

Factory Yield Ramp-up Approach through Process Performance Metrics Guided Improvement Activities

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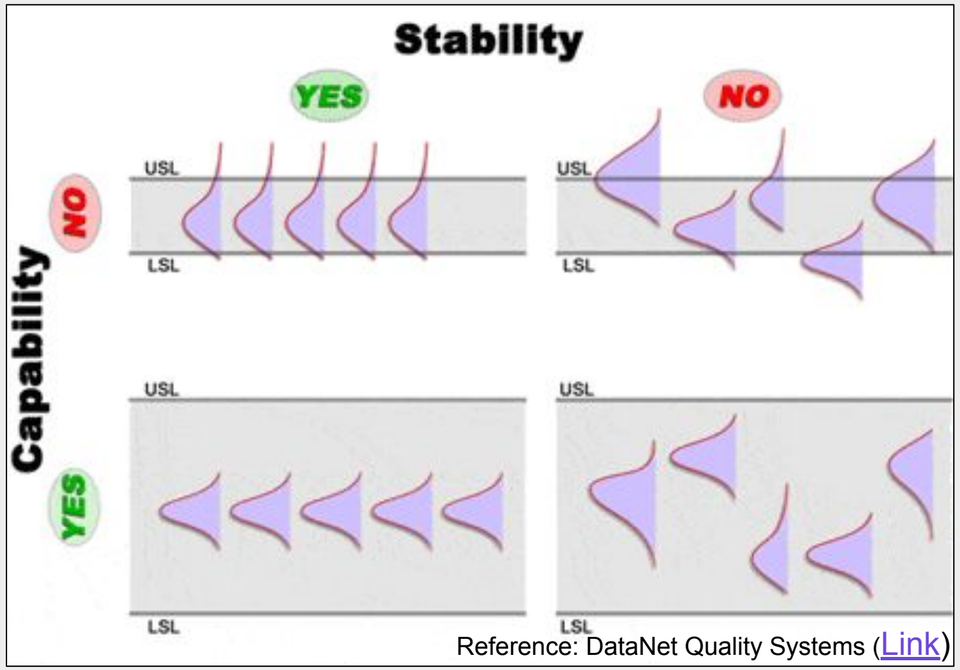
Agenda

1. Factory Process Performance Overview
2. Process Screening Tool and Control Chart
3. JMP Scripting for Automating Process Capability Analysis
4. Conclusions

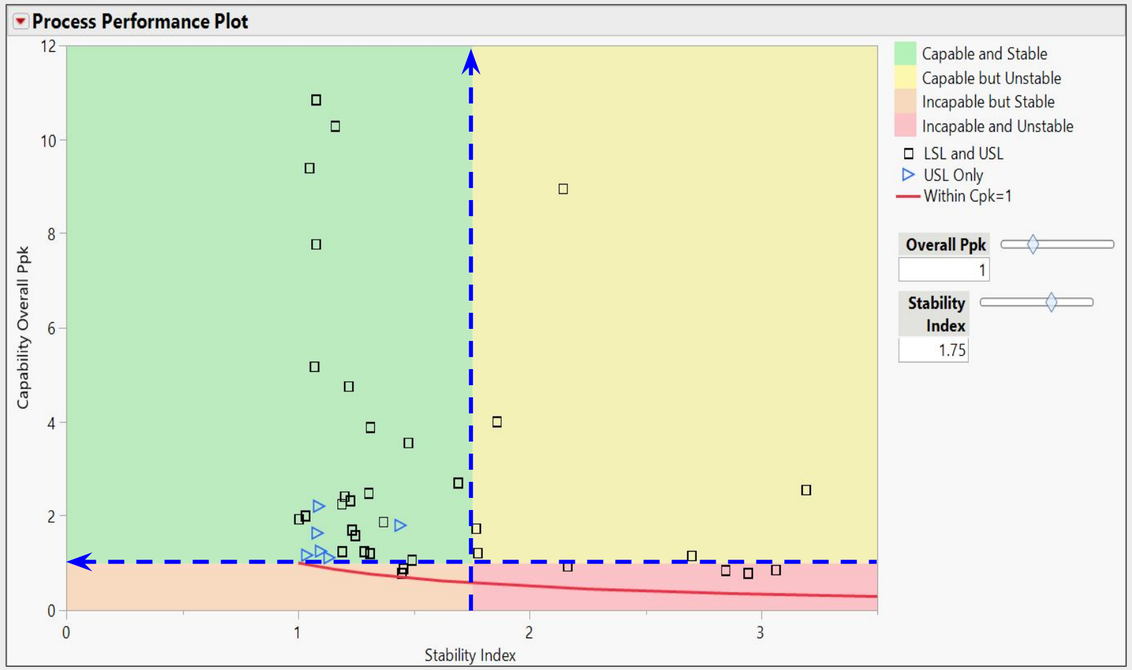
Factory Process Performance Overview (Capability vs. Stability)

