Process Control Optimization Manual
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## Revision History

<table>
<thead>
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<th>Rev</th>
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<th>Change</th>
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<tr>
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1 Purpose and Scope

1.1 Purpose
The purpose of this manual is to provide guidance and a framework for optimizing process controls within a manufacturing environment.

1.2 Scope
This manual may apply to any manufacturing process.

2 Acronyms / Terminology and Description / Definition

Approved
The supplier status is such that Skyworks' Sourcing may buy qualified products from that supplier.

3 Associated Documents

National and International Standards

- **APQP**: AIAG Advanced Product Quality Planning and Control Plan Manual
- **FMEA**: AIAG Failure Mode Effects Analysis Manual
- **MSA**: AIAG Measurement Systems Analysis Manual
- **SPC**: AIAG Statistical Process Control Manual

4 General
Process Control Optimization or PCO, was initially developed as a supplier development tool however any organization can utilize these tools to improve the effectiveness and efficiency of their manufacturing process. It is based on the premise that the focus of a process control initiative should be on the **process inputs**, not the product parameters.
5 Process Control Optimization Tools

5.1 Product Specifications

The organization must ensure that the product specifications were determined based on some type of analysis, that these are clearly defined and used for end product testing. Product specifications mandated by the customer must be communicated to the line. The organization should demonstrate how they determined their internal product specifications (i.e. customer usage, market demands, statistics, capability, competition, etc.). Where applicable, the supplier’s product specification should be compared to the most recent Skyworks specification.

5.2 Process Definition

5.2.1 Process Flowchart

A process flowchart provides a visual approach for describing, developing, analyzing and improving sequential tasks. The organization should have a process flowchart(s) that represent the entire workflow from receiving through shipping. The flowchart should be updated as the process evolves. The flowchart should show process inputs, controls, activity and outputs (see example in Figure 5-1-1). Having individual flowcharts by area is acceptable. The flowchart and actual process flow observed in the factory should match.
5.2.2 Process Control Plans

The process control plan is an output of the control plan methodology which provides a structured approach to for the design, selection and implementation of value added process controls used to minimize product and process variation (reference the *AIAG APQP and Control Plan Manual*). All columns outlined in Appendix A of ISO/TS 16949 or in the AIAG APQP Control Plan manual should be included. Critical to quality (CTQ) parameters should be identified in the control plan. The control plan should be updated when the process is modified or enhanced. The control plan should have evidence of recent process change history. Actual process observed in factory should match control plan.

![Figure 5-1-1](image)

**Figure 5-1-1**

**KEY POINT**

*The process control plan should include all process input parameters as well as significant product characteristics*

<table>
<thead>
<tr>
<th>Process Number</th>
<th>Process Name/Operations Description</th>
<th>Machine Device Jig Tools</th>
<th>Characteristics</th>
<th>Special Char Class</th>
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</tr>
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</table>

![Figure 5-11-1 Control Plan Template](image)

**Figure 5-11-1 Control Plan Template**

5.2.3 Work Instructions

The organization must ensure that established work practices have been adequately captured in order to ensure that the product design can be consistently manufactured in a factory environment. Work instructions should adequately identify the steps required to successfully execute the process with minimal explanation. Work instructions should list required material, equipment, PPE, proper chemical disposal procedures, etc. Work instructions should be available at point of use. When run concurrently with normal production, engineering builds should be properly managed. Actual practice should follow work instructions.

5.2.4 Process Failure Mode Effects Analysis

A process failure mode effects analysis or FMEA identifies and mitigates high risk process controls (see Figure 5-3-1). Reference the *AIAG FMEA Manual* for specific instructions on how to generate an FMEA. The FMEA should include all processes and all process parameters (compare FMEA to process control plan parameters).

