Reduce Paper Cup Leakage Rate

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ROADMAP

- Overview
- Define
- Measure
- Analyse
- Improve
- Control

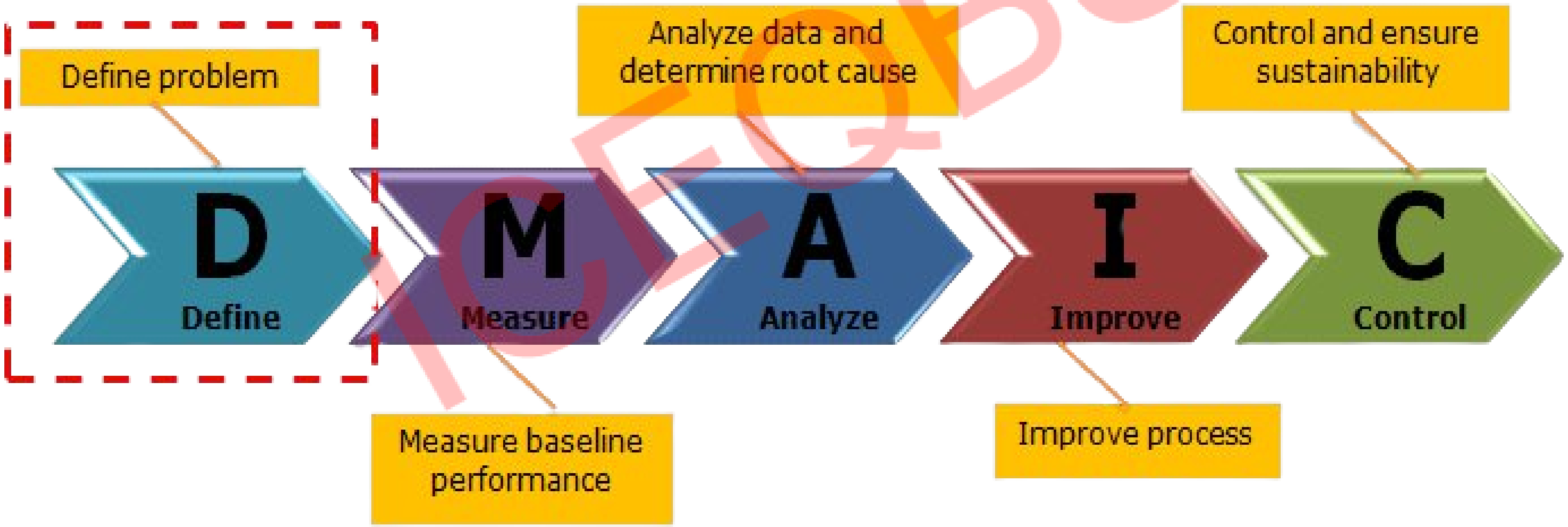
OVERVIEW

Background

Leakage in paper cups is one of the most critical quality issues impacting both production efficiency and customer satisfaction. The current leakage rate of 3.08% leads to significant material loss, increased rework, and higher production costs. In addition, leakage defects have caused multiple customer complaints, risking the company's reputation and long-term business relationships.

•Reducing the leakage rate to below 1.5% will directly lower the Cost of Poor Quality (COPQ), improve profit margins, and enhance product reliability. Improved sealing performance will also reduce downtime and maintenance needs, contributing to a higher Overall Equipment Effectiveness (OEE). This project supports the company's strategic goals of quality excellence, cost reduction, and customer retention.

DEFINE PHASE

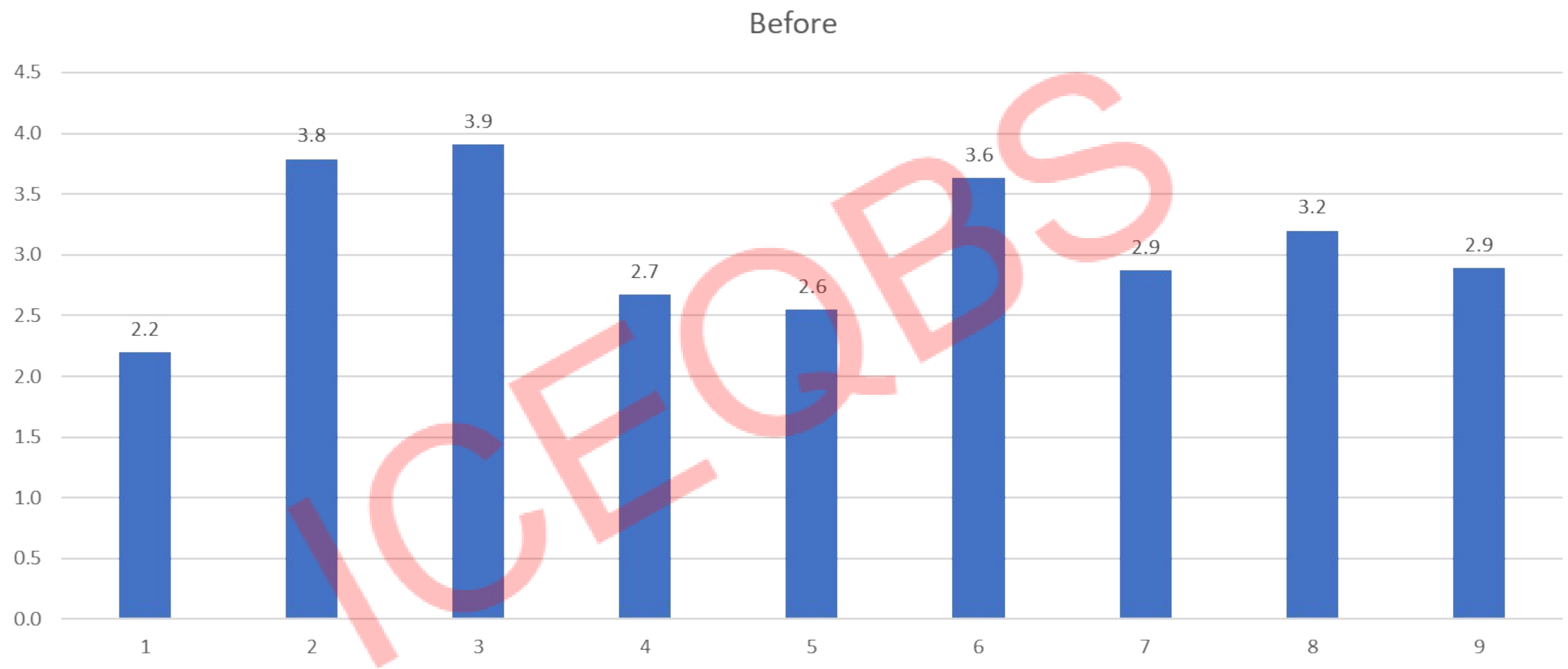


VOC & CTQ

CTQ Tree :

Voice of customer	Critical to X	Primary Metric for improvement
"Customers expect cups to be durable and leak-free during regular use. Frequent leakage is causing inconvenience and reducing confidence in product quality."	CTX – Cost	**Primar Rejection Metric-** Y = % Leakage Rejection rate **Secondary Metric -** Productivity

