

# Lean Six Sigma

Reduction of thickness variation in  
XLPE Foam Rolls

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Mr. Vinoth

# ROADMA

P

Overview

Define

Measure

Analys

Improv

Contro

OVERVIEW

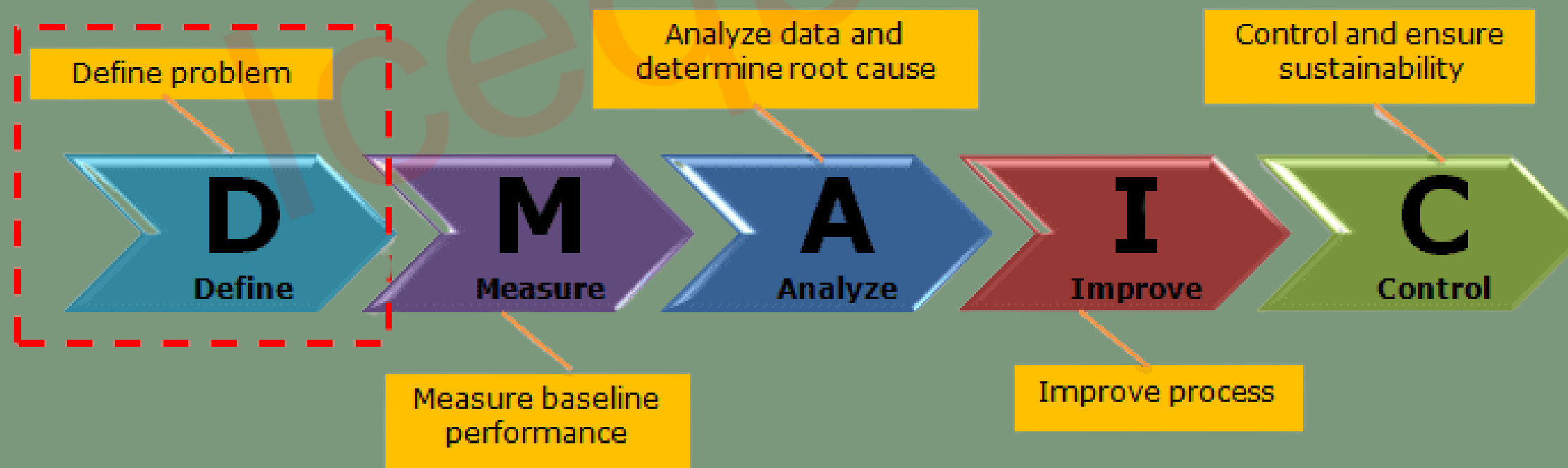


# Business Case

The XLPE foam roll production process faces thickness variation, leading to product inconsistency, customer dissatisfaction, and material wastage. This issue increases rejection and rework costs, affecting overall efficiency and profitability. The project aims to identify root causes and reduce variation using Six Sigma tools.

Achieving uniform thickness will improve quality, yield, and customer confidence. It will also lower scrap rates and enhance process capability. The initiative supports operational excellence and sustainable cost reduction.

# DEFINE PHASE





# Customers

## Internal Customers

- **Downstream Production / Lamination Team** – Needs uniform thickness for coating/lamination.
- **Cutting / Slitting / Skiving Team** – Relies on consistent thickness for correct roll/sheet size.
- **Quality Control / Testing Team** – Ensures thickness is within specs for inspection.
- **Packing / Rolling Team** – Needs proper thickness to maintain roll weight and packaging standards.
- **Process / Maintenance Engineers** – Use thickness data to adjust machines and maintain process stability.

## External Customers

- **Industrial Customers / OEMs** – Use foam in automotive, construction, insulation, or packaging; require consistent thickness for performance.
- **Distributors / Traders** – Expect uniform product for resale; thickness variation affects stock management.
- **End-Users / Consumers** – Foam in mattresses, cushions, mats, or insulation; inconsistent thickness reduces satisfaction and usability.

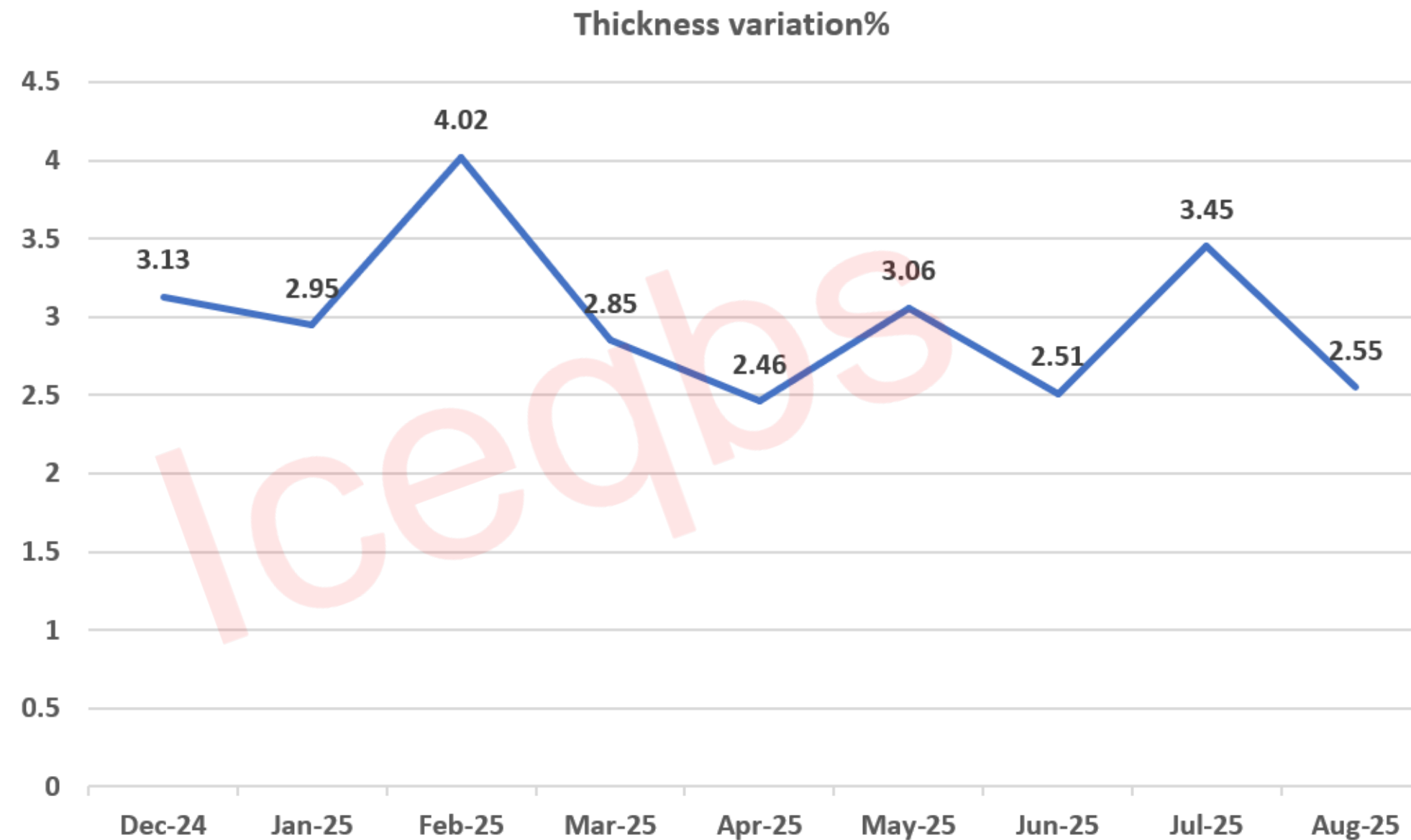
# VOC & CTQ

## VOICE OF CUSTOMER:

- **Internal:** We need XLPE rolls with uniform thickness for easier processing, fewer adjustments and minimal scrap
- **External:** We need consistent foam thickness meeting specification and reliable product performance

| Voice of customer                                                                 | Critical to X                                   | Primary Metric for improvement             |
|-----------------------------------------------------------------------------------|-------------------------------------------------|--------------------------------------------|
| We need XLPE rolls with uniform thickness for consistent and reliable performance | CTQ – Quality – variation in thickness of rolls | Y = % variation in thickness of XLPE rolls |

# Baseline Performance of Primary Metric (6 months data as Bar chart)

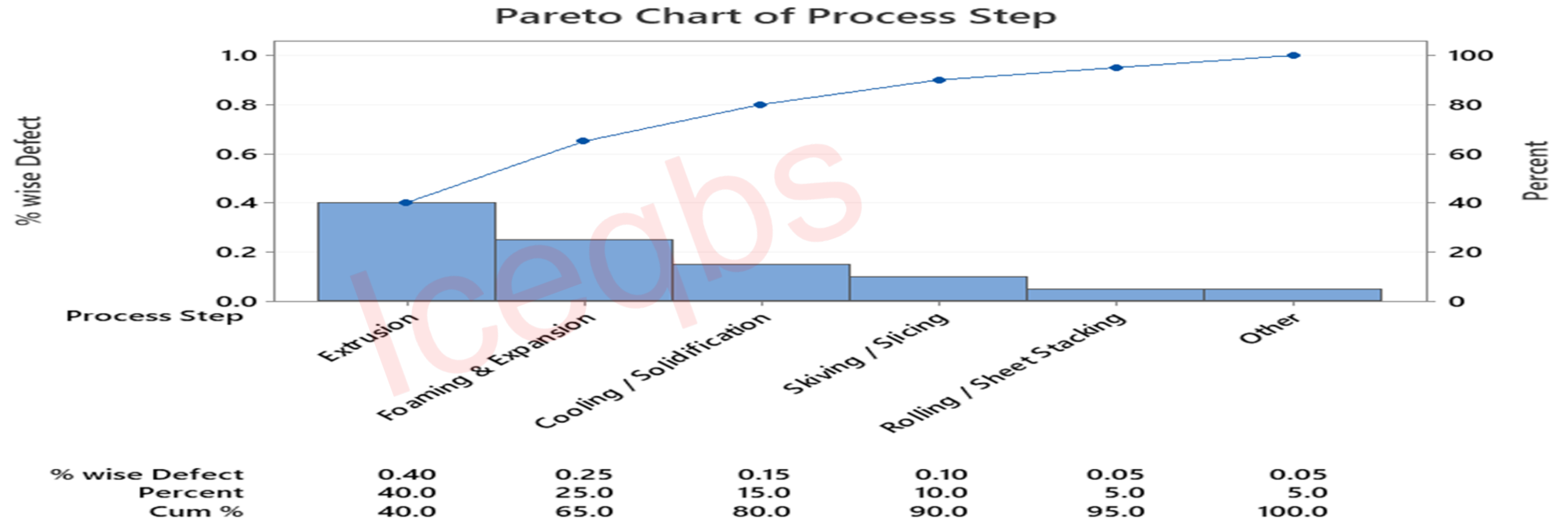


## Inference :

Last 9 months thickness variation data shows a significant variation and hence ideal problem to be taken up as a Six Sigma Project.



