Manufacturing

Industry 4.0 and Smart Manufacturing

& jmp Statistical Discovery.™ From SAS.

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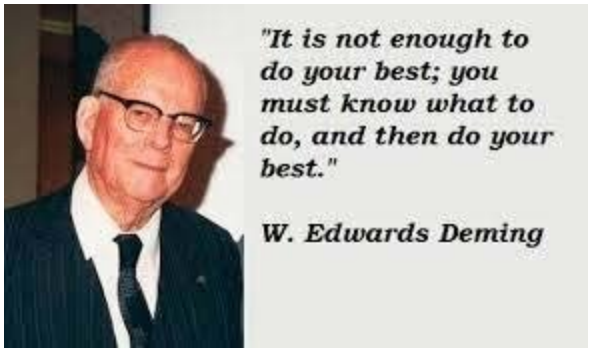
Quality Methods
SAS

Correlation and Regression
SAS



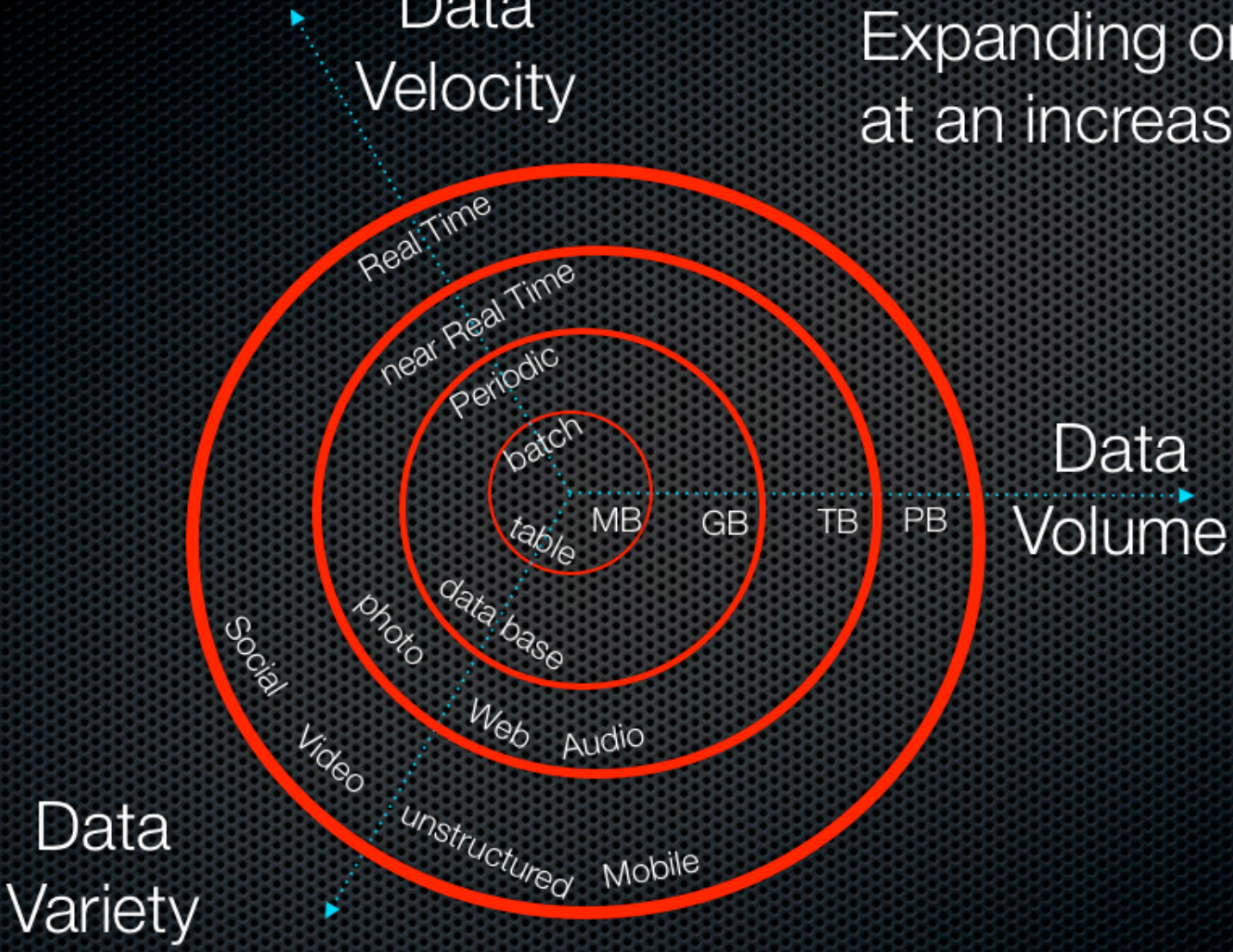
Deming on Data?

"Scientific data are not taken for museum purposes; they are taken as a basis for doing something. If nothing is to be done with the data, then there is no use in collecting any. The ultimate purpose of taking data is to provide a basis for action or a recommendation for action. The step intermediate between the collection of data and the action is ***prediction****."* – Edwards W. Deming

Dr. Deming's remark is timely with the high volume of real and near real time data collected in modern manufacturing.

How do we extract information and act quickly with this data o enable real time process control and longer-term process improvements?

Big Data: Expanding on 3 fronts at an increasing rate.



Digital Revolution is Here

In their new fully digital manufacturing facility for MAB production, Sanofi estimates that **a single production batch can generate 3 billion observations on over 5,000 parameters**.

How does one analyze and act in real time to such large volumes of manufacturing data?

How does one control a process using such large data volumes?

Clearly we need statistical software and tools that can work at this scale –must be incorporated into *Digital Twin* strategies

Why JMP for Industry 4.0 and the Digital Revolution?

JMP offers a fully integrated set of solutions for process control, process diagnosis, and process improvement.

Easy to access, extract, and format data from structured data bases; e.g., Query Builder & SQL data bases (highly recommended).

JSL makes JMP flexible and customizable for manufacturing and measurement applications; analyses are easily automated.

Full suite of platforms for process monitoring and control: Process Screening, Control Chart Builder, Tabular Cusum, Multivariate Control Charting & Model Driven Monitoring.

Easy to create and deploy Dashboards.

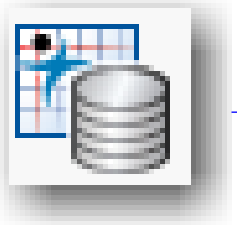
State of the art Machine Learning capabilities to generate accurate/validated predictive process models **– its all about Prediction**.

The best Design of Experiments capabilities.

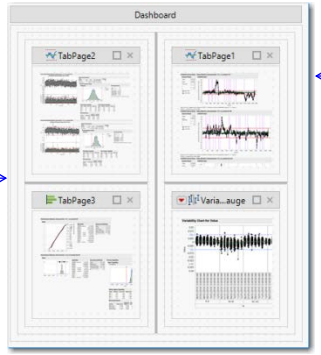
Why JMP for Industry 4.0 and the Digital Revolution?

Using JMP, statistical workflows can be standardized and automated – everyone sees the same results and knows the proper interpretation.

JSL allows considerable customization and automation – **data and analyses at the fingertips of the end users**; no need to write queries, reformat data, and decided upon analyses to be performed



Query Builder, Automate data import, formatting, and analyses in one step.



Custom Dashboards automatically updated and displayed for end users.

Drill Down Automatically

Automate Graph Builder custom visualizations.

Automatically Update Specs Process Screening

Predictor Screening for potential causes

Update or refit models in Generalized Regression

Case Study

Production yields at the beginning of process improvement.

Defining and creating an easy to use SQL database infrastructure.

How to implement standard analytics using JMP Scripting and templates.

Production yields after implementing process improvements.

Identify what is needed to implement a baseline for Industry 4.0 & Analytics.

Introduction of Case Study

Products sell for thousands of dollars.

A defective part can cause loss of life.

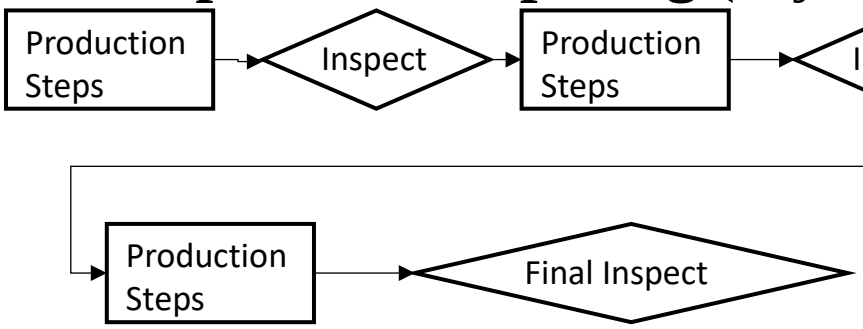
Final Inspection yields are low with a program needing greater than 90% yields.

