Reduce defects rate in coil brazing process

THEJAS

ROADMAP

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

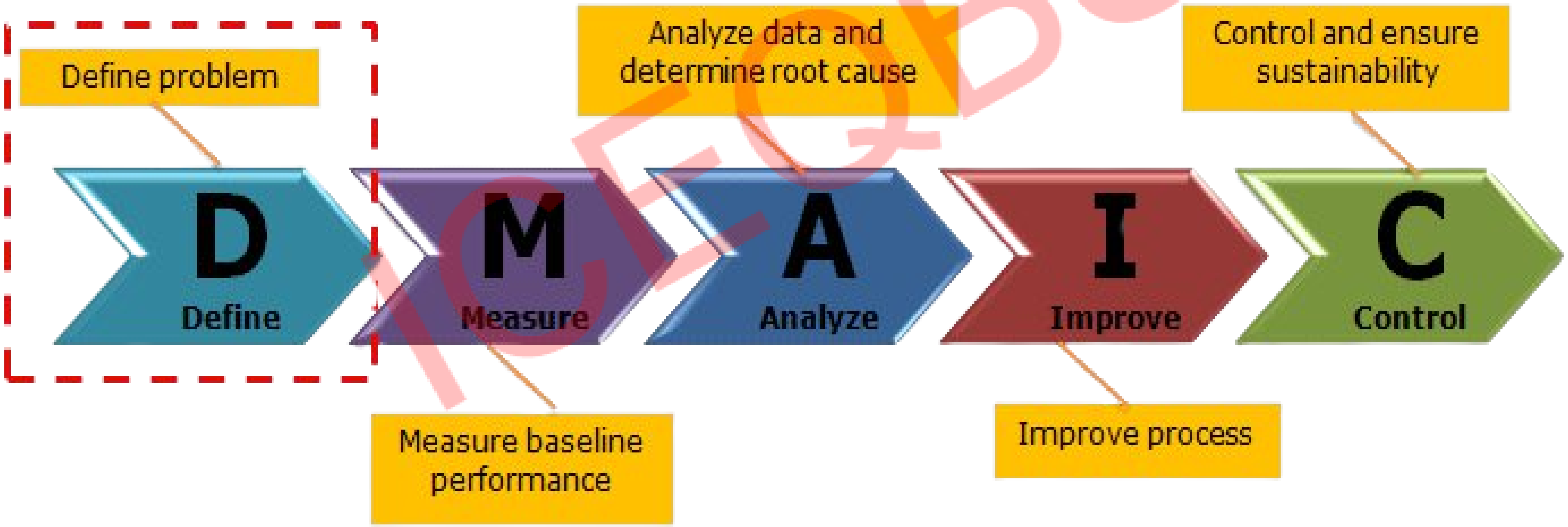
OVERVIEW

Background

The brazing process currently faces quality inconsistencies, high scrap levels, and frequent rework, leading to significant operational losses and customer dissatisfaction. Improving this process is essential to strengthen product reliability, reduce internal failures, and ensure smoother, more predictable production flow. By stabilizing brazing parameters and eliminating sources of variation, the organization can achieve annual savings of approximately $120,000, driven by reductions in rework, scrap, and warranty-related costs.

In addition to financial gains, the project will deliver enhanced productivity through shorter cycle times, improved resource utilization, and a more efficient workflow. Customers will experience improved product quality, resulting in fewer complaints, fewer returns, and higher satisfaction levels. In the long term, this initiative will help establish a robust, repeatable, and stable brazing process that performs consistently across all production shifts, enabling sustainable quality improvement and operational excellence.