# PARETO CHART



Inference :

Defect rate is more in Extrusion process and hence it is identified as the process for improvement

# SIPOC

## SUPPLIER

- Polymer Resin Supplier
- Additive Supplier
- Blowing Agent Supplier
- Maintenance Dept (Internal)
- QC Lab (Internal)

## PROCESS

- Raw Material Handling
- Weighing & Pre-Mixing
- Compounding / Masterbatch Prep
- Extrusion
- Foaming & Expansion
- Cooling / Solidification

## CUSTOMER

- Downstream Production Team
- QC Team
- Skiving / Cutting Team
- Packing / Rolling Team
- Industrial Customers
- Distributors

## INPUT

- PE Resin
- Crosslinkers, Blowing Agents, Fillers
- Additives & Stabilizers
- Energy, Water, Utilities
- Machine Settings & Parameters

## OUTPUT

- Raw foam material
- Pre-mixed material
- Homogenous polymer mix
- Foam sheet/roll (variable thickness)
- Expanded foam
- Solidified foam

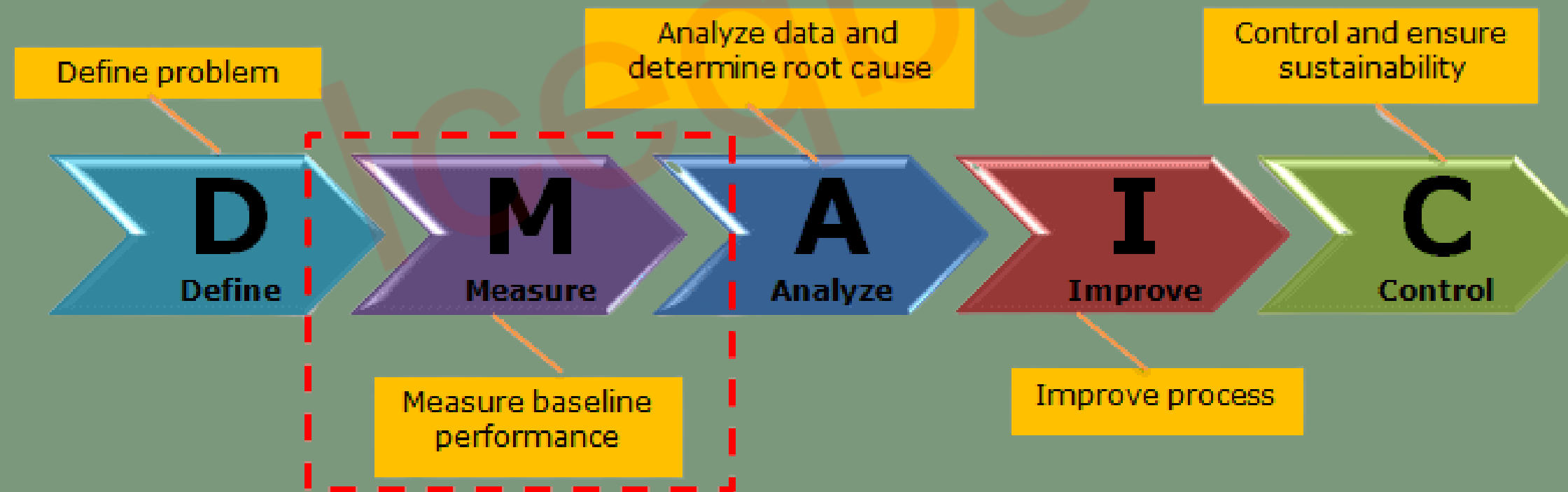
# PROJECT CHARTER

|                           |  |                                                                                                                                                                                                                                                                    |  |  |  |                              |  |                                                                                                                                                                         |  |  |  |
|---------------------------|--|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|--|--|------------------------------|--|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|--|--|
| <b>Project Title:</b>     |  |                                                                                                                                                                                                                                                                    |  |  |  |                              |  |                                                                                                                                                                         |  |  |  |
|                           |  | Reduction of thickness variation in XLPE Foam Rolls from $\pm 3\%$ to $\pm 1\%$ within 5 month                                                                                                                                                                     |  |  |  |                              |  |                                                                                                                                                                         |  |  |  |
| <b>Project Leader:</b>    |  |                                                                                                                                                                                                                                                                    |  |  |  | <b>Project Team Members:</b> |  |                                                                                                                                                                         |  |  |  |
| Name:                     |  |                                                                                                                                                                                                                                                                    |  |  |  | 1                            |  | Process Engineer                                                                                                                                                        |  |  |  |
| Business Unit:            |  |                                                                                                                                                                                                                                                                    |  |  |  | 2                            |  | Extrusion Operator                                                                                                                                                      |  |  |  |
| Email:                    |  |                                                                                                                                                                                                                                                                    |  |  |  | 3                            |  | Maintenance Engineer                                                                                                                                                    |  |  |  |
| Contact No:               |  |                                                                                                                                                                                                                                                                    |  |  |  | 4                            |  |                                                                                                                                                                         |  |  |  |
| <b>Champion/Sponsor:</b>  |  |                                                                                                                                                                                                                                                                    |  |  |  | <b>Key Stakeholder(s):</b>   |  |                                                                                                                                                                         |  |  |  |
|                           |  |                                                                                                                                                                                                                                                                    |  |  |  | 1                            |  | Process Engineer                                                                                                                                                        |  |  |  |
| Plant Manager             |  |                                                                                                                                                                                                                                                                    |  |  |  | 2                            |  | Extrusion Operator                                                                                                                                                      |  |  |  |
|                           |  |                                                                                                                                                                                                                                                                    |  |  |  | 3                            |  |                                                                                                                                                                         |  |  |  |
| <b>Problem Statement:</b> |  |                                                                                                                                                                                                                                                                    |  |  |  | <b>Goal Statement:</b>       |  |                                                                                                                                                                         |  |  |  |
|                           |  | Currently, XLPE foam rolls show thickness variation of $\pm 3\%$ from the target specification, leading to increased scrap, downstream process adjustments, and customer complaints. This affects production efficiency, material utilization, and overall product |  |  |  |                              |  | Reduce thickness variation from $\pm 3\%$ to $\pm 1\%$ within 5 months, improving process stability, reducing scrap by at least 20%, and ensuring customer satisfaction |  |  |  |

# PROJECT CHARTER

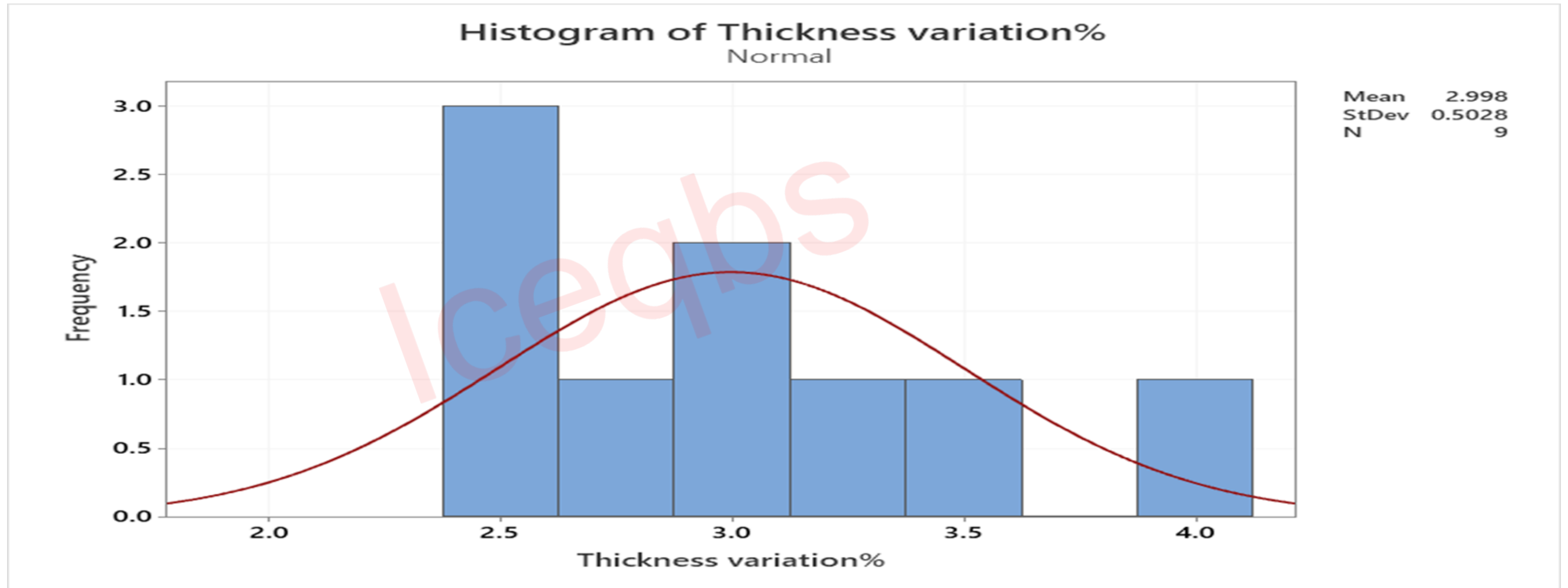
|                                                                                                                                                                      |  |  |  |  |  |  |  |  |  |                                                                                                                                                          |       |     |  |  |  |  |  |  |  |  |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|--|--|--|--|--|--|--|--|----------------------------------------------------------------------------------------------------------------------------------------------------------|-------|-----|--|--|--|--|--|--|--|--|
| Voice of the Customer (VOC):                                                                                                                                         |  |  |  |  |  |  |  |  |  | Assumptions Made:                                                                                                                                        |       |     |  |  |  |  |  |  |  |  |
| <i>Internal (Downstream, QC, Packing)Uniform thickness, easy processing, fewer adjustments, minimal scrap</i>                                                        |  |  |  |  |  |  |  |  |  |                                                                                                                                                          |       |     |  |  |  |  |  |  |  |  |
| <i>External (Industrial, Distributors, End-Users)Consistent foam thickness, meets specification, reliable product performance</i>                                    |  |  |  |  |  |  |  |  |  |                                                                                                                                                          |       |     |  |  |  |  |  |  |  |  |
| In Scope:                                                                                                                                                            |  |  |  |  |  |  |  |  |  | Out of Scope:                                                                                                                                            |       |     |  |  |  |  |  |  |  |  |
| <ul style="list-style-type: none"><li>•XLPE foam Extrusion, Foaming, Cooling, and Skiving processes.</li><li>•Measurement and monitoring of foam thickness</li></ul> |  |  |  |  |  |  |  |  |  | <ul style="list-style-type: none"><li>•Material formulation changes outside current recipe.</li><li>•Lamination, packing, or logistics process</li></ul> |       |     |  |  |  |  |  |  |  |  |
| Signatories:                                                                                                                                                         |  |  |  |  |  |  |  |  |  | Project Timeline:                                                                                                                                        |       |     |  |  |  |  |  |  |  |  |
| 1                                                                                                                                                                    |  |  |  |  |  |  |  |  |  | Stages                                                                                                                                                   | Start | End |  |  |  |  |  |  |  |  |
|                                                                                                                                                                      |  |  |  |  |  |  |  |  |  | Define                                                                                                                                                   |       |     |  |  |  |  |  |  |  |  |
| 2                                                                                                                                                                    |  |  |  |  |  |  |  |  |  | Measure                                                                                                                                                  |       |     |  |  |  |  |  |  |  |  |
|                                                                                                                                                                      |  |  |  |  |  |  |  |  |  | Analyze                                                                                                                                                  |       |     |  |  |  |  |  |  |  |  |
| 3                                                                                                                                                                    |  |  |  |  |  |  |  |  |  | Improve                                                                                                                                                  |       |     |  |  |  |  |  |  |  |  |
|                                                                                                                                                                      |  |  |  |  |  |  |  |  |  | Control                                                                                                                                                  |       |     |  |  |  |  |  |  |  |  |
| 4                                                                                                                                                                    |  |  |  |  |  |  |  |  |  |                                                                                                                                                          |       |     |  |  |  |  |  |  |  |  |

