Data Mining Study of Surface Roughness

CHINA DISCOVERY SUMMIT

APPLIED MATERIALS 应用材料

Introduction

- ❑ Surface roughness measurement is the most critical indicator of defect performance in semiconductor and display industry fabrication as roughness adversely degrades device electrical characteristics and impacts lifespan.
- ❑ This project aims to create JMP Analytics package, capable to detect the Normality Violation Modes associated with Surface Roughness Measurement Metric for Root Cause Analysis and Process Tuning.

Methodology

Project was deployed as shown below:

- ❑ **Data simulation**: JMP Random Simulation was used to create Simulated Roughness Z profile data into six Normality Violation Modes
- ❑ **13 variables calculation**: 5 Surface Roughness Variables and 8 Distribution Descriptive Statistics were calculated
- ❑ **Clustering methods analysis**: Different clustering methods were compared to see if they're powerful to differentiate 6 distributions into Light Tail Cluster and Discrete Points, and to group 13 variables into Peak Sensitive Cluster, Asymmetric Sensitive Cluster and Light Tail cluster.
- ❑ **JMP Workflow builder**: workflow was built to save time and enable more effective collaboration on projects while reducing variation and errors

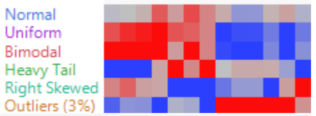
Normal		Uniform		Heavy Tail		-Right Skewed		Bimodal		Outliers (3%)	
Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
0.00	1.00	-0.00	1.00	-0.00	1.00	0.00	1.00	-0.00	1.00	0.00	1.00

Results

Two Surface Roughness Hypothesis

1st Hypothesis (6 Distributions)

- Light Tail Cluster: Uniform and Bimodal
- Discrete Points: Heavy Tail, Right Skewed, Outliers



Clustering History

Number of Clusters	Distance	Leader	Joiner
5	0.574490659	Uniform	Bimodal
4	2.094844123	Normal	Uniform
3	3.726189839	Normal	Heavy Tail
2	4.205819552	Normal	Right Skewed
1	5.358001471	Normal	Outliers (3%)

2nd Hypothesis (13 Variables)

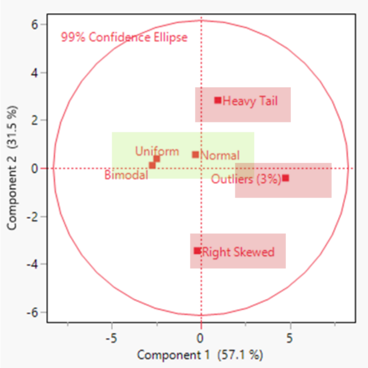
- 1st Cluster (Peak Sensitive)
- 2nd Cluster (Asymmetry)
- 3rd Cluster (Light Tail)

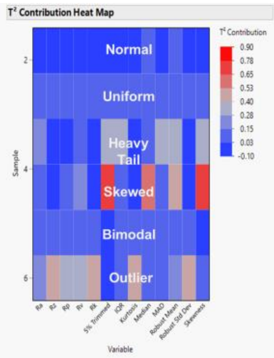
Proportion of variation explained by clustering: 0.937

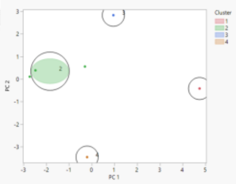
Cluster Members

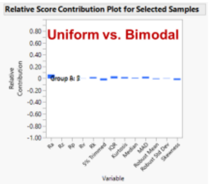
Cluster	Members	RSquare with Own Cluster	RSquare with Next Closest	1-RSquare Ratio
1	Kurtosis	0.983	0.459	0.032
1	Rk	0.982	0.46	0.033
1	Rz	0.978	0.373	0.035
1	Robust Std Dev	0.958	0.282	0.058
1	Rp	0.857	0.288	0.201
1	Rv	0.846	0.366	0.243
2	Skewness	0.983	0.047	0.018
2	5% Trimmed	0.949	0.079	0.055
2	Median	0.857	0.054	0.151
2	Robust Mean	0.844	0.26	0.211
3	IQR	0.986	0.309	0.02
3	MAD	0.985	0.33	0.022
3	Ra	0.97	0.536	0.064

