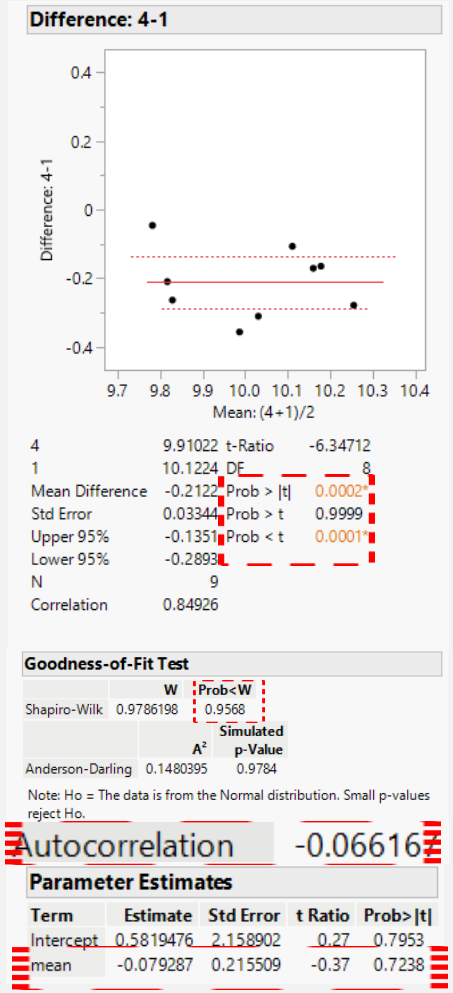
- **Objective**
  - Use Matched Pairs to conduct Paired-T test between Replication 1 and Replication 4 for Degradation Risk Evaluation

- **Results**
  - Wafer 1 has low Degradation Risk: p>0.05
  - Wafer 2 has significant Degradation risk due to paired mean = 0.21, 50% of spec range (9.8~10.2)

- **Wafer 1**



- **Wafer 2**

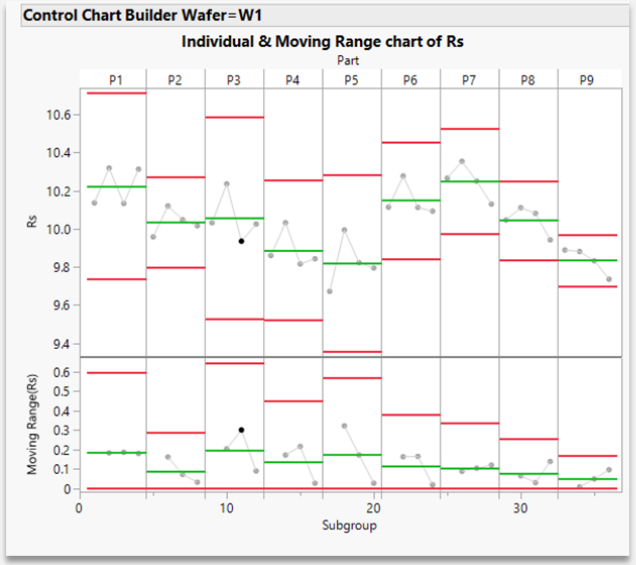


2: Repeatability Root Cause Analysis: IMR Control Chart by Phase

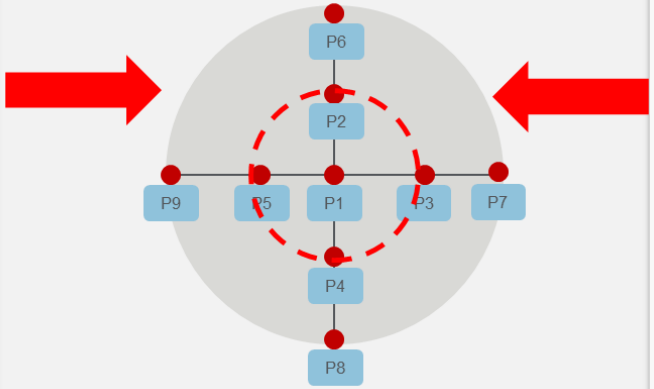
Objective

- Use IMR Control Chart by Phase to conduct repeatability test only among each part on each wafer; and to see the degradation pattern of Wafer 2 across all parts. Assign Part as Phase, By Wafer

