Implementation of Automated Process Dashboards

Jens Riege[1], Donnie Lee, Rainier Lee[2], Nercy Ebrahimi[3]

[1] jens.riege@skyworksinc.com, [2] rainier.lee@skyworksinc.com, [3] nercy.ebrahimi@skyworksinc.com
Skyworks Solutions, Inc. 2421 West Hillcrest Drive, Newbury Park, CA 91320 805.480.4400

Keywords: Data Visualization, Data Automation, Statistical Process Control, Big Data

Abstract

Process and equipment engineers are responsible for monitoring ever increasing volumes of manufacturing data as technology advances accelerate access to equipment and process data. As advanced sensors become more common on manufacturing equipment, engineers have more parameters to monitor and can have tighter control of equipment performance. However, response to out of control events is just as critical as before to minimize scrap and rework.

Applying tools to improve data visualization becomes necessary to help engineers narrow their focus to the problem areas. This paper illustrates some of these methods as applied to an engineering dashboard for statistical process control.

Introduction

The advancements in network, machine to machine and wireless communications allow for quick access to increasing amounts of process and manufacturing equipment data. Process recipe and tool parameter data, which previously was only accessible by manually transcribing values stored in memory registers and EPROMs, has evolved to continuous streams of tool performance data from many tool sensors. For example, changes in temperatures, gas flows, etch endpoint characteristics, deposition rates, chemical concentrations, power levels, and probe test data, as well as changes to tool recipes and setup parameters must be readily visible to the process and equipment engineer.

The increasing volume of data makes it more challenging to see through noise in data files and visual clutter in graphs and tables. Filtering and analysis of raw data files must summarize results to identify the parameters that need the most urgent attention.

By applying statistical filtering techniques and data visualization tools it is possible to detect shifts in manufacturing process control data in real time while safely ignoring the processes remaining in control.

Overview

A process engineer may be responsible for monitoring several hundred process control charts and must respond quickly if any charts shift out of control. If charts are reviewed manually, this can become overwhelming and would require full time attention.

We are implementing a web-based Process Engineering Dashboard that allows process and equipment engineers to see only the charts that are out of control, and provide a testing ground to evaluate the impact of implementing Western Electric Rules for any process (See Fig. 1).

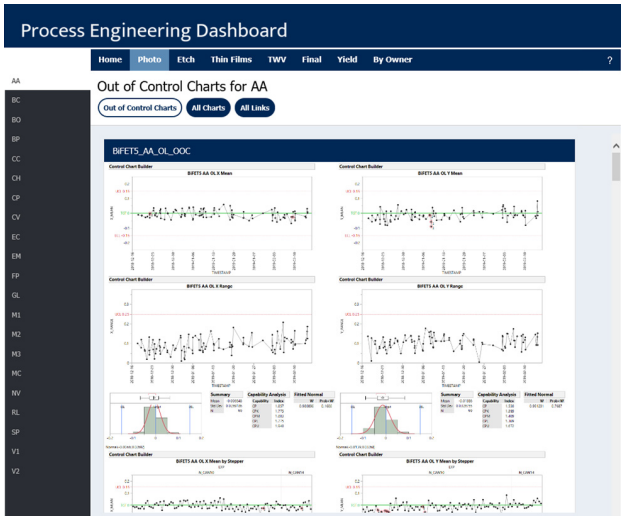

Fig. 1. Process Engineering Dashboard

Effective Data Communication

The only objective when presenting any data is to get the message across clearly and effectively. If the audience does not understand your message *within a few seconds* they may promptly look away to their smart phone or other distractions. Engineering data is no different. If it is not immediately obvious that Tool13 (out of 16 tools) is drifting and reworks (or scraps) are setting new records, the engineer will not get the message and take longer to respond. Response time *is* money.

Existing MES systems can show most manufacturing data, but only in the sense that they capture data in a database and have the option to display data in charts and tables. However, they do not have the ability to show only the most urgent data. Nor do they have the ability to spot relationships between different types of data. The usefulness of these systems as an analytical tool is limited. Therefore it is necessary to look for or create alternative means for intelligent data analysis.

Building An Engineering Dashboard

The Engineering Dashboard we created uses a very basic HTML menu structure. Pages are organized to display manufacturing data pre-filtered by

- Process Area
- Process Layer (Manufacturing Step)
- Process Engineer
- Manufacturing Technology
- Process Equipment
- Process Materials

To allow the engineer to select only the most urgent data, out of control process charts are segregated for display on a separate web page. Links to the supporting saved raw data tables allow immediate deeper data analysis. The engineer also has the option to review all control charts, on another web page.

We use JMP statistical analysis software from SAS, Inc. as a starting point for data filtering, statistical analysis, and chart generation. While our visualization improvement concepts are applied using JMP scripts, they can be adapted to any data presentation format.

With most software platforms, the default display options and formats can provide a lot of useful information. However, effective data communication requires simplicity and clarity, so judicious use of these options is critical.