- Process Capability & Stability are both extremely important aspects of any manufacturing process
  - Process capability is a measure of the ability of the process to meet specifications
  - Process stability refers to the consistency of KPIs over time
  - There is no inherent relationship between process stability and process capability
- Proposal:

  Monitoring factory processes using process performance plot (capability and stability)



Reference: DataNet Quality Systems (Link)



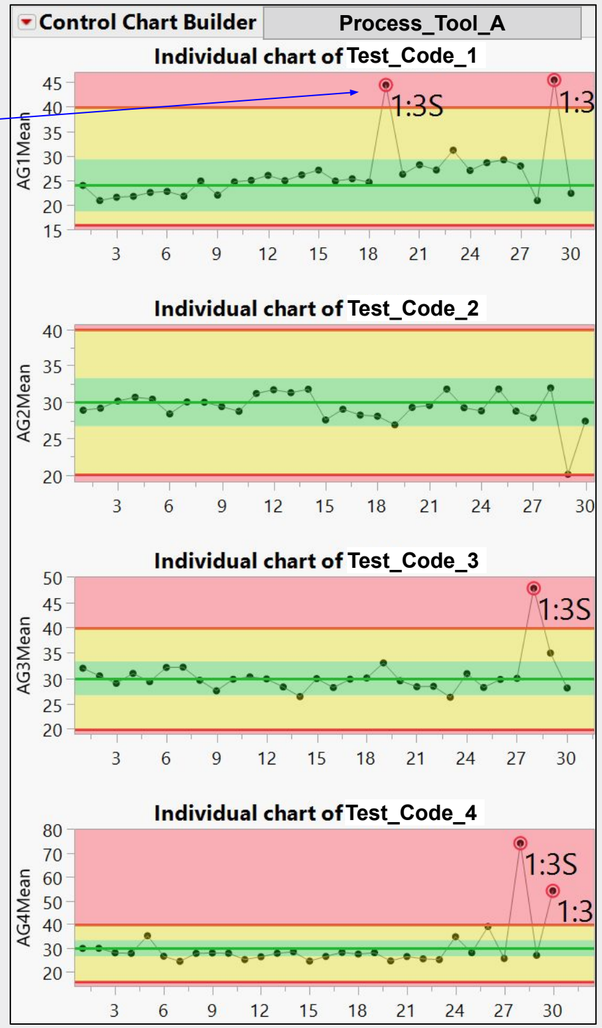
Process Screening for Process Capability/Stability Improvement

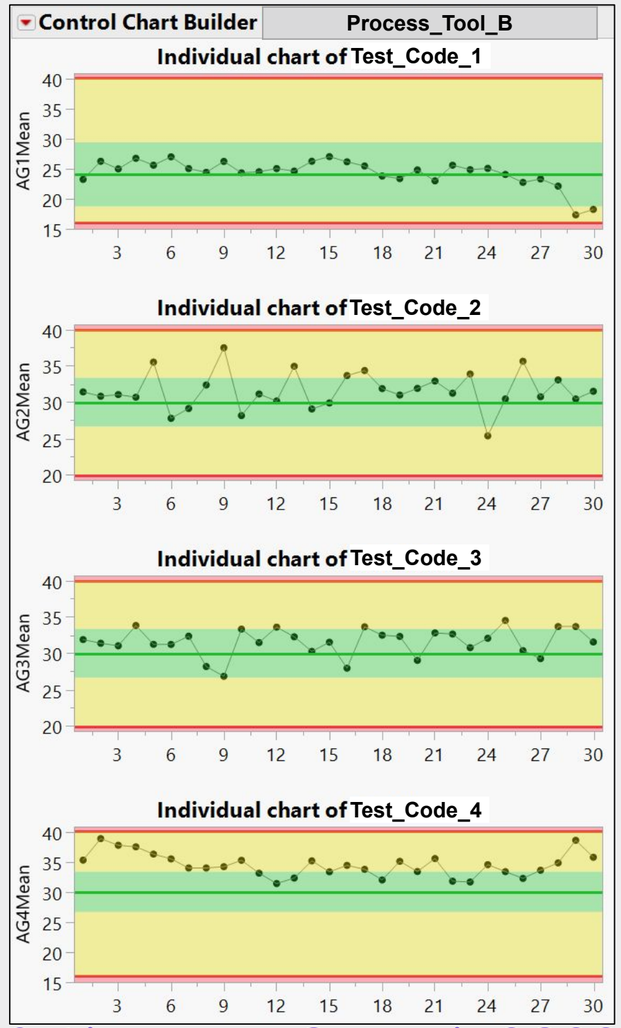
- Utilizing process screening tool to identify unstable processes
- Deploy control charts to monitor and improve process capability and stability

