

Improving process yield by utilizing smart SPC rules

Oded Tal

MAX International Engineering Group
1 Marine Plaza Suite 211 North Bergen NJ, 07047
Tel: (201) 295-2953
Fax: (201) 295-3255
Email: oded_tal@maxieg.com

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Abstract

The purpose of Statistical Process Control is to create dynamic measures that track our manufacturing, and assures that our process remains stable. Typically, there is a high cost associated with implementing a full-blown SPC mechanism both in system purchasing cost and in management overhead.

The article will give an overview of SPC, from original Shewhart charts to more recent SPC schemes like Western electric rules. We will demonstrate that most SPC tools rely on assumptions that are not valid in most compound semiconductors manufacturing fabs. However we will show that by creating good operational process control, and scrutinizing SPC measures it is possible to achieve excellent process control by just staying with a basic set of control charts, such as X Bar and R plotted for specific products, operations, and tools. Furthermore we will show the relationship between reaction times to discrepancy events and overall yield losses. Remembering that our target is to reduce discrepancies and not to manufacture charts is the clear advocate for an operational approach to controls.

INTRODUCTION

The classical definition of Statistical Process Control is a Method of monitoring a process during its operation, in order to control the quality of the products while they are being produced allowing to Identify causes of variation. This innocent text book definition has underlying assumptions that we would like to elevate to the surface, and question what is the right way to perform process control in a compound semiconductors manufacturing facility.

OVERVIEW OF SPC

Originally, SPC was designed to control the manufacturing of “widgets” a low value, high volume product. When manufacturing such a product measuring each unit in various stages of the process becomes impossible due to very high cost associated with it and with added yield issues that all that added handling causes. Thus, the ability to sample five out of a 1000 products becomes very valuable.

The method used to make sure that the fact that we measure only five out of a 1000 and still manage to catch

discrepancies in time is the most basic SPC, referred to as Shewhart charts, or control charts.

The purpose of control charts is to determine if a process is maintaining an acceptable level of quality. Acceptable means that the process have been proven stable and in control by means of measuring and thus we can start reducing the sample size from every widget in R&D mode to the much preferable five out of a thousand in high volume manufacturing. Once we have proven that the process have reached such a level of maturity, we use the control charts to make sure that the process does not deteriorate.

MASS PRODUCTION VS. COMPOUND SEMICONDUCTORS

In compound semiconductors manufacturing the value of each “widget” is such that in many cases we end up testing either every wafer, or at least one per lot in many cases. We also have the tendency to inspect and test our product many times throughout the process.

If we assume a lot size of eight wafers, which is a conservative assumption, testing just one wafer out of each lot is providing a very high sample size 125 per each 1000, or a 25 times larger sample size then is typically used in high volume manufacturing.

Such a high sample size clearly allows us to use different statistical manipulation of the data, and renders some of the elaborate charts and graphs that we create, and in particular the dynamically calculated control limits useless. It is more prudent to spend the time in determining where are the right places in the process when an inspection or a test is needed, make sure that we can associate the finding of such a test back to the root cause of the problem, and decide where to use a samples and where it is absolutely necessary to test each die on each wafer.

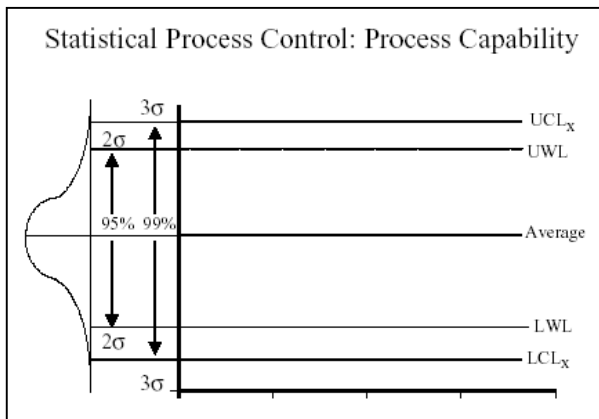
The original application of control limits has the inherent assumption that our process is stable and capable. In SPC terms, it means that our process has more then 1.3 C_p.

$$C_p = \frac{\text{Allowable process variability}}{\text{Actual process variability}}$$

Capability Index (C_p)

$$C_p = \frac{\text{Specification limits}}{\text{Process control limits}}$$

In order for C_p to be larger than 1 our process control limits should be smaller than our spec limits meaning that as long as we have the process under control our products will be in spec. However in compound semiconductor lines we have many processes where our control limits are actually larger than our spec limits, due to the fact that we use inadequate processing tools for some operations, and meaning that our capability is smaller than 1.0 C_p . Having such a capability means that our process is not in what is classically referred to as being in control.



Criteria for Capability Index (C_p)	
> 1.33	Satisfactory process
1.0 - 1.33	Capable but marginal
< 1.0	Unsatisfactory process

Using a set of charts that were designed to monitor a controlled process on a clearly out of controlled process makes no sense and apart from the opportunity to view many colorful charts we introduce statistically irrelevant data.