Wafer 1

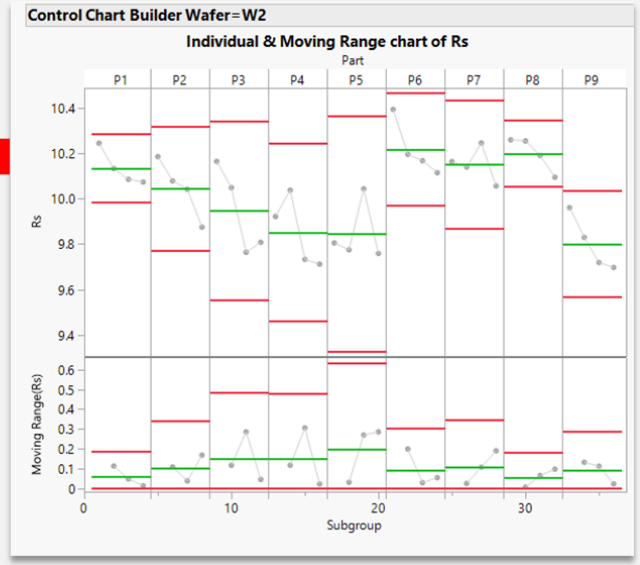


- Worst Part: 1,3,4,5
- Worst Repeat: 2



Rs Measurement Tool has worst repeatability at wafer center

Wafer 2



- Worst Part: 2,3,4,5
- Worst Repeat: degrades over repeats

Conclusions

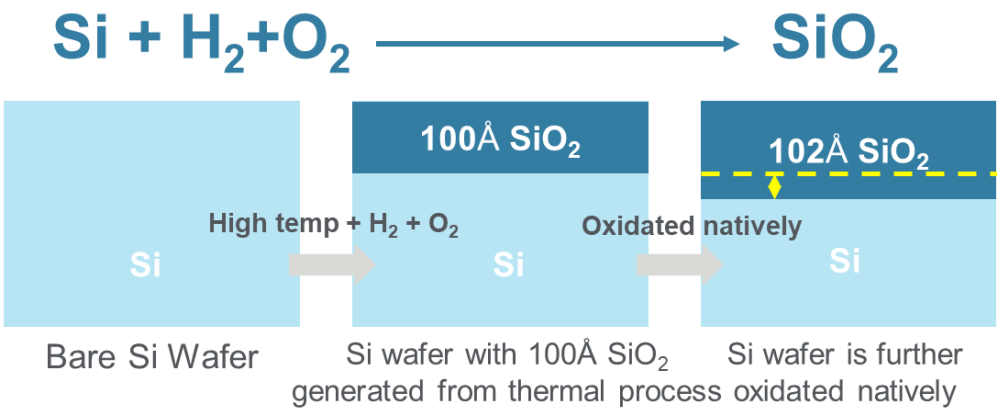
- Current PT ratio 167%>30%, Indicating metrology issue .
- Root cause : The pretreatment <Oxide layer thickness uniformity and charge distribution uniformity> may be the root cause

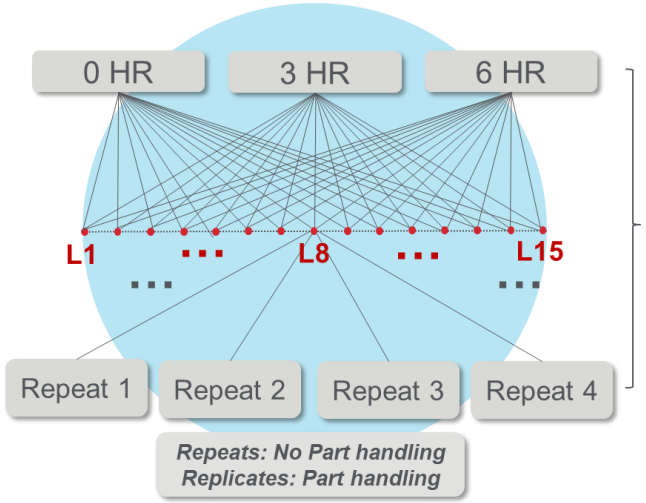
3: Project Background & Problem Statement