Process Screening

Indiv and MR

Process Name	Variability			Control Chart Alarms			Capability	
	Stability Index	Within Sigma	Overall Sigma	Alarm Rate	Test1	Latest Alarm	Ppk	Cpk
Process_1	2.57	0.00118	0.00303	0.02616	69	2334	1.073	2.759
Process_2	2.17	0.01147	0.02487	0.02654	70	2010	1.742	3.776
Process_3	1.81	0.00755	0.01369	0.01820	48	1972	10.062	18.233
Process_4	1.77	0.10269	0.18215	0.01744	46	1972	0.788	1.398
Process_5	1.77	0.08989	0.15918	0.01820	48	1972	0.931	1.648
Process_6	1.56	2.16837	3.38591	0.05684	150	4	0.857	1.338
Process_7	1.56	0.0105	0.01638	0.00986	26	1989	1.762	2.750
Process_8	1.51	2.90484	4.3897	0.00644	17	2014	1.389	2.099
Process_9	1.51	1.56135	2.35708	0.00834	22	2036	1.663	2.511
Process_10	1.43	0.0064	0.00912	0.01251	33	1971	4.529	6.455
Process_11	1.32	0.06009	0.07924	0.00644	17	1980	0.656	0.866
Process_12	1.20	28.3978	34.1432	0.00644	17	1980	2.875	3.456
Process_13	1.20	1.94939	2.33951	0.00531	14	2060	2.591	3.109
Process_14	1.16	0.0107	0.01239	0.00114	3	2272	1.238	1.434
Process_15	1.14	0.01335	0.0152	0.00341	9	2251	2.171	2.472
Process_16	1.11	2.26699	2.51921	0.00455	12	2059	2.356	2.618
Process_17	1.11	0.00366	0.00405	0.00455	12	1968	1.484	1.643
Process_18	1.10	0.00306	0.00337	0.00569	15	1969	1.946	2.143
Process_19	1.07	0.00338	0.00362	0.00493	13	1969	1.723	1.841
Process_20	1.07	0.00372	0.00396	0.00341	9	1969	1.437	1.531
Process_21	1.05	0.01589	0.01664	0.00076	2	2233	0.978	1.025
Process_22	1.02	0.0952	0.09752	0.00152	4	2255	1.706	1.748
Process_23	1.02	0.00251	0.00257	0.00227	6	2329	12.949	13.258
Process_24	0.92	0.01573	0.01452	0.00000	0	2231	1.146	1.058