**KEY POINT**

*Ensure that process failures are being considered and not product failures*

Example:

- *Part too thick* is not a process failure but rather the effect of a process failure
- *Pressure too low* is a process failure

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The FMEA should show that a cross functional team approach is being used to develop the FMEA. There should be evidence that actions are continuously being taken on the highest RPNs, not based on an RPN threshold. The FMEA should show evidence that it is being updated as a result of every process change, new process or new equipment or customer complaints. The FMEA should be a living document. The factory floor should demonstrate that any FMEA actions were actually deployed. Emphasis should be on prevention and error proofing (e.g. Poka-Yoke) versus detection.

**Figure 5-3-1**

### 5.3 Process Validation

#### 5.3.1 Initial Process Studies

The initial process capability studies will provide early demonstration that the combination of people, machine, methods, material, and measurements will produce a product that will consistently meet the design requirements. Process studies should be performed on critical to quality process parameters. These parameters should have been determined using design of experiments. The process study should first demonstrate process stability using appropriate control chart methodology. Sub group size should be calculated based on desired probability of detecting a shift. Capability studies should be performed on critical to quality process parameters once these can demonstrate stability and should achieve Cpk ≥ 1.67.

**KEY POINT**

Process studies should be performed on all critical to quality process parameters. Process capability can only be determined if the process is **stable**.
5.3.2 Internal Process Qualification

When suppliers perform internal process qualification activities, the qualification requirements should address the appropriate suite of manufacturing process validation data as well as any pertinent reliability concerns. Manufacturing data will include stability and capability data, as well as the manufacturing data from downstream processes. Parts submitted for reliability testing should be representative of a frozen manufacturing process. For applicable reliability tests, industry standards should be used as guidance for minimum requirements. Where possible, Skyworks test requirements should be adopted or equivalent tests need to be developed. Internal qualifications plans and results should be reviewed and approved by cross-functional teams within the supplier organization.

5.3.3 Change Control Process

The process change control system of the supplier should define classes of changes, process validation requirements, approvers, customer PCN and change documentation requirements. All changes regardless of classification should have a some level of process validation, require cross-disciplinary review, and provide PCN output consistent with JESD46.

5.3.4 Control Charts and Process Stability

Control charts are used to measure the stability of a process (reference the AIAG SPC Manual). They should be used on critical to quality process parameters. Data should be gathered using a measurement system with a gage R&R less than 10% (see paragraph 5.10). If the data becomes out of control, the reaction plan documented on the control plan (see paragraph 5.14) should be followed.
5.3.4.1. Determining the Subgroup Size

The subgroup size should be calculated based on process standard deviation and desired probability of detecting a process shift using the following formula:

$$n = \frac{(Z_{\alpha/2} + Z_{\beta})^2 \sigma^2}{D^2}$$

- **n** Subgroup size
- **$Z_{\alpha/2}$** The number of standard deviations above zero on the standard normal distribution such that the area in the tail of the distribution is $\alpha/2$ ($\alpha$ is the type I error probability and is typically 0.0027 for control chart applications). As such, this value is typically $Z_{0.00135}$ or 3
- **$Z_{\beta}$** The number of standard deviations above zero on the standard normal distribution such that the area in the tail of the distribution is $\beta$ ($\beta$ is the type II error probability)
- **$\sigma$** The standard deviation of the characteristic being charted
- **D** The difference you are trying to detect

**Z\_\alpha/2 Values**

**KEY POINT**

SPC chart data should only be gathered using a measurement system with a gage R&R less than 10%
\[ Z_{0.00135} = 3 \]
\[ Z_{0.01} = 2.33 \]
\[ Z_{0.025} = 1.96 \]
\[ Z_{0.05} = 1.64 \]
\[ Z_{0.10} = 1.28 \]
\[ Z_{0.20} = 0.84 \]

**Example**

Suppose a bottling plant is filling containers labeled as 12 ounces. The process standard deviation (\( \sigma \)) is estimated to be 0.12 ounces. What sample size is required to detect a shift (\( D \)) of 0.18 oz with 80% probability of success, or a 20% probability that the chart does not detect the shift (\( Z_\beta \))?