DEFINE PHASE

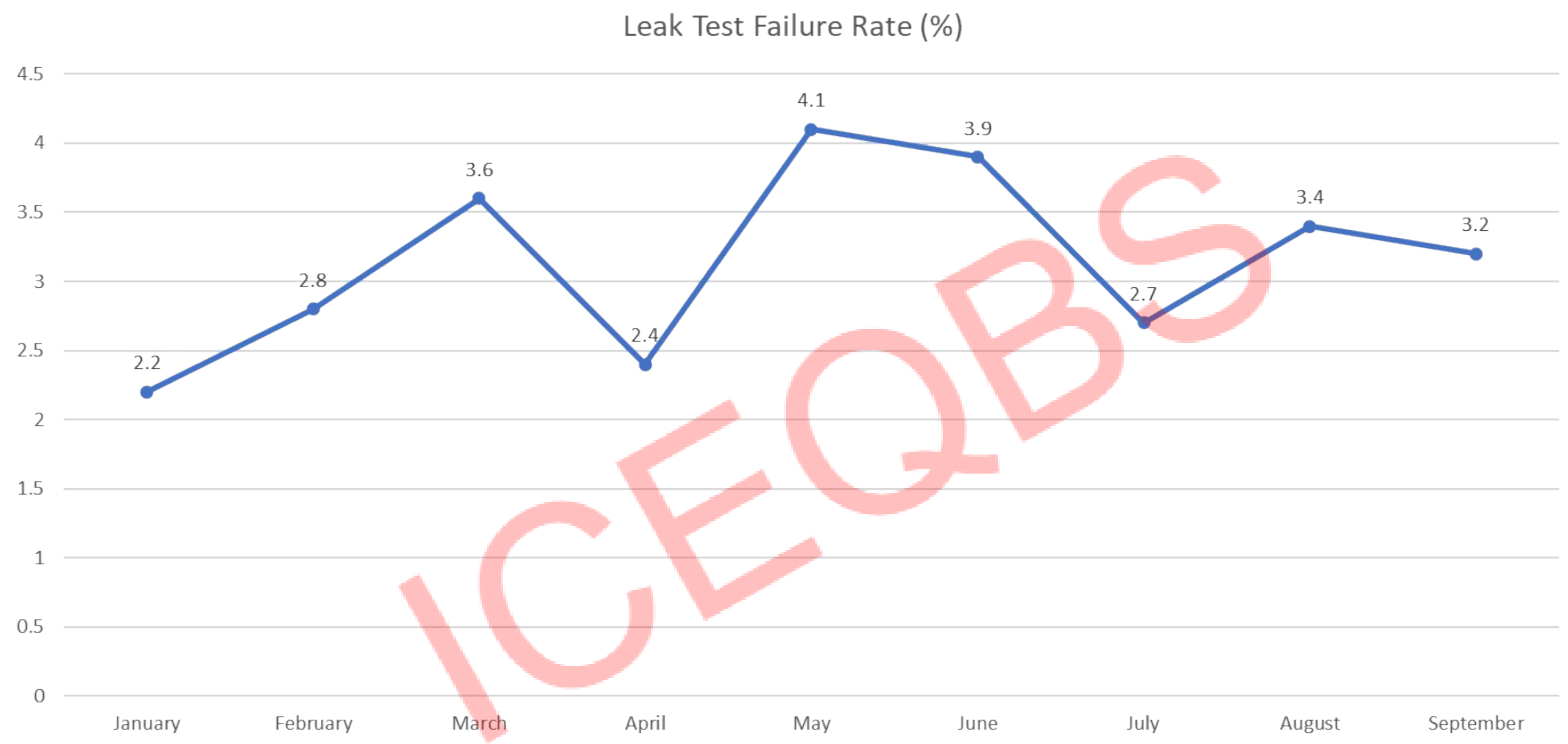


VOC & CTQ

CTQ Tree :

Voice of customer	Critical to X	Primary Metric for improvement
The coil should never leak during product life."	CTC – Cost	**Primar Metric - Leak-free and strong brazed joint** Y = Leak Test Failure Rate (%) **Secondary Metric -** **Rework Rate (%)**

Baseline Performance of Primary Metric (9 months data as Line chart)



Inference :

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

Pareto chart

Inference :

- Brazing Process contributes substantially and included in the scope of the project

SIPOC

Suppliers	Inputs	Process Steps	Outputs	Customers
Copper tube supplier	Copper tubes	Preparation Of Raw Material: Arrange Fins & Cu Tube as per the job requirements.	Brazed HVAC coils	HVAC assembly line
Aluminum, Cu fin supplier	Aluminum/Cu fins	Coil Assembly & Expansion: Arranging of the coil casing, lacing the coils and expansion.	Leak test results	Quality Assurance department
Brazing rod supplier	Brazing filler rod	Brazing Operation: Perform brazing using torch and filler rod	Inspection reports	End customers (OEMs, Distributors)
Compressed gas supplier (O_2, N_2)	Gas supply for brazing (O2,N2)	Leak Testing: Perform pressure/leak test for joint integrity.	Process records	
Maintenance team	Brazing torch or automated brazing machine	Inspection & Tagging: Inspect joints visually, check coil dimensions and label accepted units.		
Trained operators	Standard Operating Procedure (SOP)	Record & Dispatch: Document process data and move coils to next stage.		
	Quality checklist			