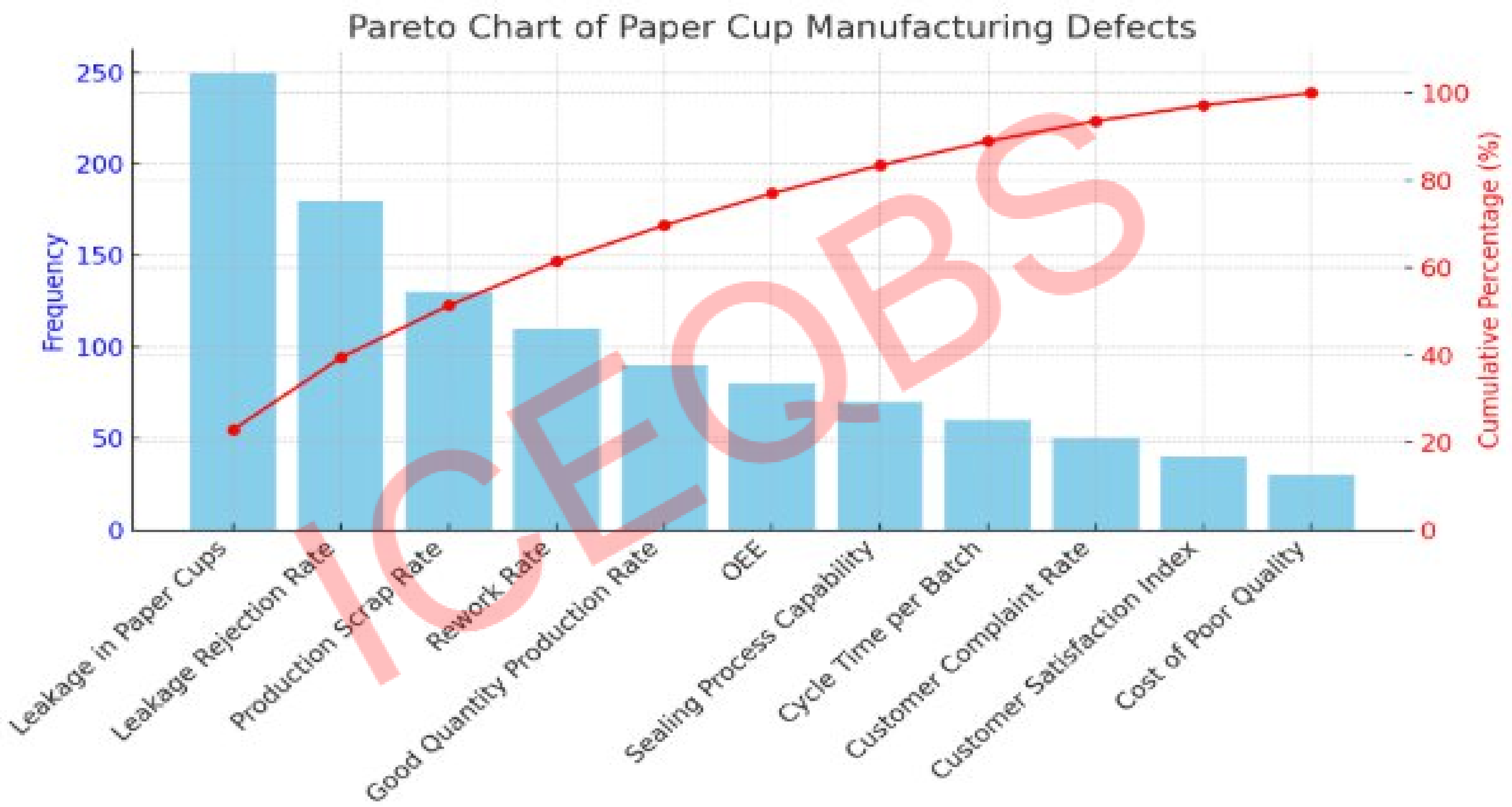
Baseline Performance of Primary Metric



Inference :

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

Pareto chart



Inference :

•Leakage contributes and included in the scope of the project

SIPOC

• Suppliers (S)	• Inputs (I)	• Process (P)	• Outputs (O)	• Customers (C)
• **- PE-coated paper roll suppliers**	• - PE-coated paper and bottom roll (specified GSM)	• 1. Receive PE-coated paper rolls and bottom rolls	• - Finished paper cups (leak-free)	• - End customers / distributors
• **- Bottom roll suppliers**	• - Machine parameters (temperature, pressure, speed)	• 2. Printing and cutting of blanks	• - Rejected cups due to leakage or sealing defects	• - Quality assurance department
• **- Printing & cutting section**	• - Sealing tools and heaters	• 3. Forming paper cups (side sealing)	• - Process data (leak % reports, OEE reports)	• - Production planning department
• **- Maintenance team**	• - Operator skills and training	• 4. Bottom insertion and sealing	• - Customer delivery batches	• - Management / business owners
• **- Operators & production staff**	• - Work instructions and SOPs	• 5. Curling and finishing		
		• 6. Leak testing (manual/automatic)		
		• 7. Visual inspection and packing		
		• 8. Rework or scrap of defective cups		

Project Charter

Project Title:	Leakage Rejection Rate

Project Leader	Project Team Members:
Mahesh Pillai	Mr.Nithin, Mr.William , Mr.Hamza Yahia

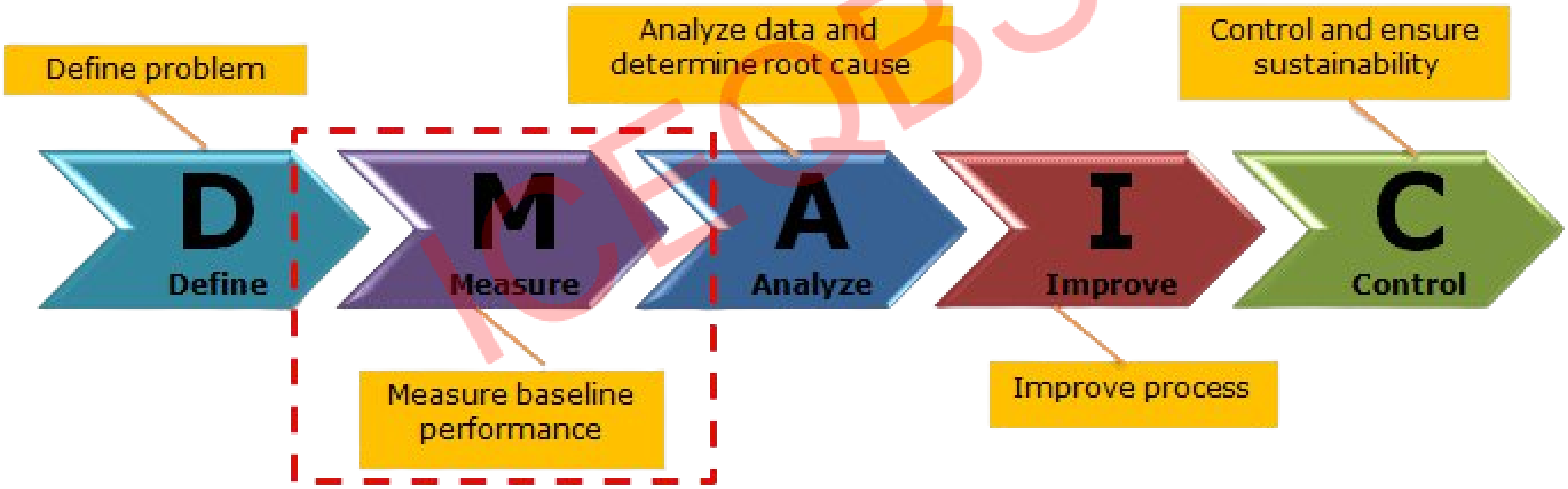
Champion/Sponsors:	Key Stake Holders
Mr.Hamid Akther	Production, QC, Sales, Procurement, R&D, Logistics, Finance Distributors, Retailers, Brands, Event Companies, Caterers, Exporters, Consumers

Problem Statement:	Goal Statement:
During the period from **January to September**, the average leakage rate in paper cup production was **3.08%**, exceeding the acceptable quality standard of **1.5%**.. This defect results in increased production rejections, higher rework and scrap rates, and customer complaints. The issue impacts overall equipment efficiency (OEE)	The objective of this project is to **reduce the paper cup leakage rate from the current average of 3.08% to below 1.5%** within the next **6 months**

Project Charter

Tangible and Intangible Benefits:	Risk to Success:
Reduced scrap, rework, and COPQ Improved OEE and sealing consistency Lower production costs and higher yield Higher customer satisfaction and fewer complaints Better operator skills and process discipline	Variations in machine settings or temperature control Operator inconsistency or lack of adherence to SOPs Raw material quality fluctuations Delayed maintenance or lack of spare parts
In Scope:	**Out of Scope:**
Sealing process analysis and improvement Machine parameter optimization Operator training and skill enhancement New machine purchases Cup design or raw material changes	Casting, forging, heat treatment, coating, and assembly processes
Signatories:	**Project Timeline:**
Mr.Hamid Akther Mr.Daniel Mendoza	6 Months

MEASURE PHASE

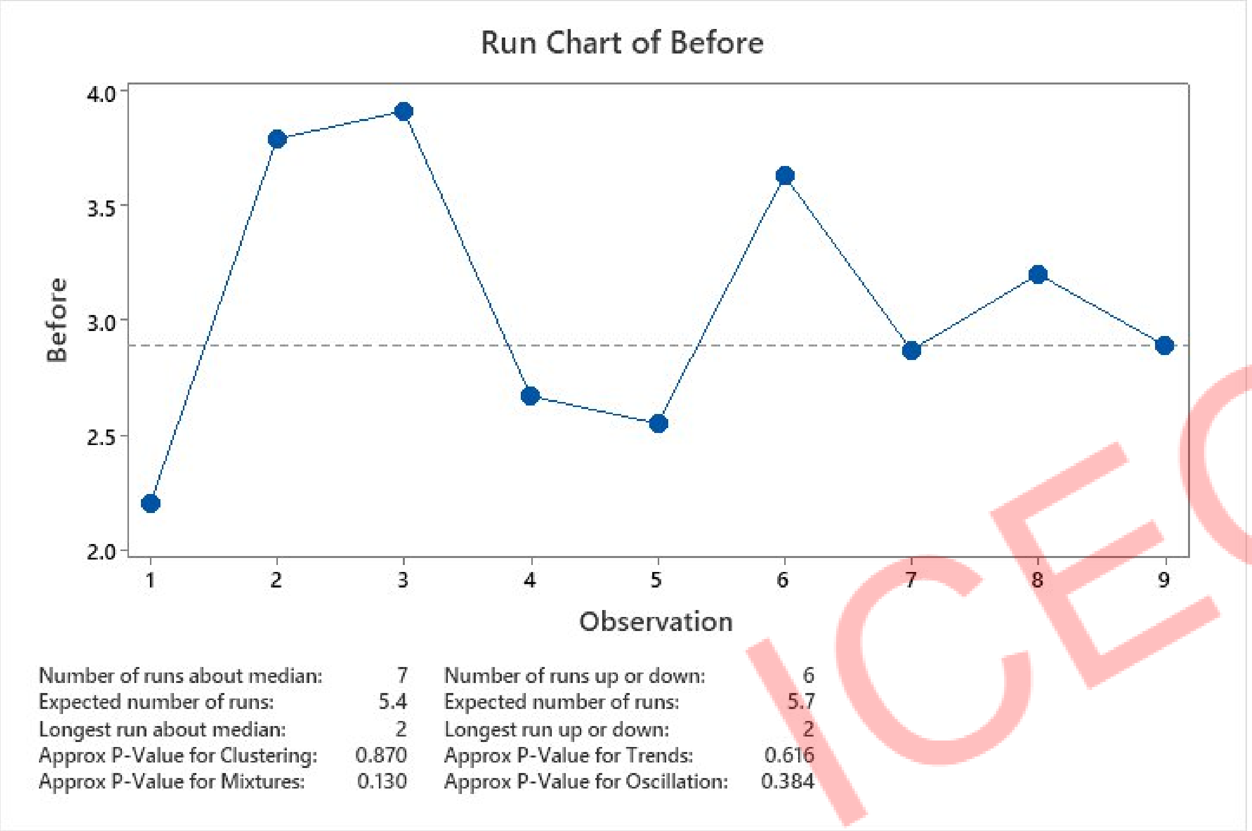


Data collection – Histogram (Before improvement)