Each part must meet between 1,800 to over 7,000 characteristics.

Engineers can only view data for one process and one part at a time.

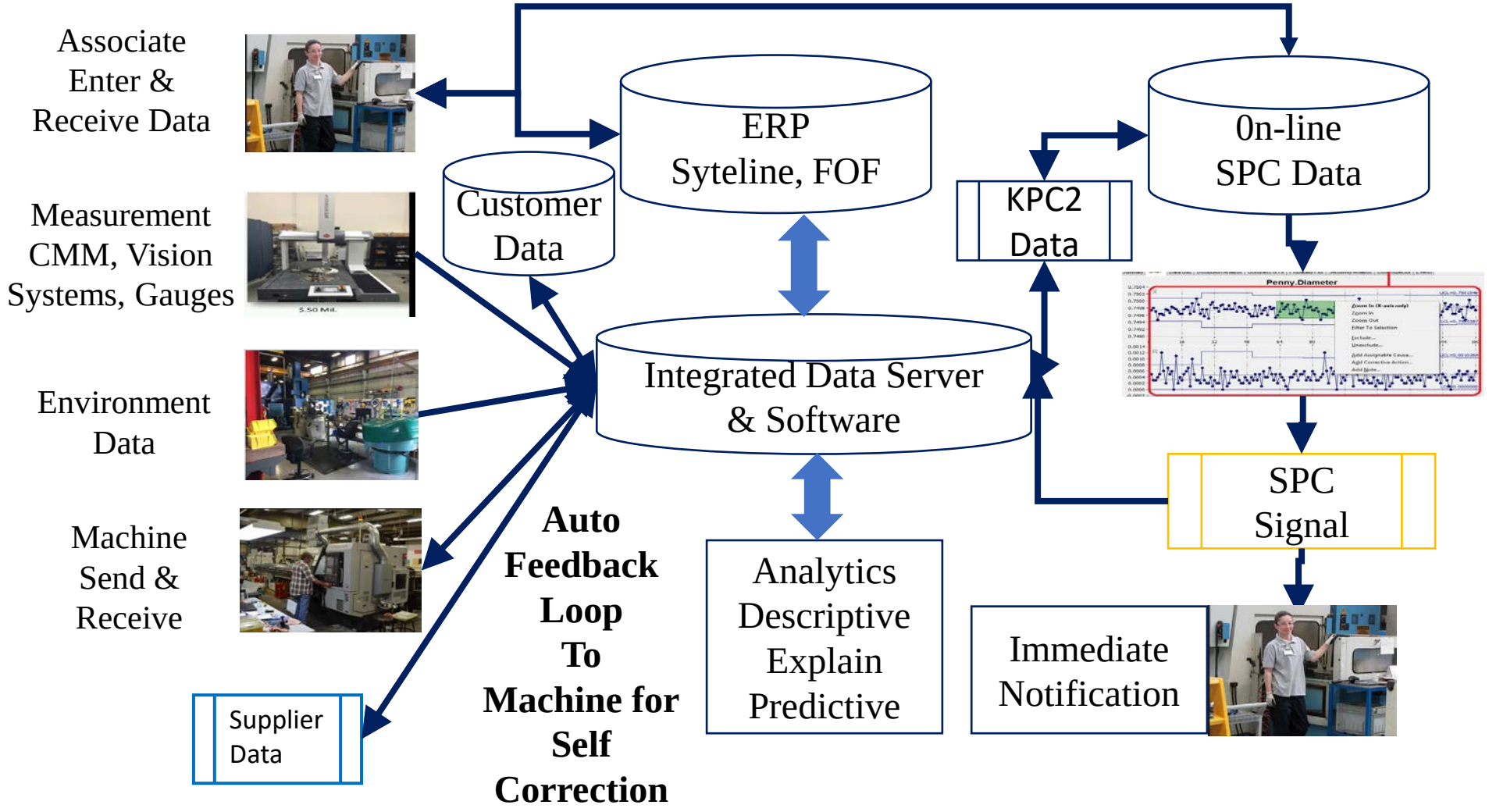
Excessive rework with constant rework loops is the normal production.

Constant **process tampering** (adjustments) by process engineers.

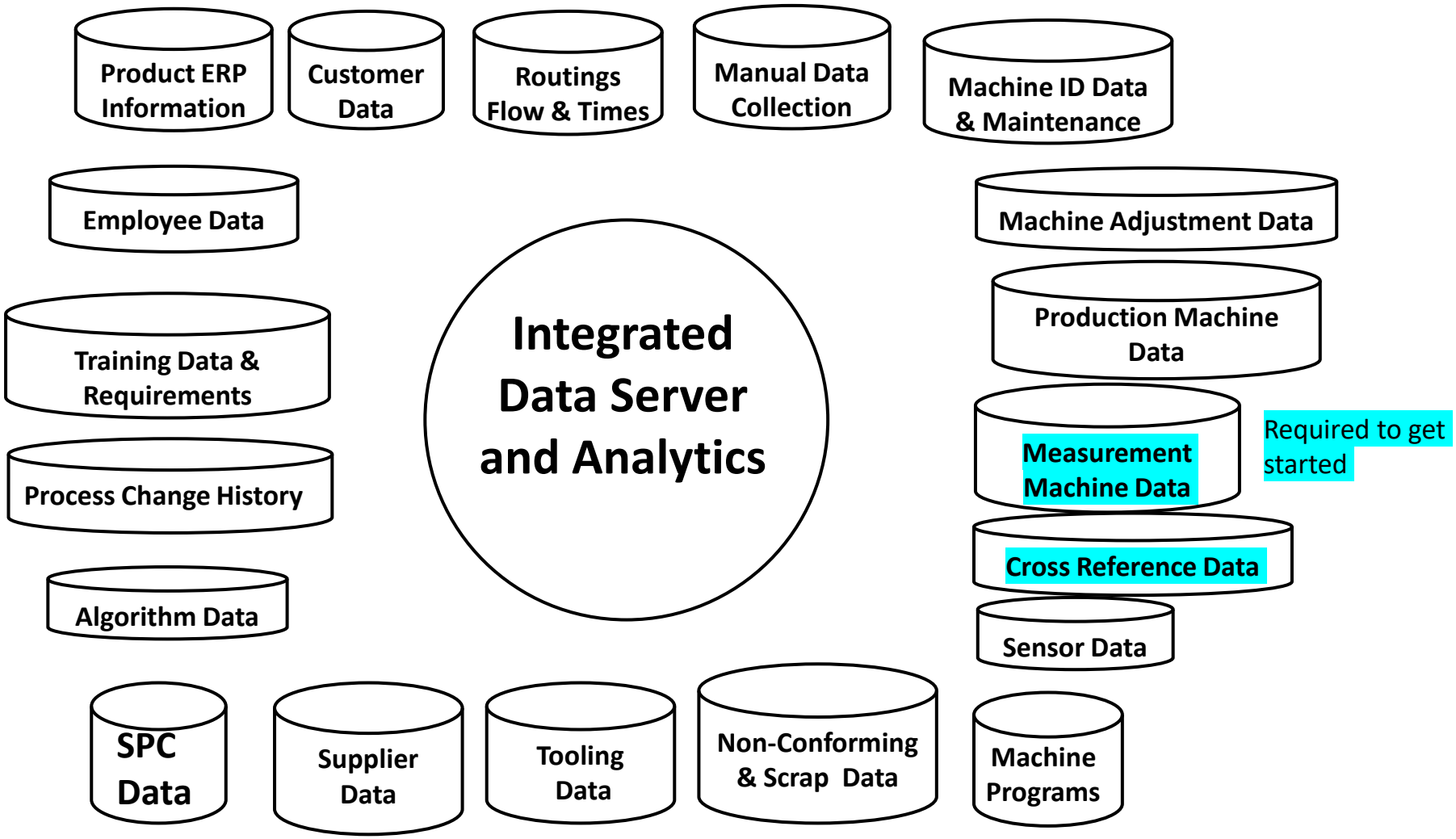


Process requires many weeks to complete and has several outside processes.