Project Charter

Project Title:	Reduce defects rate in coil brazing process

Project Leader	Project Team Members:
Thejas	Ms. Priya Nair Mr. Arjun Patel Mr. Sanjay Mehta Ms. Kavita Desai
Champion/Sponsors:	**Key Stake Holders**
Mr. Rakesh Sharma - Plant Head	Production / Brazing Technicians Quality Team Maintenance Team Production Manager / Plant Manager
Problem Statement:	**Goal Statement:**
The current coil brazing process in the HVAC coil manufacturing line shows a high defect rate and inconsistent brazing quality. Over the past six months:	The goal of this Six Sigma project is to: **Reduce brazing defects from 3.2% to ≤1%** within six months. **Reduce rework time by 30%.** **Improve process yield by 10%.**
Secondary Metric	**Assumptions Made:**
Rework Rate	Material and component specifications remain consistent during the project. No major equipment upgrades or tooling changes will occur.

Project Charter

Tangible and Intangible Benefits:

Reduced rework and scrap costs.
Lower warranty claims and improved productivity.
Higher customer satisfaction (fewer complaints/returns).
More stable, repeatable brazing process across shifts.

Risk to Success:

Operator variability in brazing technique.
Inconsistent equipment heating performance.
Unplanned machine downtime.

In Scope:

Brazing process parameters, setup, and operator methods.
Defect reduction, rework analysis, and cycle time improvement.

Out of Scope:

Upstream machining or downstream finishing processes.
Supplier-related material quality improvement activities.

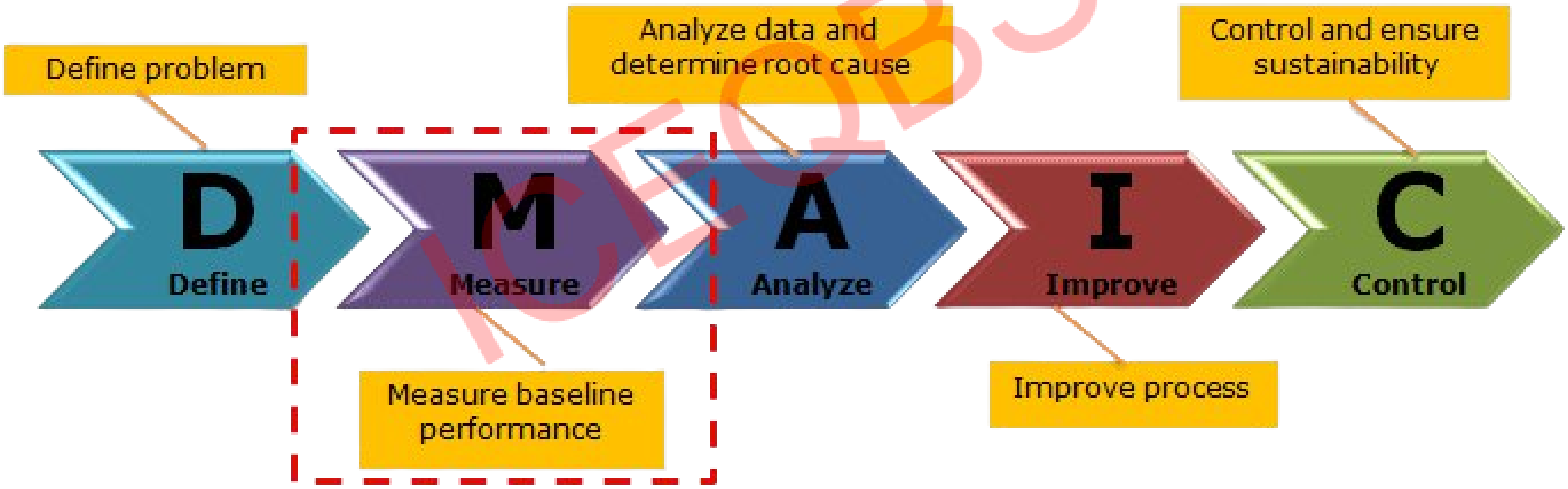
Signatories:

Project Sponsor – Mr. Rakesh Sharma
Finance – MS Neha Gupta

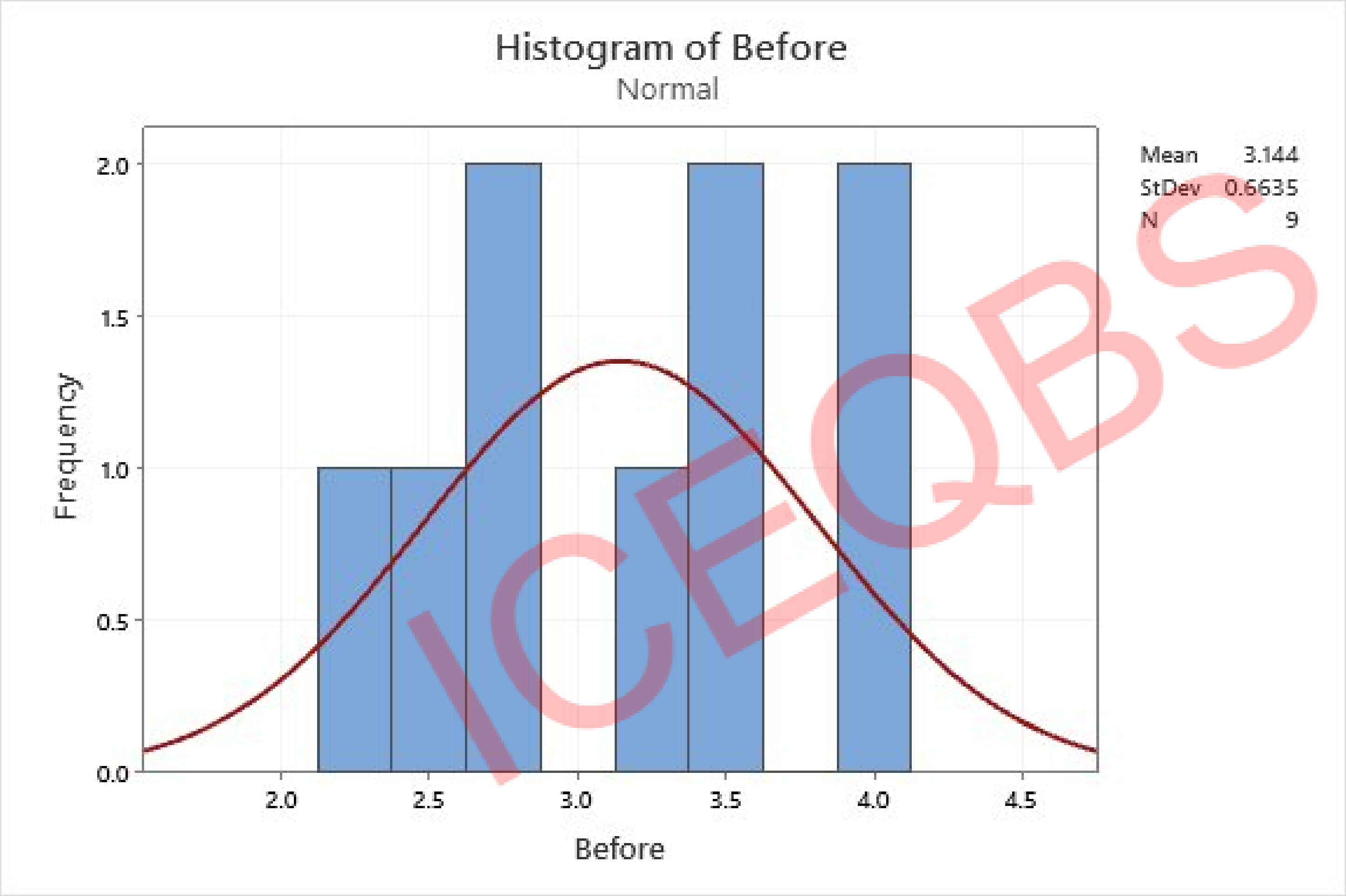
Project Timeline:

6 Months

MEASURE PHASE



Data collection – Histogram (Before improvement)