Inference :

•Data is normally distributed over the mean

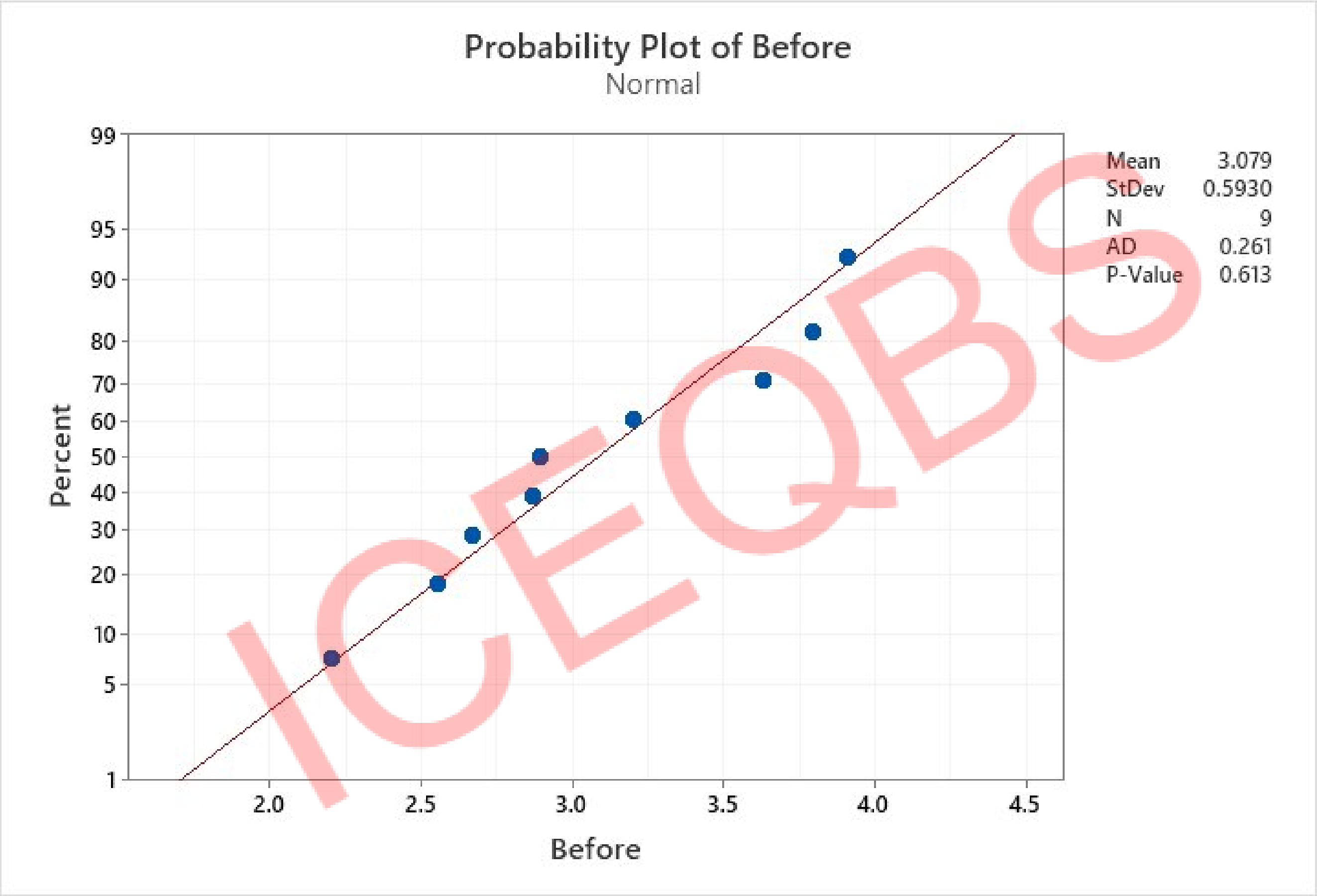
Data collection – Run Chart (Before improvement)



Inference :

P > 0.05 – No special causes in the process. Data can be used for further analysis

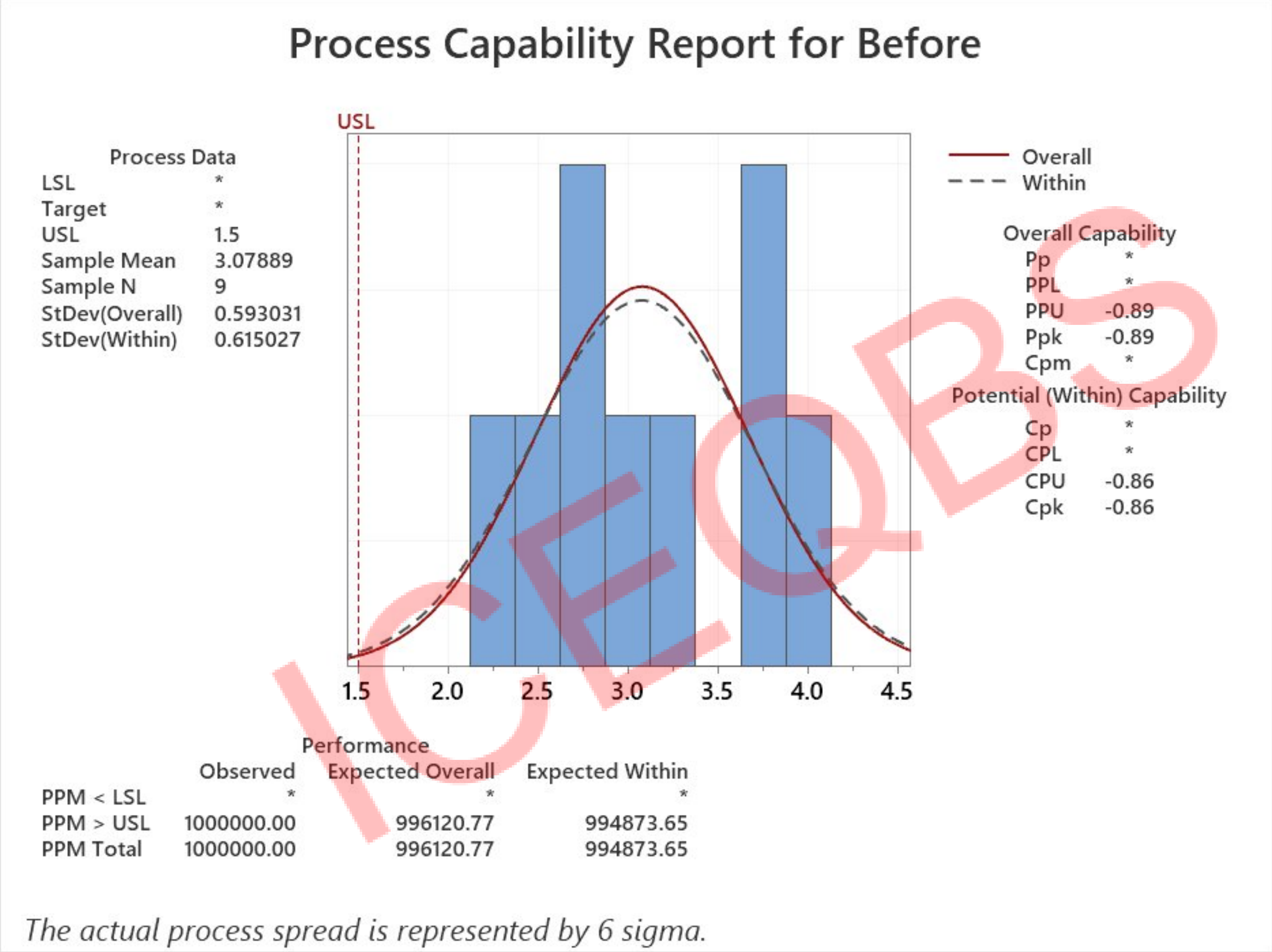
Data collection – Normality plot (Before improvement)



Inference :