# MEASURE PHASE





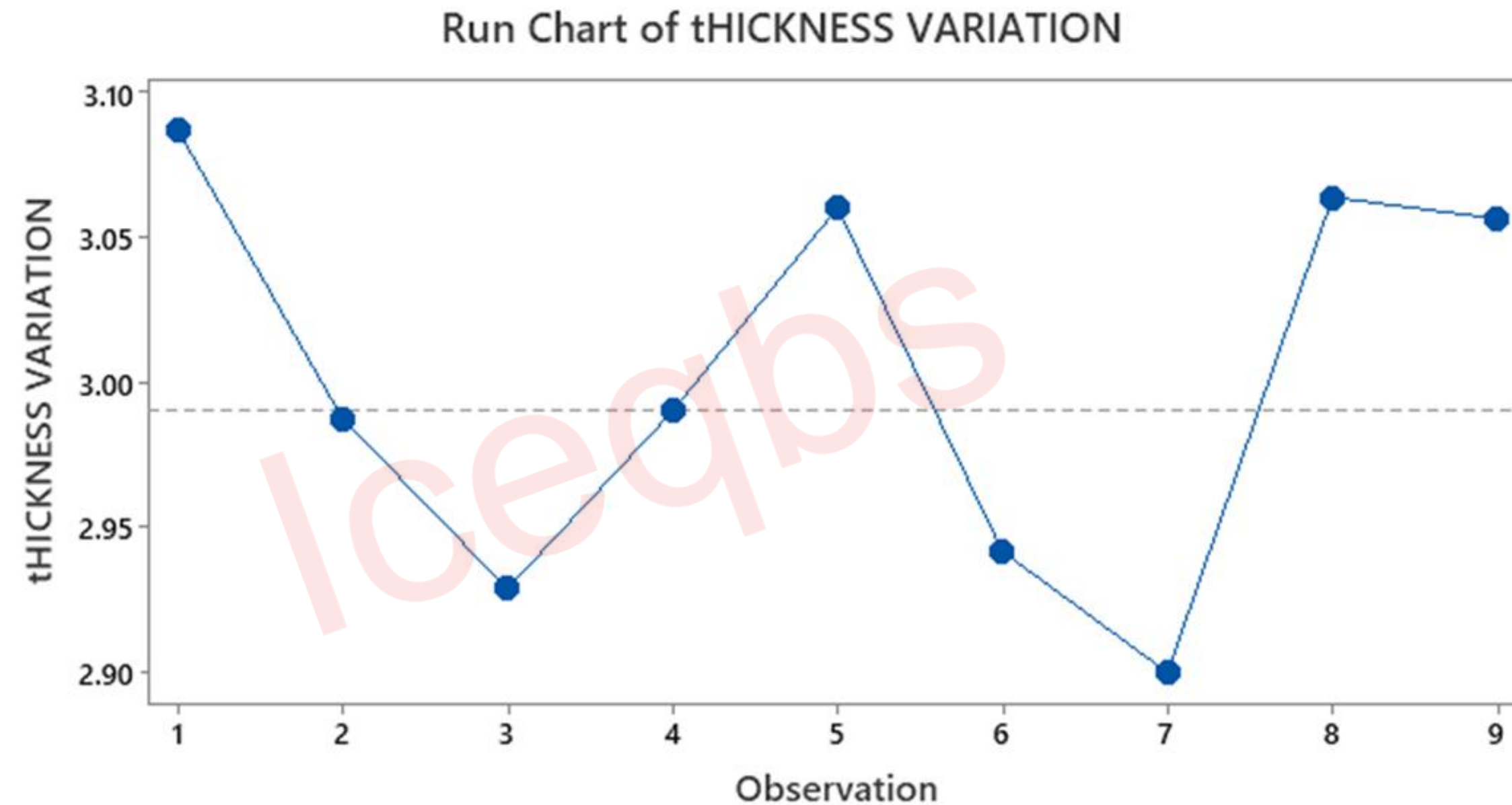
# Data collection – Histogram (Before improvement)



Inference :

Data is normally distributed over the mean

# Data collection – Run Chart (Before improvement)

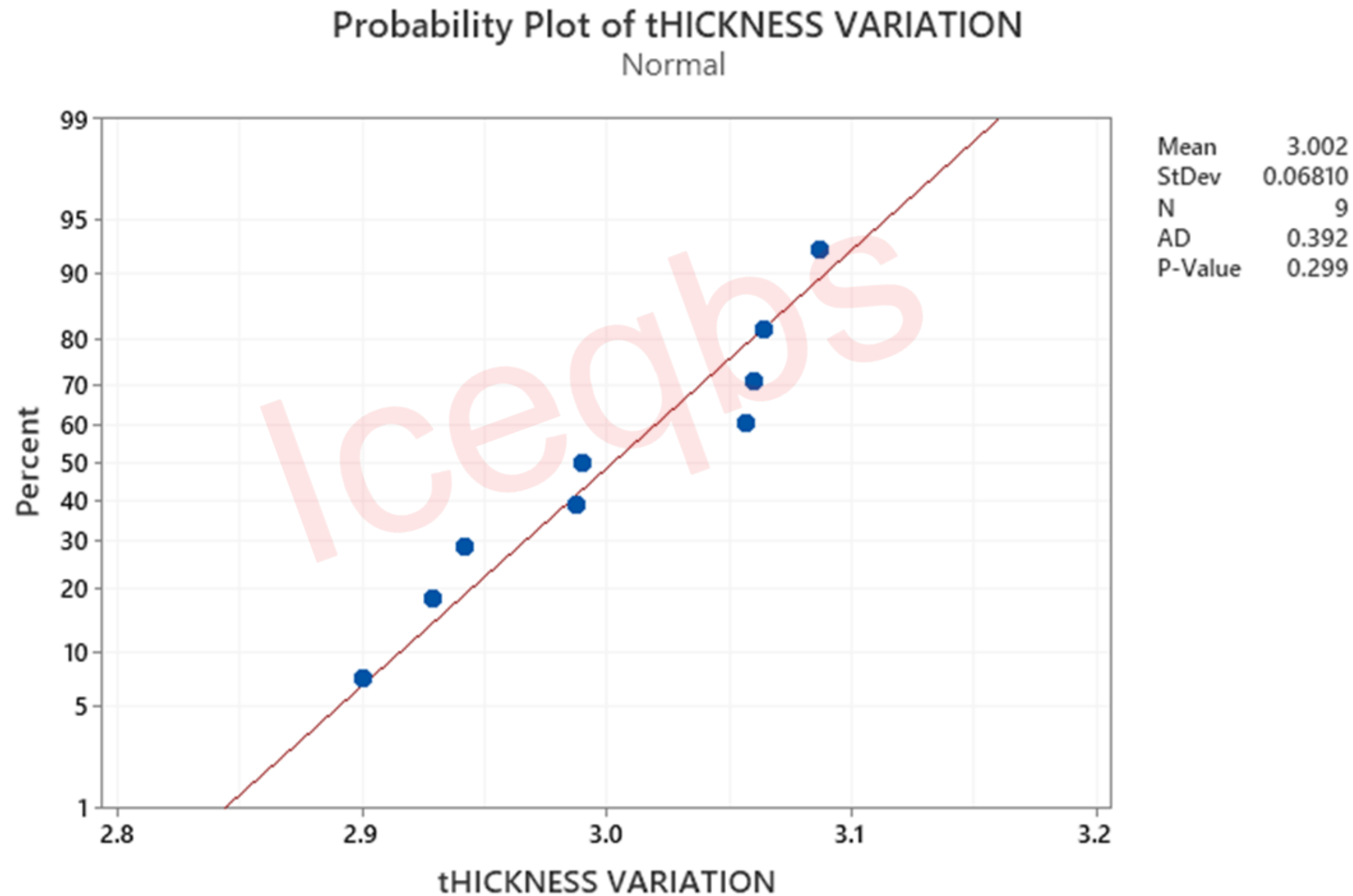


|                                |       |                                 |       |
|--------------------------------|-------|---------------------------------|-------|
| Number of runs about median:   | 5     | Number of runs up or down:      | 5     |
| Expected number of runs:       | 5.4   | Expected number of runs:        | 5.7   |
| Longest run about median:      | 3     | Longest run up or down:         | 2     |
| Approx P-Value for Clustering: | 0.374 | Approx P-Value for Trends:      | 0.278 |
| Approx P-Value for Mixtures:   | 0.626 | Approx P-Value for Oscillation: | 0.722 |

Inference :

All 4 P values  $> 0.05$  – No special causes in the process

# Data collection – Normality plot (Before improvement)

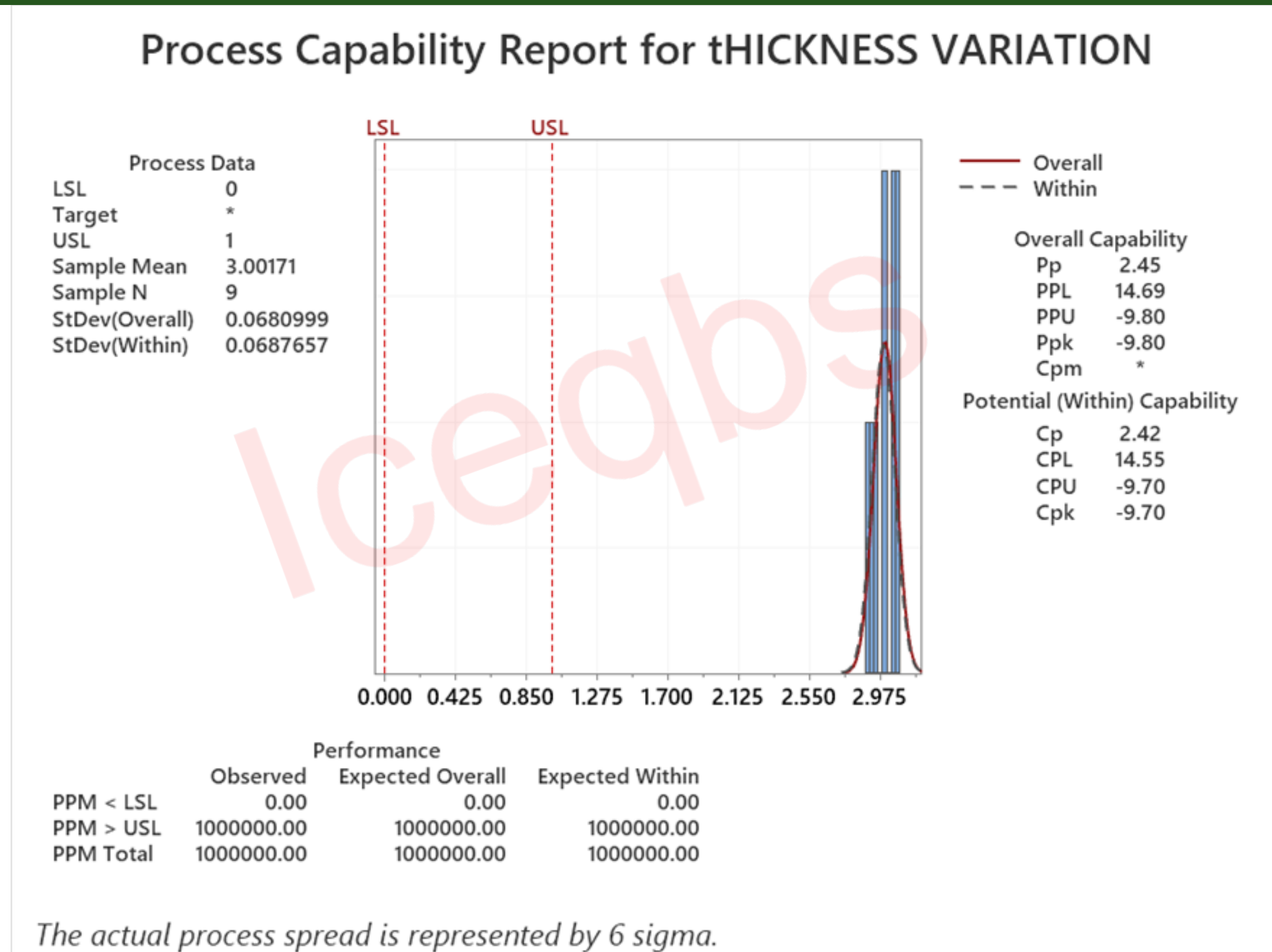


Inference :

$P > 0.05$  the data is normally distributed



# Data collection – Process capability (Before improvement)



Inference –

- CpK negative, process is highly incapable.

