PREDICTIVE STATISTICAL PROCESS CONTROL

An update on data-driven CNC machining at L&S Machine Company

Statistical process control (SPC) has long been one of our most valuable advanced manufacturing tools. And we aggressively apply traditional SPC techniques to every part we make for the nuclear, medical and aerospace industries.

These techniques include the ongoing measurement of tolerances on thousands of part features, using the probes on our HAAS 3- and 5-axis CNC machines as well as our fleet of coordinate measurement machines (CMM). The amount of SPC data we've collected over the years is immense. Every year, we generate roughly a million new SPC data points and generate thousands of control charts.

Like many manufacturers, we've used our SPC data to great advantage. It helps us meet our customers' high expectations for quality. It also helps maximize our yields and machine utilization, which lets us keep costs low for our customers.

Yet for all the benefits of our existing SPC program, we believe we have barely scratched the surface of what's possible. In the past, our control charts mostly played a descriptive role, helping us diagnose the root cause of a defect after the process strayed out of tolerance. But we had not made the jump to a truly predictive SPC system that flags discrepancies before they happen—until now.

Equation 1. *Our previous SPC method derived process capability values from samples that did not necessarily reflect what an in-control process should look like, which made it difficult to predict out-of-control conditions with any accuracy.*

$$C_{pk} = \min\left(\frac{USL - mean}{3 \times std.Dev}, \frac{mean - LSL}{3 \times std.Dev}\right)$$

Equation 2.

$$UCL = x + 3\sigma$$

$$LCL = x - 3\sigma$$

Updated SPC Method

Working with the Industrial Engineering Department at the University of Pittsburgh, we recently developed an upgraded approach to SPC that allows us to predict out-of-tolerance conditions before they happen. We still use control charts, but we use them very differently than in the past.

Past practice. In our previous approach, we created control charts for the size and location of part features using tolerance data provided by our customers and measured samples from the CNC probes. The tolerance data from customers determined the control chart's upper and lower specification limits, while the measured samples gave us control limits.

We then calculated our process capability (Cp) and process capability index (CpK) from this control chart using standard methods (see Equation 1). This approach did a good job flagging any defects that fell outside the customer specifications, and it did keep parts with defects from ever making it through to final inspection.

However, our original approach to SPC did not give us advance warning that a machining process was trending out of control (see Figure 1). We did briefy consider using one of the well-known SPC rule sets, such as the Western Electric Rules. These rules can anticipate that a process is trending out of control, even when samples lie within ± 3 standard deviations. But we ultimately decided not to use the rules because they would have been difficult to implement in real-time on our existing shop-floor control systems.

Current practice. To pave the way for predictive analytics of SPC data, we first revamped the way we create our control charts. We now start with historical measurements of part features, which is data we have in abundance in our SPC database. These historical samples are carefully chosen according to three rules:

- The samples must represent a snap-shot of the process at a time it was under tight statistical control.
- The samples must not contain any outliers due to random process variation.
- All data points must lie between ± 3 standard deviations of the sample mean.

Once we chose appropriate samples, we then use them to calculate the mean and standard deviation to establish upper and lower control limits for a given part feature (see Equation 2). We then add the specification limits that correspond to the customer tolerance requirements.

The resulting control chart helps us reduce variation, which in turn yields higher Cp and CpK values.