1st Hypothesis (6 distributions)

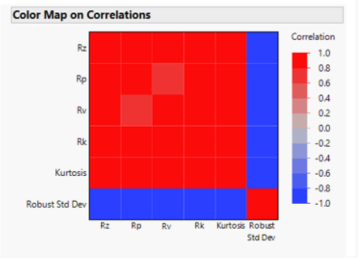








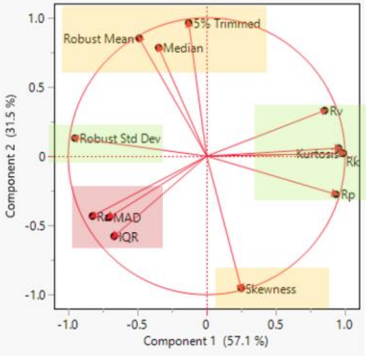
2nd Hypothesis (13 variables)



Correlations

	Rz	Rp	Rv	Rk	Kurtosis	Robust Std Dev
Rz	1.0000	0.9190	0.9440	0.9632	0.9634	-0.9436
Rp	0.9190	1.0000	0.7375	0.9014	0.9016	-0.9065
Rv	0.9440	0.7375	1.0000	0.8963	0.8964	-0.8585
Rk	0.9632	0.9014	0.8963	1.0000	1.0000	-0.9814
Kurtosis	0.9634	0.9016	0.8964	1.0000	1.0000	-0.9813
Robust Std Dev	-0.9436	-0.9065	-0.8585	-0.9814	-0.9813	1.0000

The correlations are estimated by Row-wise method.



Conclusions

- ✓ Different clustering methods were compared to evaluate surface roughness.
- ✓ JMP Surface Roughness clustering workflow was built to detect process failure mode and shorten troubleshooting time, and to promote data mining application in Applied Materials.

References & Acknowledgements

Thanks to Charles C Chen and Jiaping Shen for mentoring and technical support for this project!

Thanks to Applied Materials China Management Team for the great support for the JMP program!

Data Collection and Hypothesis

1. Data collection

- JMP Random Simulation platform was used to create Simulated Roughness Z profile data into six Normality Violation Modes.
- Five Surface Roughness Variables and eight Distribution Descriptive Statistics are calculated.

Normal		Uniform		Heavy Tail		-Right Skewed		Bimodal		Outliers (3%)	
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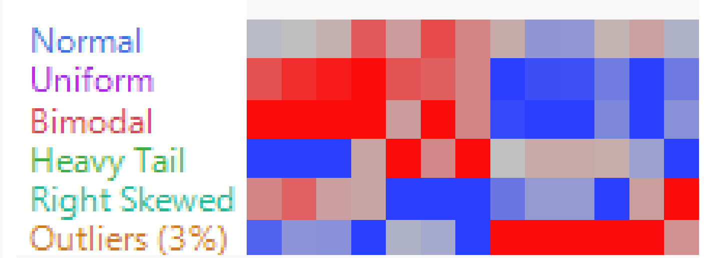
2. Two Surface Roughness Hypothesis

1st Hypothesis (6 Distributions)
- Light Tail Cluster: Uniform and Bimodal
- Discrete Points: Heavy Tail, Right Skewed, Outliers

2nd Hypothesis (5 Roughness and 8 Descriptive Statistics)
- 1st Cluster (Peak Sensitive), 2nd Cluster (Asymmetry), 3rd Cluster (Light Tail)



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3. Select appropriate JMP Data Mining Platforms