Visualization concepts from data scientist Edward Tufte were used to help make data stand out from data constructs:

1) Control chart limits are typically depicted with red lines and process targets with green lines. The JMP default color scheme starts with the primary computer monitor colors (red, green, blue) for the first three data series. By creating a JMP add-in that uses a different color scheme we avoid having data hidden behind target and control limit lines. Gridlines, if used at all, are a very light grey color, again to provide a reference and not a distraction to the actual data message. Axis lines can be fully eliminated.

2) Default JMP statistical tables can display many statistical calculation results. When trying to view hundreds of charts quickly, these extra numbers distract from the data of interest, so one can turn these calculations off, wherever possible. This is an application of Tufte's "data-ink ratio" concept: If any pixel does not help communicate the data clearly and quickly, turn it off. The user can always dig deeper if more information is needed. It helps remove what he calls "Chartjunk" or elements that do not add and only subtract from the data.

3) Rather than chart data for one tool at a time increase the "data density" of the chart. Tufte describes data density as the ability to display multiple dimensions of data as long as the additional data sets clearly add to the message being told. An example could be to plot etch rate data from multiple tools or tool chambers over the same time scale along with data from gas flows or chuck bias levels to allow visual comparisons and immediate data exploration.

4) In areas were wafers can be reworked, wafers are measured twice (once before and once after rework) which creates multiple data values for a single measurement step. To keep only the last measurement we use a JMP script to sort the data in reverse time order and then use a join function to join the table to itself and drop all multiple data values. This leaves only the last measurement in the table.

Maintaining and Deploying the Dashboard

One requirement of any system of this scale is to have the ability to make broad changes quickly. Since much of the web page structure is similar among the pages, we use scripts in the Python programming language to replicate JMP script templates and web page layouts.

Using Windows Scheduler and a batch file, we run a master JMP script that calls out JMP scripts for each engineer. The individual scripts contain a list of JMP scripts for each process layer, process tool, test parameter or material for which the engineer is responsible.

This JMP script template can be replicated with a Python script so that engineers extracting similar data from the same database can quickly generate a new JMP script and web page. Once replicated, the engineer updates to the parameter values (data table name in query, control chart and process limits and targets) and the location to save the new charts.

Script Enhancements

Visualization improvements are not only applied to the data tables and charts in the web pages but also within JMP scripts themselves.

Learning to script in JMP is unlike most programming languages, so it can take some time to become fluent. However, we have found that when we modularize our code new users more quickly understand what the code does. This makes it easier for engineers to copy and reuse code elements and enhances scripting skills. The intention is to allow code segments to be moved and reused like LEGO© blocks.

Each JMP script is reformatted from the default formats created by the JMP software by parameterizing:

- Data connection strings to data sources
- Query commands
- Output file names
- Chart control limits
- Process targets

To isolate charts where data is out of control, each JMP script appends a column to the data table with a formula that captures alarms triggered by active Western Electric rules. If a rule is flagged, the corresponding chart is saved to the web page for out of control charts. Engineers can toggle the active Western Electric rules for the data set and rerun the script to see how each rule flags out of control points.

Successes

We have already identified several process shifts not readily visible in the MES system:

- By comparing critical dimension data from a process from wafers measured on two different CD SEMs, we found that a slight shift in the mean was responsible for a low process C_{pk}
- A shift over time in stepper overlay mean and range values flagged the need to retarget stepper scaling and translation offsets
- A shift in exposure dose was detected in critical dimension data for a specific process layer on an individual stepper which was not seen on other steppers
- By applying tighter Western Electric rules (Rule 2) for resist thickness from one coat track we were able keep a the track from drifting to trigger a Rule 1 failure
- Data review of wafer grinders by grinder chuck allowed us to make adjustments to the grinder. Previously data stratification by grind chuck was not readily available

Conclusions

The concept of finding process shifts using statistical control charts on a web page is not what is novel about this engineering dashboard. What is unique is that data is pre-analyzed for process control and filtered to only show the most important data as defined by Western Electric rules for process control.

Charts are displayed in a single location with raw data already saved and ready for further analysis. The code in the JMP scripting templates have been restructured to promote reuse and faster learning so that engineers can add to their web page and stratify their data by tool subcomponent.

Python scripts promote quick duplication of JMP script templates and updates to the web pages.

Future plans are to integrate upstream data to allow process control of input variables (such as process materials and consumables) and automated analysis of input and output variables.

Acknowledgements

One of our authors, Donnie Lee, a summer intern at Skyworks Solutions, is an undergraduate student at UCLA and was a significant help in creating the HTML pages and Python scripts to automate the rollout of the JMP script templates.

References

[1] E. Tufte, *Visual Display of Quantitative Information.* Graphics Press (1983).

[2] J. Wubbel, *JMP Connections: The Art of Utilizing Connections in your Data*, Wiley/SAS Business Series (2018).

[3] Western Electric Company *(1956), Statistical Quality Control Handbook. (1 ed.),* Indianapolis, Indiana*: Western Electric Co., p. v,* OCLC 33858387

Acronyms

CD: Critical Dimension
C_{pk}: Capability Index
EPROM: Erasable Programmable Read Only Memory
M2M: Machine to Machine
MES: Manufacturing Execution Systems
SEM: Scanning Electron Microscope