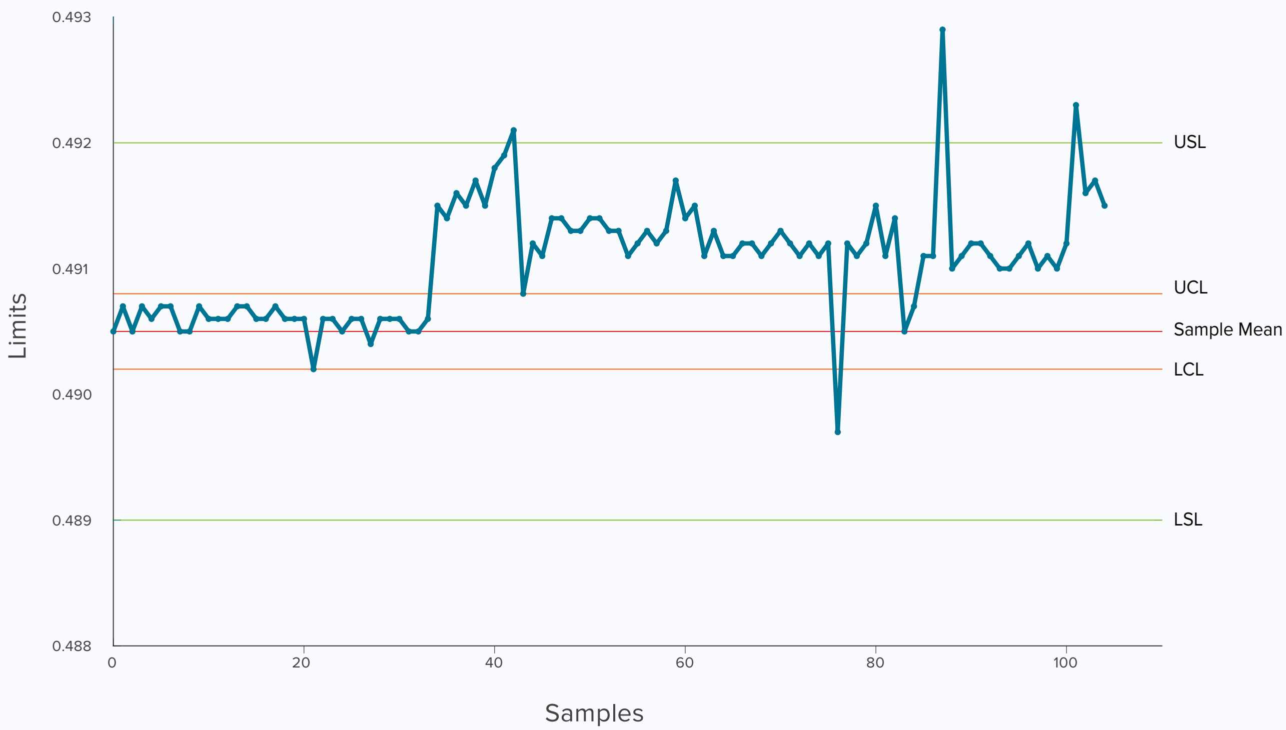
What's Different?

In some ways, our updated approach to SPC does not break any new ground. Many manufacturers in a variety of industries calculate process capability and control limits just as we described, or they use one or more of the SPC rule sets. What sets our new approach apart is how we use our vast store of historical data and apply SPC on our shop floor in real time.

Figure 1.

Acute Process Change

In this example from historical data, there's evidence of acute process changes that resulted in out-of-spec production. Our new SPC system focuses on trends within the control limits, and can prevent defects before they occur.



Many modern machine shops, including ours, use SPC as a pass-fail system. They probe parts on the CNC machine and look for any measurements that fall outside limits determined by the SPC charts. In our case, we have always had logic in our CNC controllers to shut down the machine if a probed measurement fell outside the process's specification limits. We still have that system in place.

Now, however, we have added a deeper layer of SPC intelligence. We've implemented new machine controller logic that performs a trend analysis on the probed measurements as we collect them and compares them to our revamped control charts. The trend analysis serves as an early warning system, giving us time to correct a process before it produces a defect.

The numerical methods we use for our early-warning system qualify as a simple time series analysis. However, getting the system to run seamlessly as part of our machine controllers was anything but simple and required a significant engineering investment.