- **Problem Statement**
  - Thickness of thermally generated SiO2 would increase over time if not measured timely. It might distort the true thickness, affecting process qualification like uniformity tuning, chamber matching, etc. during Tier2 & Tier3

- **Objective**
  - Apply JMP GRR platforms to analyze the measurement GRR capability and stability, and part degradation risk due to Measurement Queue Time

- **Sampling Plan**
  - Part: 15 coupon * 1 wafer ~ 15 parts
  - Repeatability: 4 repeats for one part one time
  - Reproducibility: 0 & 3 & 6 hour
  - Tolerance spec: **LSL-USL = 97-103A** for each part
  - Fast Repeat





3: GRR Performance Analysis: Main effect vs. Crossed

- Main Effect GRR (ANOVA w/o interaction)

Gauge R&R

Measurement Source		Variation (6*StdDev)	% of Tolerance	
Repeatability	(EV)	0.1009628	1.68	Equipment Variation
Reproducibility	(AV)	0.5229593	8.72	Appraiser Variation
Q Time		0.5229593	8.72	
Gauge R&R	(RR)	0.5326161	8.88	Measurement Variation
Part Variation	(PV)	1.6004816	26.67	Part Variation
Total Variation	(TV)	1.6867784	28.11	Total Variation

Summary and Gauge R&R Statistics

6	k
31.5759	% Gauge R&R = 100*(RR/TV)
0.33278	Precision to Part Variation = RR/PV
4	Number of Distinct Categories = Floor(sqrt(2)*(PV/RR))
97	Lower Tolerance (LT)
103	Upper Tolerance (UT)
6	Tolerance = UT-LT
0.08877	Precision/Tolerance Ratio = RR/(UT-LT)

P/TV = 31.58%
Tolerance = 6
P/T = 8.88%

- Crossed GRR (ANOVA with interaction)

Gauge R&R

Measurement Source		Variation (6*StdDev)	% of Tolerance	
Repeatability	(EV)	0.1003660	1.67	Equipment Variation
Reproducibility	(AV)	0.5231173	8.72	Appraiser Variation
Q Time		0.5229501	8.72	
Q Time*Part		0.0132243	0.22	
Gauge R&R	(RR)	0.5326584	8.88	Measurement Variation
Part Variation	(PV)	1.6004666	26.67	Part Variation
Total Variation	(TV)	1.6867775	28.11	Total Variation

Summary and Gauge R&R Statistics

6	k
31.5785	% Gauge R&R = 100*(RR/TV)
0.33281	Precision to Part Variation = RR/PV
4	Number of Distinct Categories = Floor(sqrt(2)*(PV/RR))
97	Lower Tolerance (LT)
103	Upper Tolerance (UT)
6	Tolerance = UT-LT
0.08878	Precision/Tolerance Ratio = RR/(UT-LT)