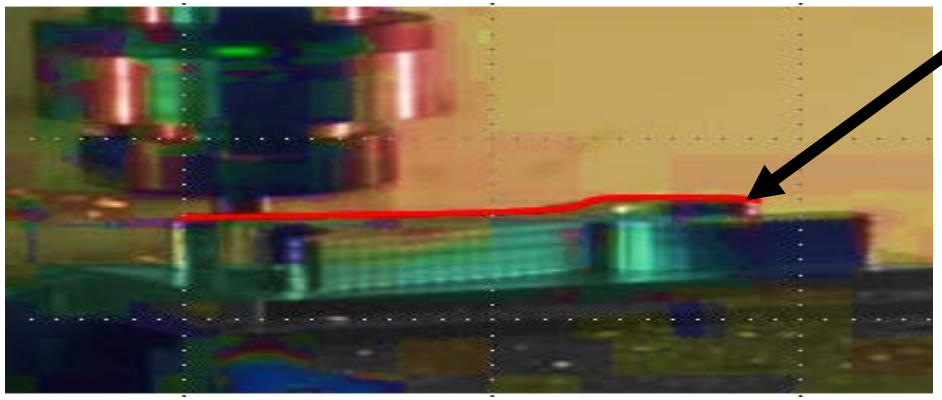
Manufacturing Industry 4.0 and Machine Learning



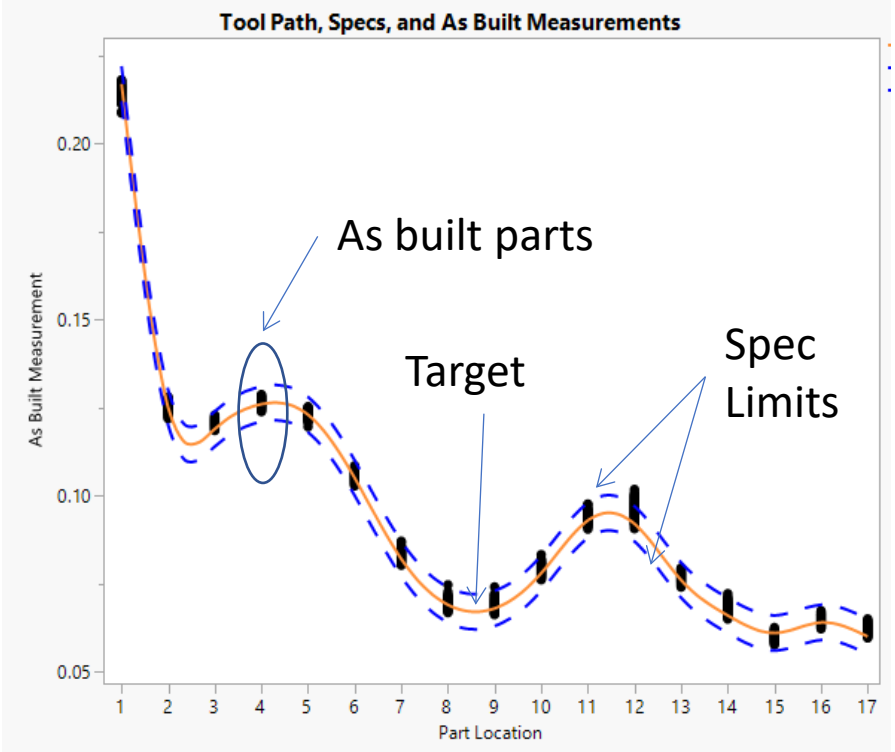
Industry 4.0 Data Server Content



Evaluating CNC Machine Tool Path Capability



There are 17 points measured along the tool path, and the targets dimensions are stored in a CAD model.

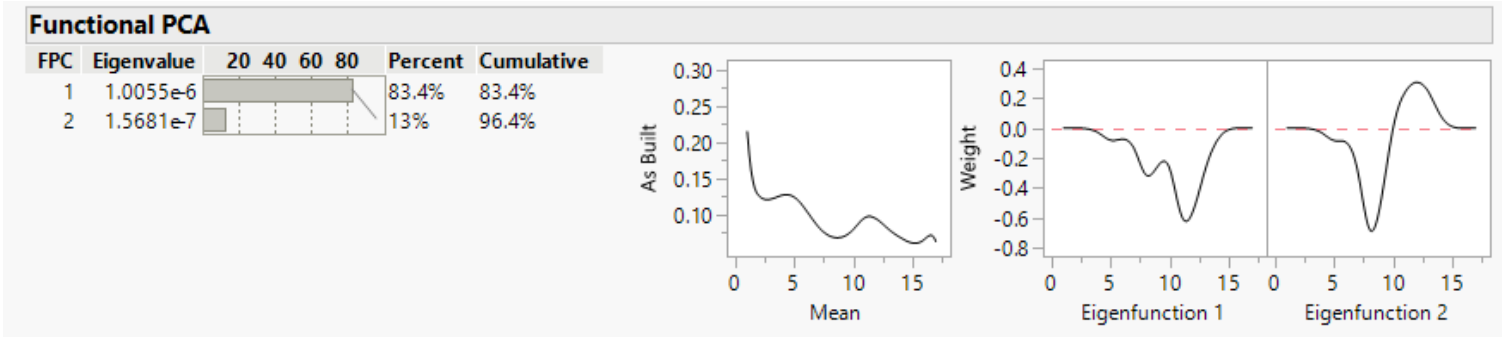


Plot to the left shows the actual part shape (tool path), the target dimensions and specification limits. The as-built dimensions for 1117 parts are plotted.

Some parts are clearly out of spec!

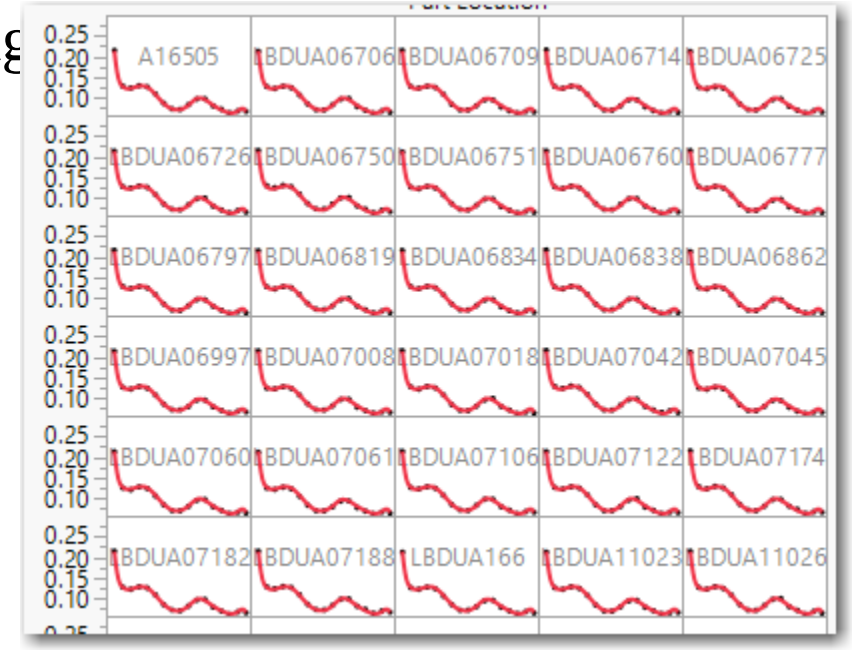
Evaluating CNC Machine Tool Path Capability

The part shapes can be evaluated with the JMP Functional Data Explorer.