•P > 0.05 in all scenarios, thus all the data is normally distributed

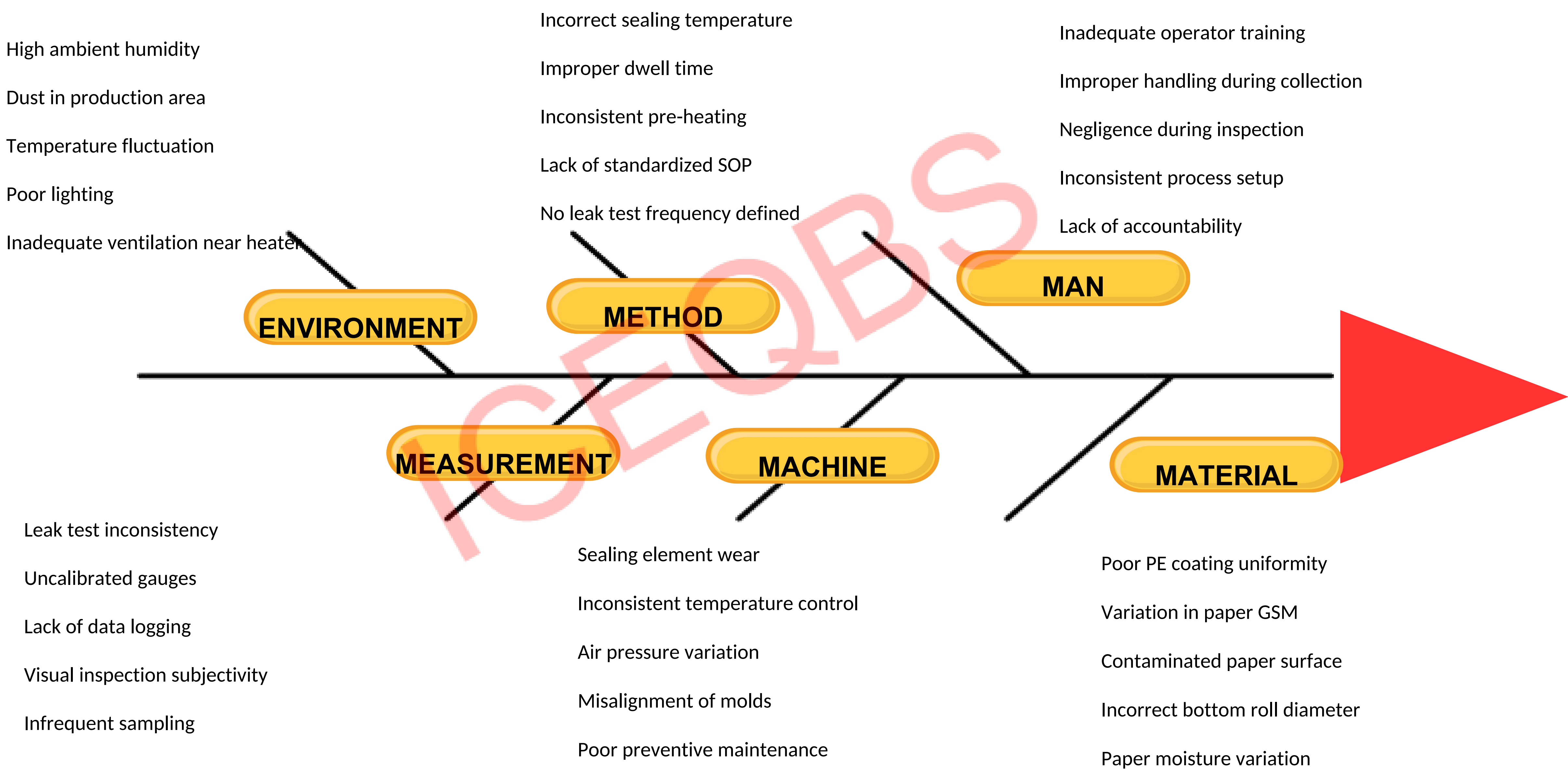
Data collection – Normality plot (Before improvement)



Inference :

The process is not capable, as all output values exceed the USL and capability indices (Ppk/Cpk) are negative, indicating severe misalignment with specifications.

Fish Bone Diagram



Common Causes & Special Causes

Common Causes

- Inadequate operator training
- Improper handling during collection
- Negligence during inspection
- Sealing element wear
- Poor preventive maintenance
- Poor PE coating uniformity
- Variation in paper GSM
- Incorrect sealing temperature
- Improper dwell time
- Inconsistent pre-heating
- High ambient humidity
- Dust in production area
- Temperature fluctuation
- Visual inspection subjectivity
- Lack of standardized SOP

Special Causes

- Inconsistent temperature control
- Air pressure variation
- Misalignment of molds
- Contaminated paper surface
- Incorrect bottom roll diameter
- Paper moisture variation
- Lack of leak test frequency
- Uncalibrated gauges
- Leak test inconsistency
- Lack of data logging
- Infrequent sampling
- Poor lighting
- Inadequate ventilation near heater
- Inconsistent process setup
- Lack of accountability

3M Analysis for Waste

MUDA

- Excess scrap of paper cups
- Overproduction
- Waiting time

MURA

- Inconsistent cup sealing
- Variable production output
- Irregular supply of raw materials

MURI

- Machine overloading
- Operators handling multiple machines
- Excessive manual labor

8 Wastes Analysis

Defects	Cups leaking due to improper sealing. Misprinted logos or labels on cups requiring rework or disposal.
Overproduction	Producing extra cups “just in case” without actual demand. Running machines at maximum speed to finish a batch faster than needed
Waiting	Machine downtime due to paper roll jams or lack of material. Operators waiting for maintenance staff to fix a defective sealing unit
Non-Utilized Talent	Operators not involved in problem-solving or improvement discussions. Lack of training opportunities to enhance skill in precision machining.
Transportation	Moving paper rolls multiple times between storage and production. Transferring semi-finished cups between different machines instead of inline processing
Inventory	Stocking more paper rolls than needed for current production. Storing large batches of finished cups due to irregular shipping schedules
Motion	Operators walking back and forth to fetch sealing glue or tools. Reaching repeatedly for control panels that are not ergonomically placed
Overprocessing	Applying extra coating or finishing steps not required for the product standard. Inspecting every single cup manually when a sampling method would suffice

Action Plan for Low Hanging Fruits

Muda (Waste)

Waste Type	Lean Tool	Action Plan	Benefit
Supplier Quality Management	Inspect rolls on receipt; use approved suppliers	Fewer defects, higher product quality	Supplier Quality Management

Mura (Unevenness)

Issue	Lean Tool	Action Plan	Benefit
Variable cup output per shift	Standard Work & Visual Management	Visual boards for target output & clear SOPs	Smooth workflow, predictable production

Muri (Overburden)

Issue	Lean Tool	Action Plan	Benefit
Running sealing machine continuously at max speed	SMED / TPM	Schedule short machine breaks & maintenance; avoid continuous max load	Increased machine life, stable output

Action Plan for Low Hanging Fruits

Waste	Lean Tool	Action Plan	Benefit
Overproduction	Extra cups produced due to batch scheduling	Kanban / Pull System	Implement small batch production aligned with actual demand
Transportation	Moving semi-finished cups between machines	Layout Improvement	Rearrange line for inline flow
Motion	Operators walking long distances to fetch glue or tools	5S	Place tools and consumables near workstation
Overprocessing	Extra coating / inspection beyond standard	Standard Work	Define and enforce minimal required coating & inspection
Defects	Improper sealing temperature	5S & Standard Work	Standardize machine temperature settings & checklist before start
Waiting	Operators waiting for paper rolls or spare parts	5S & TPM	Organize material close to machine; maintain spare parts inventory

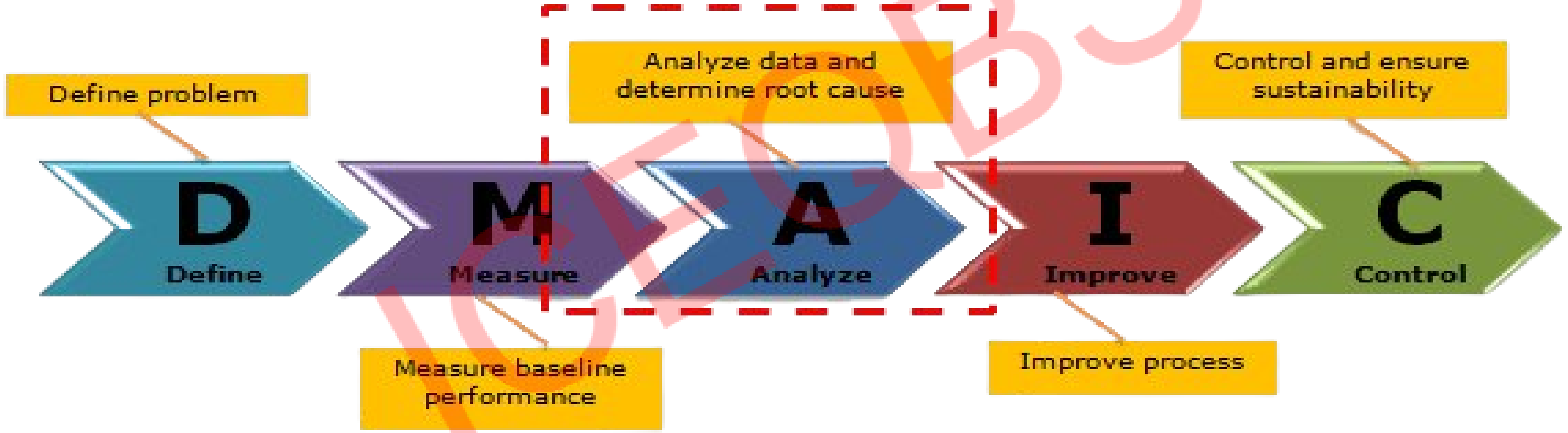
Top 12 Prioritized Root Causes (Based on Net Score)

Cause	Score
Sealing temperature variation	222
Paper roll quality	195
Misalignment of sealing jaws	195
Machine speed inconsistency	162
Machine maintenance frequency	162
Glue viscosity / quality	141
Operator skill level	140
Operator fatigue	140
Cup handling during transfer	135
Humidity in production area	135
Machine vibration	120
Batch size (overproduction)	105