Inference :

- Data is normally distributed over the mean

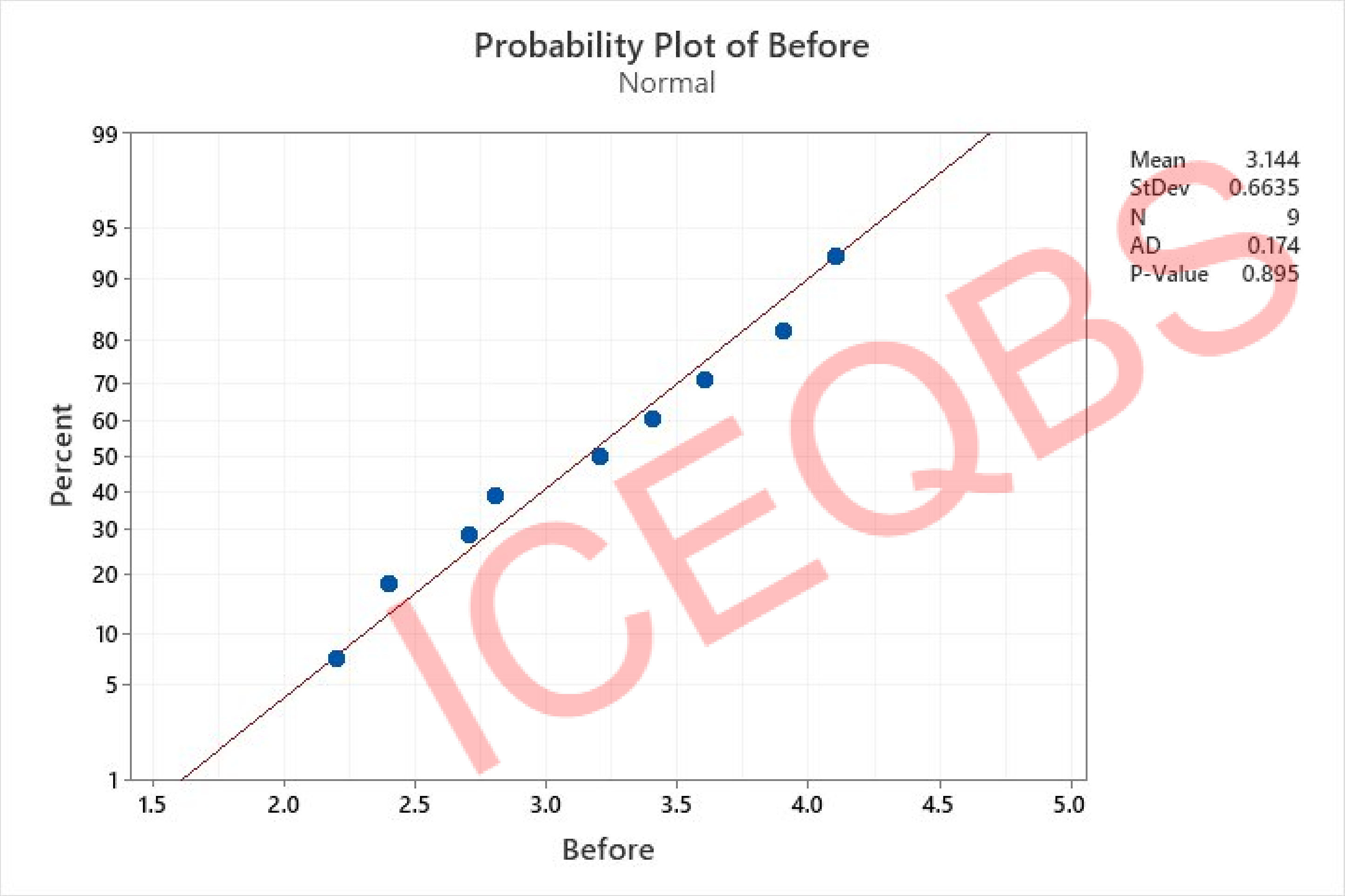
Data collection – Run Chart (Before improvement)

Number of runs about median:	7	Number of runs up or down:	6
Expected number of runs:	5.4	Expected number of runs:	5.7
Longest run about median:	2	Longest run up or down:	2
Approx P-Value for Clustering:	0.870	Approx P-Value for Trends:	0.616
Approx P-Value for Mixtures:	0.130	Approx P-Value for Oscillation:	0.384