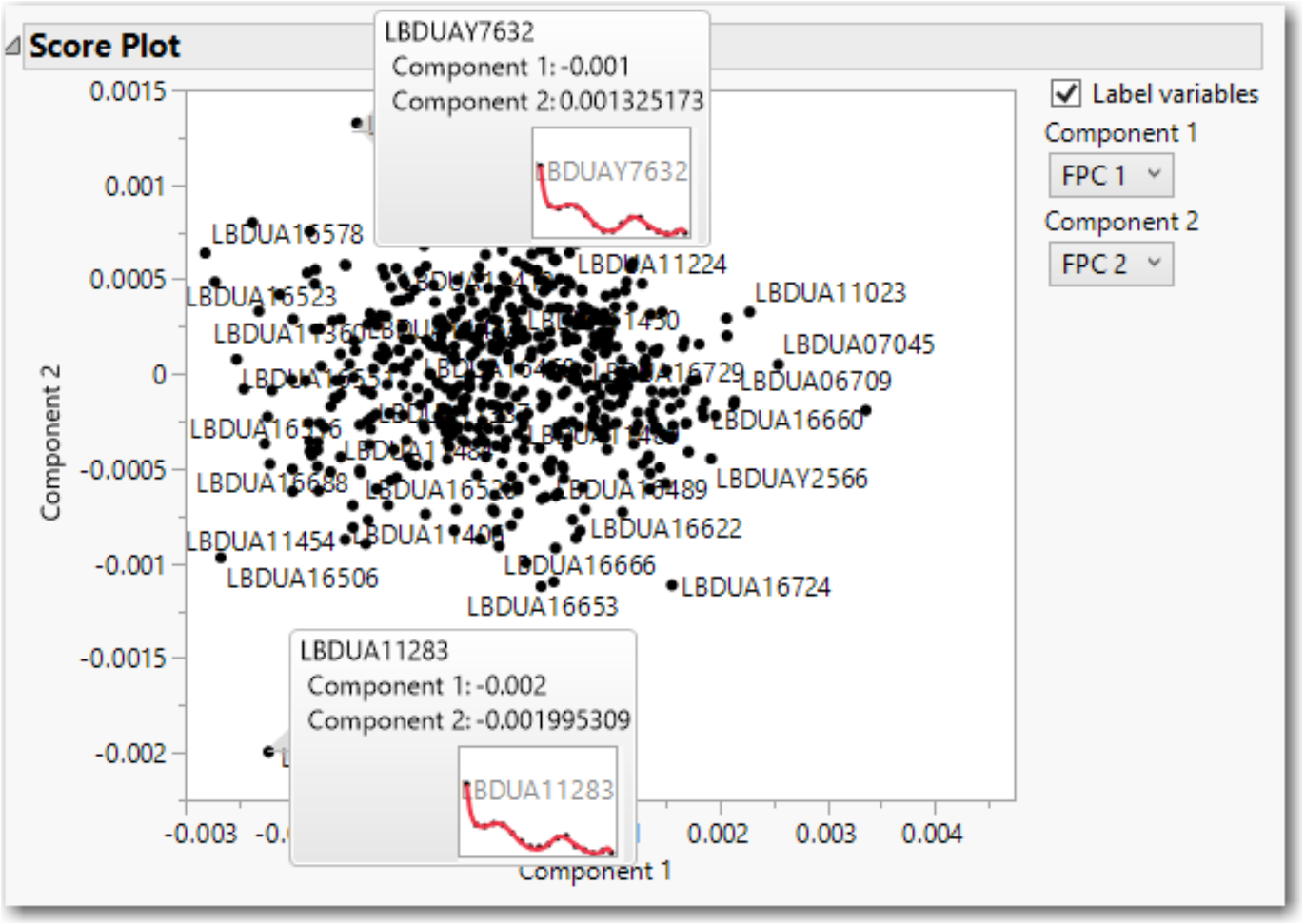
Largest deviation from target is occurring around locations 10 through 12.

The parts appear to be too thick in these locations.



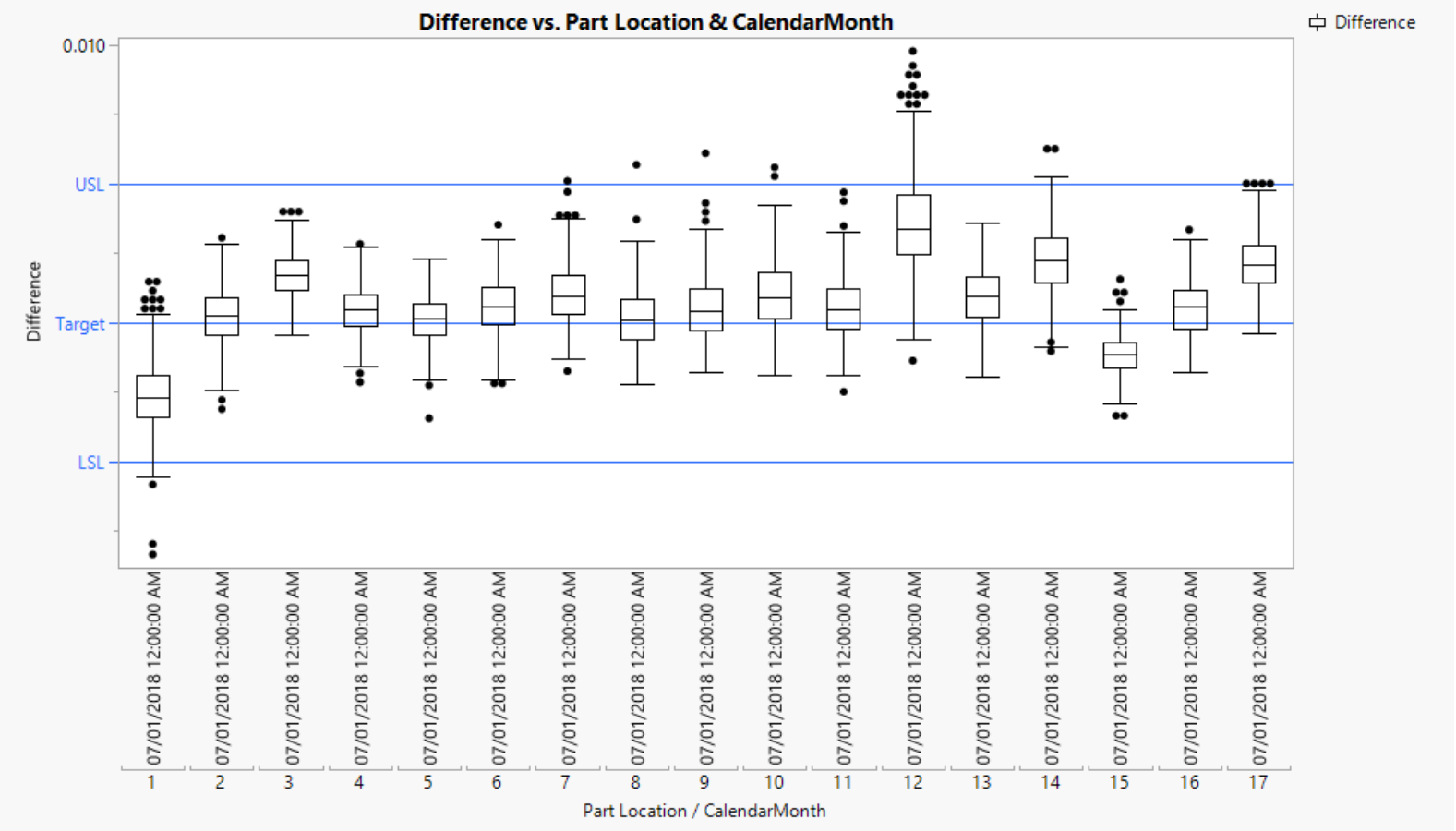
Evaluating CNC Machine Tool Path Capability

Shapes of individual parts can be explored in the Score Plot



Evaluating CNC Machine Tool Path Capability

Using Graph Builder to examine deviation from the target dimensions it is clear that parts are too thick at Location 12.



Matching Part Interference

There are actually two parts, A and B, that fit together, however a gap of at least 0.00125 is specified at all locations; the two part surfaces cannot be in contact.

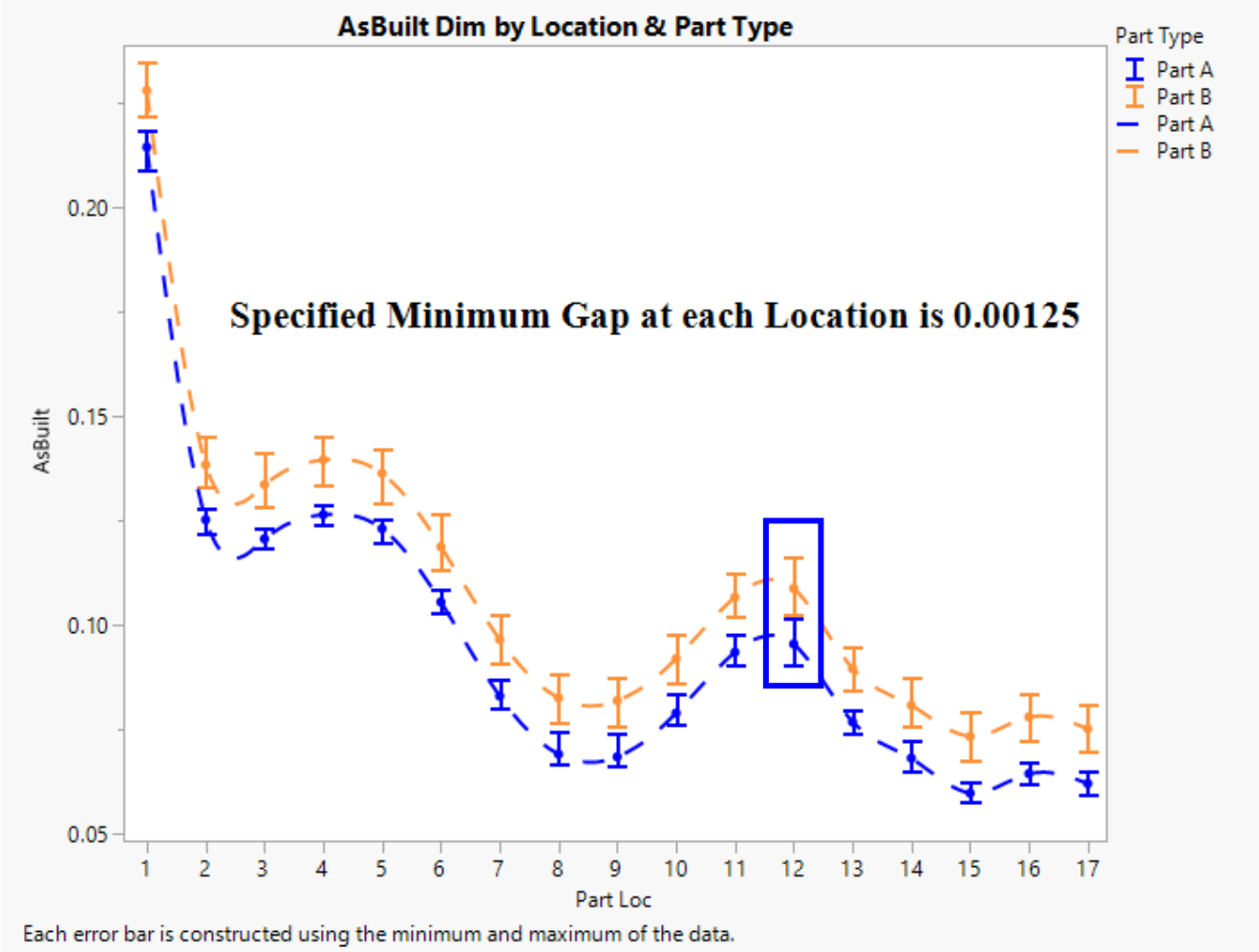
A layer of epoxy is sandwiched between the two parts.