We have:
\[ Z_{\alpha/2} = Z_{0.00135} = 3 \]
\[ Z_\beta = Z_{0.20} = 0.84 \]
\[ \sigma = 0.12 \]
\[ D = 0.18 \text{ oz} \]

\[
n = \frac{(3 + 0.84)^2(0.12^2)}{0.18^2} = 6.55
\]

Thus, the required sample size (\( n \)) is rounded up to 7

**5.3.4.2. Steps for Constructing a Control Chart**

The steps for constructing a control chart are as follows:

- Determine subgroup size or \( n \) (see 5.14.1.1)
- Collect 20 to 25 subgroups or Xs and Rs
- Calculate X (the average of all of the Xs)
- Calculate the R (the average of all of the Rs)
- Calculate the control limits using factor table

\[
\begin{array}{cccc}
 n & A_2 & d_2 & D_3 \\
 2 & 1.880 & 1.128 & 0.000 & 3.267 \\
 3 & 1.023 & 1.693 & 0.000 & 2.575 \\
 4 & 0.729 & 2.059 & 0.000 & 2.282 \\
 5 & 0.577 & 2.326 & 0.000 & 2.114 \\
 6 & 0.483 & 2.534 & 0.000 & 2.004 \\
 7 & 0.419 & 2.704 & 0.076 & 1.924 \\
 8 & 0.373 & 2.847 & 0.136 & 1.864 \\
 9 & 0.337 & 2.970 & 0.184 & 1.816 \\
 10 & 0.308 & 3.078 & 0.223 & 1.777 \\
 11 & 0.285 & 3.173 & 0.256 & 1.744 \\
 12 & 0.266 & 3.258 & 0.283 & 1.717 \\
 13 & 0.249 & 3.336 & 0.307 & 1.693 \\
 14 & 0.235 & 3.407 & 0.328 & 1.672 \\
 15 & 0.223 & 3.472 & 0.347 & 1.653 \\
\end{array}
\]

**Figure 5-14-1-2-1 Control Limit Factor Table**
5.3.4.3. Control Vs. Capability

Figure 5-14-1-2-2 There is a direct relationship between the process distribution and the control limits.

If the specification limits were superimposed, a capable process will show specification limits to be beyond the control limits.

If the specification limits are within the control limits, this is a sign of an incapable process, even if all points are within the control limits.
5.3.4.4. **Recognizing Out of Control Patterns**

The typical out of control patterns of a control chart are (see Figure 5-14-1-4-1):

- One point outside of control limit
- Five or more points trending up
- Five or more points trending down
- Five or more points on same side of the mean

![Diagram of typical out of control patterns](image)

*Figure 5-14-1-4-1 Typical Out of Control Patterns*

5.3.4.5. **Other Control Chart Patterns**

The examples on the following pages will assist in recognizing typical control chart behavior and what may be behind it.
5.3.4.6.  **Trends**
- machine wear
- tool wear
- raw material deterioration

5.3.4.7.  **Shifts in Process Level**
- changes in proportions of materials coming from different sources
- shift changes or operator rotation
- changes in method or process
- changes in inspection or test devices
- over control or over adjustment

5.3.4.8.  **Recurring Cycles**
- changes in environment (temperature, humidity, etc.)
- seasonality
- shift changes or operator rotation
5.3.4.9. Saw Tooth Pattern
- tool changes
- preventive maintenance
- chemical changes

5.3.4.10. Out of Control Point
- assignable cause such as:
  - misprocess
  - incorrect part used
  - incorrect raw material used
  - operator error
  - machine malfunction

5.3.4.11. Sudden Shift In Process
- process improvement
- change in raw materials
- machine malfunction
- tool failure or replacement
- inspection or test equipment replacement, calibration or malfunction
5.3.4.12. Reduction in Variability
- process improvement
- machine run-in or burn-in
  - once causes have been understood, control limits should be recalculated

5.3.4.13. Lack of Variability
- control limits calculated incorrectly
- control limits calculated a long time ago

5.3.4.14. When To Recalculate Control Limits
Control limits should be recalculated after a process change once the data clearly demonstrates a shift in process that is understood and can be explained.