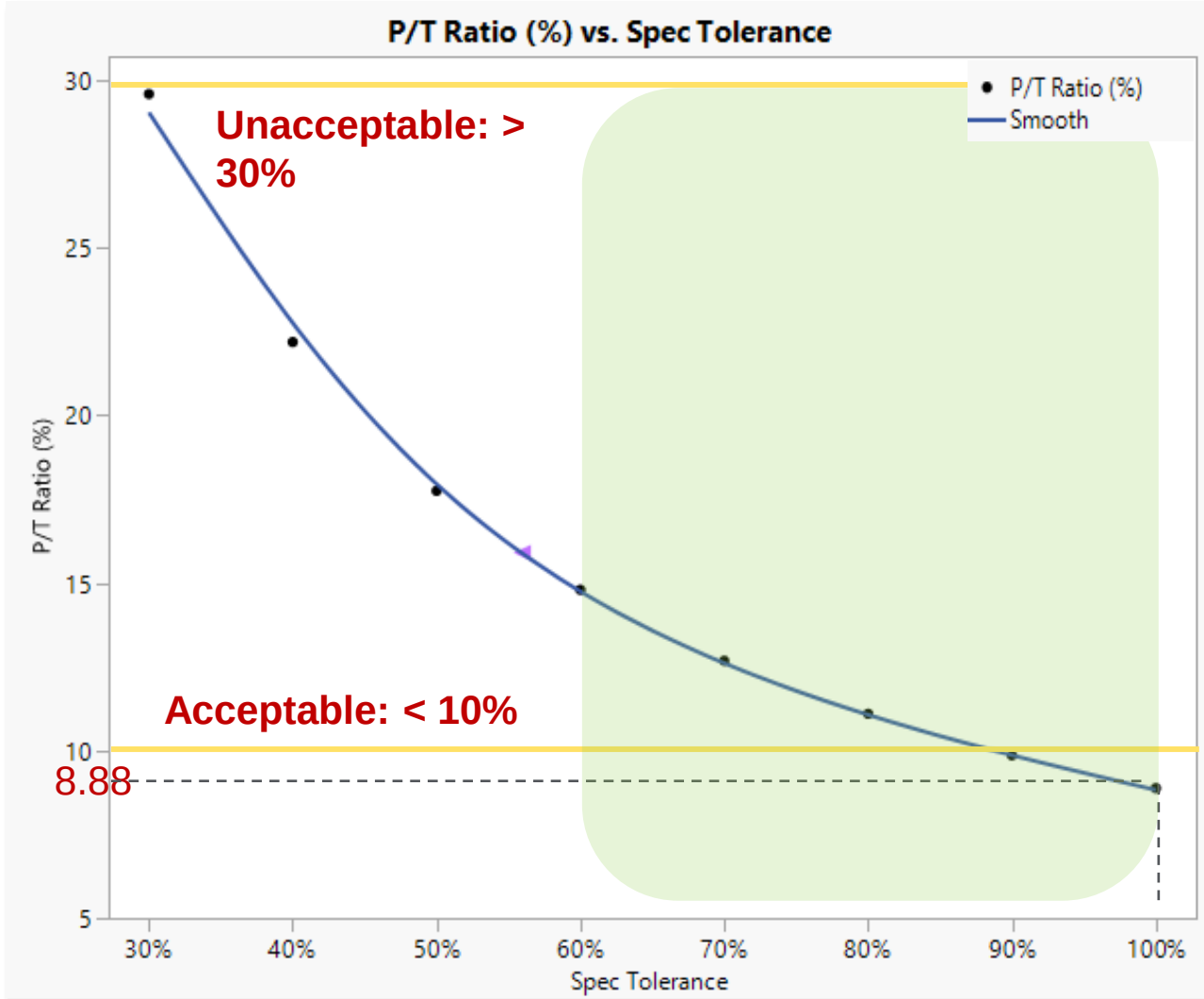
P/TV Ratio is much higher than P/T ratio which may indicate the selected GRR samples are too tight