Both parts are manufactured on the same equipment.

Our goal to evaluate the manufacturing capability to determine if any potential interference fits may occur.

Matching Part Interference

From the Graph Builder display it appears that potential interference could occur at location 12.



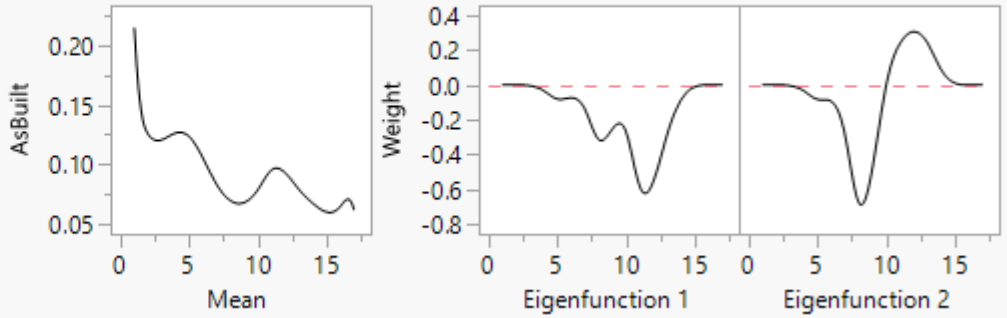
Matching Part Interference

The Functional Data Explorer was used to see if the patterns of variation are similar across the two parts given they are made by the same process.

The Functional PCA Report indicates the patterns are different.

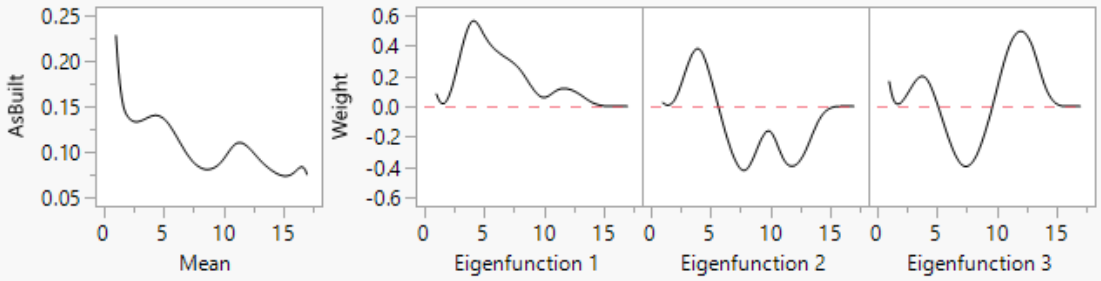
Functional PCA - Part A

FPC	Eigenvalue	Percent	Cumulative
1	1.0055e-6	83.4%	83.4%
2	1.5681e-7	13%	96.4%



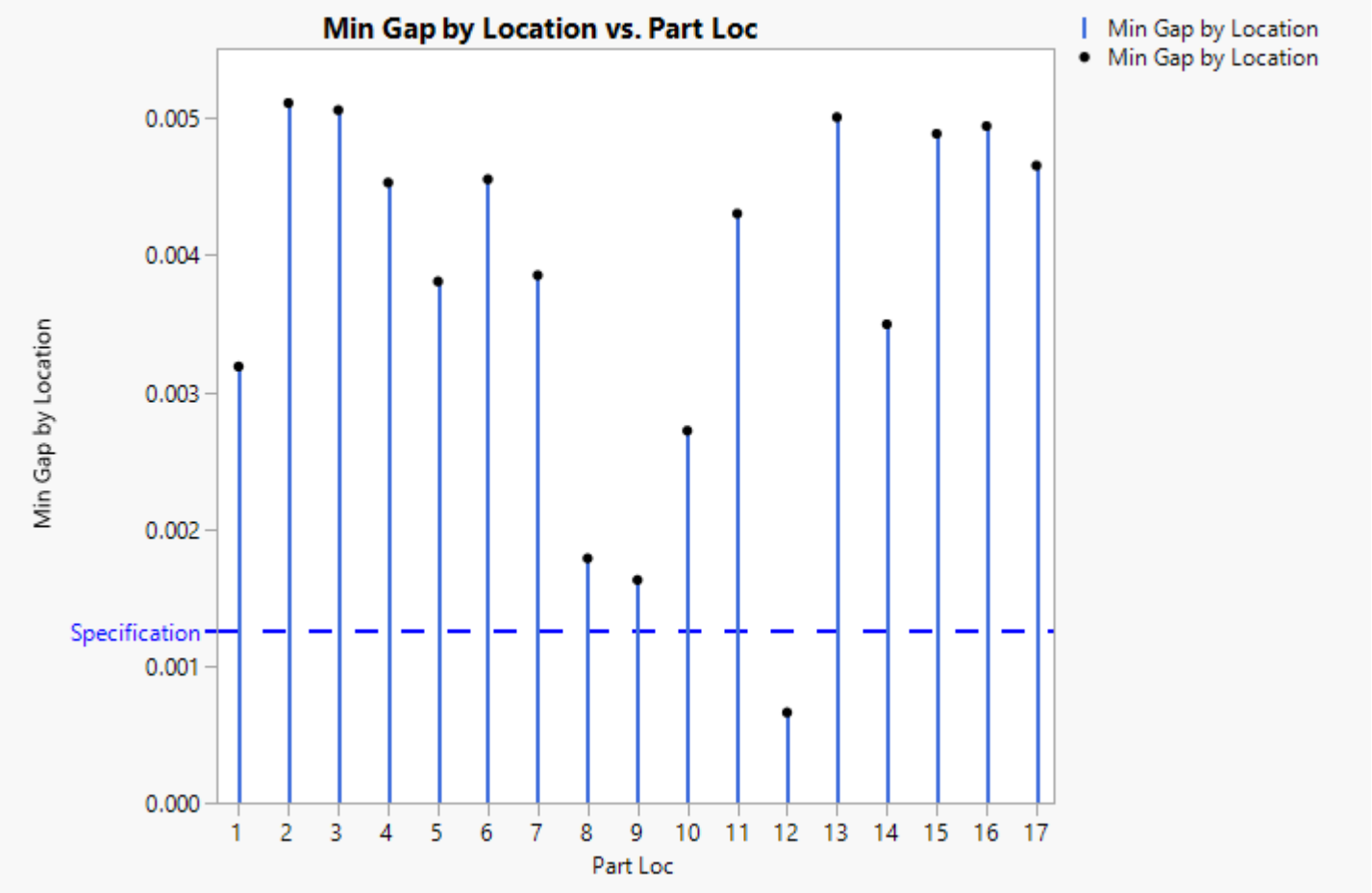
Functional PCA

FPC	Eigenvalue	Percent	Cumulative
1	7.6516e-8	49.3%	49.3%
2	3.5092e-8	22.6%	71.9%
3	2.4962e-8	16.1%	88%



Matching Part Interference

Using the Tabulate platform one can easily calculate the observed minimum gap by part location – only location 12 seems a problem.