Only The Beginning

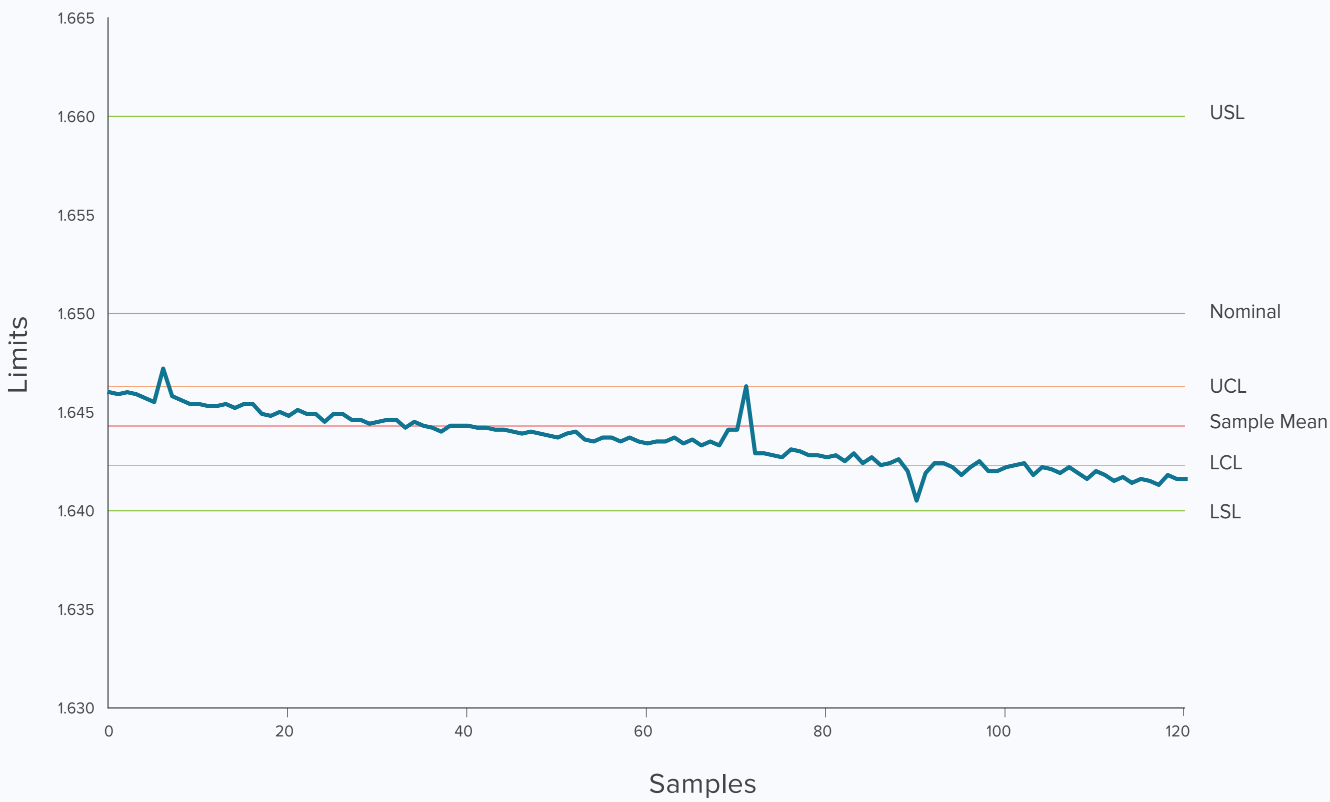
Our new approach to SPC was launched in mid-2016 and has already started to improve our machining processes. Currently, the system is set up to notify our industrial engineering team whenever a process starts to trend out of control, even if the process is still producing in-tolerance parts. We're now able to intervene in the process before defects even occur. With this system in place, we've all but eliminated any defects related to machine malfunctions, operator error or processes drifting out of control due to tool wear.