*Note:* This can be confirmed via a t-Test or other statistical test.
5.3.5 Process Capability

A process capability study will determine the likelihood of a process to produce parts that are within specification (see Figure 5-14-2-1). This assumption is based on an understanding of the process spread as compared to the tolerance width.

Figure 5-14-2-1 Components of the Process Capability Study

5.3.5.1. Measures of Central Tendency

The measures of central tendency describe how the data are grouped together:

- The mode is the more frequently occurring number in a data set
- The mean (or average) is the total of all the data points divided by the number of data points

\[
\bar{X} = \frac{\sum X}{n}
\]

- The median is the middle number of the data points sorted by ascending order

5.3.5.2. Measures of Dispersion

The measures of dispersion describe the spread of the data:

- The range is the difference between the largest and smallest values in a set of data
- The standard deviation shows how much variation there is from the average (or mean)

\[
\sigma = \sqrt{\frac{\sum (X - \bar{X})^2}{n}}
\]
### 5.3.5.3. Histograms

A histogram stacks up numbers within certain ranges or “buckets”

![Histogram Diagram]

**Figure 5-14-2-3-1 Depiction of how to construct a Histogram**

**KEY POINT**

A useful feature of the Standard Deviation is that almost all (i.e. 99.7%) of the data sits within +/- 3 Standard Deviation units from the mean.

**Figure 5-14-2-3-2 For this set of data we can say that there is a 99.7% probability that all of the data falls between 81 and 99**
5.3.5.4. Capability Indices

There are several capability indices that can be calculated:

5.3.5.4.1. Capability Ratio or \( C_R \)

\[
C_R = \frac{6S}{	ext{ToleranceWidth}}
\]

5.3.5.4.2. Capability Index or \( C_P \)

\[
C_P = \frac{\text{ToleranceWidth}}{6S}
\]

Figure 5-14-2-4-1 The problem with \( C_P \) and \( C_R \) ratios is that they don’t take process centering into account

5.3.5.4.3. Capability or \( C_{pk} \)

\( C_{pk} \) is a capability index that does consider process centering. \( C_{pk} \) is the lesser of:

\[
C_{pk} = \frac{\bar{X} - LSL}{3S} \quad \text{or} \quad C_{pk} = \frac{USL - \bar{X}}{3S}
\]

\( \text{USL} \) is the upper specification limit

\( \text{LSL} \) is the lower specification limit

\( \bar{X} \) is the process average

\( S \) is the process standard deviation
The figures show the relationship between Cpk values and process capability.

- **Cpk = 1.0**
  - Process: 3 Sigma

- **Cpk = 1.33**
  - Process: 4 Sigma

- **Cpk = 1.67**
  - Process: 5 Sigma

- **Cpk = 2.0**
  - Process: 6 Sigma

Figure 5-14-2-4-2 These figures show the relationship between Cpk values and process capability.
Figure 5-15-1
5.4 Process Monitoring

5.4.1 Maverick Lot Program (Outlier Identification and Management System)

Outliers should be identified for all CTQ (critical to quality) parameters in relation to the characterized parametric results of the process. In addition, yield results should be monitored to flag abnormally yielding product. For both parametric and yield limits, maverick or outlier status should result in required engineering investigation and disposition. Should outlier material be deemed suitable for shipment, the supplier must formally notify Skyworks.

5.4.2 Defect Monitoring and Reduction

Defined means for defect monitoring should be implemented, monitored and analyzed. Defect detection methods should be evident in both the process control plans and process FMEAs. The data from such tools should be monitored, and used to drive process improvement.

5.4.3 Yield Monitoring and Improvement

The organization should have a system and resources designated for the monitoring and analysis of process/product yield data. Yield analysis best practices include use of: Pareto analysis, stacked wafer analysis, radial zone analysis, and tool commonality correlation. The organization should be able to demonstrate regular review of statistical limits and the effective use of yield data to drive process improvement.