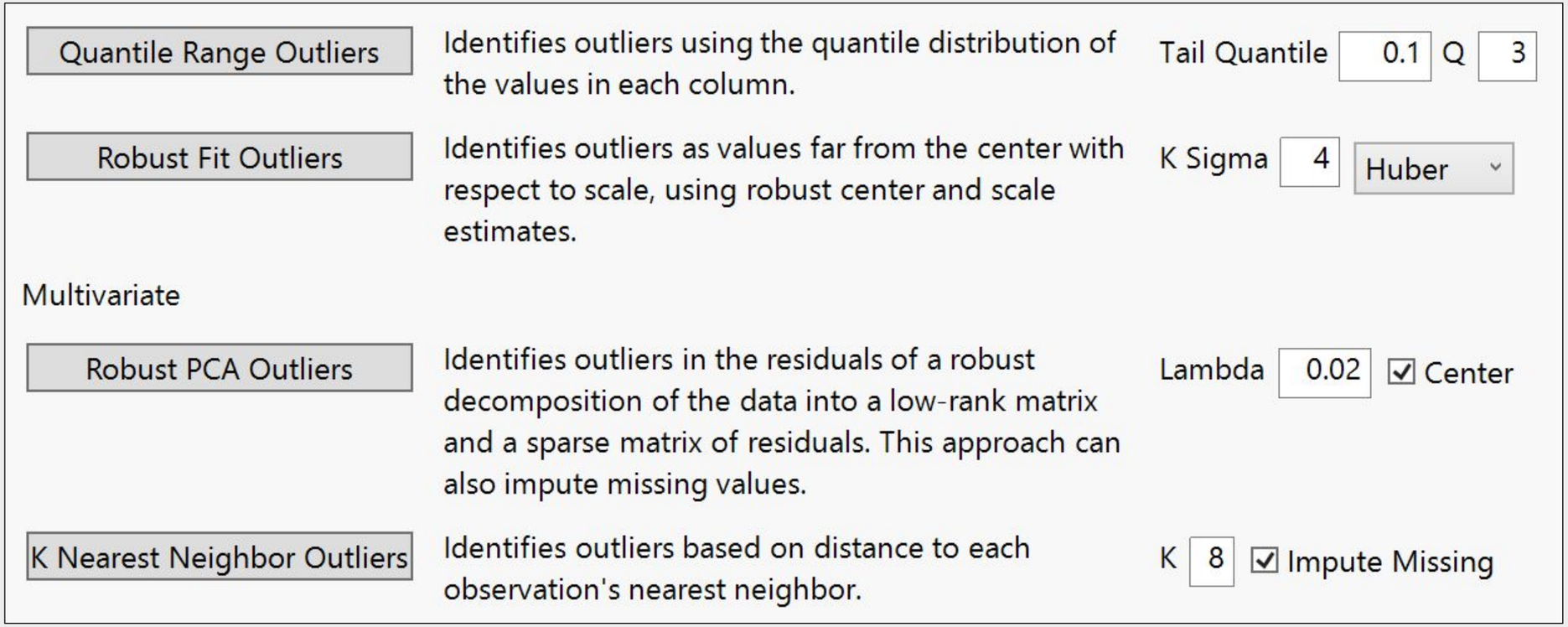




Process Capability Analysis Outlier Removal Method

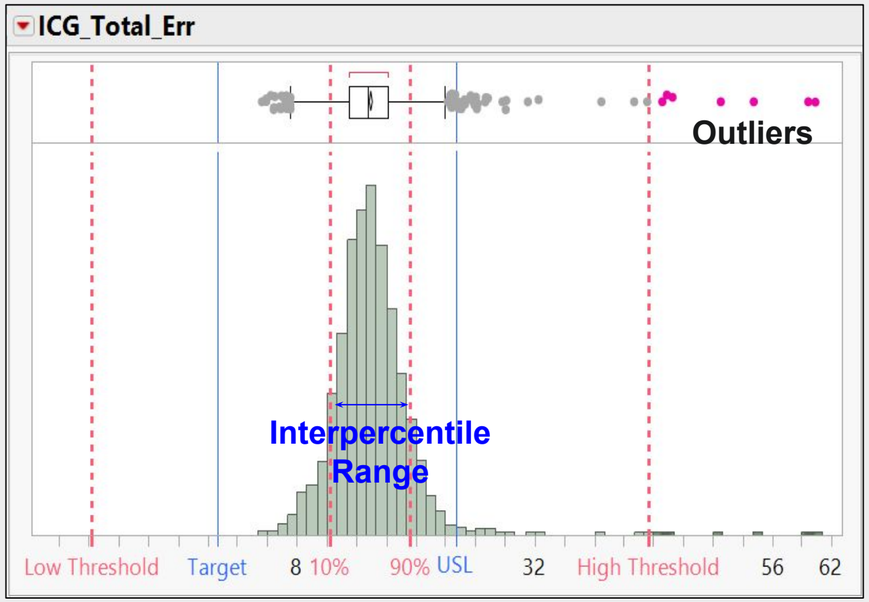
Link

- Cpk calculation changes dramatically due to outliers especially when sample size is small
  - Outliers (special cause) can add bias to process capability analysis
  - Apply outlier removal method to remove outliers
- Options in JMP "Analyze/Screening/Explore Outliers" to exclude the extreme values