The recent improvements to our SPC practices are just the beginning of our push to become the leader of data-driven machining. A second research project is underway in partnership with the University of Pittsburgh. It will apply more advanced multivariate statistical methods to the CNC data we collect with the goal of making even more robust defect predictions.

For questions or more information on our manufacturing processes, contact our industrial engineering team at **info@lsmachineco.com**.

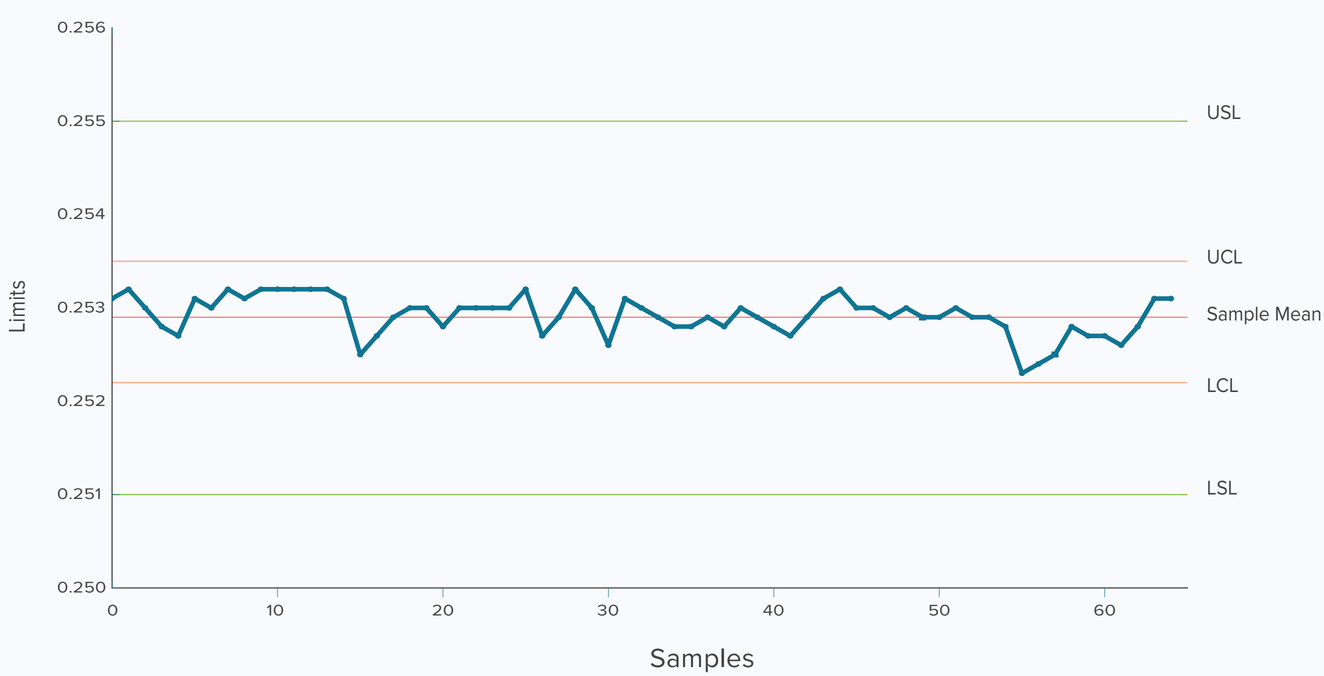
In Control, But Trending Out

This process remains well within the specification limits, so the parts meet customer requirements. But the negative trend in the process warns us to take corrective action long before the process produces an actual defect.