Data Mining Tasks	JMP Tool Menu	JMP Platform
Clustering (Unsupervised)	Analyze >> Clustering	Hierarchical Clustering
		K-Means Cluster
		Normal Mixtures
		Cluster Variables
Multivariate Statistics	Analyze >> Multivariate Methods	Multivariate
		Principal Components
Quality and Process	Analyze >> Quality and Process	Model Driven Multivariate Control Chart

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1st Hypothesis (6 Distributions)

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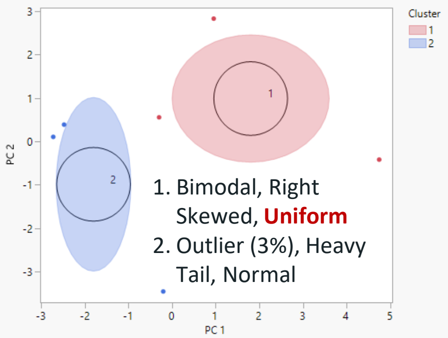
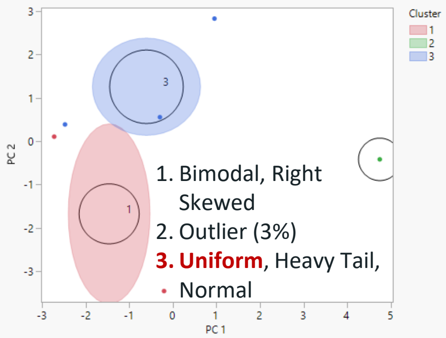
1. K-means Cluster

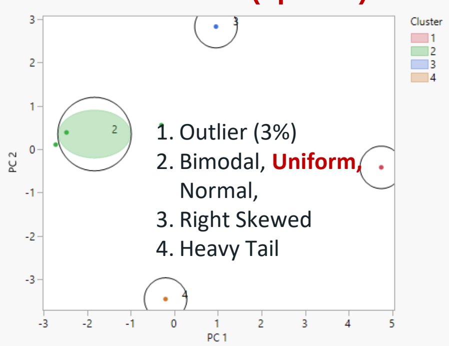
2 Clusters



3 Clusters



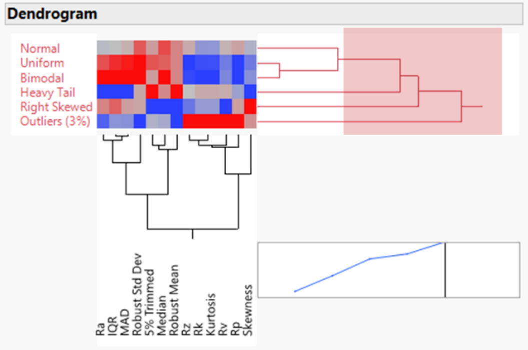
4 Clusters (optimal)



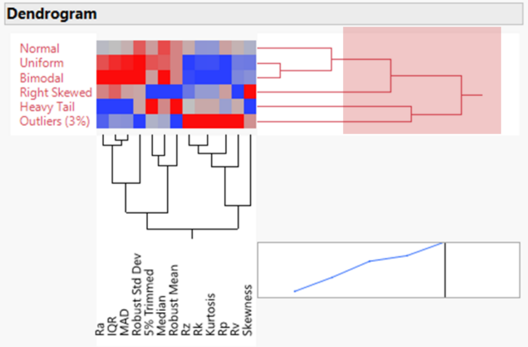
» Different Cluster Numbers may impact the K-Means Clustering Patterns based on the first two Principal Components (questionable)

2. Hierarchical Cluster

Ward (ANOVA)



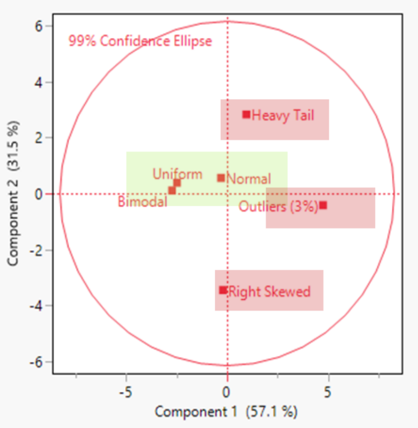
Complete (Maximum)