Identify Top Issues

Use JMP Process screening platform to identify the top issues across thousands of characteristics, and perform a quick drill down.

The chart below is a copy of the top 7 variables with the highest number of defects across the entire process.

Process Screening

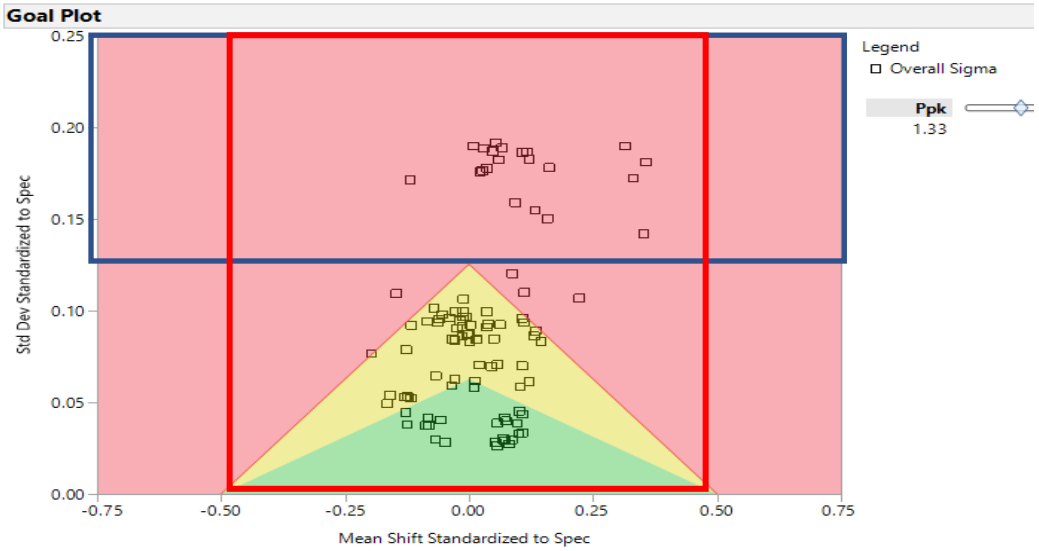
Indiv and MR

	Variability			Summary		Control Chart Alarms						Capability						
Column	Stability Index	Within Sigma	Overall Sigma	Mean	Count	Alarm Rate	Any Alarm	Test1	Test2	Test3	Latest Alarm	Ppk	Cpk	Cp	Target Index	Out of Spec Count	Out of Spec Rate	Latest Out of Spec
Variable 1	1.32	0.00975	0.01291	0.01712	206	0.05204	14	13	0	1	51	-0.055	-0.072	0.513	1.756	150	0.7282	6
Variable 2	1.30	0.01111	0.01445	0.01412	206	0.04461	12	11	0	1	51	0.020	0.026	0.450	1.271	91	0.4417	7
Variable 3	1.21	0.01045	0.0126	-0.0301	203	0.01859	5	5	0	0	21	0.129	0.156	1.116	2.882	85	0.4187	6
Variable 4	1.15	0.01162	0.01331	-0.0127	206	0.01487	4	3	0	1	148	0.057	0.065	0.430	1.096	75	0.3641	14
Variable 5	1.12	0.00347	0.00387	-0.0073	268	0.00743	2	1	1	0	2	0.231	0.259	0.961	2.109	60	0.2239	3
Variable 6	1.24	0.01193	0.01484	-0.0279	203	0.02230	6	6	0	0	21	0.159	0.198	0.978	2.340	56	0.2759	6
Variable 7	1.11	0.00349	0.00387	-0.0062	268	0.00372	1	1	0	0	2	0.324	0.359	0.956	1.790	46	0.1716	3

Use the red triangle to view the associated control charts of each selected row(s).

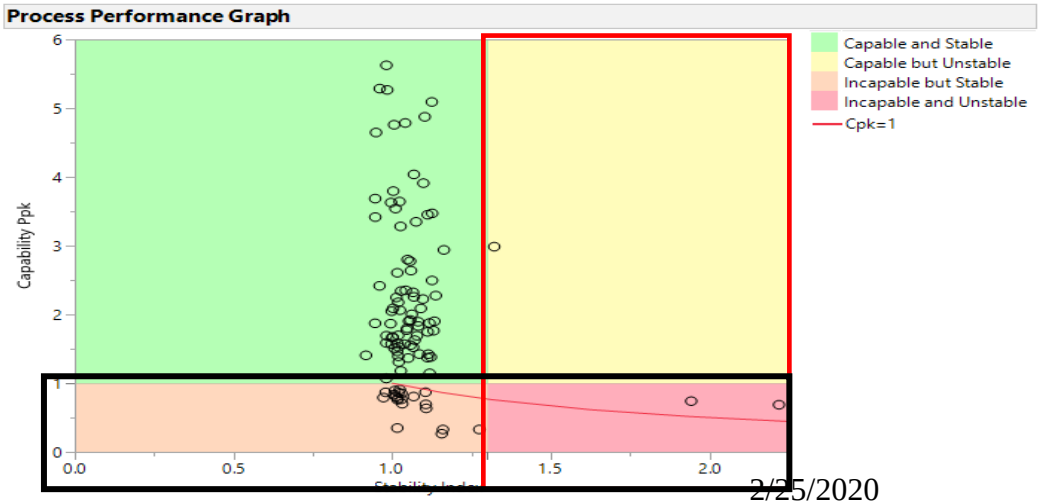
JMP Process Screening (Continued)

Evaluate thousands of characteristics using two graphs



Points within blue box reports process have too much variation to meet desired PPK.

X axis reports how far off the characteristic is from target (0.00). Reference Deming and Taguhci loss function information.