SPC CHARTS VS. SPC OPERATIONAL CONTROLS

Although we just proved that our manufacturing process is not satisfactory for using dynamic statistical process control charts, in the classic interpretation, if we do not attempt to use our data for fancy statistical analysis, the

basic control charts can prove valuable in tracking a process behavior. To avoid trying to correct reality with statistical wizardry lets look at just the basic controls needed to isolate discrepancies.

The first step in creating an operational control is creating a real time process control mechanism. This can take form as a homegrown database or a full fledged commercial on line system. The emphasis is on creating a quick response to the event based on pre-defined rules and not on charting capabilities. It is manufacturing responsibility to keep a close watch on the process and elevate any discrepancies as fast as possible, but the metrics, measures, and inspections we use as the base for such a system should be designed by the process engineering community.

To minimize yield losses, we need to get the data input as close to the inspection or measurement point as possible. Our system needs to compare the new data with spec and control limits and then create a corrective action process. For each data point we will define whether it is critical or not.

- A. Out of spec – if the data is critical, we will instruct the operator to put the lot on hold and initiate a rework process where possible.
- B. Out of control – We will take down the tool for qual, or create a tool realignment process, to be performed before loading the next lot.

Now of course we would like to have a couple of charts to look at and share with everyone in the organization, but our experience shows that the main factor is reaction time and cause effect understanding.

We need to link the measurement to the right tool or operation in the process, and have the action taken as soon as possible.

LOOKING AT JUST TWO SPC CHARTS

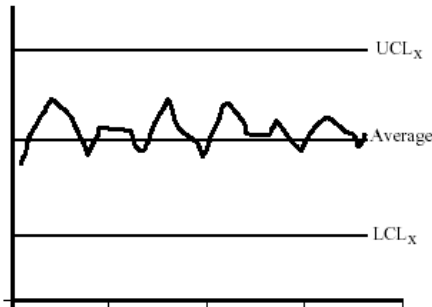
If the above-mentioned operational rules will be carried then simple X Bar and R charts are all we need to show the data graphically and give us some trending data. Our experience shows that in low yield processes (50% and down) a good understanding of these two charts will provide a sound statistical analysis for control purposes.

Interpretation of Control Charts:

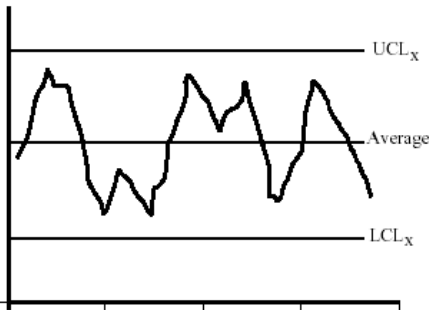
- Presence of an out-of-limits point – First symptom that there could be something wrong with the process – It could be sampling or graphing error
- Presence of more than one out-of-limits points – Clear indication that the process needs attention
- If X-bar is out of limits but not the range, the problem might be serious, our process is keeping a tight range but trending in a specific direction

- If R is out of limits, but not X-bar there might be an oscillation in the process, or if the trend persists our process variation is widening.

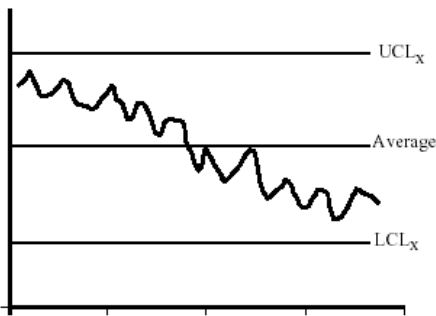
Normal Line Behavior



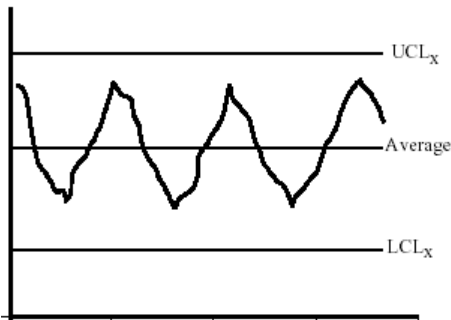
Random Cycles



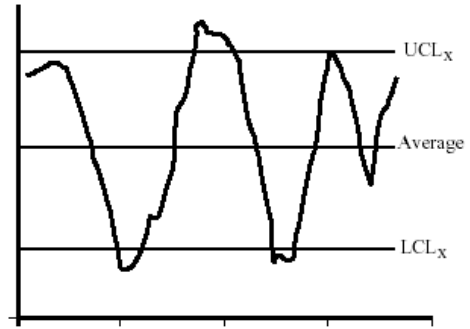
Trends



Recurring Cycles



Excessive Variability (Typical CS manufacturing)



THE RELATIONSHIP BETWEEN REACTION TIMES AND YIELD LOSSES

To further show the true meaning of getting corrective action fast to the floor we will model a theoretical compound semiconductor fab manufacturing 24x7 on a moderate volume of a 1000 wafers a month.