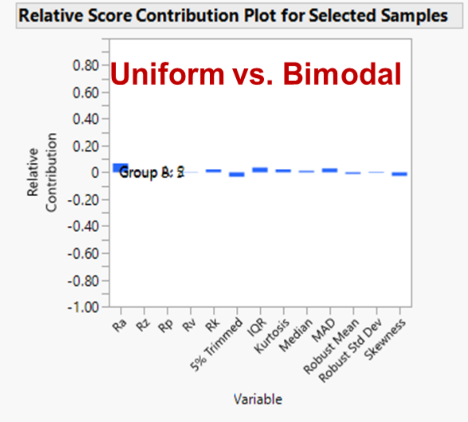


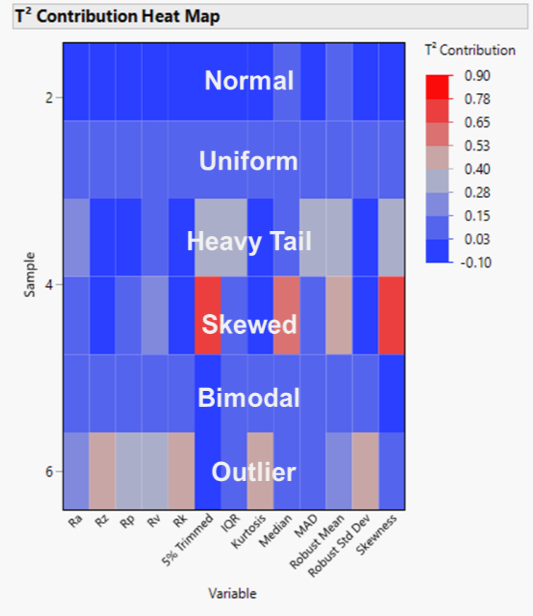
» Different Clustering Method may impact the Hierarchical Clustering History among six distributions

»4 K-means Clusters method has shown closer results with Hierarchical Clustering

3. Principal Component Analysis, Relative Score Contribution Plot , T-Square Contribution Heat Map







» PCA and Heat map has good detection power to differentiate 6 distributions.

»Relative Score Plot has the best detection power

»Heat Map can provide a better visualization capability, compared with other clustering tools

2^{nd} Hypothesis (13 Variables)

1. Cluster Variables vs. Multivariate Correlation

Cluster Summary

Cluster	Number of Members	Most Representative Variable	Cluster Proportion of Variation Explained	Total Proportion of Variation Explained
1	6	Kurtosis	0.934	0.431
2	4	Skewness	0.908	0.279
3	3	IQR	0.981	0.226

Proportion of variation explained by clustering: 0.937

Cluster Members

Cluster	Members	RSquare with Own Cluster	RSquare with Next Closest	1-RSquare Ratio
1	Kurtosis	0.983	0.459	0.032
1	Rk	0.982	0.46	0.033
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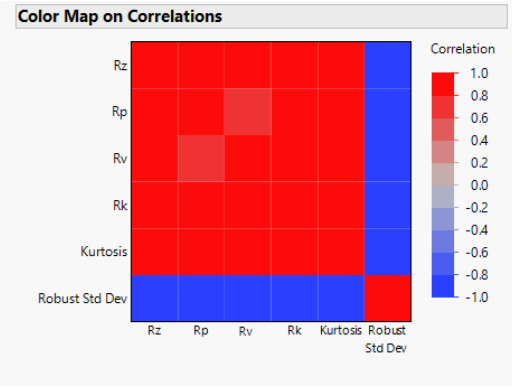
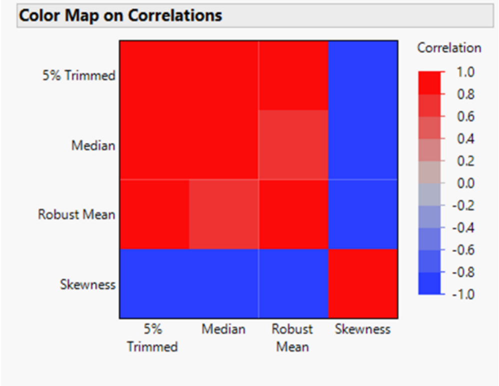
3	MAD	0.985	0.33	0.022
3	Ra	0.97	0.536	0.064