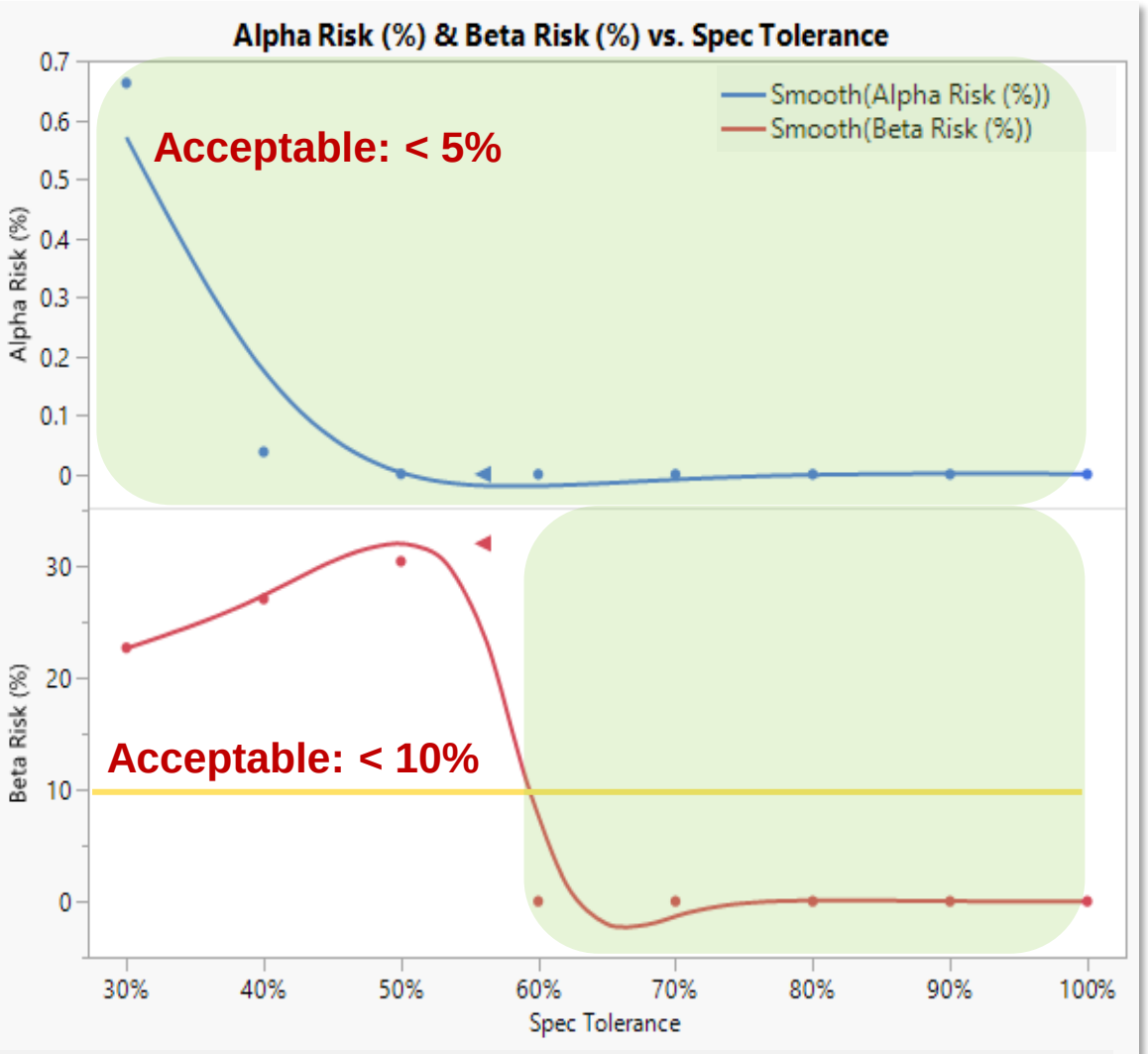
» ANOVA GRR W/WO Interaction Models show similar results since < 1% Interaction variation

» **P/T ratio is preferred** to evaluate the GRR performance on tolerance

– **P/T ratio < 10%**: adequate GRR measurement capability

3: P/T ratios, Alpha/Beta Risks vs. Spec Tolerance

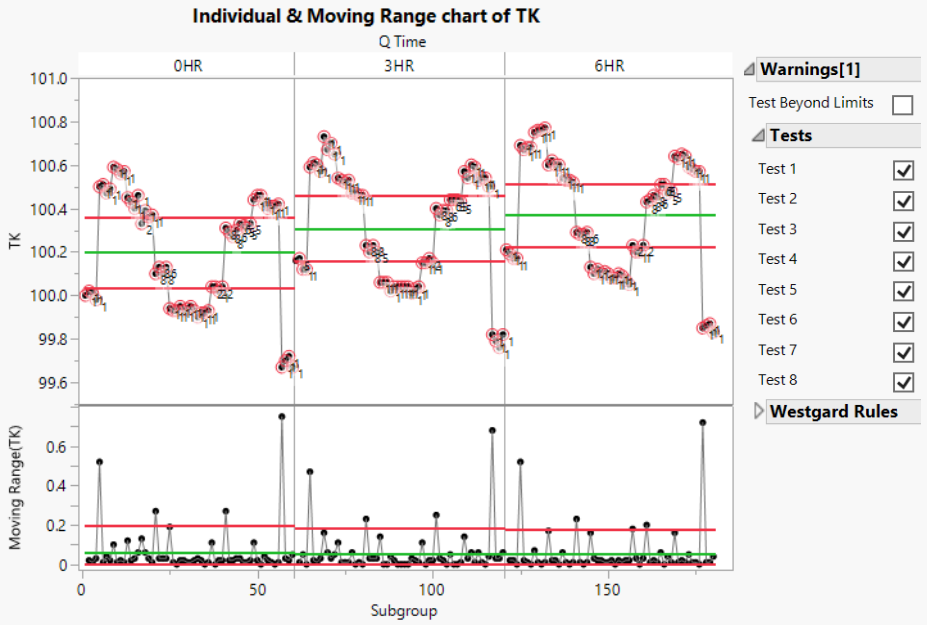




- With today's Measurement GRR Capability, we can tighten Tolerance Range by 40% from 6 to 3.6 while keeping P/T Ratio around 15% (competitive advantage)