Top 12 Root Causes from C&E Matrix

S. No.	Input / Root Cause (X)	What to Measure	Measurement Method	Frequency	Responsibility	Why Collect
1	Sealing temperature variation	Actual sealing temperature vs setpoint (°C)	Digital sensor reading	Hourly	Operator	To verify sealing consistency
2	Paper roll quality	GSM, coating uniformity, and moisture content	GSM tester, visual inspection	Per batch	QC	To identify effect of raw material variability
3	Misalignment of sealing jaws	Gap and alignment difference (mm)	Vernier / dial gauge	Once per shift	Maintenance	To confirm sealing accuracy
4	Machine speed inconsistency	Variation in cycle speed (cups/min)	Machine data logger	Hourly	Production	To check for unstable operation
5	Machine maintenance frequency	Preventive maintenance performed as per plan	Maintenance record	Weekly	Maintenance	To correlate downtime with defect occurrence
6	Glue viscosity / quality	Viscosity (cP) and brand consistency	Viscosity cup / lab test	Per batch	QC	To ensure sealing quality
7	Operator skill level	Certification / training level	Training record review	Once	HR / Production	To correlate skill with defect %
8	Cup handling during transfer	% cups dropped or damaged during transfer	Observation / tally count	Daily	Line Supervisor	To assess material handling effect
9	Humidity in production area	Relative humidity (%)	Hygrometer reading	Hourly	Production	To correlate environment with sealing performance
10	Operator fatigue	No. of hours worked without break	Shift log	Per shift	HR / Supervisor	To identify fatigue-related variation
11	Machine vibration	Amplitude level (mm/s)	Vibration sensor	Daily	Maintenance	To detect misalignment and wear
12	Batch size (overproduction)	No. of cups produced per batch vs demand	Production record	Per batch	Planner	To control overproduction waste

ANALYSE PHASE



Analyse – Hypothesis testing

Regression Equation

Leakage_% = -4.78 + 1.816 Sealing_Temp_Variation_C + 19.07 Jaw_Misalignment_mm + 0.5646 Machine_Speed_Variation_rpm + 0.001867 Glue_Viscosity_cP

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	-4.78	1.52	-3.14	0.004	
Sealing_Temp_Variation_C	1.816	0.142	12.75	0.000	1.05
Jaw_Misalignment_mm	19.07	1.24	15.42	0.000	1.10
Machine_Speed_Variation_rpm	0.5646	0.0355	15.91	0.000	1.01
Glue_Viscosity_cP	0.001867	0.000661	2.83	0.009	1.15

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.472266	96.93%	96.44%	95.14%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	4	176.253	44.0634	197.56	0.000
Sealing_Temp_Variation_C	1	36.238	36.2383	162.48	0.000
Jaw_Misalignment_mm	1	53.007	53.0073	237.66	0.000
Machine_Speed_Variation_rpm	1	56.464	56.4642	253.16	0.000
Glue_Viscosity_cP	1	1.780	1.7805	7.98	0.009
Error	25	5.576	0.2230		
Total	29	181.829			

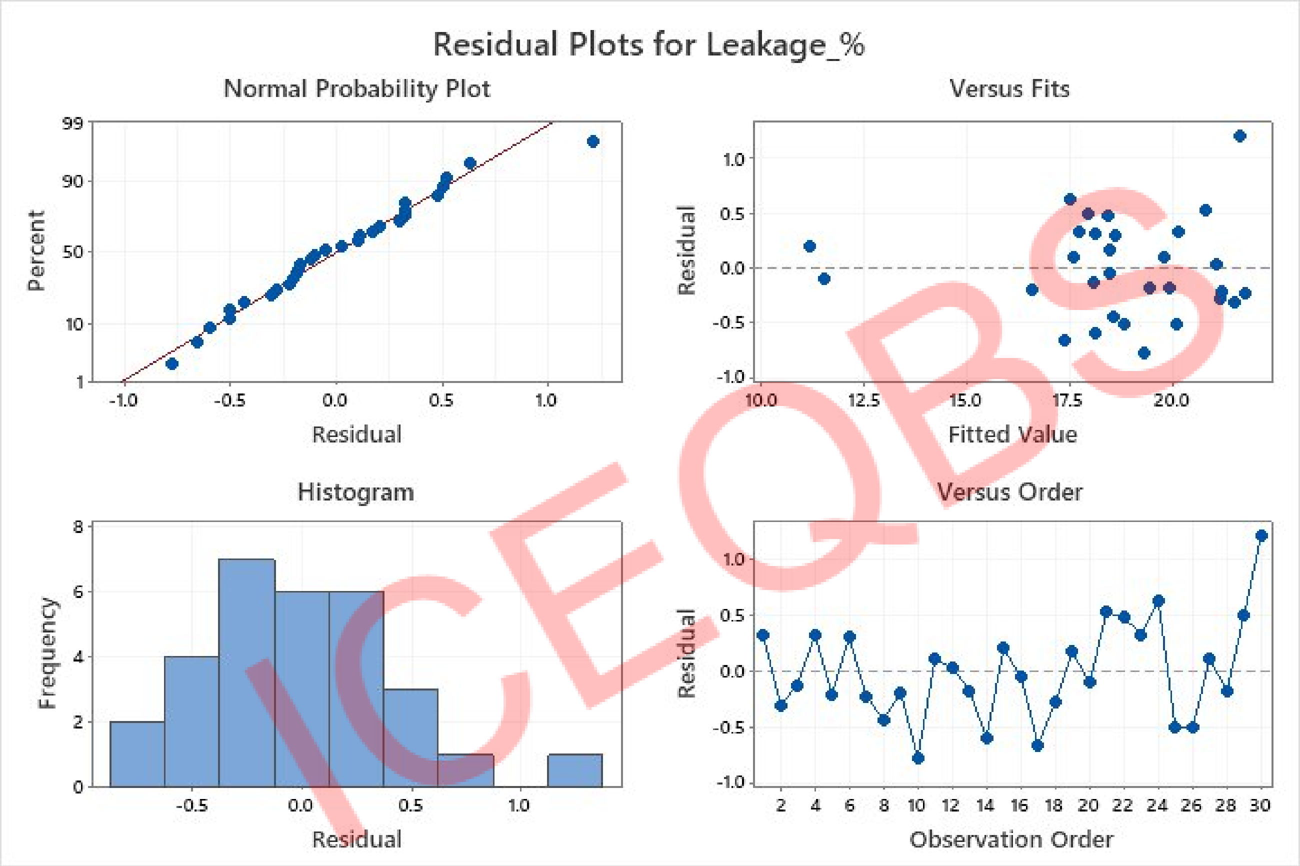
Fits and Diagnostics for Unusual Observations

Obs	Leakage_%	Fit	Resid	Std Resid	
30	22.861	21.650	1.212	3.07	R

Inference :

- Since p < 0.05, thus not all means are equal

Analyse – Hypothesis testing



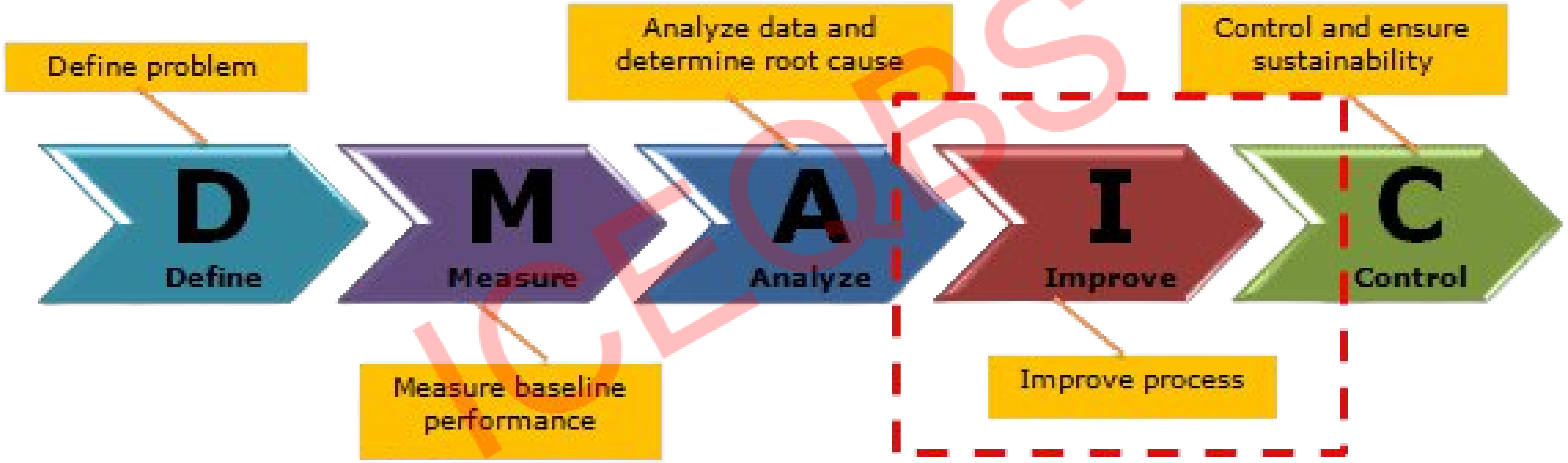
Inference :

•Both plots confirm that the residuals are normal, independent, and random — meaning the model fits the data well, and the underlying assumptions for regression or process analysis are satisfied.