All three Cluster are Significant

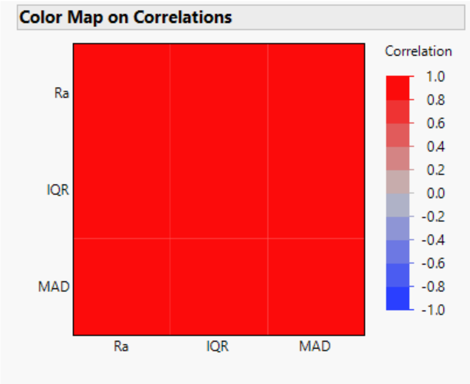
Cluster 1



Cluster 2

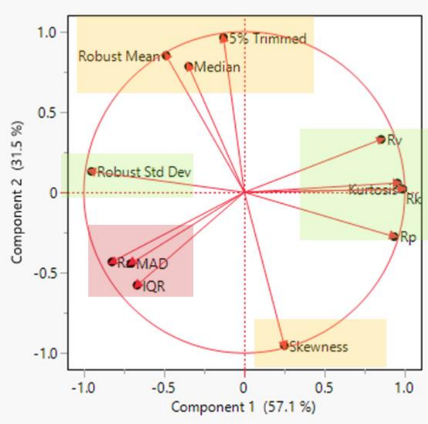


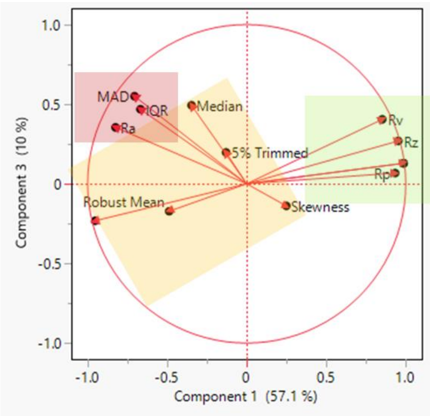
Cluster 3

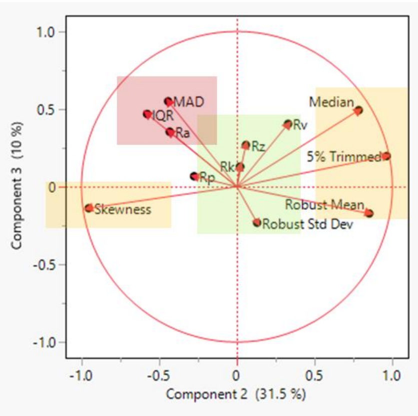


- » Clustering Variables method has split 13 variables into 3 clusters, all > 0.8 of R-Square with own cluster
- » Within each cluster, there are extremely strong correlations between Multivariate Correlation and Cluster Variables

2. Principal Component Analysis

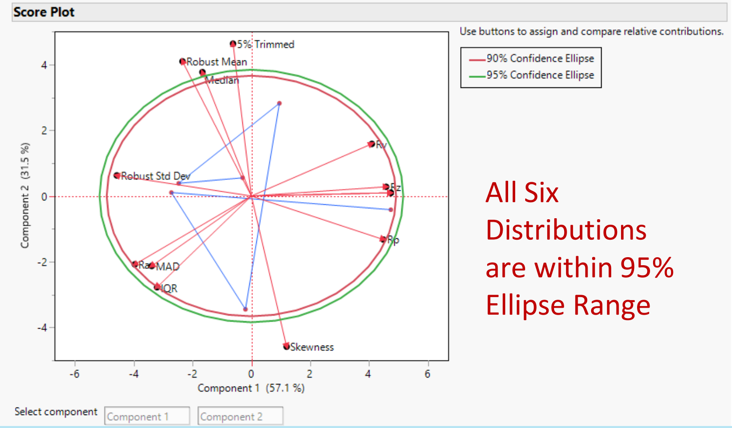






- » all three Loading Plots across the first three Principal Component Pairs show extremely strong correlations between PCA and Cluster Variables