Process Capability Analysis Outlier Removal Method – cont'd

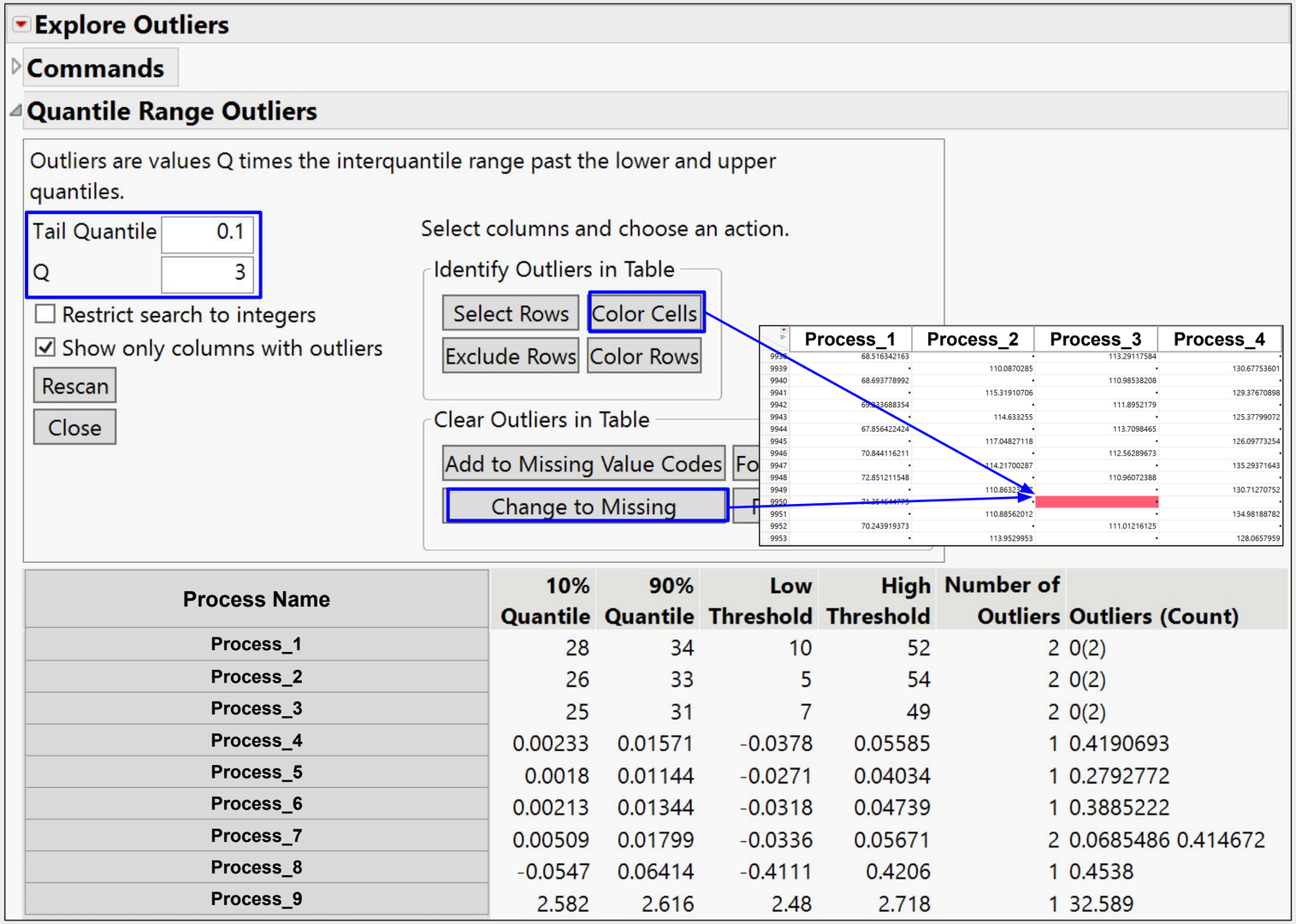
- Quantile Range Outliers method uses the quantile distribution to exclude the extreme values



Interpercentile Range = 90% Percentile - 10% Percentile

Low Threshold = 10% Percentile - 3*Interpercentile Range

High Threshold = 90% Percentile + 3*Interpercentile Range



Process Name	10% Quantile	90% Quantile	Low Threshold	High Threshold	Number of Outliers	Outliers (Count)
Process_1	28	34	10	52	2	0(2)
Process_2	26	33	5	54	2	0(2)
Process_3	25	31	7	49	2	0(2)
Process_4	0.00233	0.01571	-0.0378	0.05585	1	0.4190693
Process_5	0.0018	0.01144	-0.0271	0.04034	1	0.2792772
Process_6	0.00213	0.01344	-0.0318	0.04739	1	0.3885222
Process_7	0.00509	0.01799	-0.0336	0.05671	2	0.0685486 0.414672
Process_8	-0.0547	0.06414	-0.4111	0.4206	1	0.4538
Process_9	2.582	2.616	2.48	2.718	1	32.589