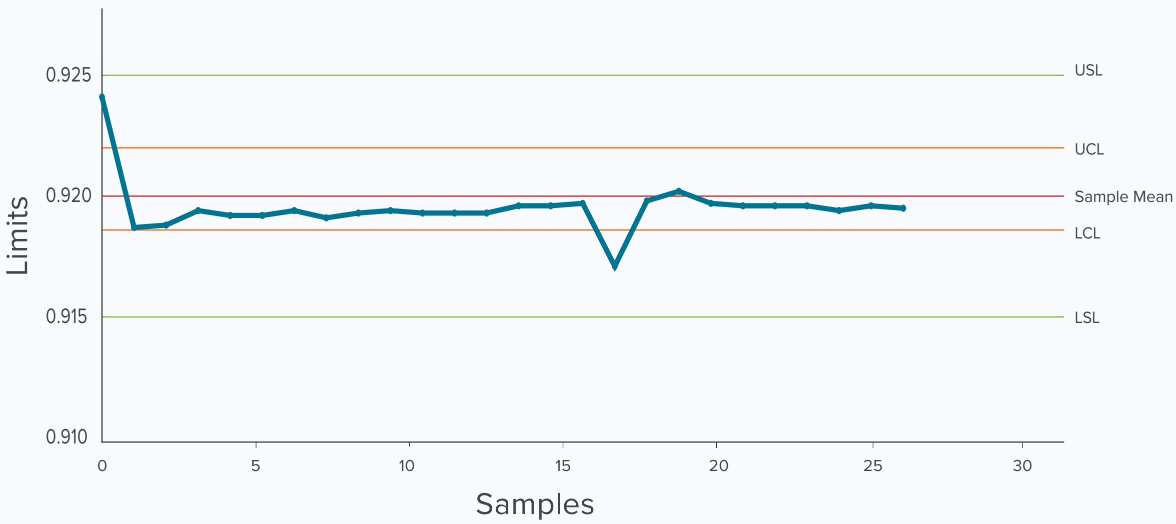
In Control

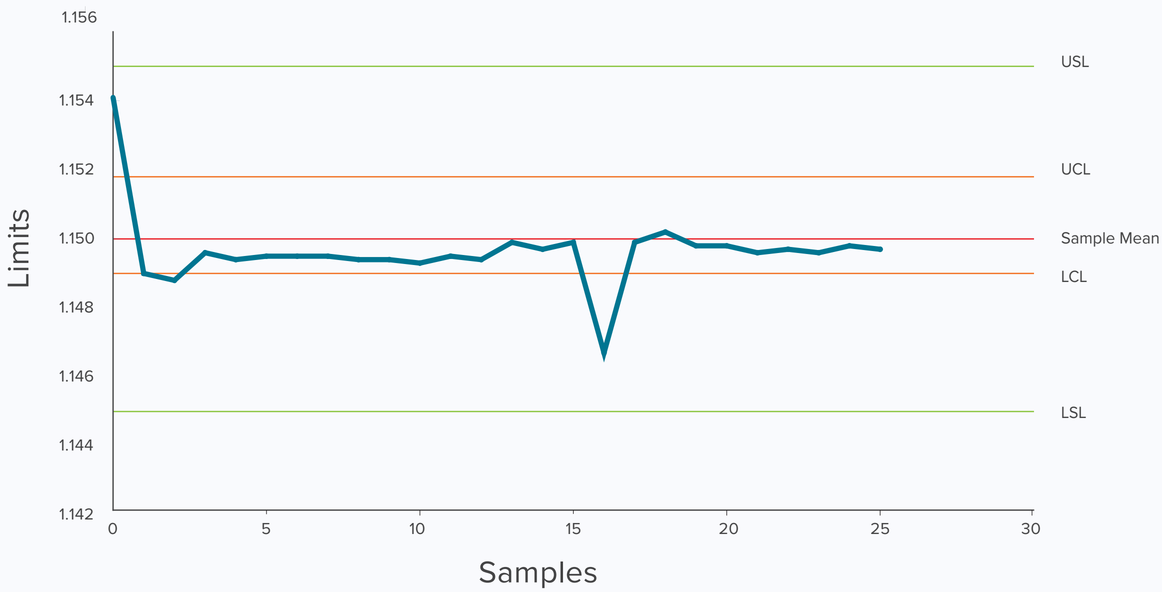
When under control, the process shows some variation within tight limits, but no obvious trends indicating it may go out of control.