5.4.4 On-going Reliability Monitoring

Means for the monitoring of product reliability should be implemented for the production line. The on-going testing method, frequency and requirements should be defined. Failures should result in immediate corrective actions. Lastly, the test results should be regularly reviewed by management and available to customers upon request.

5.4.5 Measurement System Analysis

The objective of measurement system analysis or MSA is to understand, measure and minimize the amount of variation in the measurement systems used to determine product acceptability or gather SPC data (reference the AIAG MSA Manual). The organization’s MSA should include:

- Bias
- Stability
- Linearity
- Repeatability and Reproducibility

MSA should be performed on a regularly scheduled basis or after a measurement process change. Gage R&R studies should be performed using the ANOVA method based on the process variation width, not the tolerance width.

![Figure 5-10-1 Reproducibility and repeatability can be expressed as a percentage of the total specification width.](image-url)
Figure 5-10-2 or as a percentage of the total process variation (ANOVA). Using the specification width makes the Gage R&R values appear much lower however, may not provide an accurate assessment of the system’s ability to detect process shifts.

KEY POINT

Gage R&R measured as a percentage of total process variation is a better indicator of measurement system capability than measuring the percentage of tolerance width.
5.4.6 Test Sample Size and Frequency

Test sample size and frequency should be carefully selected to ensure product quality. Process control plans should show correct sample size / AQL and frequency. Actual test and inspection practice should match AQL, sample size and AQL listed in control plan. Where sample inspection is used, the organization should be able to explain how sample size and AQL were selected. Sampling plans should be based on sound statistical principles (OC curves) ANSI/ASQ Z1.4 or equivalent and should be zero acceptance (c=0) type plans. AQL sampling is only acceptable if there is an inspection point upstream that can detect any discrepant parts.

<table>
<thead>
<tr>
<th>Lot Size</th>
<th>Sample Size</th>
<th>Index Values (Associated AQLs)</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>0.010 0.015 0.025 0.040 0.065 0.10 0.15 0.25 0.40 0.65 1.0 1.5 2.5 4.0 6.5 10.0</td>
</tr>
<tr>
<td>2 to 8</td>
<td>* * * *</td>
<td>* * * * * * * * * * * * 5 3 2 2</td>
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<td>9 to 15</td>
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<td>* * * *</td>
<td>* * * * * * * 32 20 13 8 5 5 5 3</td>
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<tr>
<td>500,001 and over</td>
<td>* * * *</td>
<td>556 435 303 244 189 143 102 64 40 29 15 9</td>
</tr>
</tbody>
</table>

Figure 5-7-1 Zero Acceptance Sampling Plan. Using this chart, an AQL of .10 means that there is a 95% probability that no more than 0.10% of the parts in the lot are discrepant. That means that there is a 5% probability that more than 0.10% of the parts in the lot are discrepant.

5.5 Problem Solving Methodology

5.5.1 Methodology Requirements

The organization should use a comprehensive, proven and defined problem-solving methodology such as five-phase, 8D (see Figure 5-5-1), five-why, drill deep and wide, cause & effect, fishbone (see Figure 5-5-2), DMAIC, DISC, etc. There should be evidence of how problem solving techniques were used while developing the production process.

The problem solving methodology should include:

- problem definition
- containment
- how these techniques identified all root causes (i.e. symptoms, contributing and systemic causes)
- demonstrate all actions were actually deployed and that show actions were realistic and sustainable
- verify actions were successful in preventing the problem from reoccurring
5.5.2 Root Cause Analysis Tools

5.5.2.1 Failure Analysis

Failure analysis techniques appropriate to the suppliers manufacturing technology should be identified. Plans for potential utilization of such resources and techniques should exist. If FA resources exist at the supplier, the FA lab should fall within the formal QMS certification scope of the supplier.