3: Use Control Limits to Conduct the Mis-Classification Risks

- Control Limits from **I-MR** chart (**by phase**)



TK Limit Summaries

Points plotted	Q Time	LCL	Avg	UCL	Limits Sigma
Individual	0HR	100.0371	100.198	100.3589	Moving Range
Individual	3HR	100.1583	100.3088	100.4593	Moving Range
Individual	6HR	100.2258	100.37	100.5142	Moving Range
Moving Range	0HR	0	0.060508	0.197653	Moving Range
Moving Range	3HR	0	0.05661	0.184919	Moving Range
Moving Range	6HR	0	0.054237	0.177168	Moving Range

Alarm Report

Position	Total Samples Out of Control	Alarm Rate
1	179	0.994444
2	0	0

Position	Warnings Tested
1	Test 1, Test 2, Test 3, Test 4, Test 5, Test 6, Test 7, Test 8
2	

Misclassification Probabilities

Lower Tolerance = 100.0371, Upper Tolerance = 100.3589

Description	Probability
P(Good part is falsely rejected)	0.03764534
P(Bad part is falsely accepted)	0.03004577

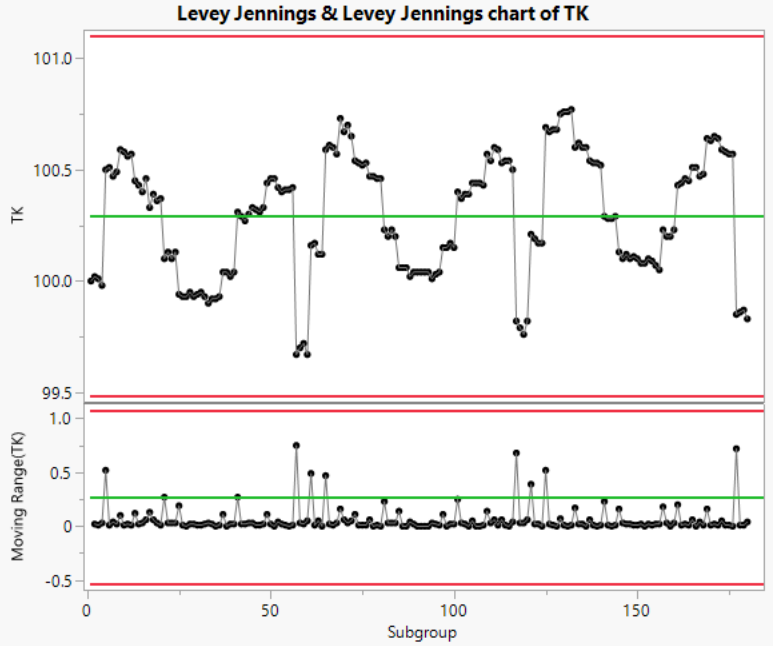
Lower Tolerance = 100.1583, Upper Tolerance = 100.4593

Description	Probability
P(Good part is falsely rejected)	0.04607137
P(Bad part is falsely accepted)	0.03320448

Lower Tolerance = 100.2258, Upper Tolerance = 100.5142

Description	Probability
P(Good part is falsely rejected)	0.03605981
P(Bad part is falsely accepted)	0.02376130

- Control Limits from **Levey Jennings** Chart



TK Limit Summaries

Points plotted	LCL	Avg	UCL	Limits Sigma
Individual	99.48641	100.2923	101.0981	Levey Jennings
Moving Range	-0.53724	0.268621	1.074485	Levey Jennings

Misclassification Probabilities

Lower Tolerance = 99.48641, Upper Tolerance = 101.0981,

Description	Probability
P(Good part is falsely rejected)	0.00228467
P(Bad part is falsely accepted)	0.25691057
P(Part is good and is rejected)	0.00227891
P(Part is bad and is accepted)	0.00064724
P(Part is good)	0.99748066

- I-MR CL: Alpha/Beta risks: <5%
- Levey CL: Alpha/Beta risks: 0%/26%

3: Continuous Improvement (Competitive Advantage)