Factory Process Capability Comparison (pre vs. post outlier removal)

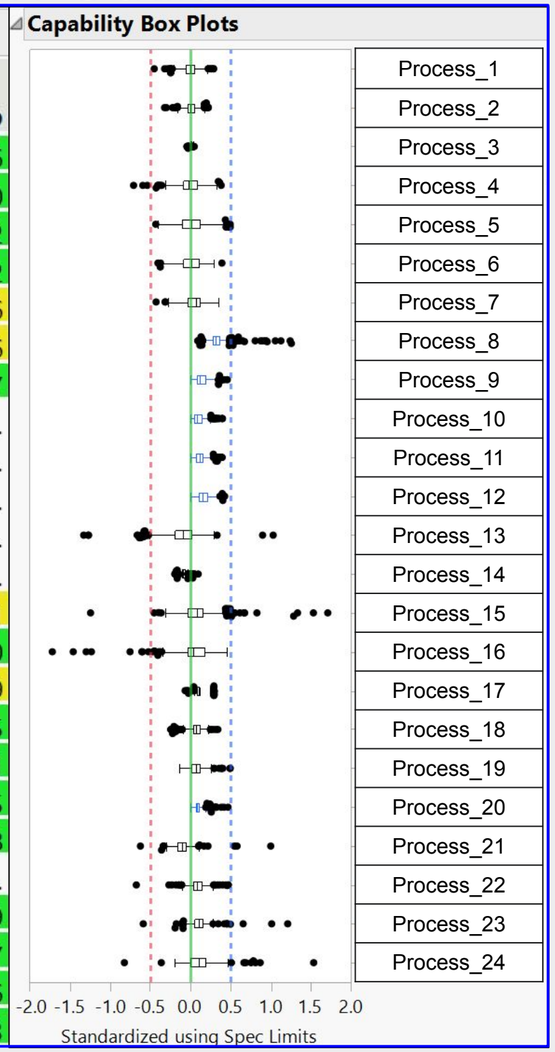
- Cpk values remain equal or better post outlier removal
- Quantile range outliers parameters can be tuned if necessary