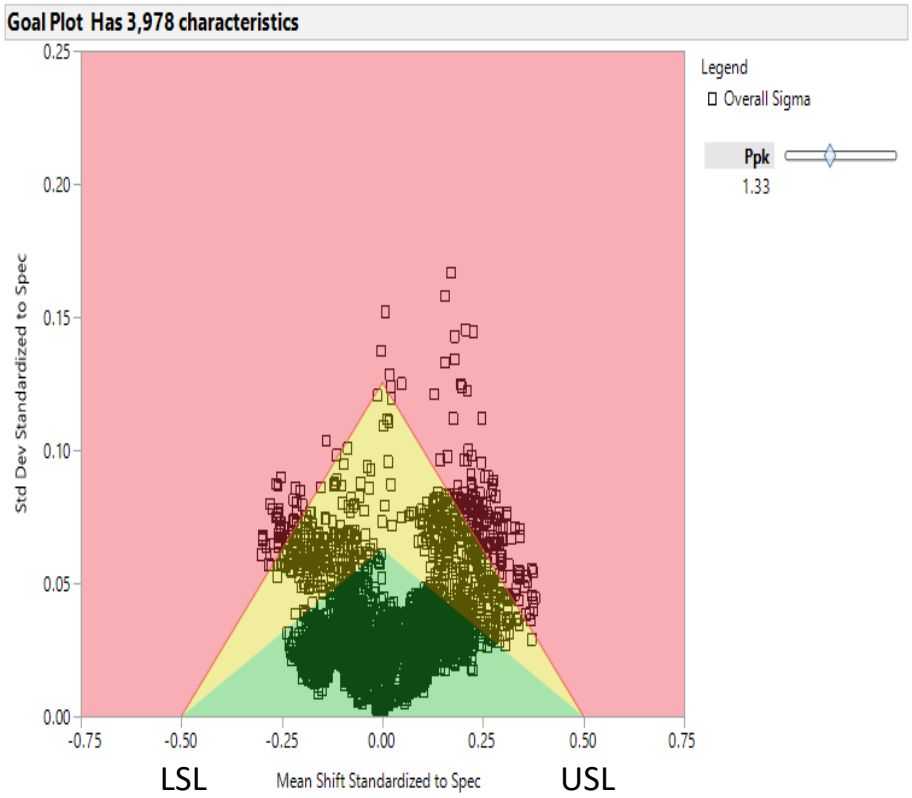


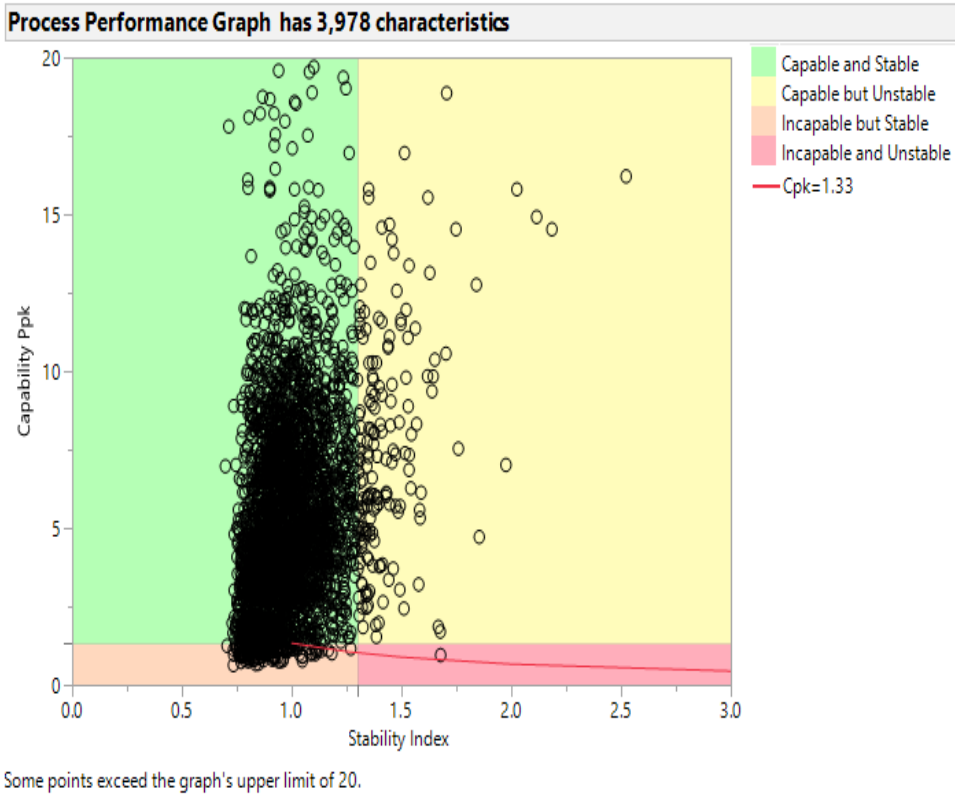
Points in red and black box may lead to more variation when process is managed by specification, and not SPC. Google Deming Funnel effect for details.

Identify Top Issues

JMP easily monitors 4K Characteristics and establish priorities for improvement.

JMP has quick, fast and efficient drill down to control charts for top issues that are biggest contributors to defects.





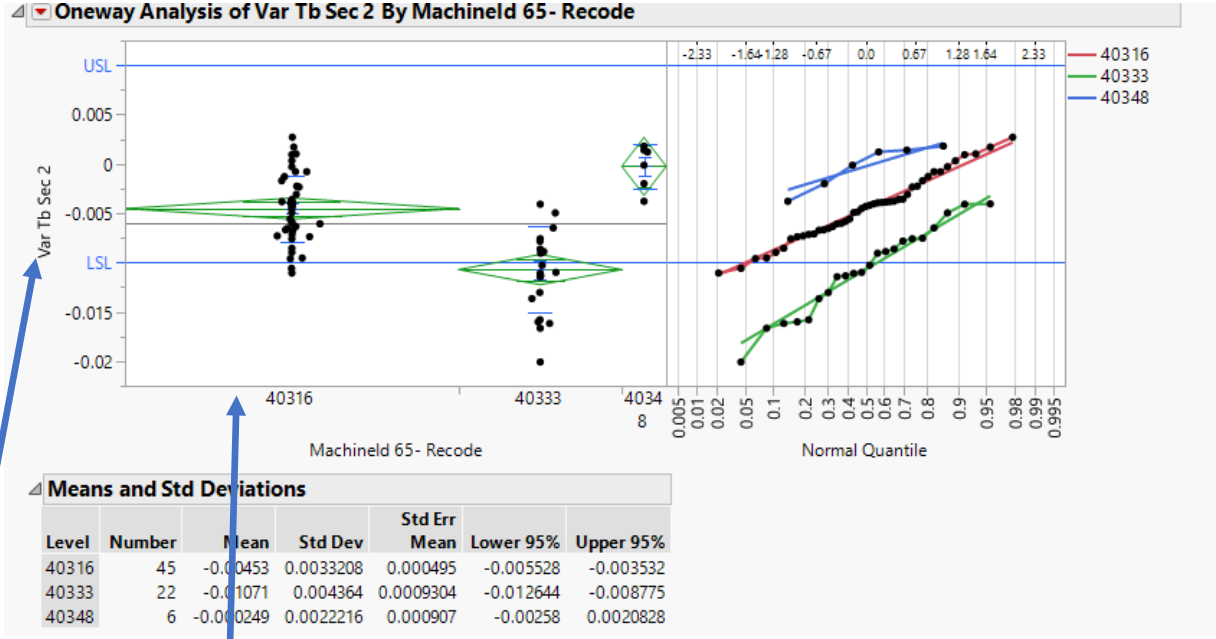
-0.50 represent Lower Specification Limit.

0.50 represents Upper Specification Limit.

Combine Data From Multiple Processes

The data in this chart uses the Final Inspection data (Y axis) and production machines (X axis) used to make parts in production.

Parts manufactured many weeks before Final Inspection measured parts.



X axis contains the machine number that manufactured the part **several weeks** prior to Final Inspection.

Y axis has measurement data from Final Inspection.

The use of a control chart to qualify the new machine and setup would have reduced the number off target parts from 50 to 2.

Process Analysis Capability and Correlation

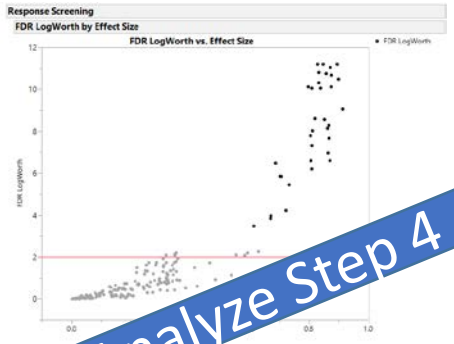
Analyze Step 1

Process Screening
Identifies Top Issue

Column	Variability Stability Index	Within Sigma	Overall Sigma	Summary Mean	Count	Control Chart Alarms Alarm Rate	Any Alarm	Test1	Test2	Test3	Latest Alarm	Capability Ppk	Cpk	Out of Spec Count	Out of Spec Rate	Latest Out of Spec
Var Tb Sec 2	1.59	0.00304	0.00482	-0.006	74	0.01553	5	5	0	0	254	0.274	0.435	14	0.1892	241
Var Ta Sec 2	1.57	0.00307	0.00481	-0.0051	74	0.01553	5	5	0	0	254	0.338	0.529	12	0.1622	241
Var Tb Sec 1	1.48	0.00295	0.00435	-0.0028	74	0.00621	2	2	0	0	242	0.551	0.813	6	0.0811	255
Var Ta Sec 4	2.15	0.00136	0.00293	0.0031	74	0.03416	11	10	1	0	143	0.786	1.691	1	0.0135	167
Var Tb Sec 3	1.49	0.00234	0.0035	-0.0017	74	0.01242	4	2	2	0	205	0.789	1.178	1	0.0135	275
Var Tb Sec 4	1.92	0.00157	0.00302	0.00249	74	0.04037	13	9	4	0	143	0.828	1.594	0	0	.
Var Ta Sec 3	1.52	0.00214	0.00324	-0.0007	74	0.00892	3	2	1	0	205	0.959	1.454	0	0	.
Var Ta Sec 1	1.43	0.0031	0.00444	-0.0012	74	0.00000	0	0	0	0	.	0.663	0.948	0	0	.

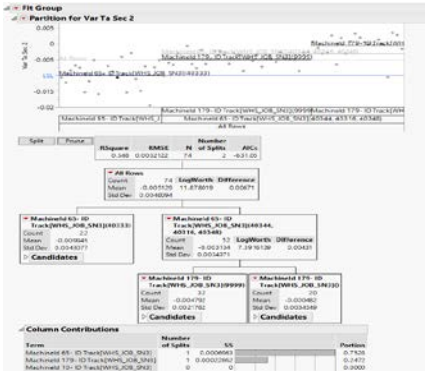
Analyze Step 2

Response Screening
Identifies Special Causes



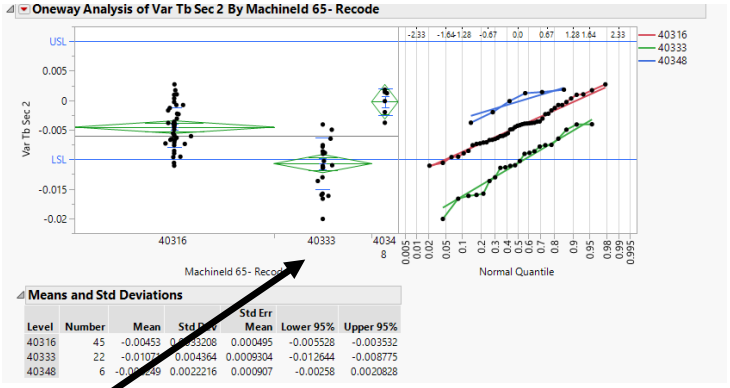
Analyze Step 3

Partition Model
Identifies Major Source



Analyze Step 4

Graph Reports Significant Correlation to Machine ID



The new machine manufactured 53 parts off target. Using a SPC chart would have reduced the number of parts being machined off target to 2 parts.