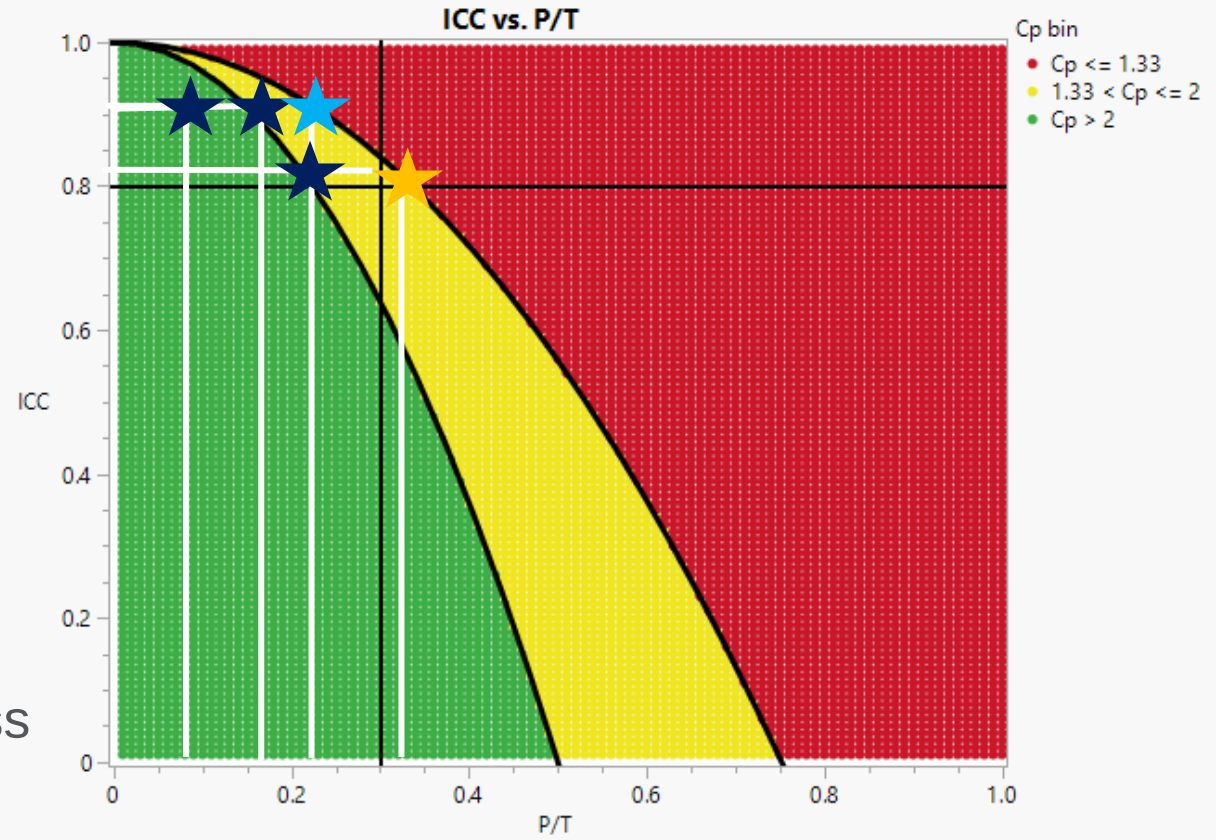
Continuously improve GRR and Ppk

★ When Cp >= 2, P/T < 0.3
=> Tighten Spec until Cp=1.33

★ When Cp <= 1.33, P/T < 0.3
=> Improve Process Part-Part Capability (Reduce ICC) until Cp = 2

★ When Cp <= 1.33, P/T > 0.3
=> Improve GRR < 0.3 (also improve Cp)

