Cpk Calculation on Highly Correlated Data
Relationship Between Scrap Based on Certain Criteria & Cpk Value

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Company Background

- The world's first full-service semiconductor foundry
- The world's second largest independent foundry
- First foundry to ramp High K Metal Gate 32/28nm technology to high volume
- Dedicated to foundry innovation leadership and customer-centric services

Problem Definition & Objectives

1. Find the right minimum sample size that is required for C_{pk} confidence interval calculation, taking data correlation into account
2. Use C_{pk} value to predict the number of wafer scrap at ET, taking data correlation into account

Data Analysis

Assumptions Testing

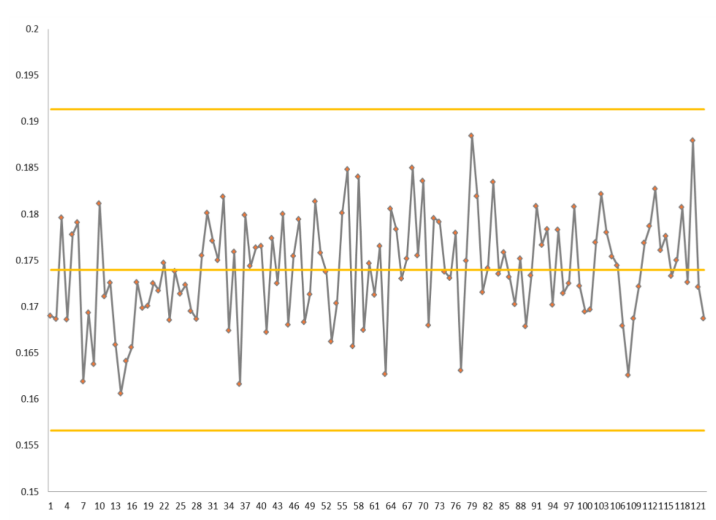


Fig 1: Process in control