5.5.2.2 Five-Why Analysis

Five-why analysis is a question based method used to determine the cause and effect relationships related to a particular problem. Five-why analysis is used to determine the root cause of a problem or defect. It is based on the premise that asking "why" five times will get to the root cause of the problem. Best practices include use of a "3 by 5-Why" approach where three 5-Why analyses are conducted. The three dimensions of this analysis are generally called: Predict, Prevent and Protect. The "Predict 5-Why" addresses the root cause of the system's failure to plan / foresee the problem. The "Prevent 5-Why" addresses the failure of the system to stop the failure from happening. The "Protect 5-Why" addresses the cause of the failure to detect and contain the problem once it had occurred.
5.5.2.3. **Fishbone Diagram**

The fishbone diagram (or Ishikawa diagram) allows a team to explore and graphically display all of the causes and contributing causes related to a problem. The team members brainstorm the major causes and place them in the appropriate category. Then they repeatedly ask "why" for each cause until the team runs out of causes. This results in a nested list of causes, contributing causes and root causes.

![Fishbone Diagram](image)

*Figure 5-5-2 Fishbone Diagram or Ishikawa Diagram*

5.6 **Preventive Maintenance**

By proactively maintaining manufacturing equipment, performance will be predictable and equipment availability will be maximized. The organization should perform preventive maintenance on key process equipment and there should be a plan in place that defines the activities and frequency. Best practices include the use of data to determine predictive maintenance plans and the use of failure mode effects analysis (FMEA) to gauge and reduce equipment risks.

5.7 **Incoming Material Certification**

Material used in the factory should always conform to specifications and be consistent, predictable and stable. Sample size and criteria should be defined and based on sound statistical methods. There should be evidence that material is being inspected as stated on the control plan. Control charts should be used to monitor consistency of incoming material (see Figure 5-6-1).

**KEY POINT**

The output of any process (no matter how good the controls are) depends largely on the quality of the input materials.
5.8 Error / Mistake Proofing

Error or mistake proofing places an emphasis on the use of controls that make it physically impossible to make a mistake. Error proofing methodologies should be captured in the control plan. The organization should be able to show examples of error proofing and mistake proofing approaches used to improve the production process. Mistake proofing alerts the operator that an error has been made. Error proofing physically prevents the operator from making a mistake. Targets for error proofing should be identified based on scrap cost Pareto analysis (i.e. allocates error proofing resources to highest offenders resulting on the best return on investment) and FMEA risk assessments.

5.9 Five-S

The Five-S philosophy ensures the organization has a clean workplace that is free from clutter, where things are easy to find, easy to use and easy to put back in place. Five-S is based on the following five principles:

- Sort - eliminate unnecessary tools, parts, equipment: only keep essential items
- Straighten - a place for everything and everything in its place
- Shine - clean the area in a manner consistent with the needs
- Standardize - work practices should be documented for the first 3 S’s
- Sustain - continuously maintain and review work practices
A review of the work area should show that:

- unneeded items have been removed
- required items (e.g. tools, materials, work instructions) are within the immediate vicinity
- the area is free from clutter
- items are easy to locate and easy to put back in place
- the 5S standardized checklist is being used on a regular basis

*Figure 5-16-1 Area is well organized, items are labeled*

*Figure 5-16-2 Before and After Five S*
5.10 Process Floor Layout

The process floor layout helps optimize material travel, handling, value added use of floor space and facilitates synchronous material flow (i.e. the right amount of material in the right sequence and position). The organization should have a floor layout that represents the entire manufacturing process from receiving through shipping. The floor layout should be updated as new equipment is introduced or as equipment is retired. Having floor layouts by area is acceptable. Spaghetti Diagram approach is preferred. The floor layout and actual factory layout should match.

KEY POINT

Five-S is not a housekeeping standard but rather a method to maintain a safe and efficient workspace.
Figure 5-2-1 This example depicts the process flow of a school kitchen before process and floor layout analysis and optimization. The lines represent the employee and food travel. The boxed numbers represent the process steps.
Figure 5-2-2 Note how the travel was optimized to minimize movement and certain process steps were combined or eliminated.