Iteratively and continuously improve the Process Capability and Measurement Capability



$$C_p = \frac{\sqrt{1 - ICC}}{P/T}$$

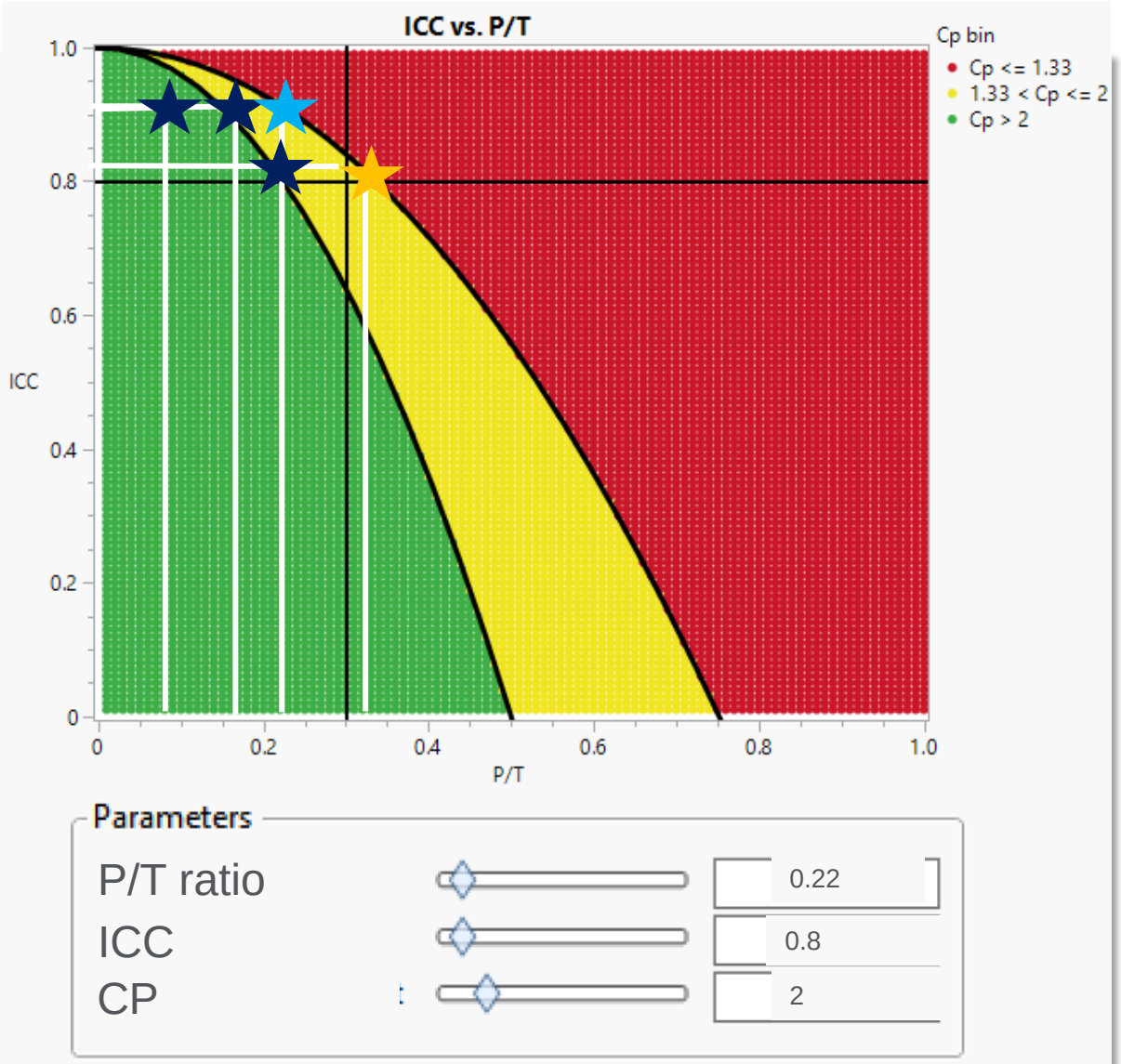
$$ICC = \frac{\sigma^2_{part}}{\sigma^2_{part} + \sigma^2_{gauge}}$$

$$P/T = \frac{6\hat{\sigma}_{gauge}}{USL - LSL}$$

3: Profiler Development

- **Background**
  - Need to digest continuous improvement direction, but current calculations are manual, lower efficiency

- **Possible Features**
  - Profiler free adjustment function.
  - Provide auto optimization suggestion basing on current PT ratio and ICC data to reach CP>2 target：
    - If CP> 2, what is the prolife suggestion?
    - If Cp <= 1.33, P/T < 0.3 what is the prolife suggestion?
    - If Cp <= 1.33, P/T > 0.3 what is the prolife suggestion?
    - …

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