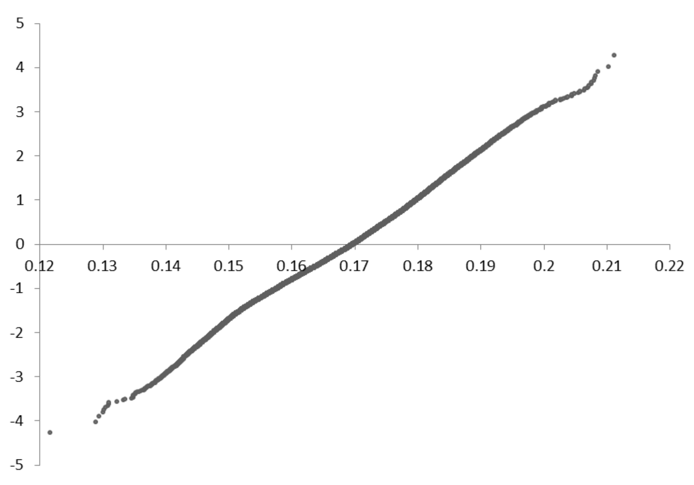


Fig 2:Normality

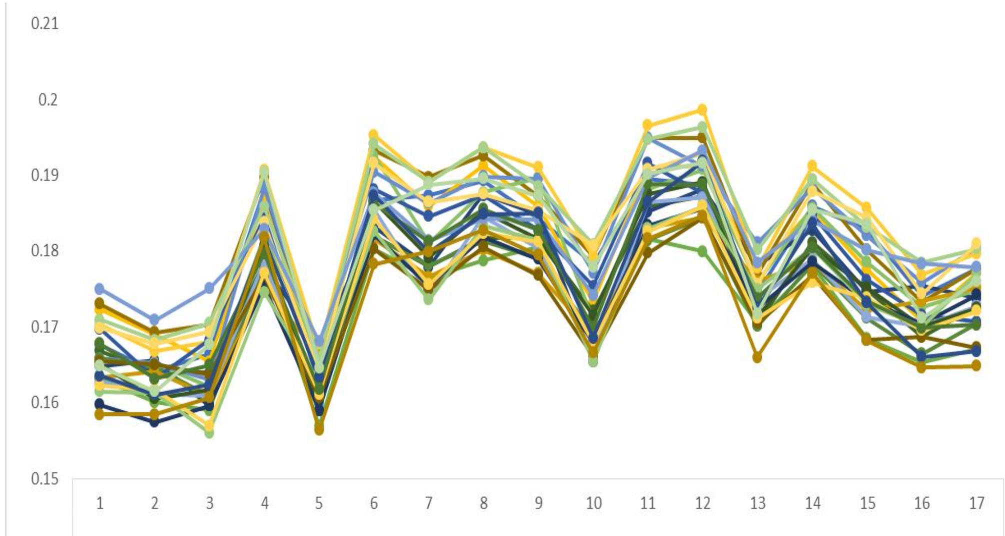


Fig 3: Wafer Correlation

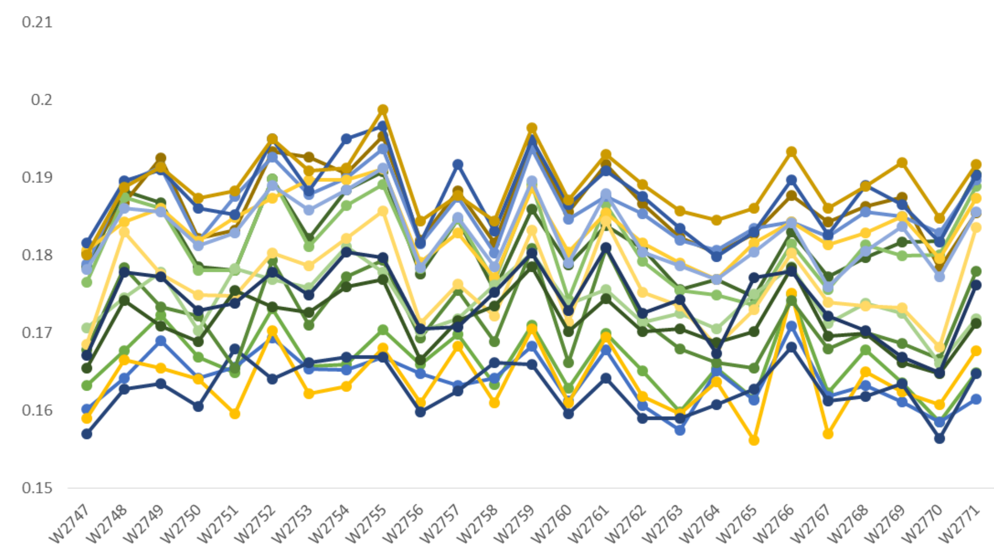


Fig 4: Site Correlation

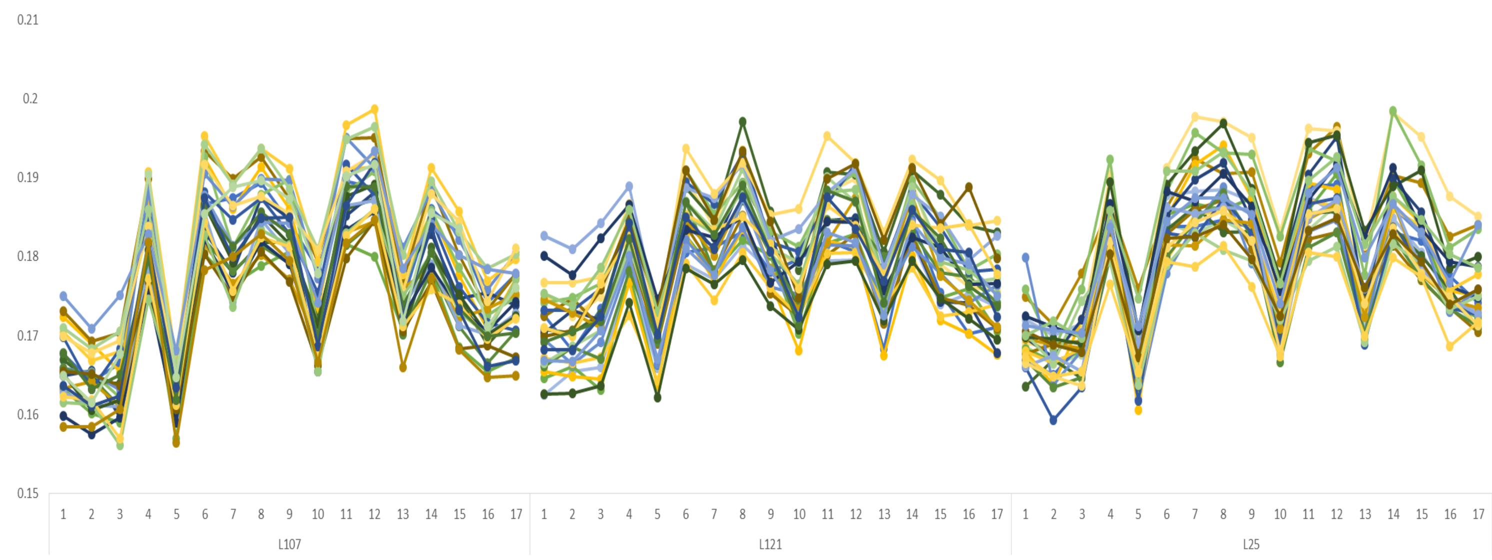


Fig 5: Between Lots Correlation

There are three assumptions for Cpk calculation:

- process in control
- normality
- i.i.d.

The first two assumptions are proven to be true by Fig 1 and 2.

Analysis for Data Correlation:

- From Fig 3, a clear pattern could be observed. Wafers are nearly identically. One wafer could be used to represent an entire lot.
- The variation between lots and sites are much higher as shown in Fig 4 and 5.
- Such observations are further proven by mixed effect ANOVA model.

Partition the sources of variation attributable to their components using **Nested Linear Mixed Effect Model**.