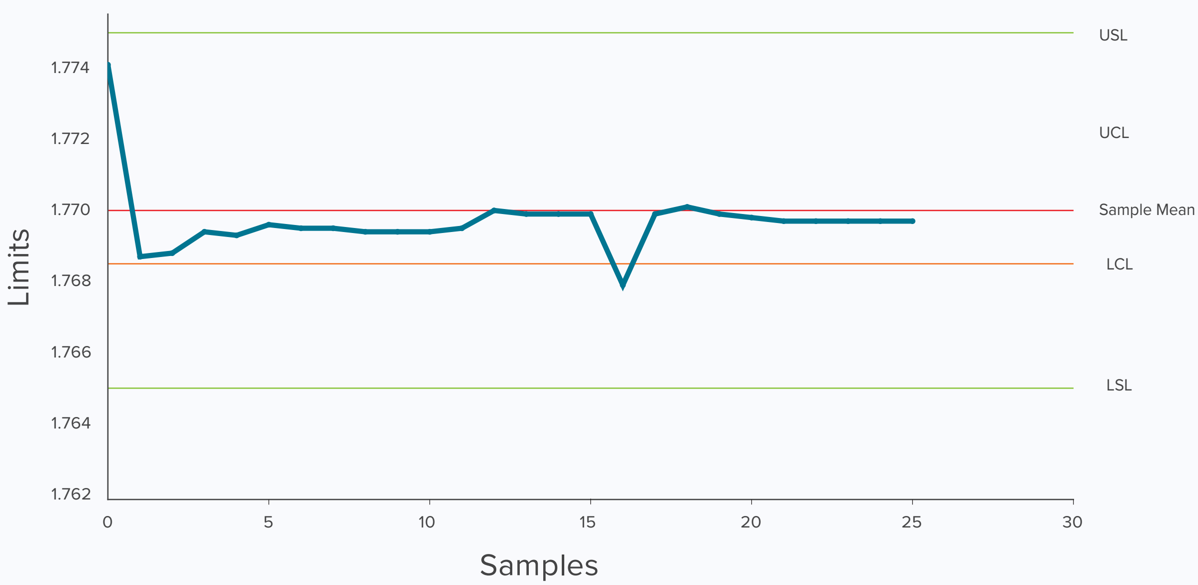


Predictive Tool Wear

Tool wear is easily identified through a careful monitoring of process control charts. In these three examples, the same tool used on three different features on the same part shows variation at the same sample, indicating the presence of tool wear.