# Data collection – Process capability (Before improvement)

## MUDA

- Scrap foam due to off-spec thickness.
- Rework or re-processing of foam rolls/sheets.
- Manual inspection time repeated due to inconsistent measurements.

## WASTE – NON-VALUE ADDED ACTIVITIES

## MURA

- Fluctuating extrusion temperature causing variable thickness.
- Uneven cooling across conveyor leading to warping.
- Inconsistent feeding of material into extruder causing density and thickness variation

## VARIATION – UNEVENNESS IN PROCESS

## OVERBURDEN – STRAIN ON PEOPLE OR MACHINES

## MURI

- Operators manually adjusting machines frequently due to process instability.
- Overworking skiving or extrusion machines to meet production despite variation.
- QC inspectors under pressure to check every roll due to unpredictable thickness

# Wastage according to DOWNTIME

## DEFECTS

- Foam rolls/sheets rejected due to thickness out of specification.
- Scrapped material from uneven skiving or poor foaming.
- Producing extra foam to compensate for expected scrap.
- Running longer extrusion batches than required due to thickness variation

## OVERPRODUCTION

## WAITING

- Operators waiting for machines to stabilize before starting production.
- Delays in downstream lamination or cutting due to off-spec foam

## NON-UTILIZED TALENT

- Skilled operators spending time manually rechecking thickness instead of optimizing process.
- QC staff repeatedly measuring due to poor real-time monitoring

## TRANSPORTATION

- Moving foam rolls multiple times due to rework or quality inspection.

## INVENTORY

- Excess raw polymer stored to buffer against material-related thickness issues.

## MOTION

- Operators walking frequently between extrusion and skiving stations to adjust machines

## EXTRA PROCESSING

- Additional trimming or skiving to correct thickness variation.
- Re-running foam through cooling or compression steps to standardize thickness.

# Action plan to address Low Hanging fruits

| Area / Issue              | Special Cause / 3M / Waste      | Action / Lean Tool                                                             | Expected Benefit                                      | Responsibility                 | Timeline |
|---------------------------|---------------------------------|--------------------------------------------------------------------------------|-------------------------------------------------------|--------------------------------|----------|
| Manual Adjustments        | Muri (Overburden)               | Introduce Standard Operating Procedures & SOP boards                           | Reduce operator strain and process variation          | Process Engineer               | 2 weeks  |
| Fluctuating Temperature   | Mura (Unevenness)               | Install real-time process monitoring / control charts                          | Stable extrusion → consistent thickness               | Process Engineer / Maintenance | 4 weeks  |
| Scrap Foam                | Muda (Waste – Defects)          | Implement Visual Management / 5S to identify and segregate scrap rolls quickly | Minimize rework and material loss                     | Production Team                | 1 week   |
| Rework & Extra Processing | Muda (Waste – Extra Processing) | Adjust extrusion and cooling process using Kaizen event                        | Reduce unnecessary rework, improve yield              | Production & Process Team      | 3 weeks  |
| Manual Handling           | Waste – Motion & Transportation | Introduce material handling carts / roller conveyors                           | Reduce operator walking & roll handling time          | Production Team                | 2 weeks  |
| Waiting for Machines      | Waste – Waiting                 | Implement SMED / Quick Changeover on extrusion and skiving                     | Reduce idle time, increase throughput                 | Production & Maintenance       | 3 weeks  |
| Inventory Buffers         | Waste – Inventory               | Optimize batch sizes using Kanban / FIFO                                       | Reduce overstock and scrap from off-spec material     | Production Planning            | 4 weeks  |
| Ambient Environment       | Mother Nature (Mura)            | Control plant temperature & humidity                                           | Reduce thickness variation from environmental effects | Facility Team                  | 4 weeks  |



# Data Collection – Fishbone Diagram (format)

| CATEGORY (M)                | POTENTIAL CAUSES (5 EACH)                                                                                                                                                                                                                                                                   |
|-----------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Man (Operators / People)    | <ol style="list-style-type: none"><li>1. Inconsistent operator skill or experience</li><li>2. Improper machine setup</li><li>3. Lack of adherence to SOPs</li><li>4. Inadequate training on extrusion parameters</li><li>5. Incorrect adjustments during skiving</li></ol>                  |
| Machine                     | <ol style="list-style-type: none"><li>1. Die gap not uniform</li><li>2. Screw speed fluctuation</li><li>3. Extruder temperature variation</li><li>4. Cooling conveyor uneven speed</li><li>5. Worn/dull skiving blades</li></ol>                                                            |
| Material                    | <ol style="list-style-type: none"><li>1. Inconsistent polymer resin quality</li><li>2. Variation in additive/blowing agent batch</li><li>3. Moisture in raw materials</li><li>4. Improper storage causing degradation</li><li>5. Inconsistent filler particle size</li></ol>                |
| Method (Process)            | <ol style="list-style-type: none"><li>1. Improper mixing/compounding sequence</li><li>2. Uneven feeding of material into extruder</li><li>3. Incorrect foaming/blowing ratio</li><li>4. Poor cooling or uneven belt contact</li><li>5. Skiving sequence or speed not standardized</li></ol> |
| Measurement                 | <ol style="list-style-type: none"><li>1. Inaccurate thickness gauges</li><li>2. Improper placement of measurement points</li><li>3. Irregular inspection frequency</li><li>4. Manual reading errors</li><li>5. Lack of real-time monitoring</li></ol>                                       |
| Mother Nature / Environment | <ol style="list-style-type: none"><li>1. Ambient temperature variation in plant</li><li>2. Humidity affecting foam expansion</li><li>3. Dust or contamination in production area</li><li>4. Vibration affecting extruder stability</li><li>5. Power supply fluctuations</li></ol>           |

# Data Collection – (X-Y diagram)

## Top 12 Root Causes (Based on Net Score)

Die gap not uniform – 114

Extruder temperature variation – 114

Screw speed fluctuation – 108

Inconsistent polymer resin – 48

Variation in additive / blowing agent – 48

Cooling unevenness - 48

Improper mixing sequence – 48

Manual adjustments / operator error – 48

Worn/dull skiving blades – 44

Inaccurate thickness gauge – 44

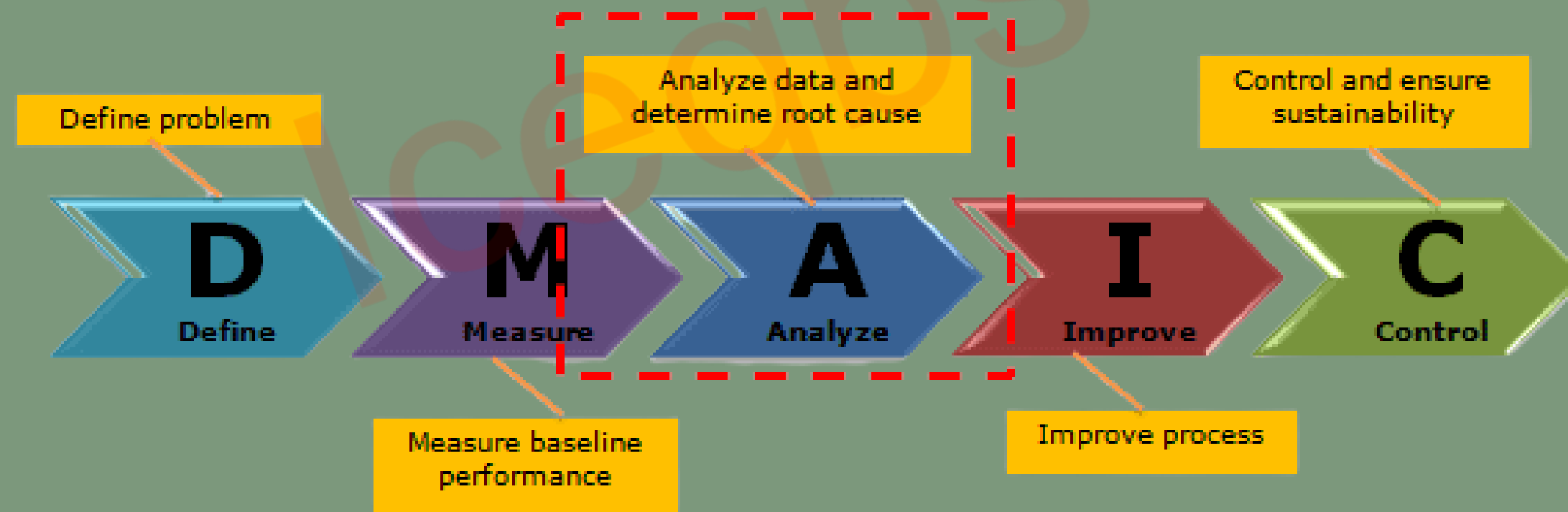
Improper placement of measurement points – 24

Ambient temperature / humidity – 24

# Data Collection Plan

| ROOT CAUSE                          | PROCESS STEP        | WHAT TO MEASURE                    | MEASUREMENT METHOD / TOOL              | FREQUENCY                      | SAMPLE SIZE / NOTES         | RESPONSIBLE                 |
|-------------------------------------|---------------------|------------------------------------|----------------------------------------|--------------------------------|-----------------------------|-----------------------------|
| DIE GAP NOT UNIFORM                 | Extrusion           | Die gap across width               | Vernier caliper / dial gauge           | Every shift / 3 points per die | 3 measurements per roll     | Maintenance / Operator      |
| EXTRUDER TEMPERATURE VARIATION      | Extrusion           | Barrel and die temperature         | Thermocouples / SCADA readings         | Continuous / hourly log        | Record min, max, avg        | Operator / Process Engineer |
| SCREW SPEED FLUCTUATION             | Extrusion           | Screw RPM / throughput             | Machine display / SCADA                | Continuous                     | Log every 30 min            | Operator / Process Engineer |
| MANUAL ADJUSTMENTS / OPERATOR ERROR | Extrusion / Skiving | Number and type of adjustments     | Observation / Logbook                  | Each shift                     | Record type & time          | Operator / Team Leader      |
| WORN / DULL SKIVING BLADES          | Skiving             | Blade sharpness / replacement date | Visual inspection / gauge              | Every shift                    | Check edges & document      | Maintenance / Operator      |
| INACCURATE THICKNESS GAUGE          | Measurement         | Gauge calibration                  | Calibration certificate / verification | Monthly / before use           | Document calibration status | QC / Instrument Technician  |