Inference :

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

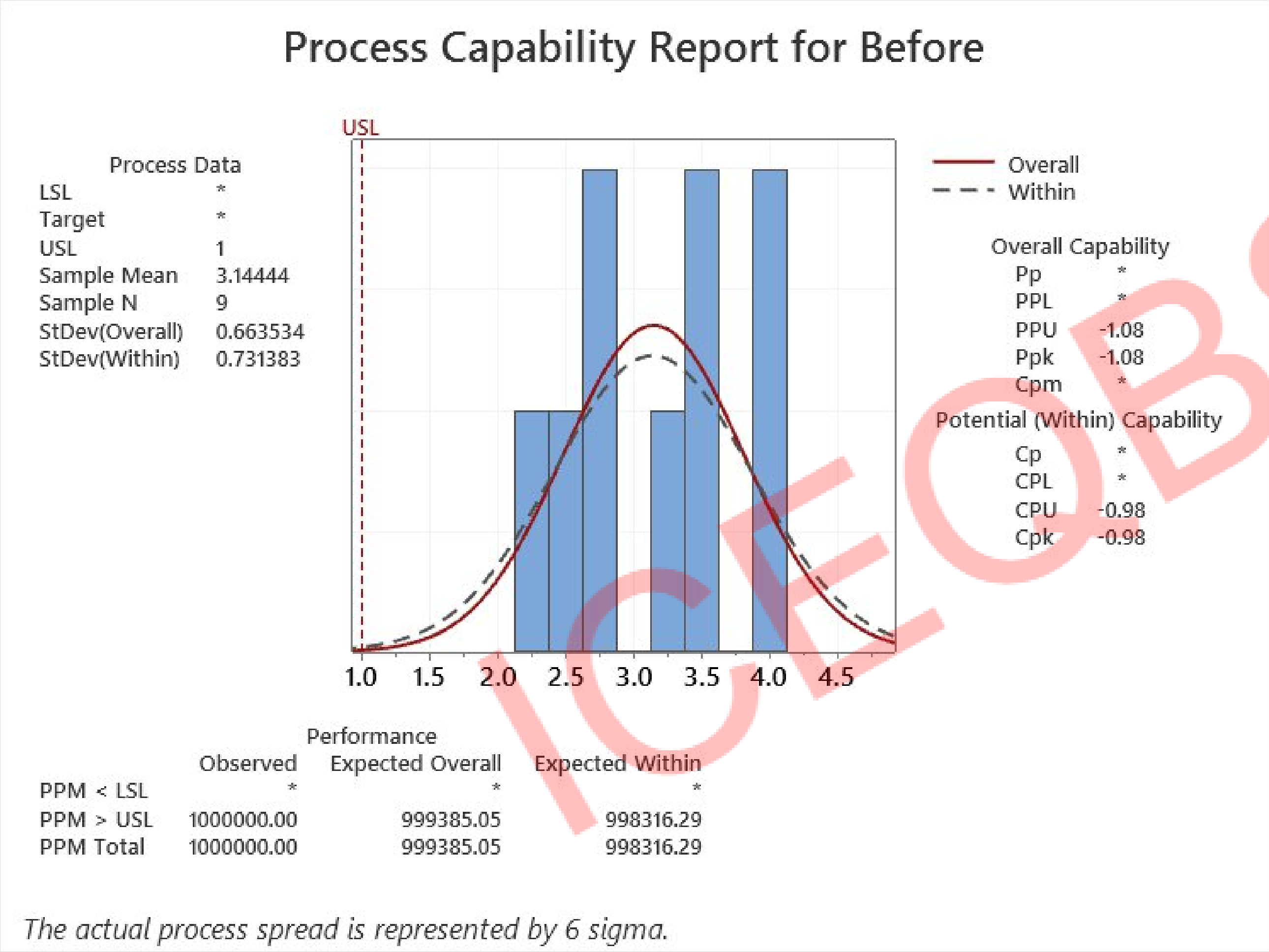
Data collection – Normality plot (Before improvement)



Inference :

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

Data collection – Normality plot (Before improvement)



Inference :