Parameter	Value
Working hours (24x7)	722.4
Wafers per month	1000
Lot size	8
Steps	200
Moves per month	200000
Tools	50
Layers	15
Critical Tool X moves	4000
Critical Tool X Lots	500

We can easily calculate that with those fairly typical numbers a lot will be moved out of critical tool X every **1.44 hours**. To be conservative we will assume that the measurement that will discover the problem is done at tool X with no time delay. In the event that critical tool X develops a processing problem our reaction time will determine how many lots we loose on an hourly basis.

Delay Time	Bad Lots
1	0.69
2	1.38
3	2.08
4	2.77
5	3.46
6	4.15
7	4.84
8	5.54
9	6.23
10	6.92
11	7.61

It is easy to see that based on the fact that in many cases our response time to get data to a qualified engineer to shut down a process can take as much as a 10 hour shift and theoretically loose 7 lots instead of just 1. We see that by applying simple calculation to our lot arrival distribution, working with such a reaction time we will probably on the average loose **four lots instead of one** due to bad reaction time on every low yield critical step.

To put the number in perspective the same fab runs 1500 lots a year. On a critical step that has a 50% yield on an annual base will cause us to loose **750** lots. Applying the same logic to the annual loss and assuming we improve reaction time from twelve hours to six on the average will cause that step to loose only **375** lots improving our critical step yield to 75%.

Calculations

$$\text{Critical Tool X Moves} = \frac{\text{Wafers per month}}{\text{Steps per Wafers}}$$

$$\text{Critical tool X lots} = \frac{\text{Moves per month}}{\text{Lot Size}}$$

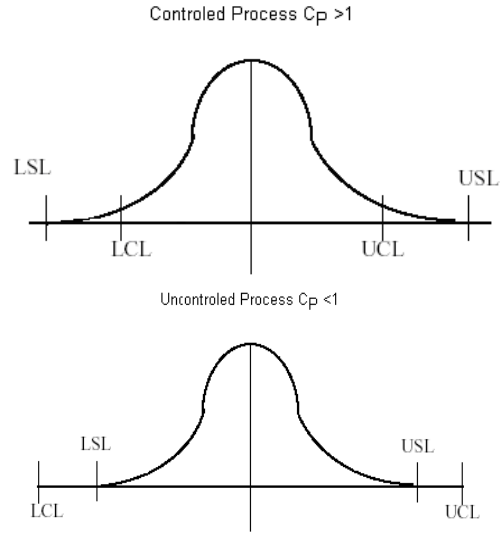
$$\text{Lot move out arrival times} = \frac{\text{Critical Tool X lots}}{\text{Work hours}}$$

$$\text{Possible Annual Loss} = \frac{\text{Current Yield Loss} \times \text{Improved Reaction time}}{\text{Old Reaction time}}$$

NOISE VS. VALUE ADDED WHEN LOOKING AT ALL THAT DATA.

A closer look at the ratio between noise and value that “modern SPC” and the dynamic calculation of control borders creates, will further help match the right SPC strategy based on the nature of your organization and technology. As the manufacturing process becomes more stable and the control becomes much wider then the spec limits, the more of sampling we can introduce to our manufacturing, and the lees 100% measuring we will have. Only at the point in time where our process has a Cp of more then 1.33 we can start implementing a real SPC sampling scheme and dynamically calculate control limits as we go.

C _p	Specification limits	Units per million defectives
1.0	± 3σ	2700
1.33	± 4σ	63
1.67	± 5σ	0.57
2.00	± 6σ	0.002



The implementation of more sophisticated SPC measures like Western Electric (WECO) rules in a stable process increases our ability to catch discrepancies earlier. While the WECO rules increases a Shewhart chart sensitivity to trends or drifts in the mean, there is a severe downside to adding the WECO rules to an unstable process that we must understand. When following the standard Shewhart "out of control" rule (i.e., signal if and only if you see a point beyond the plus or minus 3 sigma control limits) you will have "false alarms" every 371 points on the average. Adding the WECO rules increases the frequency of false alarms to once in every 91.75 points, on the average. In 100% sampling that we do in many cases, adding WECO rules will mean that we wrongfully scrap on e in every 11.5 lots, versus one in every 46 lots without WECO rules.

CONCLUSIONS

Although we demonstrated that sophisticated SPC implementation in a compound semiconductor fab should be taken with a grain of salt, we are firm believers in continues process improvements. Building a fast reacting Simple statistical process control mechanism will allow manufacturing to deal with even a very low C_p process. It is manufacturing responsibility to keep a close watch on the process and elevate any discrepancies as fast as possible, but the metrics, measures, and inspections we use as the base for such as system should be designed by the process engineering community. The emphasis of any successful SPC program would be on response times, and root cause analysis.

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