New Machine off target. Mean Below LSL

Use Historical Performance To Your Advantage

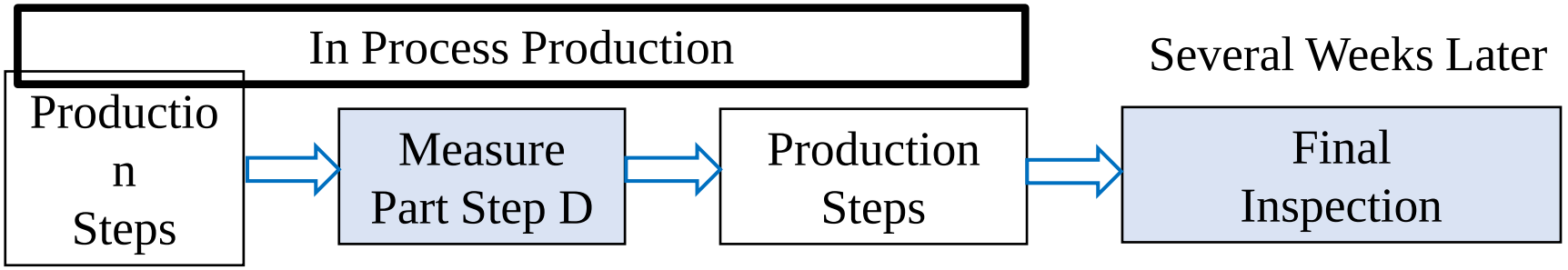
Use the following process to qualify a new machine or setup when the population mean and variance is known.

1. Create a control chart using the 95% CI of the mean and standard deviation of a known process.

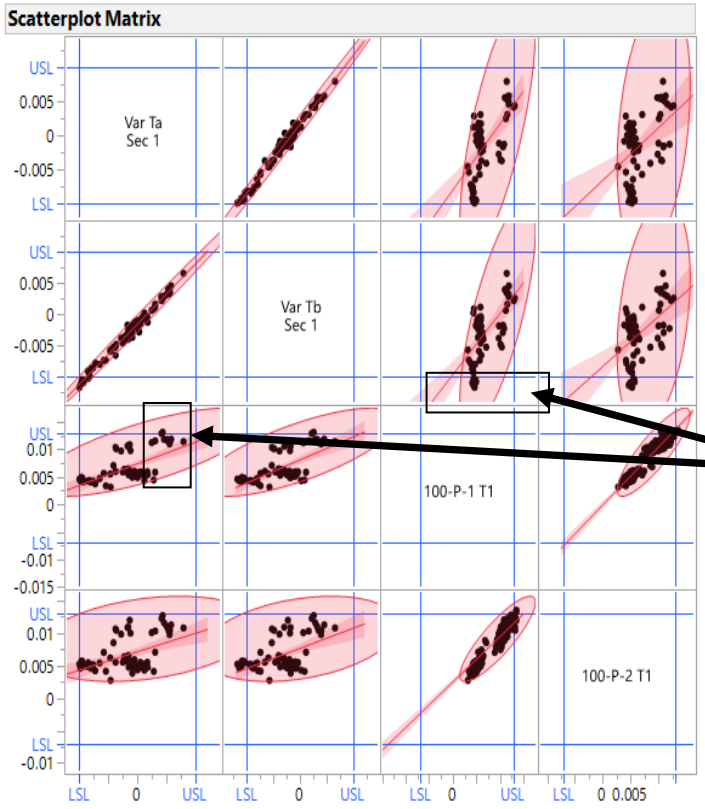
2. Use control chart to know when to investigate and/or adjust process when process isn't in statistical control. Use on-line SPC or JMP control chart platform to qualify and monitor new machines.

Process Steps One and Two will minimize rejects and the over adjustment the process. Google Deming Funnel Effect for details.

Scatter Plots and Multivariate Plots Identify Correlations



Use Multivariate and Scatter Plots to determine effectiveness of in-process me



Measurement at Step D is expected to ensure characteristic is within specification at Final Inspection. Characteristics 100 P-1 11 and 100 P-2 11 are in process measurements that are measured several weeks before Final Inspection.

Black Box indicates the in process specification limits at Step D need to be evaluated for 100-P-T1 for predicting Var-Tb Sec 1 conformance to specification and binomial distribution.

Additional Actions Completed

We used many other JMP platforms and other activities to understand and resolve unacceptable process performance. Examples of other actions are:

- JMP Response Screening, Fit model, Scatter Plot Matrix to identify interactions and validate in-process and product specifications.
- JMP DOEs, prediction profiler for machine learning.
- Obtaining data from machines, machines controllers, sensors and other sources of data.
- Using analytics to create machine learning and using algorithms in the machine controllers to dynamically adjust processes.

Results of Industry 4.0 and JMP

Current Final Yields are >90%, but still need improvement to meet objective.

- The journey continues from a starting point of 0 to 25% yields.

Measurable Results

- Higher skilled and empowered workforce.
- Higher yields for new products.
- Implement preventive actions, faster problem resolution, and decision making for quicker corrective actions.
- Greater use of JMP Analytics by associates.
- Greater use of Lean/Six Sigma tools by associates.

Training Associates to Enable Change

Associates using JMP should complete the following training:

- JMP free on-line "**Statistical Thinking for Industrial Problem Solving**"
  - JMP awards a "Badge" after completing training and passing a test. https://www.jmp.com/en_us/statistical-thinking.html
- Internal training and additional testing of associates using company data.
- Using outside experts to train associates in special subjects. Having an external resource that knows the latest analytical methods.
- Last step is to train associates in the use of JMP tables created for importing and analyzing data.

Skills Needed for Industry 4.0 Data Analytics

SME - Subject Matter Expert

Six Sigma	Big Data Analytics
External Resource	SME 2 Data Analytics Professional that is outsourced for medium to small companies.
Master Black Belt - No testing of individual's knowledge of databases.	SME1 – Master Black Belt Individual that has a comprehensive understanding of process and database structure. Supported by a Database Engineer.
Black Belt	Individual that has a good understanding of process and database structure.
Green Belt	Individual qualified in Statistical Thinking for Industrial Problem Solving JMP testing.
User of JMP Templates	Associates trained in JMP templates and reaction to analysis.

JMP on-line training

1) Short videos that are less than 10 minutes each subject
2) Self paced on-line training for each individual participating in training.
3) Use JMP training sessions as a reference when solving problems.

Standard Work and Leadership Responsibility

- Standard Work Definition
  Associates using the same JMP scripts tables and platforms for analyzing process/product data and presenting information to organization in a uniform manner.
- Implement “Standard Work” after training associates in analytics and use of JMP template tables and scripts.
- **Each review period has set expectations for metrics and analysis that is completed prior to the review.**
- Leadership sets the expectations and participates in the use of Standard Work during TIM reviews.

Review of Accomplishments

- Created an integrated SQL database with all sources of data.
- Created JMP QRYs, Scripts, and Tables For Analytics.
- Defined Standard Work for Analytics.
- Defined standard metrics and periodic reviews.
- Performed external and internal training of associates.
- Trained & tested associates in use of databases and analytics
- Created a support structure to help associates in using analytics.
- Many engineering efforts were used to redesign tooling, implemented process adjustments, and SPC charts based on the analytics presented at Technical Interchange Meetings and subsequent investigations.

Implementing Industry 4.0 – Organizational View

- Culture – Leader involvement/accountability in implementation.
- Create a vision and plan for implementing Industry 4.0
- Consistently communicate commitment and progress for Industry 4.0 and Lean/Six Sigma to all associates.
- Create an integrated SQL database with all process information.
- Process knowledge is required for effective analytics.
- Be statistically driven in problem solving and actions.
- Create incentive for associates to learn new skills.
- Assist support functions in applying analytics and JMP to perform their function.
- Follow the process for creating an integrated SQL database.
- Hold associates accountable for analytics and reporting at TIM reviews, measuring process, and problem solving.