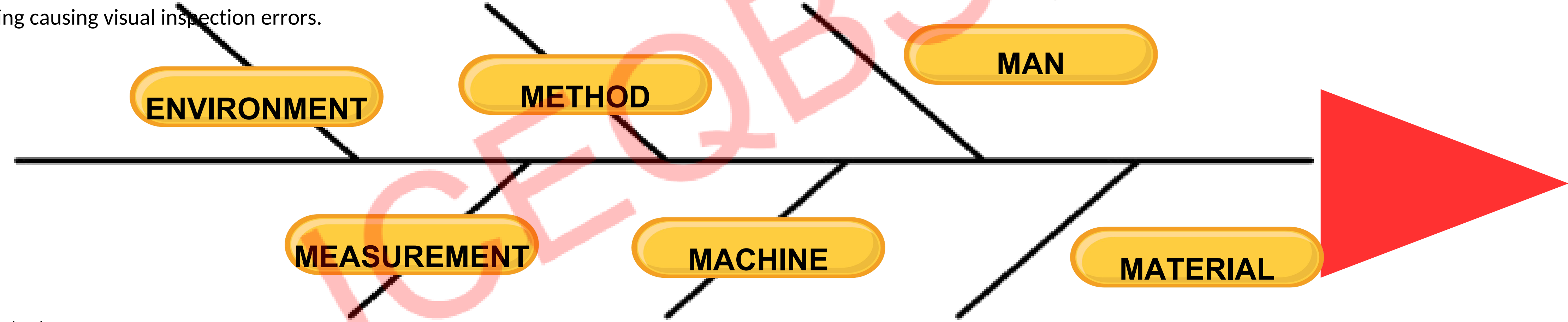
- The process is not capable, as the mean is too close to the USL and both Ppk and Cpk are negative, indicating the process is performing poorly and producing high defects.

Fish Bone Diagram

1. High humidity affecting flux performance.
2. Poor ventilation causing contamination or incomplete combustion.
3. Ambient temperature fluctuations impacting brazing heat consistency.
4. Inadequate lighting causing visual inspection errors.

1. No standardized SOP for brazing parameters (temperature/time).
2. Variation in pre-heating or cooling times.
3. Inconsistent joint gap due to manual assembly.
4. Lack of visual control or process checkpoints.

1. Inconsistent brazing skill levels among operators.
2. Inadequate training on brazing temperature and technique.
3. Operator fatigue due to long working hours.
4. No standardized feedback or error-reporting system



1. Inaccurate leak test pressure gauges.
2. Lack of real-time monitoring of brazing temperature.
3. Inconsistent inspection criteria among shifts.
4. Manual recording errors in process data.

1. Gas torch pressure variation due to regulator malfunction.
2. Poor maintenance or calibration of brazing equipment.
3. Worn-out nozzles causing uneven flame.
4. Inconsistent gas flow leading to non-uniform heating.

1. Variation in copper tube wall thickness.
2. Poor surface cleanliness (oxidation, oil residues).
3. Inconsistent quality of brazing filler rod or flux.
4. Use of incompatible filler alloy for base materials.

Data collection – Normality plot (Before improvement)

Common Causes

- Operator skill variation
- Inadequate training
- Operator fatigue
- Poor equipment maintenance
- Worn nozzles
- Inconsistent gas flow
- Misaligned fixtures
- Tube thickness variation
- Surface contamination
- Poor filler quality
- Uneven preheating
- Lack of visual control

Special Causes

- Gas pressure variation
- Incompatible alloy
- No standard SOP
- No rework protocol
- No feedback system
- No defect trend tracking
- Temperature fluctuations

3M Analysis for Waste

MUDA

- Rework of leaking joints due to poor brazing quality.
- Excessive flux usage leading to unnecessary cleaning time and material waste.
- Waiting time for equipment availability or gas cylinder replacement

MURA

- Inconsistent heating times between operators or shifts causing variable joint strength.
- Fluctuating gas flow rates leading to uneven brazing temperature.
- Variation in inspection standards across quality inspectors or shifts.

MURI

- Operators working long hours without rotation, leading to fatigue and mistakes.
- Equipment overused without preventive maintenance, causing performance drops.
- Excessive production targets pressuring operators to rush and skip standard steps.