# ANALYSE PHASE





# Analyse – Hypothesis testing

## Regression Equation

Scrap\_pct = 1.144 + 0.02489 DieGap\_Variation\_um + 0.4974 Extruder\_Temp\_SD\_C  
+ 0.8265 ScrewSpeed\_CV\_pct

## Coefficients

| Term                | Coef    | SE Coef | T-Value | P-Value | VIF  |
|---------------------|---------|---------|---------|---------|------|
| Constant            | 1.144   | 0.182   | 6.30    | 0.000   |      |
| DieGap_Variation_um | 0.02489 | 0.00244 | 10.19   | 0.000   | 1.01 |
| Extruder_Temp_SD_C  | 0.4974  | 0.0157  | 31.64   | 0.000   | 1.01 |
| ScrewSpeed_CV_pct   | 0.8265  | 0.0311  | 26.56   | 0.000   | 1.01 |

## Model Summary

| S        | R-sq   | R-sq(adj) | R-sq(pred) |
|----------|--------|-----------|------------|
| 0.348503 | 92.74% | 92.59%    | 92.27%     |

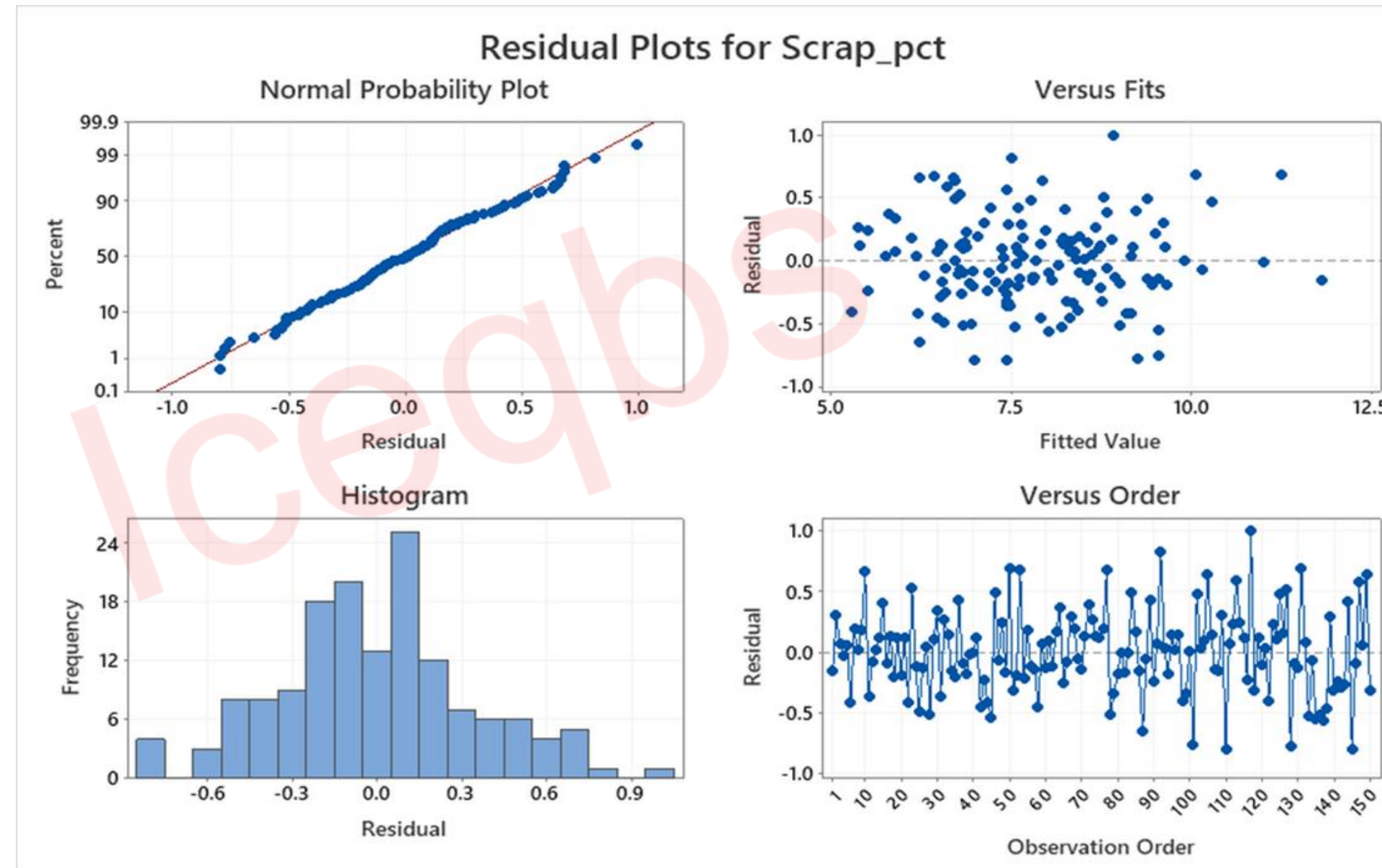
## Analysis of Variance

| Source              | DF  | Adj SS | Adj MS  | F-Value | P-Value |
|---------------------|-----|--------|---------|---------|---------|
| Regression          | 3   | 226.37 | 75.456  | 621.27  | 0.000   |
| DieGap_Variation_um | 1   | 12.62  | 12.621  | 103.92  | 0.000   |
| Extruder_Temp_SD_C  | 1   | 121.59 | 121.586 | 1001.08 | 0.000   |
| ScrewSpeed_CV_pct   | 1   | 85.68  | 85.679  | 705.44  | 0.000   |
| Error               | 146 | 17.73  | 0.121   |         |         |
| Total               | 149 | 244.10 |         |         |         |

Inference :

Since  $p < 0.05$ , Diegap variation, Extruder temperature and Screwspeed CV are validated as critical root causes

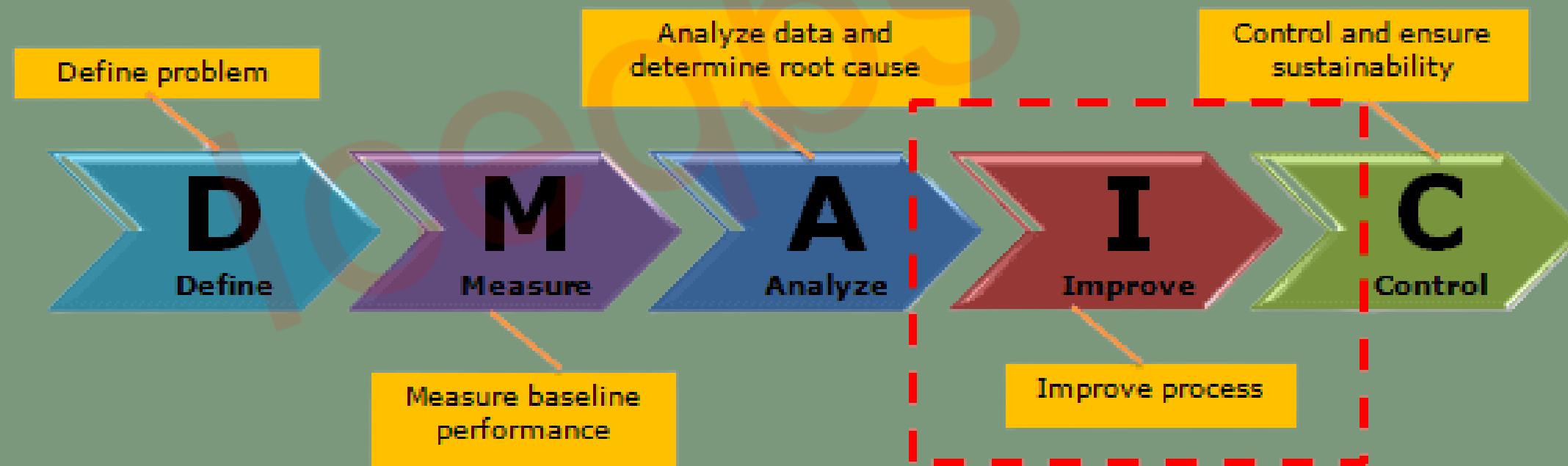
# Analyse – Hypothesis testing



Inference :

Since  $p < 0.05$ , Diegap variation, Extruder temperature and Screwspeed CV are validated as critical root causes