CpK
Green Cpk > 1.5
Yellow 1.0 < Cpk < 1.5
Red Cpk < 1.0

With Outliers

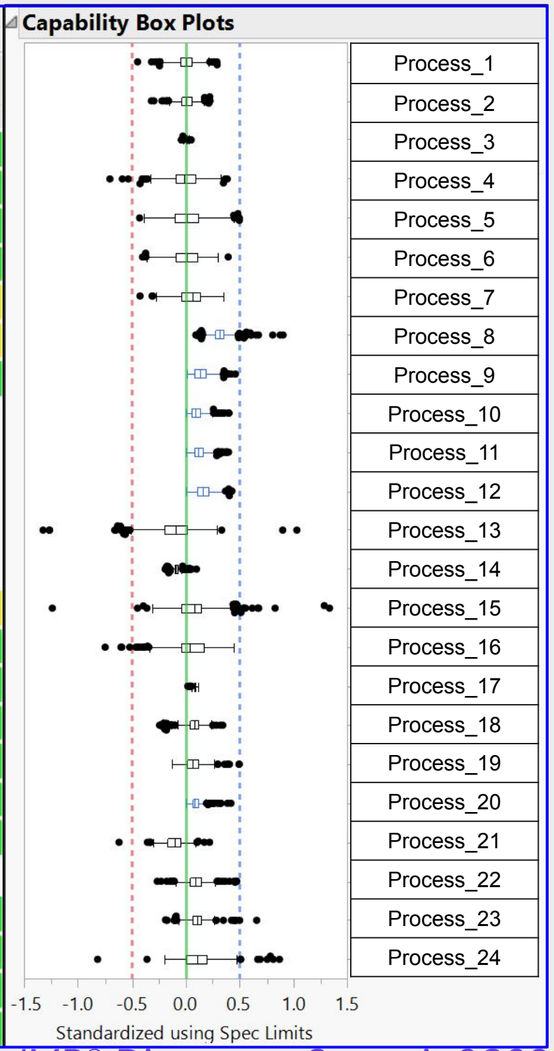
Within Sigma Capability Summary Report

Process Name	Product Spec LSL	Target	USL	Within Sigma	Cpk	Cp
Process_1	-0.5	0	0.5	0.094	1.76	1.76
Process_2	-0.1	0	0.1	0.013	2.47	2.50
Process_3	-0.1	0	0.1	0.002	13.37	13.42
Process_4	-0.01	0	0.01	0.001	2.75	2.82
Process_5	-0.05	0	0.05	0.016	1.04	1.06
Process_6	-0.05	0	0.05	0.016	1.06	1.06
Process_7	-0.05	0	0.05	0.011	1.44	1.57
Process_8	.	0	24	2.199	1.30	.
Process_9	.	0	0.025	0.004	1.64	.
Process_10	.	0	0.025	0.003	2.14	.
Process_11	.	0	0.025	0.003	1.84	.
Process_12	.	0	0.025	0.004	1.53	.
Process_13	0.7	0.9	1.1	0.060	0.86	1.11
Process_14	0.55	0.7	0.85	0.006	6.45	7.80
Process_15	1	1.5	2	0.112	1.27	1.49
Process_16	7.175	7.675	8.175	0.101	1.49	1.65
Process_17	15.909	16.409	16.909	0.015	9.22	11.31
Process_18	2.408	2.558	2.708	0.011	3.77	4.35
Process_19	1.787	1.887	1.987	0.010	2.75	3.18
Process_20	.	0	360	28.996	3.38	.
Process_21	13	28	50	1.765	2.24	3.49
Process_22	13	28	50	2.310	2.56	2.67
Process_23	13	28	50	2.157	2.82	2.86
Process_24	13	28	50	3.033	2.02	2.03