Summary of Statistically validated Root causes

- Sealing Temperature Variation, Jaw Misalignment (Sealing Tool Alignment) and Machine Speed Variation are validated as critical root causes

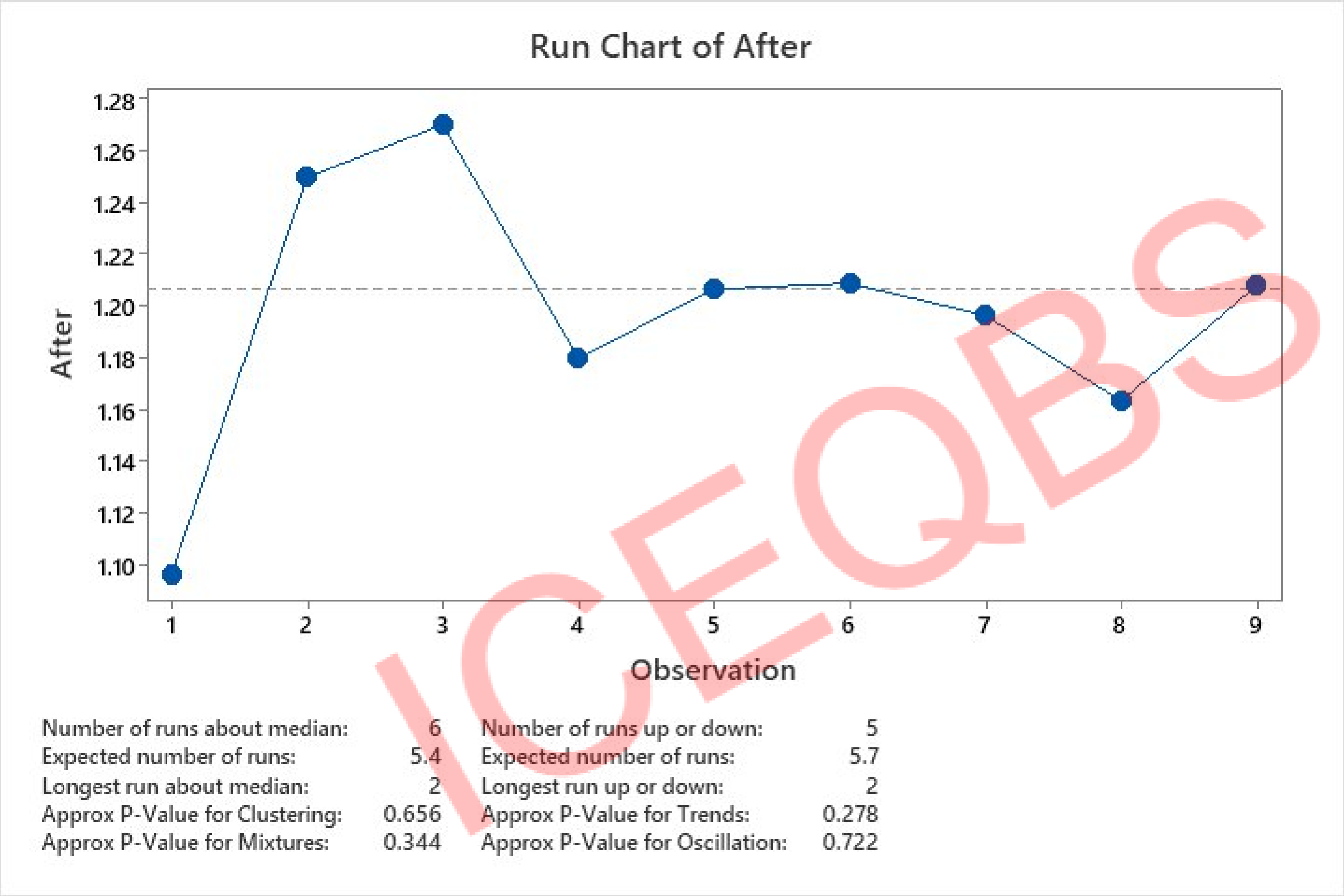
IMPROVE PHASE



Improve

Root Cause	Improvement Action	Responsibility	Timeline
Sealing Temperature Variation	1. Standardize sealing temperature window (DOE to define optimum range). 2. Calibrate temperature sensors monthly. 3. Install temperature display & alarm for deviation ±5°C. 4. Train operators and display visual standards.	Process Engineer / QA / Maintenance	1–3 weeks
Jaw Misalignment (Sealing Tool Alignment)	1. Develop alignment check SOP and define gap tolerance. 2. Include jaw alignment check in daily start-up checklist. 3. Introduce PM schedule for jaw inspection/replacement. 4. Add poka-yoke for correct jaw positioning.	Maintenance / Production / QA	1–4 weeks
Machine Speed Variation	1. Conduct DOE to define optimum speed range for each product. 2. Lock speed control (password or key). 3. Record actual speed vs. leakage % in daily log. 4. Include drive system check in PM schedule.	Production / Maintenance / QA	1–3 weeks
Common Control Actions	1. Update SOPs and parameter sheets. 2. Maintain control charts for Leakage %. 3. Certify operators on “Critical 3 Xs”. 4. Conduct Layered Process Audits weekly.	QA / Production Head	Continuous

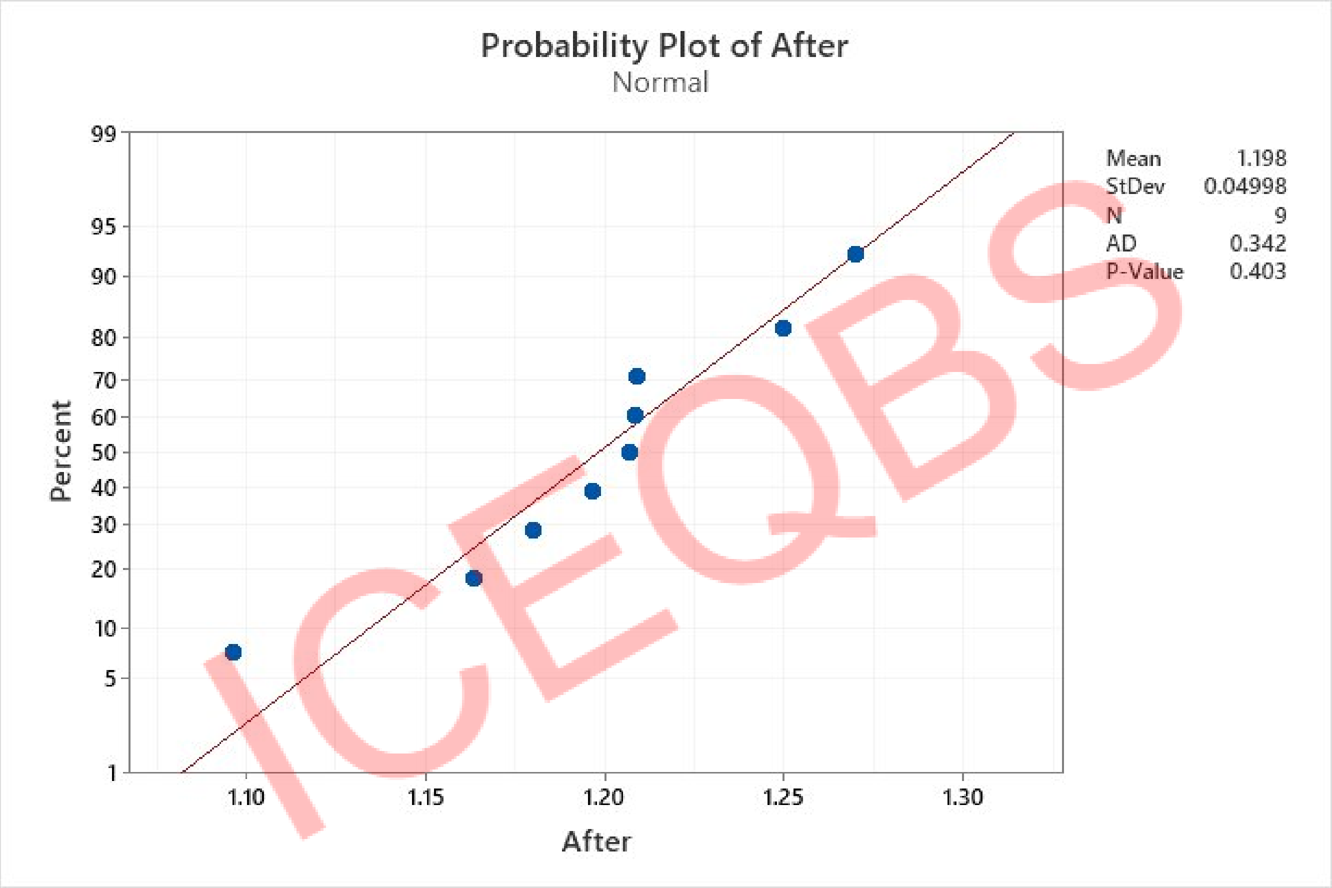
Improve – Run chart and Normality Test (After Improvement)



Inference:

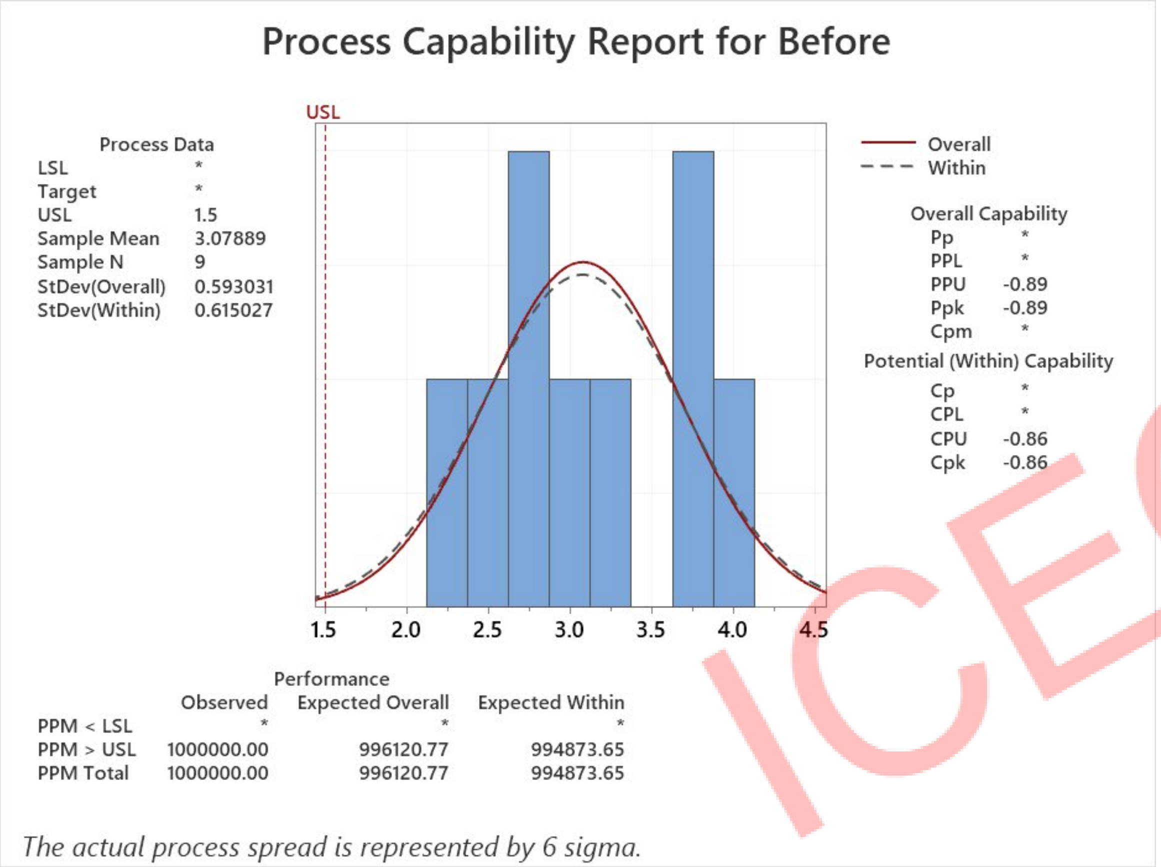
•Run chart – process is stable there is no special causes in the process (p value > 0.05)

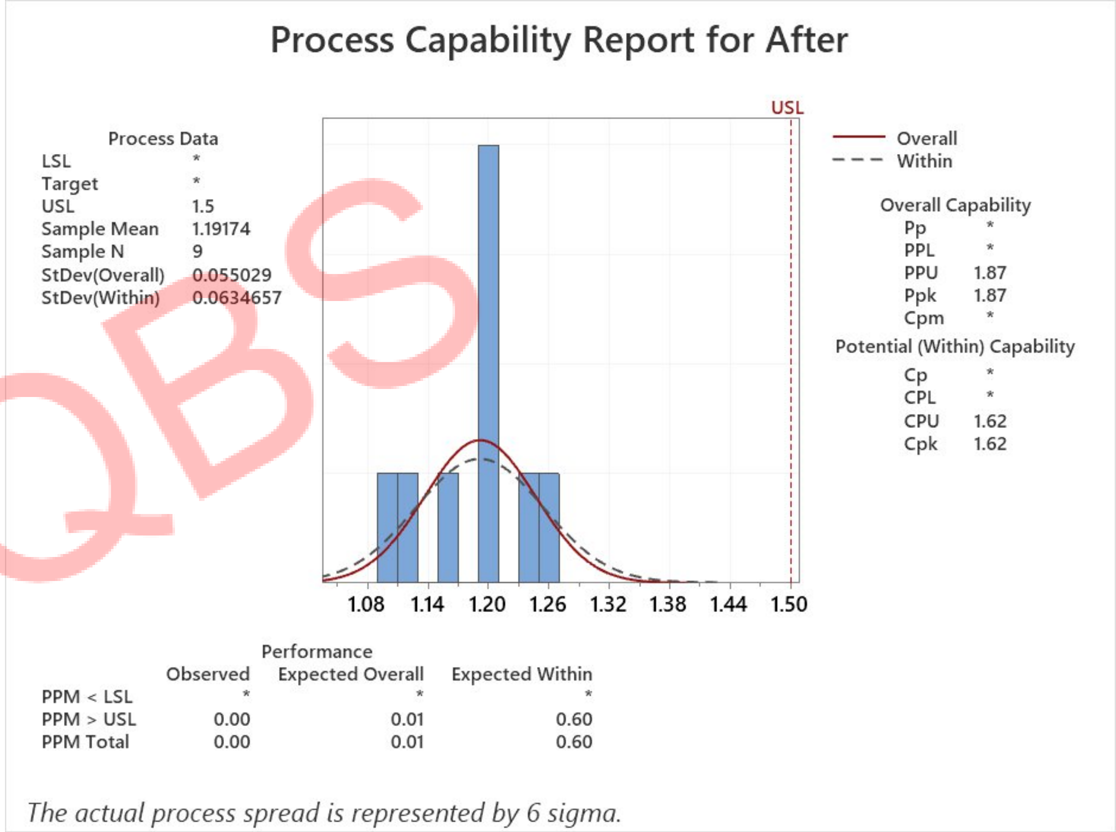
Improve – Run chart and Normality Test (After Improvement)



Inference:
•Normality test – Data are normally distributed

Improve – Process capability – Before & After Improvement





Inference :

- Before Cpk < After Cpk, 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

Improve –After Improvement (Statistical validation for Improvement – Hypothesis Testing)

Two-Sample T-Test and CI: Before, After

μ_1: population mean of Before
μ_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
Before	9	3.079	0.593	0.20
After	9	1.1977	0.0500	0.017

Estimation for Difference

Difference	95% CI for Difference
1.881	(1.424, 2.339)

Test

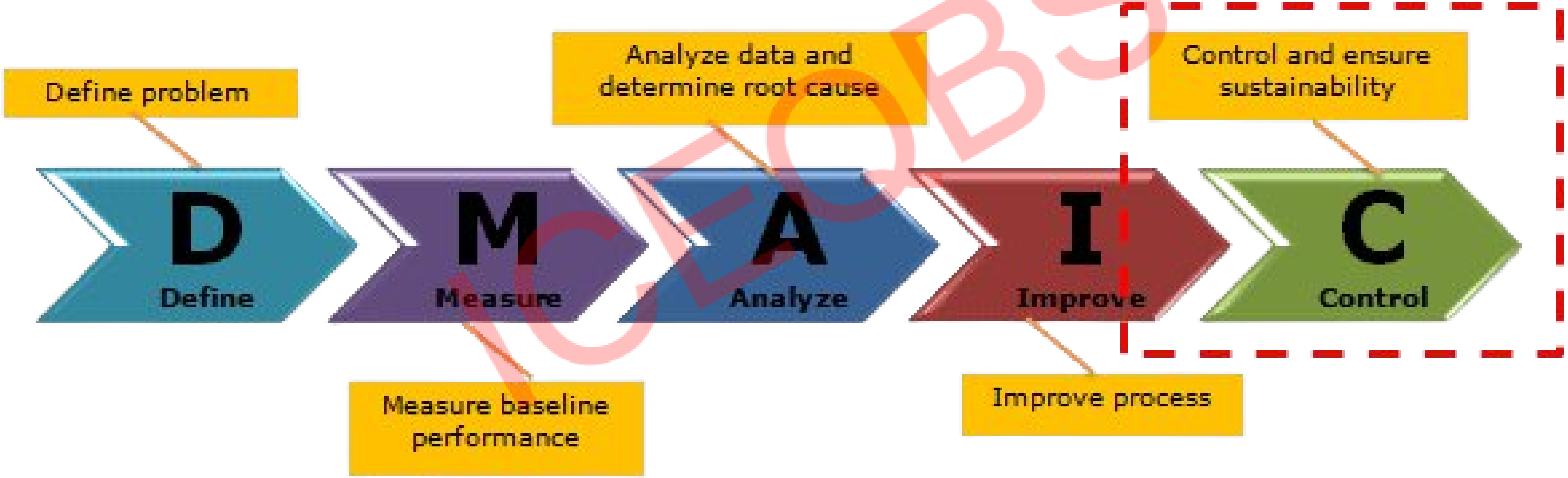
Null hypothesis H_0: $\mu_1 - \mu_2 = 0$
Alternative hypothesis H_1: $\mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
9.48	8	0.000