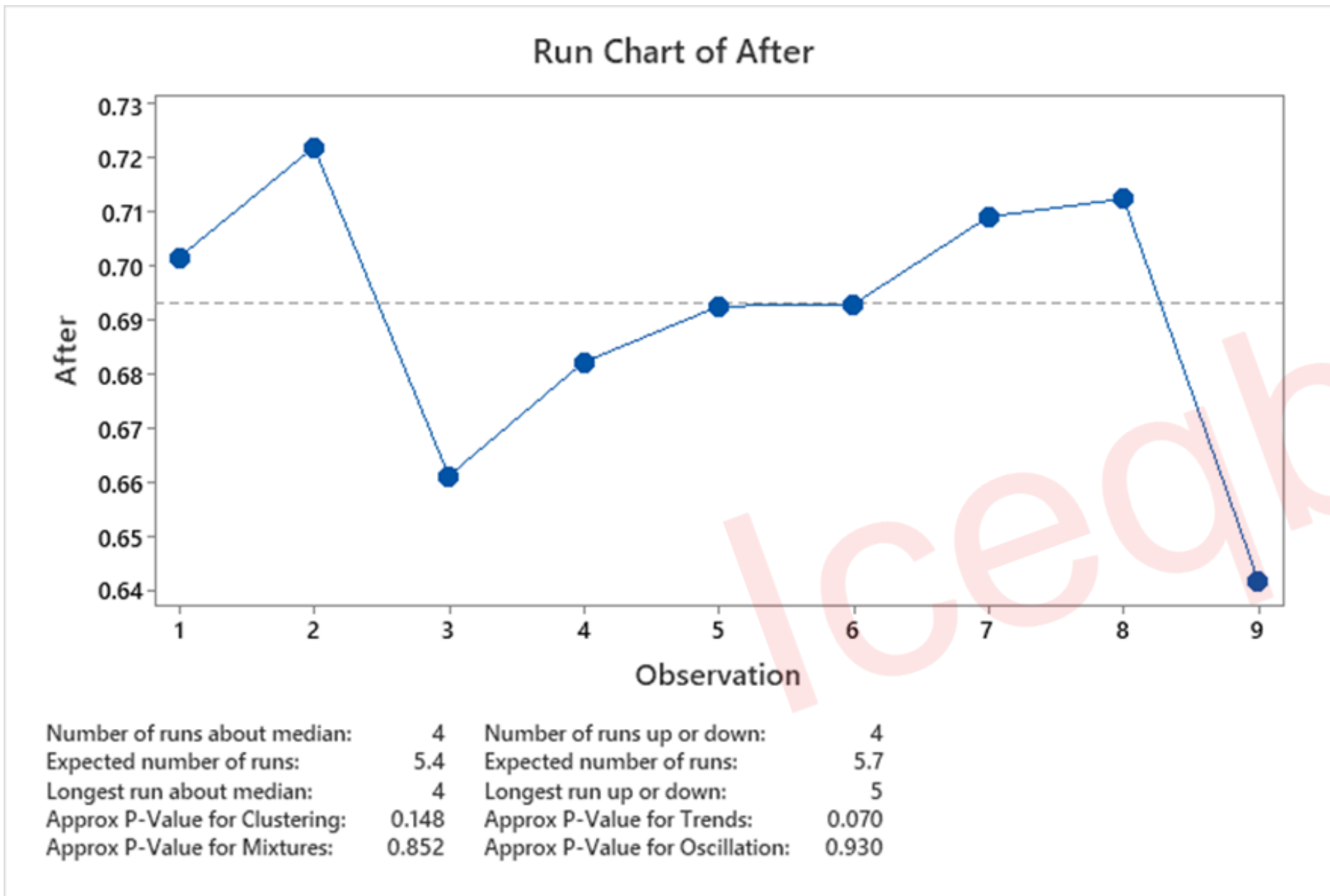
# IMPROVE PHASE



# Improve – Action Plan

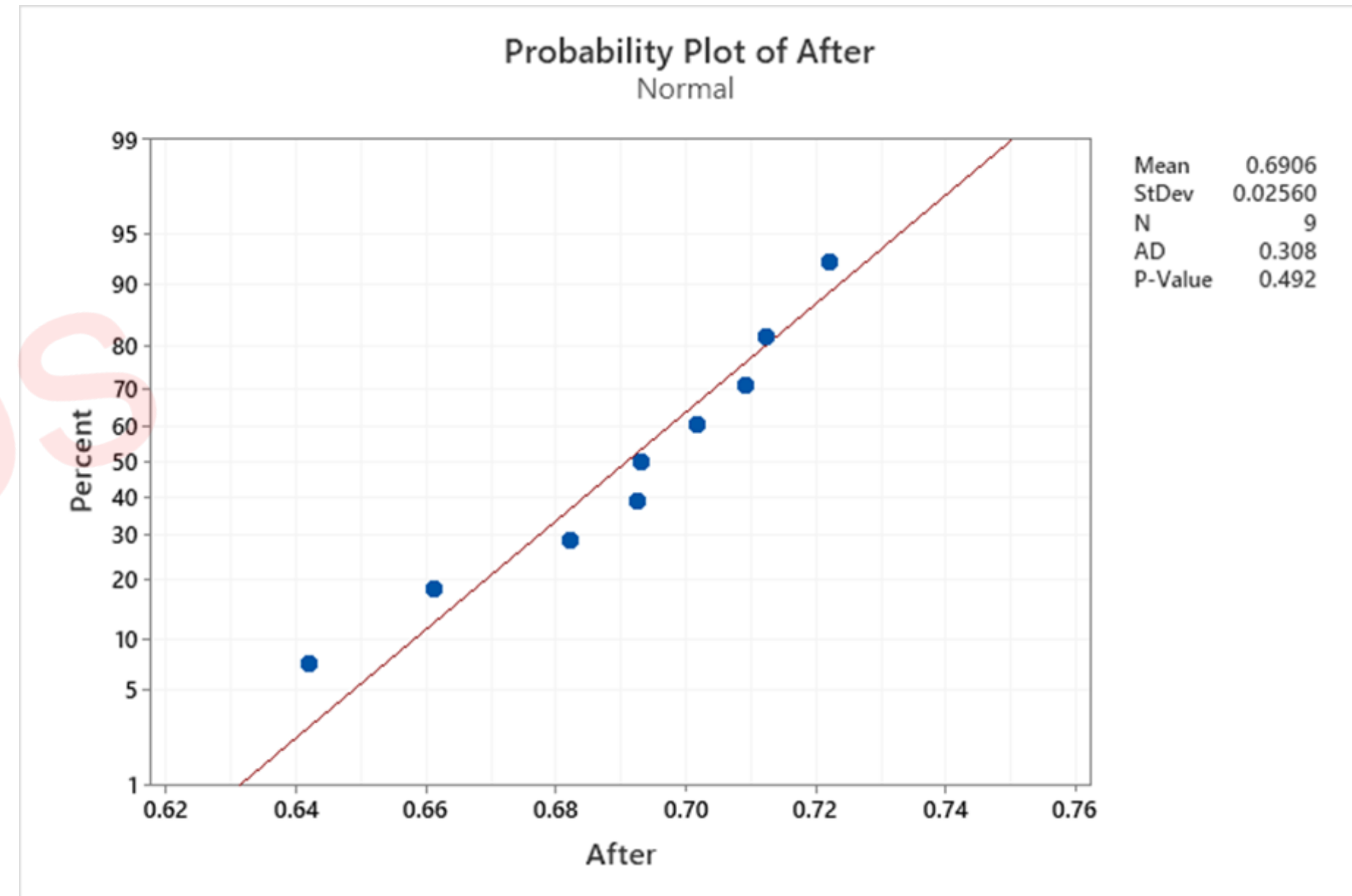
| ROOT CAUSE                             | ACTION PLAN                                                                                                                                                                  | RESPONSIBLE PERSON       | TOOL / METHOD USED                   | TARGET / EXPECTED OUTCOME                               | TIMELINE |
|----------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|--------------------------------------|---------------------------------------------------------|----------|
| Die Gap Variation                      | - Calibrate die gap weekly using feeler gauge and laser gap sensors-<br>Implement SPC chart to monitor die gap deviation- Introduce “Setup Checklist” for start-up alignment | Production & Maintenance | Calibration SOP, SPC Chart           | Reduce die gap variation to $\leq \pm 0.02$ mm          | 2 weeks  |
| Extruder Temperature Instability       | - Install PID controllers for better temperature control- Set automatic alarms for $\pm 2$ °C deviation- Insulate heating zones to minimize external heat loss               | Maintenance & Process    | Temperature Logger, DOE Verification | Reduce temp SD from $\pm 3$ °C $\rightarrow$ $\pm 1$ °C | 3 weeks  |
| Screw Speed Fluctuation                | - Calibrate VFD drives weekly- Maintain screw speed CV $\leq 1\%$ by real-time PLC feedback- Train operators on ramp-up/ramp-down speed settings                             | Process & Electrical     | VFD Calibration Log, Control Charts  | Improve screw speed stability (CV < 1%)                 | 2 weeks  |
| Operator Handling                      | - Conduct operator skill training on setting and monitoring parameters- Use visual dashboard to show live process data                                                       | HR & Process Engineer    | Training Log, Dashboard              | Improved parameter awareness                            | 4 weeks  |
| Material Variation<br>(Support Factor) | - Implement raw material moisture check before feeding- Record compound batch properties                                                                                     | QA & Mixing Dept.        | Moisture Analyzer, Record Sheet      | Reduce material-related variability                     | 3 weeks  |

# Run chart and Normality Test (After Improvement)



Inference:

Run chart – process is stable there is no special causes in the process ( p value > 0.05)

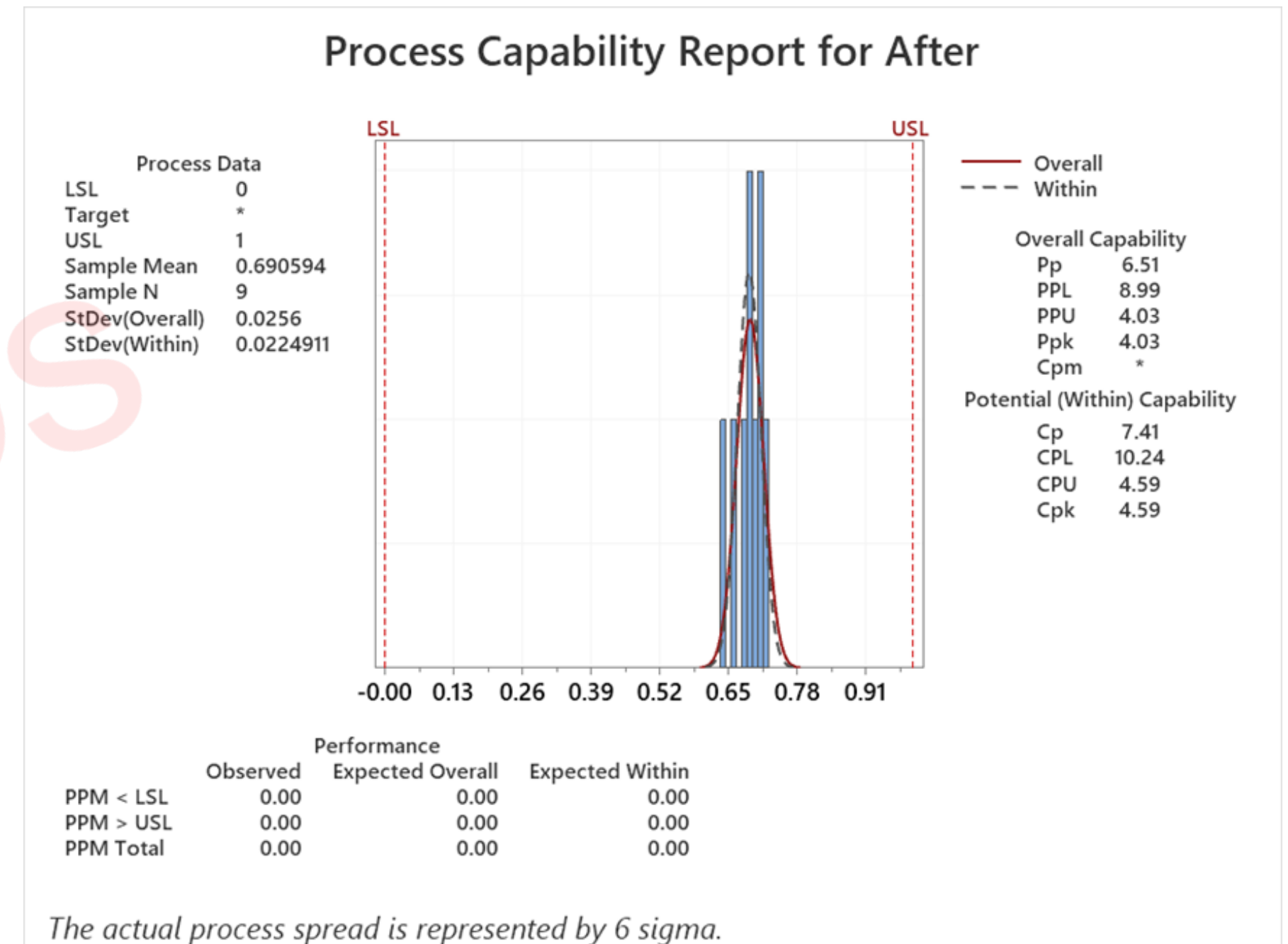
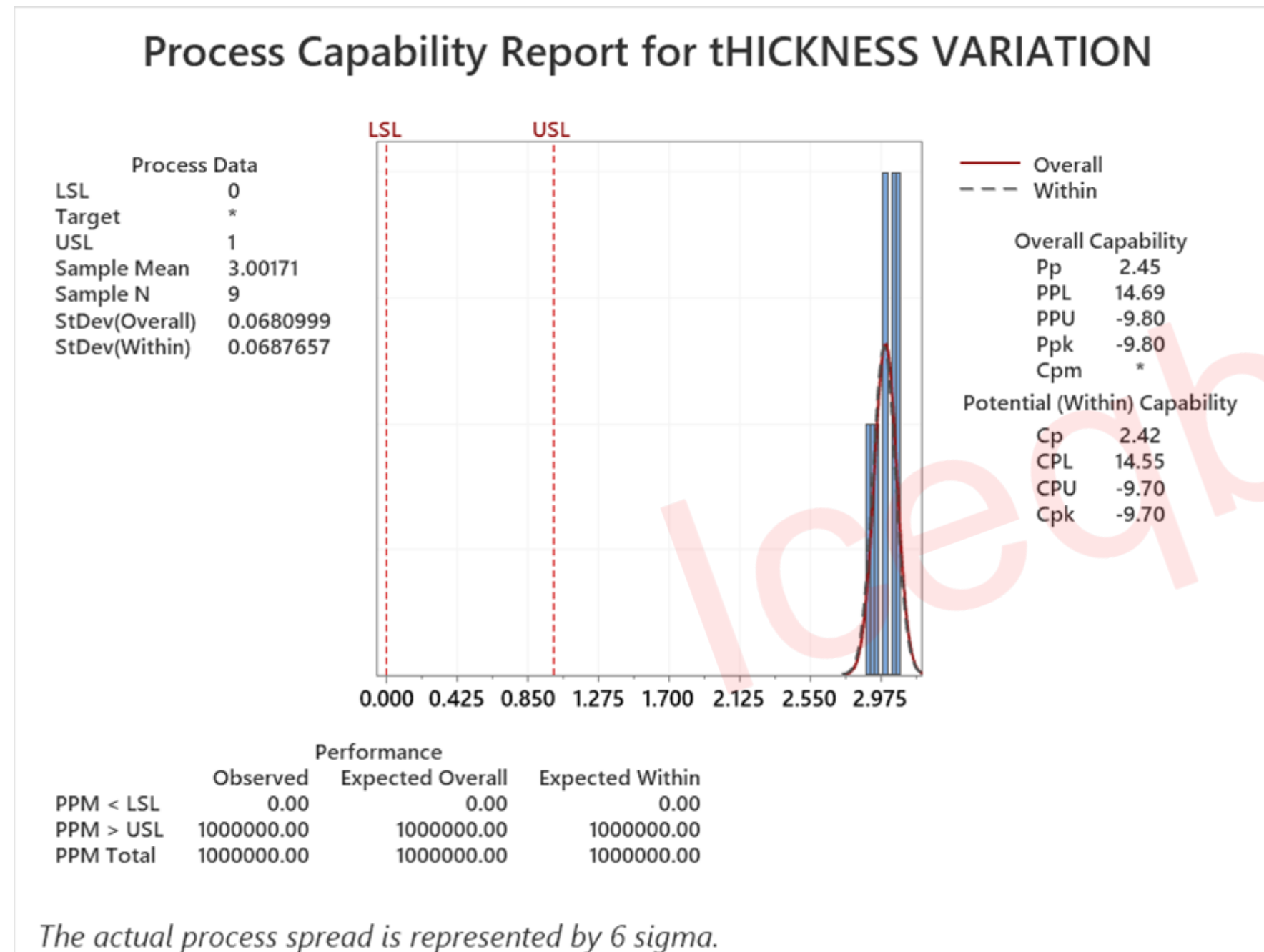