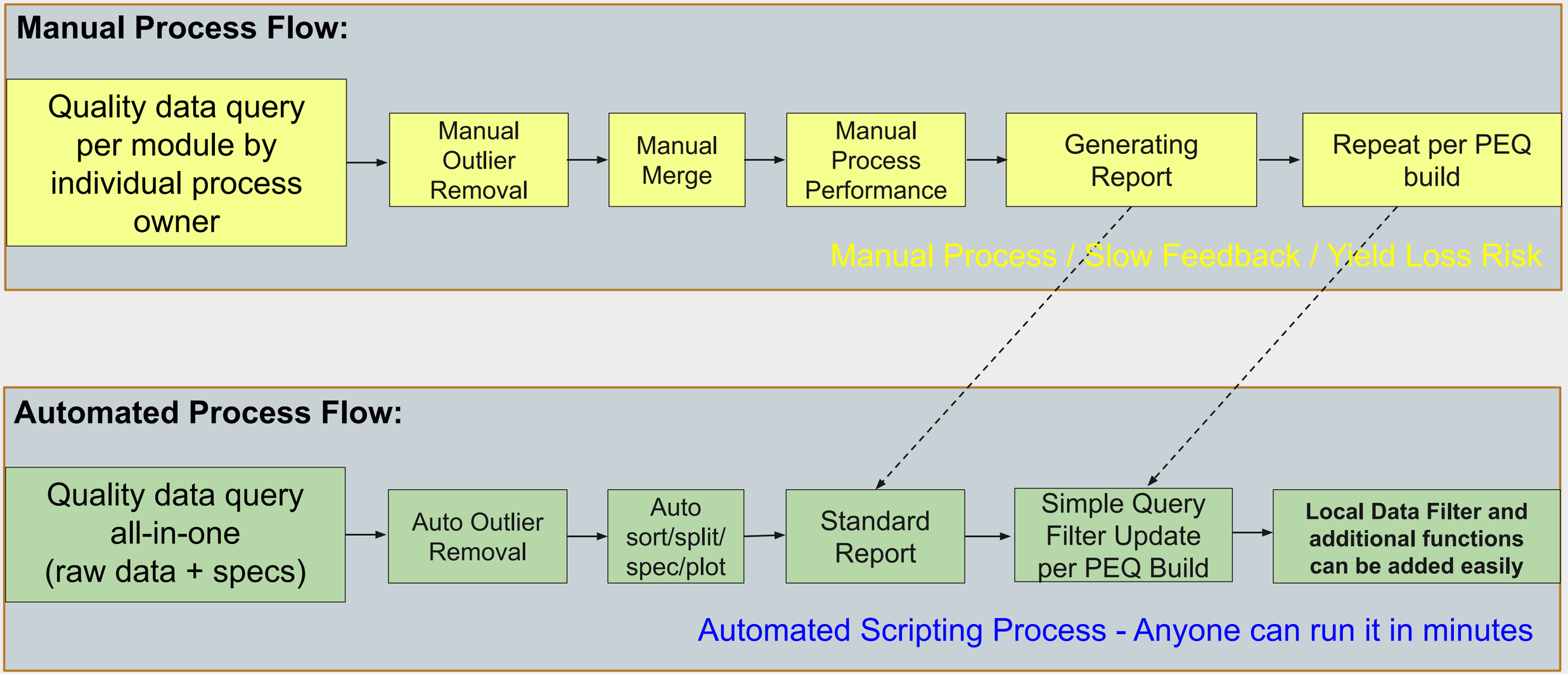


Without Outliers

Within Sigma	Cpk	Cp
0.095	1.75	1.75
0.013	2.47	2.50
0.003	13.26	13.30
0.001	2.76	2.83
0.016	1.02	1.05
0.016	1.06	1.06
0.011	1.43	1.56
2.168	1.34	.
0.004	1.64	.
0.003	2.14	.
0.003	1.84	.
0.004	1.53	.
0.060	0.87	1.11
0.006	6.46	7.81
0.103	1.40	1.62
0.090	1.65	1.85
0.008	18.23	22.07
0.011	3.78	4.36
0.010	2.75	3.18
28.398	3.46	.
1.561	2.51	3.95
2.267	2.62	2.72
1.949	3.11	3.16
2.905	2.10	2.12



Process Performance Monitoring Process Flow



Key Scripting Components for Process Capability Analysis

Split raw data table for process performance plot

```
// Split data table
// → Data Table( "ML_Process_Split" )
dt_ML_Process_Capability_Split = dt_ML_Process_Capability << Split(
    Split By( :Process, :TestLabel ),
    Split( :TestValue ),
    Group( :SerialNumber, :DateTime ),
    Output Table( "ML_Process_Specs_Split" ),
    Remaining Columns( Drop All ),
    Sort by Column Property
);
```

Launch Process Capability Analysis

```
// Add Process Capability to dt_ML_Process_Capability_Split
dt_ML_Process_Capability_Split << New Script(
        "Process Capability",
        Process Capability(
            Process Variables(
            // Hidden due to ML policy
            ),
            Spec Limits(
        Import Spec Limits(
            dt_ML_Process_Specs
            )),
            Moving Range Method( Average of Moving Ranges ),
            Within Sigma Summary Report( 1 ),
            Overall Sigma Summary Report( 1 ),
            Process Performance Plot( 1 ),
            Goal Plot( 0, Show Overall Sigma Points( 0 ) ),
            Capability Index Plot( 1 ),
            Process Performance Plot( 1 ),
```

Outlier Removal using Quantile Range Outliers Method

```
// Get column names from dt_ML_Process_Capability_Split
colsToScreen = dt_ML_Process_Capability_Split << Get Column Names(Numeric, "Continuous");

// Screen for outliers using Quantile Range Outliers method
OL_Platform = dt_ML_Process_Capability_Split << Explore Outliers(Y(Eval(colsToScreen)),
Quantile Range Outliers( 1 ), Show Only Columns With Outliers(1), Invisible);

// Using the report to find the columns that have outliers
OL_Rep = Report(OL_Platform);
dt_OL_Rep = OL_Rep[TableBox(1)];
colList = OL_Rep[StringColBox(1)];
// Loop over the columns with outliers
nCols = NItems(colList << get);
for(i=1, i<=nCols, i++,
    // Select this column (described by a row in outlier screening report)
    CMD = Expr( dt_OL_Rep << setSelectedRows({colTBD}) );
    SubstituteInto(CMD, Expr(colTBD), Eval(i));
    CMD;
    // Cells that were considered outliers are changed to missing
    OL_Platform << ChangeToMissing(1);
    //OL_Platform << ColorCells(1);
    );
OL_Rep << closeWindow;
```


Conclusions

- Analyzing process performance data using JMP is super critical to drive yield improvements in modern factories with many process and metrology steps to ensure healthy product lines and high quality products
- Analysis of performance data, including long-term and short-term process capability, stability and statistical process control is particularly useful when monitoring hundreds of process KPIs retrospectively
- During the production ramp-up phase, identifying the processes of most concern is highly challenging and using JMP scripting and quality data analysis, Magic Leap's Eyepiece Manufacturing factory implemented an automated process which can pull, analyze, visualize, correlate, predict and verify factory yield improvement based on a variety of performance metrics
- Magic Leap's Eyepiece Manufacturing Factory demonstrated >90% RTY 6 month ahead of ML2 product launch driven by continuous process improvement activities guided by automated process performance analysis using JMP scripting and quality platform tools

Thank you