$Y_{ijk} = \mu + \alpha_i + \beta_{ij} + \gamma_k + \varepsilon_{ijk}$

Data = mean + lot effect + lot:wafer effect + site effect + individual effect

Groups	Variance
Lot: Wafer	2.050E-05
Lot	3.365E-05
Sites	4.665E-05
Residual	2.091E-05

Solutions

Part I: Re-examining the C_{pk} Confidence Interval Formulation

Method 1: Use one wafer to represent one lot

An approximate 100(1-α)% confidence interval for C_{pk} is

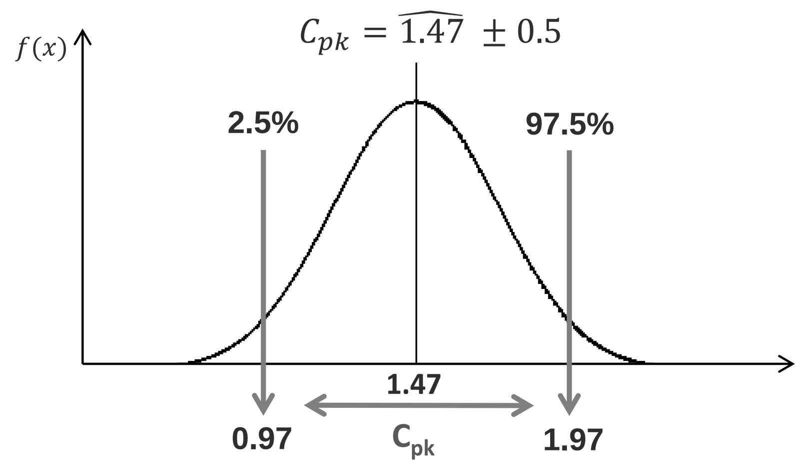
$$\widehat{C_{pk}}\left[1 - z_{\alpha/2}\sqrt{\frac{1}{9n\hat{C}_{pk}^2}+\frac{1}{2(n-1)}}\right] \le C_{pk} \le \widehat{C_{pk}}\left[1 + z_{\alpha/2}\sqrt{\frac{1}{9n\hat{C}_{pk}^2}+\frac{1}{2(n-1)}}\right]$$

Based on the process nature and further supported by data analysis, 1 wafer is typically representative of the lot

Example:

Using the data above, for 95% confidence interval

$C_{pk} = \overline{1.47} \pm 0.5$

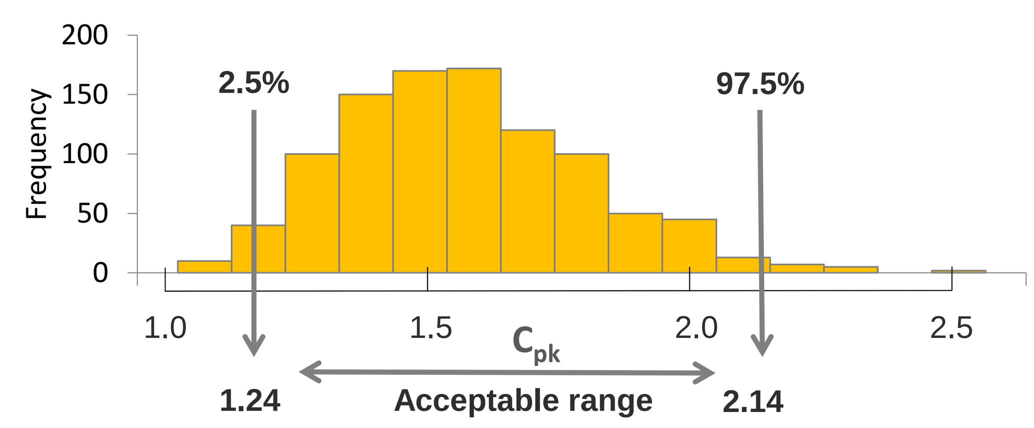


Method 2: Monte Carlo Simulation

If customer buys *x* lots, we do Monte Carlo Simulation with *x* lots

1. Randomly select *x* lots from the entire pool
2. Repeat for 1000 times
3. Sort and obtain 25th and 975th data as the Confidence Interval
4. If customer's C_{pk} falls within the range, it is acceptable

Example: if *x* = 5 within 108 lots



Method 3: Effective Sample Size

$$N^* = \left[\frac{\sigma_b^2}{\sigma_b^2+\sigma_e^2}\sum_{i=1}^{B}\left(\frac{n_i}{N}\right)^2 + \frac{1}{N}\frac{\sigma_e^2}{\sigma_b^2+\sigma_e^2}\right]^{-1}$$

σ_b^2	Batch Variance
σ_e^2	Individual Variance
n_i	Number of samples in ith batch
N	Total sample size
B	Number of Batches

Step 1: Taking wafer effect as batch effect, Calculate the effective sample size for a single lot, N^*_1

σ_b^2 = 2.05E-05; σ_e^2 = 6.76E-05; n_i = 17; N = 17*25 = 425; B = 25 ➡ N^*_1 = 89.95

Step 2: Taking lot effect as batch effect, Calculate the overall sample size for L lots, N*

σ_b^2 = 3.37E-05; σ_e^2 = 8.81E-05; n_i = 89.95; N = 89.95*108 = 9714.6 ; B = 108 ➡ N^*_2 = 380

Confidence Level	Effective Method	Original Method
95% CI-Low	1.379	1.48
95% CI-High	1.601	1.50

Part II: Predicting the Wafer Scrap Rate with Multivariate Normal Distribution

P(Wafer defective) = P(>50% sites defective)

- P(3 sites defective)
- P(4 sites defective)
- P(5 sites defective)

Considerations

- ✓ Each site follows normal distribution
- ✓ Joint distribution of the sites
- ✓ Take correlation into account
- ✓ Scrap criteria = 50%

Formulation with *n* sites:

$$f_x(x_1, \ldots, x_n) = \frac{1}{\sqrt{(2\pi)^n|\epsilon|}}\exp\left(-\frac{1}{2}(x-\mu)^T\sum\nolimits^{-1}(x-\mu)\right)$$

$x \sim MVN\ (\mu, \epsilon)$

For predicting scrap rate using Cpk confidence interval, a table is developed by MVN

- ✓ Less accurate but still a good approximation
- ✓ More cost effective
- ✓ Less data intensive

5 Sites	Average Correlation					
Cpk	0.3	0.4	0.5	0.6	0.7	0.8
0.5	7,600	11,200	15,700	21,000	27,400	***34,500***
0.6	1,400	2,600	4,200	6,400	9,000	***12,400***
0.7	209	470	889	1,521	2,460	***3,755***
0.8	23	66	157	296	575	955
0.9	2	8	23	51	84	195
1.0	0	1	2	15	23	33

If $C_{pk} \approx 0.6 \pm 0.1$ with correlation 0.8, scrap rate ≈ [3,755 – 34,500] ppm

Evaluation and Conclusion

Summary

- Identified key sources of variation in correlation
- Proposed 3 methods of computing confidence interval catering to different needs
- Developed new method of predicting wafer scrap rate given C_{pk} CI

Future Development

- Implement and automate the methods with an easy-to-use User Interface
- Validate the methods proposed by regular assessment of the process effectiveness
- Determine the most cost effective and accurate method through empirical study

IE3100R Systems Design Project AY13/14, Department of Industrial & Systems Engineering
Group Members :Huang Chengyuan | Huo Haiyan | Khor Yuan Jun | Liu Yehan
GlobalFoundries Supervisor: Lee Koong Leng | NUS Supervisors: A. Prof. Ng Szu Hui | A. Prof. Chen Nan