Inference:

Normality test – Data are normally distributed



# Process capability – Before & After Improvement



## Inference :

- Before  $C_{pk} <$  After  $C_{pk}$ , which shows process is much more capable after improvement
- There is less variability in system since stdev reduced after improvement
- After improvement the data are normally distributed near the target within specified limit

# After Improvement

## (Statistical validation for Improvement – Hypothesis Testing)

### Two-Sample T-Test and CI: tTHICKNESS VARIATION, After

$\mu_2$ : population mean of After

Difference:  $\mu_1 - \mu_2$

*Equal variances are not assumed for this analysis.*

#### Descriptive Statistics

| Sample               | N | Mean   | StDev  | SE Mean |
|----------------------|---|--------|--------|---------|
| tTHICKNESS VARIATION | 9 | 3.0017 | 0.0681 | 0.023   |
| After                | 9 | 0.6906 | 0.0256 | 0.0085  |

#### Estimation for Difference

| Difference | 95% CI for Difference |
|------------|-----------------------|
| 2.3111     | (2.2571, 2.3651)      |

#### Test

Null hypothesis  $H_0: \mu_1 - \mu_2 = 0$

Alternative hypothesis  $H_1: \mu_1 - \mu_2 \neq 0$

| T-Value | DF | P-Value |
|---------|----|---------|
| 95.30   | 10 | 0.000   |

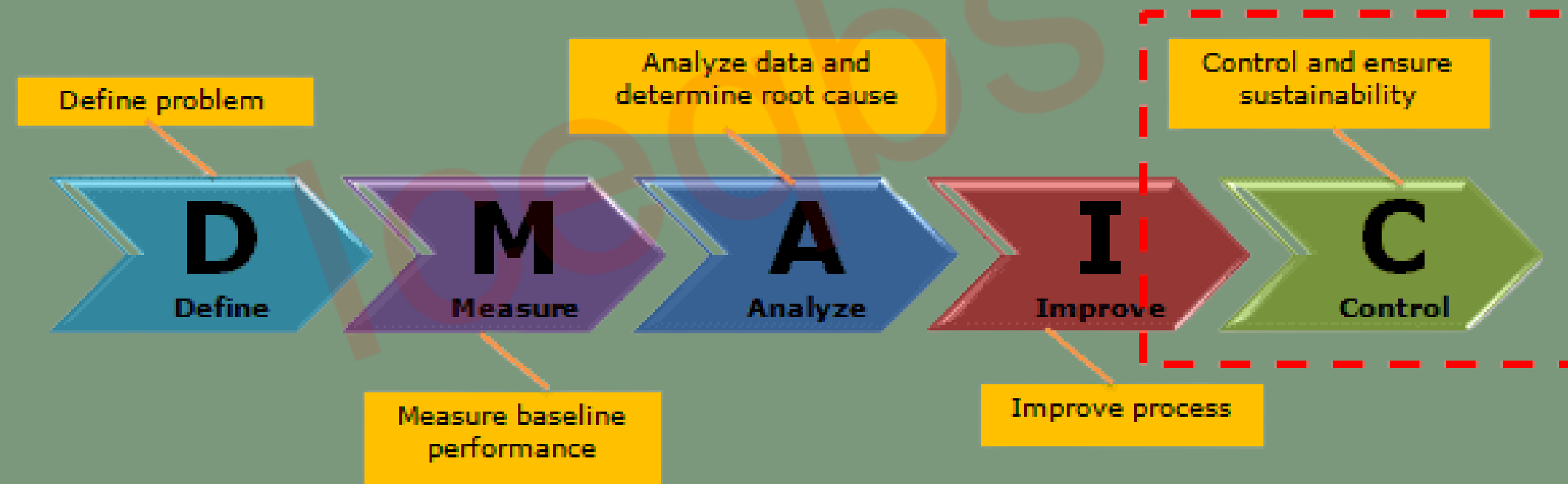
### Inference:

- Since P value is less than 0.05, there is enough evidence to reject the null hypothesis and we can conclude that the difference between the population means is statistically significant.
- It is also visible from the individual value plot & box plot, there is clear difference in mean after improvement which is closer to required thickness