3. Multivariate Model Driven Score Plot



All Six Distributions are within 95% Ellipse Range

- » Score Plot has the same pattern as PCA Loading Plot since both are based on Principal Component Model

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Appendix

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1. Summary

1st Hypothesis (6 Distributions)
- Light Tail Cluster: Uniform and Bimodal
- Discrete Points: Heavy Tail, Right Skewed, Outliers

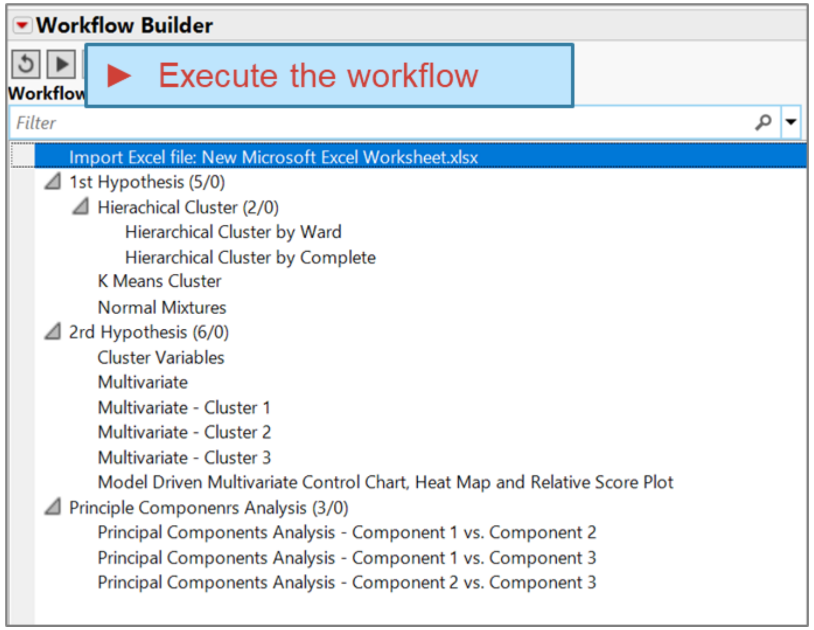
2nd Hypothesis (5 Roughness, 8 Descriptive Statistics)
- 1st Cluster (Peak Sensitive)
- 2nd Cluster (Asymmetry)
- 3rd Cluster (Light Tail)

Data Mining Tasks	JMP Platform	Criteria	Hypothesis #1	Hypothesis #2
Clustering (Unsupervised)	Hierarchical Clustering	Clustering History	Fair	Good
	K-Means Cluster	Cluster Group ID	Fair	
	Normal Mixtures	Cluster Group ID	Poor	
	Cluster Variables	Cluster Members		Good
Multivariate Statistics	Multivariate	Correlations		Good
	Principal Component Analysis	Loading Plot	Good	Good
Quality and Process	Model Driven Multivariate Control Chart	Contributin Plot	Poor	
		Score Plot		Good
		Heat Map	Good	
		Relative Contribution Plot	Good	

- **Data Mining techniques is more powerful to achieve the 2nd Hypothesis than the 1st Hypothesis**
- **Next Step: Establish Database (Roughness, Raw Z-Profile, Roughness Metric, Process Tuning)**

2. JMP Workflow Builder

Execute Function
- able to skip the mess and frustration and get straight to experimentation and discovery



- **JMP Workflow Builder can save time and enable more effective collaboration on projects while reducing variation and errors, especially for JMP beginners**
- **Workflow can promote JMP Data Mining project applicable across Applied Materials**