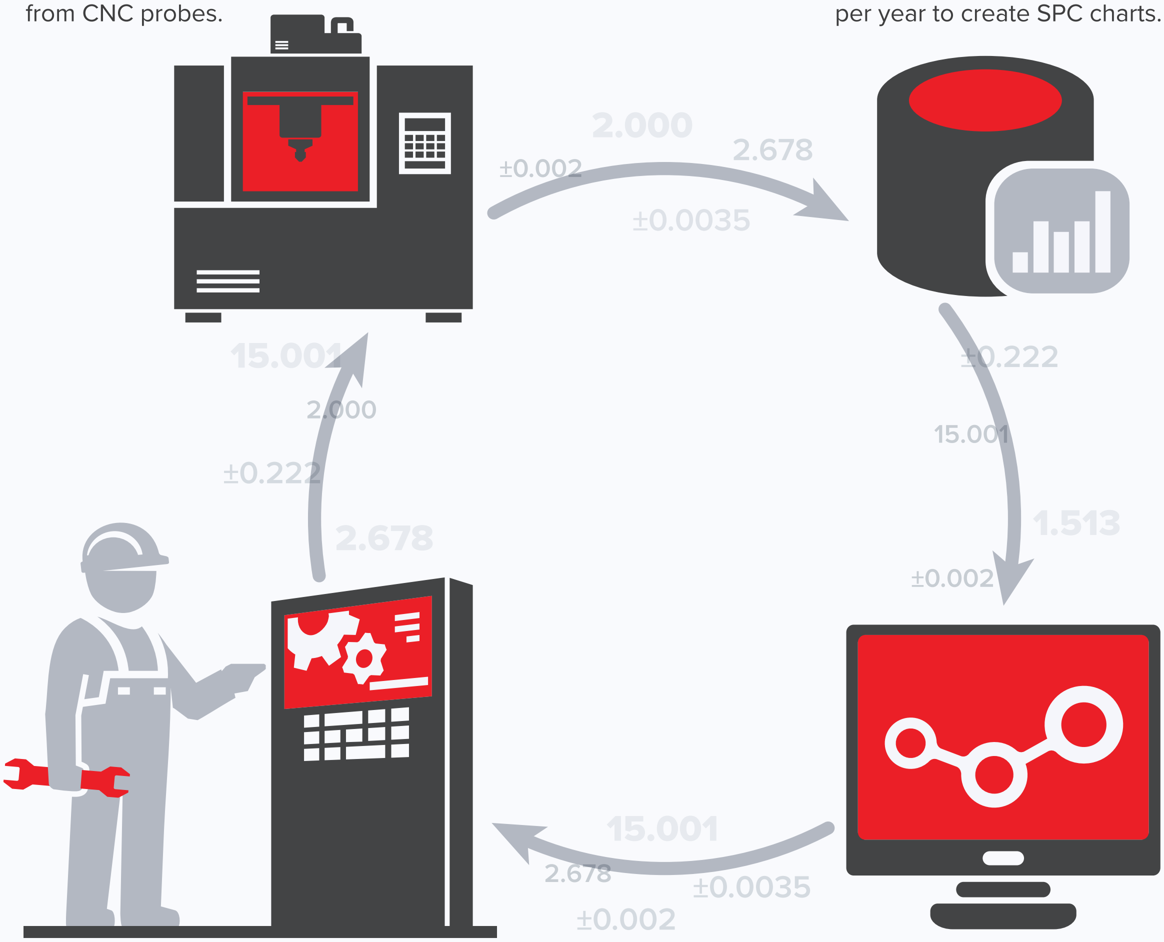


PREDICTIVE CONTROL

Traditional statistical process control (SPC) methods are evolving to become more predictive. Through careful trend analysis of our real-time SPC charts, we can pre-emptively avoid defects rather than simply identify them after the fact.

Collect
Real-time dimensional data from CNC probes.

Process
More than 1 million data points per year to create SPC charts.



Adjust
Process before defects occur based on trend analysis.

Analyze
SPC charts to identify trends that predict out-of-control conditions.

About L&S Machine Company

Our long experience serving the nuclear industry has honed our ability to machine parts to the most demanding quality and tolerance specifications. We've now expanded our operations to offer the same expertise to aerospace, medical and precision-industrial customers.

Modern Machines. We operate an extensive lineup of Haas machining and turning centers. With an average age of just three years, our machining center lineup is the most modern you'll find. As specialists in parts with complex geometries, we offer 5-axis machining and waterjet cutting.

Advanced Quality Systems. Our commitment to quality is visible throughout the plant, from tool-setting systems to a suite of advanced quality measurement equipment.

A computer network ties together all of our machining centers for the purpose of statistical process and quality control (SPC and SQC).

Clean and Efficient. Beyond the machines and quality systems, our plant meets the highest standards for efficiency and cleanliness.

See for yourself

Take a virtual tour of our facility. http://lsmachineco.com/virtual-tour

L&S Machine Company, LLC 709 Donohoe Road, P.O. Box 391, Latrobe, PA 15650 **T:** 724-837-5500 **F:** 724-836-1021 **www.lsmachineco.com**