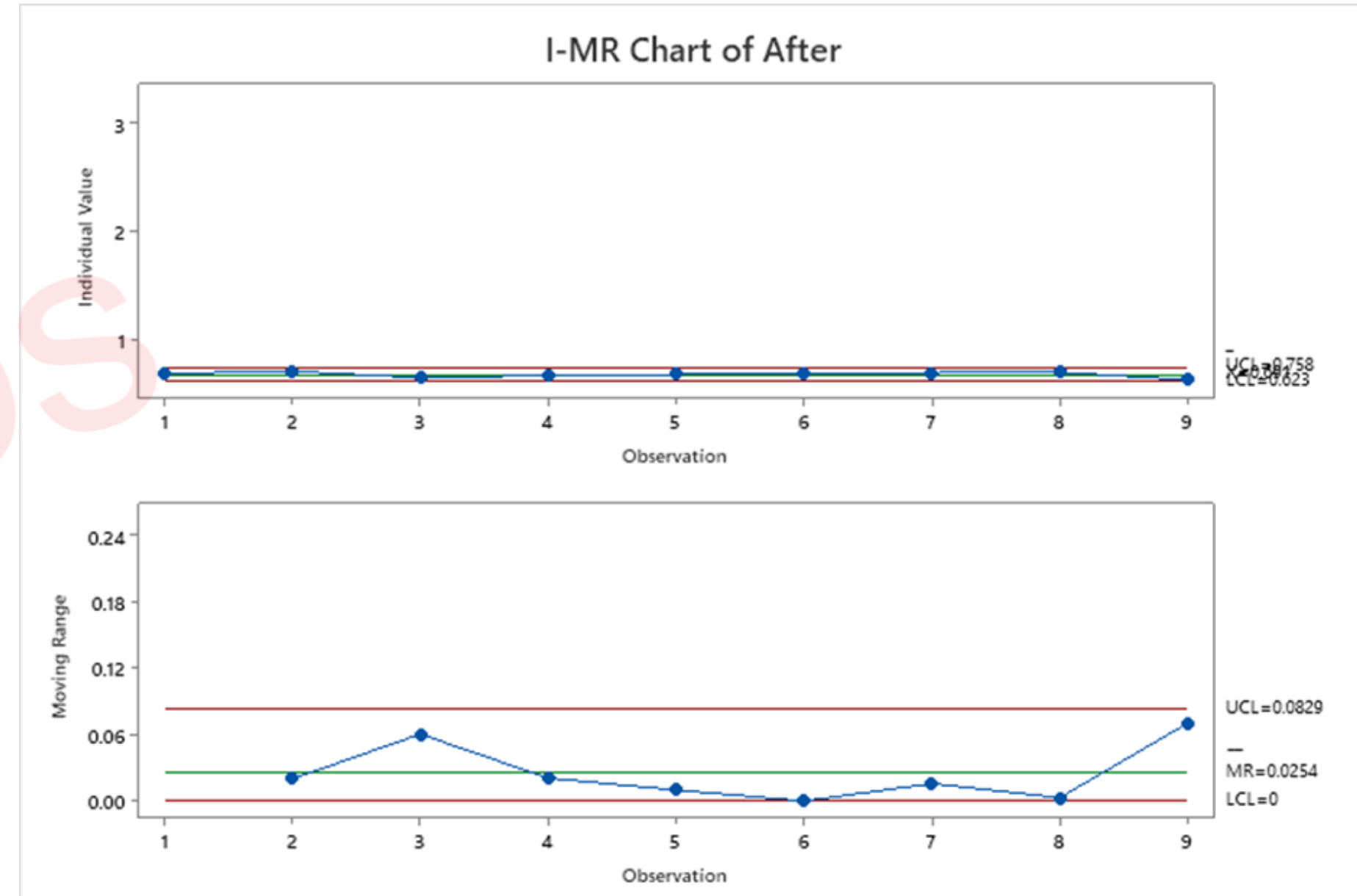
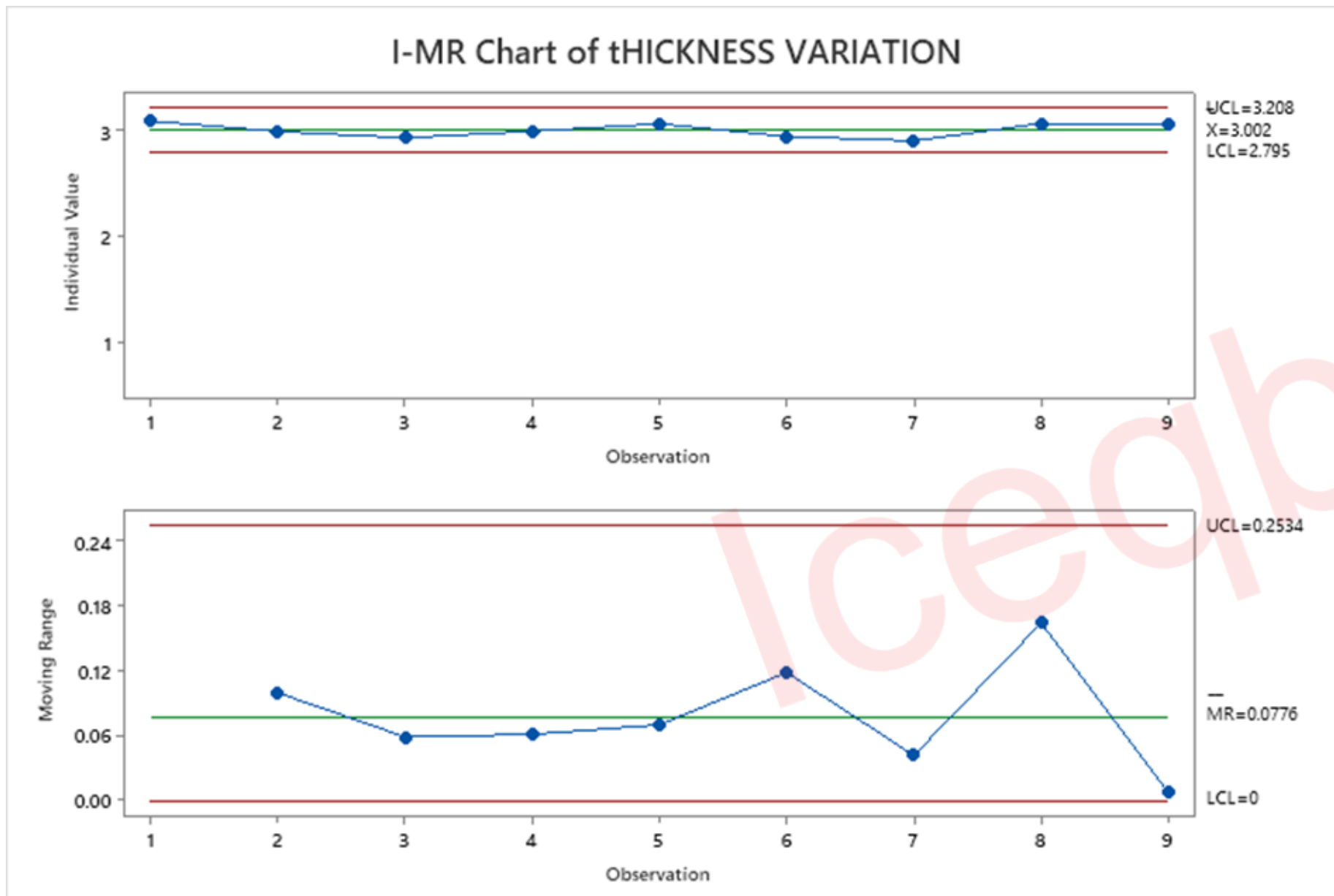
| FMEA |                                         |                                 |                                       |   |                                   |                    |   |                     |   |     |                                                                                                          |            |         |
|------|-----------------------------------------|---------------------------------|---------------------------------------|---|-----------------------------------|--------------------|---|---------------------|---|-----|----------------------------------------------------------------------------------------------------------|------------|---------|
| #    | Process / Improvement Item              | Potential Failure Mode          | Effect on Customer / Process          | S | Potential Cause                   | Current Controls   | O | Detection Method    | D | RPN | Recommended Actions (Owner)                                                                              | Target O/D | New RPN |
| 1    | Die-gap calibration & setup             | Gap set uneven / wrong shims    | Thickness out-of-spec, scrap spike    | 8 | Missed shim, torque uneven        | Feeler gauge check | 4 | First-piece check   | 5 | 160 | Add digital feeler + shim color code, torque pattern sheet, setup checklist; LPA audits (Prod Eng/Maint) | O=2, D=2   | 32      |
| 2    | Extruder zone temperature control (PID) | Temp drift / sensor failure     | Density/cell change → thickness swing | 9 | Loose thermocouple, PID not tuned | Manual watch       | 3 | SCADA trend review  | 4 | 108 | Auto alarms ±2 °C, spare sensors, quarterly PID autotune, zone insulation (Maint/Process)                | O=2, D=3   | 54      |
| 3    | Screw speed/VFD stability               | RPM drift / wrong setpoint      | Flow variation → thickness shock      | 7 | VFD drift, manual overrides       | RPM display only   | 4 | Hourly log          | 5 | 140 | Speed lock & interlock (>±5 RPM), weekly VFD cal, SOP ramp-up profile (EE/Process)                       | O=2, D=3   | 42      |
| 4    | Resin lot & MFI control                 | Wrong lot/MFI mismatch loaded   | Expansion mismatch → off-thickness    | 8 | No lot verification               | Paper COA          | 3 | Visual bag check    | 6 | 144 | Barcode scan + MFI window at receipt, quarantine rules, first-article MFI spot check (QA/Stores)         | O=1, D=2   | 16      |
| 5    | Skiving blade management                | Dull/damaged blade kept running | Edge taper, local thin/thick          | 6 | No replacement freq               | Visual look        | 5 | Scrap review        | 4 | 120 | Blade life counter (pcs/hrs), spare-cart, quick-change jig, 5S shadow board (Maint)                      | O=2, D=3   | 36      |
| 6    | Thickness gauge MSA/Cal                 | Gauge out of calibration        | False accept/reject                   | 8 | Missed cal, wear                  | Annual cal         | 3 | QC review           | 6 | 144 | MSA (R&R), pre-shift verification block, cal sticker + lockout when expired (QA)                         | O=2, D=2   | 32      |
| 7    | Sampling discipline                     | Checks skipped / wrong interval | Late detection of drift               | 7 | High load, no reminder            | SOP only           | 4 | End-of-shift review | 6 | 168 | HMI timer/light every 50 rolls, e-log must confirm sample, supervisor LPA (Prod/QC)                      | O=2, D=2   | 28      |
| 8    | Cooling airflow balance                 | Fan imbalance/duct blocked      | Across-width thickness variation      | 7 | Dust, damper shift                | Periodic cleaning  | 3 | Visual only         | 5 | 105 | Fixed-position dampers, monthly ΔT profile, PM clean checklist (Maint)                                   | O=2, D=3   | 42      |
| 9    | Operator standard work                  | SOP not followed                | Parameter drift; rework               | 8 | Training gap                      | Induction only     | 4 | Occasional audit    | 5 | 160 | One-point lessons at machine, standard work sheet on HMI, layered audits; skill matrix (Ops/HR)          | O=2, D=3   | 48      |
| 10   | SPC/alarms & review                     | Alarms disabled / not reviewed  | Drift goes unnoticed                  | 7 | Alert fatigue                     | Email only         | 3 | Weekly review       | 6 | 126 | Andon + audible stack light, daily SPC huddle, escalation rule (Process/Shift Lead)                      | O=2, D=2   | 28      |



# CONTROL PHASE



# Control – Control Chart for % scrap Before & after improvement



## Inference:

- There is significant improvement on scrap reduction after improvement

# Sustain Action Plan – 5S

| STEP                      | OBJECTIVE                                      | ACTIONS FOR XLPE LINE                                                                                                                                                                                                                     | Outcome / Control Benefit                                               |
|---------------------------|------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------|
| 1. Sort (Seiri)           | Eliminate unnecessary tools/materials          | <ul style="list-style-type: none"> <li>Remove unused gauges, tools, and old die shims.</li> <li>Separate “current” vs “obsolete” calibration tools.</li> <li>Tag damaged or out-of-calibration instruments for removal.</li> </ul>        | Prevents confusion and ensures only correct measurement tools are used. |
| 2. Set in Order (Seiton)  | Place tools and materials in defined positions | <ul style="list-style-type: none"> <li>Mark positions for feeler gauges, thermocouple sensors, torque wrenches, and alignment jigs.</li> <li>Use shadow boards for die tools and temperature probes.</li> </ul>                           | Faster setup and alignment — reduces die-gap errors.                    |
| 3. Shine (Seiso)          | Keep the area clean and inspectable            | <ul style="list-style-type: none"> <li>Daily cleaning of die and extruder vent area.</li> <li>Weekly cleaning of temperature sensor slots and fan vents.</li> <li>Introduce “Clean-Inspect-Lubricate” (CIL) checklist.</li> </ul>         | Maintains stable thermal conditions — reduces temperature drift.        |
| 4. Standardize (Seiketsu) | Establish standard procedures                  | <ul style="list-style-type: none"> <li>Visual SOPs for die setup, start-up temperature, and screw RPM.</li> <li>Laminated one-point lessons near machine.</li> <li>Standard inspection frequency for thickness every 50 rolls.</li> </ul> | Ensures uniform operating conditions.                                   |
| 5. Sustain (Shitsuke)     | Discipline and regular audits                  | <ul style="list-style-type: none"> <li>Conduct monthly 5S audit with red-tag tracking.</li> <li>Display “5S Scoreboard” for each machine.</li> <li>Link 5S compliance with operator evaluation.</li> </ul>                                | Reinforces habit, ensures long-term control.                            |

# Sustain Action Plan – Poka Yoke

| Area                     | Error to Prevent                       | Poka-Yoke Mechanism                                                                                                                                                                            | Benefit                                               |
|--------------------------|----------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------|
| Die Gap Setup            | Wrong gap setting or uneven tightening | <ul style="list-style-type: none"> <li>• Use digital feeler gauge with tolerance alarm.</li> <li>• Add color-coded shims for quick identification.</li> </ul>                                  | Prevents manual setup error → uniform gap.            |
| Temperature Control      | Incorrect heating zone setting         | <ul style="list-style-type: none"> <li>• Implement PID auto-tuning with deviation alarm (<math>\pm 2</math> °C).</li> <li>• Install interlock if temp deviation exceeds 5 °C.</li> </ul>       | Prevents over/under heating → stable expansion ratio. |
| Screw Speed              | Wrong RPM entry or fluctuation         | <ul style="list-style-type: none"> <li>• Program speed lock interlock — restrict change &gt;5 RPM</li> <li>• Display RPM on visual dashboard.</li> </ul>                                       | Eliminates uncontrolled speed variation.              |
| Material Loading         | Mixing wrong batch or MFI mismatch     | <ul style="list-style-type: none"> <li>• Use barcode system for batch validation before loading.</li> <li>• Add color-coded hopper tag per compound type.</li> </ul>                           | Prevents mixing error and MFI variation.              |
| Thickness Measurement    | Skipping QC sampling                   | <ul style="list-style-type: none"> <li>• Use timed alarm or light signal every 50 rolls for sampling reminder.</li> <li>• Add “measurement confirmation” in HMI before roll change.</li> </ul> | Ensures consistent sampling frequency.                |
| Cooling Zone Fan Setting | Manual fan imbalance                   | <ul style="list-style-type: none"> <li>• Add auto-balanced fan controller with fixed RPM settings</li> <li>• Visual indicators (green = balanced).</li> </ul>                                  | Avoids uneven cooling → stable thickness.             |

# Conclusion

## RESULTS AFTER IMPROVEMENT

**Project has achieved its intended results after improving thickness by identifying the variation cause and reducing scrap rate.**