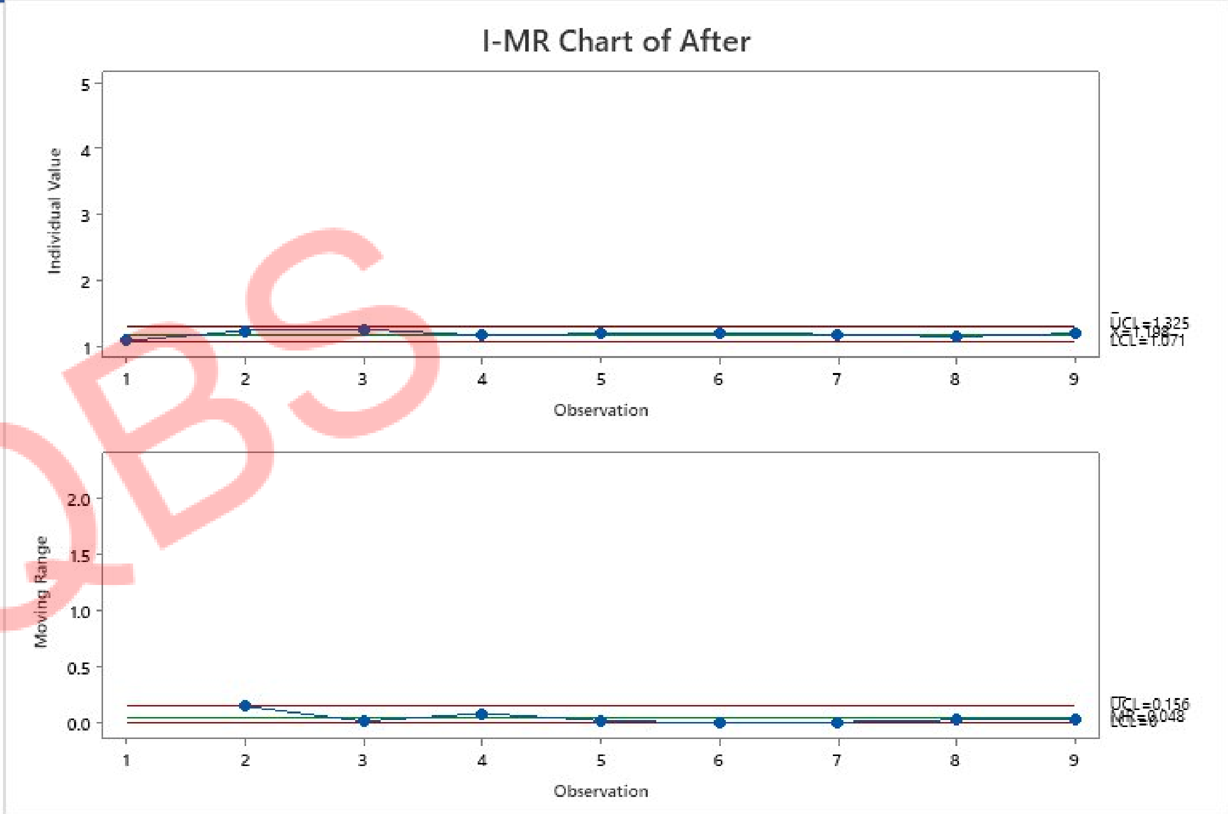
Inference:

- 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 % scrap

CONTROL PHASE



Improve (Statistical validation for Improvement – I-MR Chart)



Inference:

•As seen in control chart, before improvement mean was high and there was high variability. After improvement, it has achieved the desired target

Control Plan

5S Step	Application Area	Key Actions for Sustaining Improvements
1. Sort (Seiri)	Machine area & tool shelves	• Remove unused sealing jaws, tools, or glue containers.• Discard expired glue, damaged paper rolls, and old thermocouples.
2. Set in Order (Seiton)	Machine control panel & workbench	• Color-code temperature controllers and mark standard sealing temperature range.• Designate fixed storage for alignment gauges, torque wrenches, and thermometers.• Create visual layout for sealing machine tools.
3. Shine (Seiso)	Sealing jaws & machine surfaces	• Daily cleaning of sealing jaws to prevent glue or paper dust buildup.• Use a "Clean-Check-Start" tag system before production.• Include visual inspection for misalignment signs during cleaning.
4. Standardize (Seiketsu)	All critical process areas	• Display standard parameter sheets (Temperature, Speed, Pressure) near machines.• Develop visual SOPs showing "OK" vs "Not OK" sealing patterns.• Checklist for PM, cleaning, and start-up inspection.
5. Sustain (Shitsuke)	Operator behavior & audits	• Monthly 5S audit with scoring system.• Reward top-performing lines with "Zero Leakage" recognition.• Conduct refresher training every quarter.

Control Plan

Area	Potential Error	Poka-Yoke Mechanism	Expected Benefit
Sealing Temperature Setting	Wrong temperature input by operator	• Use programmable logic controller (PLC) with preset temperature limits (e.g., 175–185°C).• Password protection for parameter change.	Prevents overheating / underheating leading to leakage.
Jaw Alignment	Misalignment after changeover	• Dowel pins or asymmetrical mounting holes for correct alignment.• Visual alignment indicator mark on both jaws.	Ensures uniform sealing pressure.
Glue Application	Excess or insufficient glue	• Install glue flow sensor or restrictor nozzle with fixed orifice.• Visual indicator for glue level.	Maintains consistent seal bonding.
Machine Speed	Excessive speed change	• Mechanical stopper or VFD password protection to restrict range.• LED indicator for speed out of range.	Ensures adequate sealing time.
Paper Roll Loading	Wrong orientation or damaged roll	• Orientation mark on paper roll core.• Sensor to detect edge tear or roll joint.	Reduces poor seal due to paper misfeed.
Preventive Maintenance	Missed PM schedule	• Tag-based PM reminder or digital alert system.• Machine will not start if PM due not cleared.	Sustains machine stability and repeatability.

Control Plan

Process Step / Change	Potential Failure Mode	Potential Effect(s) of Failure	S (1–10)	Potential Cause(s)	Current Controls	O (1–10)	Detection Method	D (1–10)	RPN	Recommended Action(s)	Responsibility	Target Date
Standardizing sealing temperature window	Operators continue using old temperature settings	Leakage persists / customer complaints	8	Old habits, lack of awareness	Verbal instructions, training	6	Periodic QA checks	6	288	Make parameter sheets mandatory at machine, briefings at shift start, require operator sign-off on new settings	Production Supervisor / QA	2 weeks
Calibration of temperature sensors	Calibration not done as per plan	Incorrect temperature reading; wrong seal strength	9	No calibration schedule, workload, missed reminders	Informal maintenance planning	5	Audit of calibration records	5	225	Create formal calibration plan, use calibration due stickers, include in PM checklist and internal audit	Maintenance Head / QA	1 month
Installing temp/speed alarms & locks	Alarm limits not correctly set or bypassed	Machine runs outside validated window without action	8	Wrong alarm set points, password shared to all	Basic alarm setting by vendor	4	Review alarm logs, occasional audits	6	192	Freeze alarm set points, restrict password to engineer, review alarm history weekly, disciplinary policy for bypass	Process Engineer / Production Head	1 month
Jaw alignment SOP & daily checklist	Alignment check skipped or done superficially	Misaligned jaws → leakage spikes	8	Time pressure, no ownership, checklist becomes paperwork	Paper checklist	6	Random QA/ supervisor audits	5	240	Convert to Layered Process Audit item; checklists to be reviewed and signed by supervisor; link to performance KPI	QA Manager / Line Supervisor	3 weeks
Poka-yoke for jaw mounting	New jaw design not used or incorrectly fitted	Continued misalignment despite new design	7	Operators use old jaws, lack of training	Tool room control	4	Physical inspection during PM	5	140	Scrap / quarantine old jaw designs, train operators on new design, color-code new jaws	Maintenance / Tool Room	1 month

Control Plan

Process Step / Change	Potential Failure Mode	Potential Effect(s) of Failure	S (1–10)	Potential Cause(s)	Current Controls	O (1–10)	Detection Method	D (1–10)	RPN	Recommended Action(s)	Responsibility	Target Date
DOE-based speed & temp settings	DOE results not translated into simple standards	Confusion on correct settings; frequent deviation	7	DOE report too technical, not simplified	Technical report in QA files	5	Only engineer understands settings	7	245	Convert DOE output into simple “Parameter Card” with clear ranges, photos of good/defective seal; train operators	Process Engineer / QA	2 weeks
5S implementation around sealing station	5S deteriorates after initial drive	Tools misplaced, wrong tools used, contamination	6	No regular audit, low management interest	Initial 5S drive only	6	Visual observation, audits (if any)	6	216	Monthly 5S audit with score, display results, simple reward/recognition for best line; assign 5S owner	Production Manager	1–2 months
Data logging of speed, temp & leakage	Data not recorded or recorded inaccurately	No evidence of control, cannot detect drift	7	Manual entry, lack of discipline	Occasional logbook	6	QA review of logbook	6	252	Standard log format, random cross-check (log vs actual display), explore simple digital logging, train on “why”	QA / Supervisors	1 month
Operator training on “Critical 3 Xs”	Inadequate training / no skill certification	Operators don’t understand impact on leakage	8	Rushed induction, no assessment	One-time class	5	Observation, rejections trend	6	240	Formal training module, short written/practical test, create skill matrix, allow only certified operators on critical lines	Training Coordinator / Production Head	1–2 months
Preventive maintenance on drive & jaws	PM not followed; only breakdown maintenance	Speed fluctuation and misalignment recur	9	PM not prioritized, spares not available	Basic PM list	4	PM completion report review	5	180	Lock PM in calendar, track PM completion %, hold monthly review, maintain minimum spares for jaws, belts, sensors	Maintenance Manager	1 month

Sustainment Guidelines

- Maintain **I-MR or P-charts** for Leakage % trend monitoring.
- Conduct **Layered Process Audits** to ensure adherence to settings.
- Include sealing parameters in **Start-up Approval Sheet** for each batch.
- Link operator performance and quality bonus to “Zero Leakage” metric.
- Conduct **monthly review meetings** with QA, Production, and Maintenance.

Conclusion

Results after improvement

- **Project has achieved its intended results after improving Leakage Rate by identifying the variation cause and reducing rejection rate.**