8 Wastes Analysis

Defects	• Leaking joints requiring rework. • Weak brazed joints failing leak tests.
Overproduction	• Producing coils in excess of current demand. • Brazing more coils than the inspection capacity allows.
Waiting	• Operators waiting for gas cylinder replacement. • Waiting for brazing fixtures or equipment to become available.
Non-Utilized Talent	• Skilled operators not involved in process improvement suggestions. • Operator expertise ignored in troubleshooting recurring defects.
Transportation	• Moving coils unnecessarily between workstations. • Transporting coils to separate storage for rework.
Inventory	• Excess raw copper tubes and aluminum fins stored. • Large stock of filler rods and flux sitting idle
Motion	• Operators bending or reaching repeatedly to access flux or tools. • Excessive movement to adjust brazing torch or fixtures manually.
Overprocessing	• Multiple cleaning steps due to excessive flux application. • Repeated inspections caused by inconsistent joint quality.

Action Plan for Low Hanging Fruits

Special Causes (sudden failures / abnormalities)

Identified Issue / Special Cause	Lean Tool / Approach	Action	Expected Benefit / KPI
Gas pressure variation	5S + Kaizen	Calibrate gas regulators and standardize pressure settings	Reduce defect rate from leaks; improve consistency
Moisture in flux	5S / Visual Management	Store flux in sealed containers with humidity indicators	Minimize rework; ensure consistent brazing
Incompatible alloy	Standard Work / SOP	Validate filler metal type before production	Avoid rejects and warranty claims
No standard SOP	Standard Work / Kaizen	Develop and display SOP with step-by-step instructions at workstations	Reduce operator variation; improve quality
No feedback system	PDCA / Visual Management	Implement daily operator feedback log for defects	Early detection of recurring issues; faster problem-solving
No defect trend tracking	Visual Management / Control Charts	Record defects daily and plot trend for quick analysis	Track improvement; highlight process deviations

Action Plan for Low Hanging Fruits

Muda (Waste)

Waste Type	Lean Tool	Action Plan	Benefit
Rework of leaking joints	Kaizen / 5S	Optimize brazing process and operator training	Reduce scrap and rework costs
Excessive flux usage	5S / Standard Work	Visual flux indicators for correct quantity	Reduce material waste and cleaning time

Mura (Unevenness)

Issue	Lean Tool	Action Plan	Benefit
Inconsistent heating times	Standard Work / SOP	Define target heating time per coil type; use timer	Improve quality consistency
Fluctuating gas flow	Poka-Yoke / Standard Work	Install flow regulator; train operators	Stabilize brazing temperature; reduce defects

Muri (Overburden)

Issue	Lean Tool	Action Plan	Benefit
Operator fatigue	Job Rotation / Standard Work	Rotate operators and set realistic targets	Reduce errors; improve ergonomics
Overused equipment	Preventive Maintenance / 5S	Schedule routine maintenance and inspections	Reduce breakdowns; maintain quality

Action Plan for Low Hanging Fruits

Waste		Lean Tool	Action Plan	Benefit
Defects	Poka-Yoke / SOP	Implement visual defect checks	Reduce rework and scrap	High
Overproduction	Kanban / Just-in-Time	Produce based on actual demand	Reduce inventory and handling	Medium
Waiting	SMED / 5S	Pre-stage tools and materials	Reduce idle time	High
Non-Utilized Talent	Kaizen / Suggestion System	Involve operators in improvement ideas	Increase engagement; faster problem-solving	Medium
Transportation	Layout Optimization / 5S	Rearrange workstations to minimize movement	Reduce motion waste and handling time	Medium
Inventory	Kanban / JIT	Maintain minimum raw material stock	Reduce storage costs and waste	Medium
Motion	5S / Standard Work	Organize tools within easy reach	Reduce operator fatigue and cycle time	Medium
Extra Processing	Standard Work / SOP	Reduce unnecessary cleaning and inspections	Reduce cycle time and labor	High

Top 12 Prioritized Root Causes (Based on Net Score)

Root Cause	Score
SOP availability / standardization	**261**
Operator brazing skill	**225**
Joint gap consistency	**225**
Heating time control	**225**
Fixture alignment accuracy	**225**
Gas pressure variation	**216**
Copper tube cleanliness	**216**
Equipment maintenance frequency	**216**
Gas flow regulator calibration	**216**
Flux quality (moisture content)	**177**
Flux application amount	**177**
Flux storage method	**153**

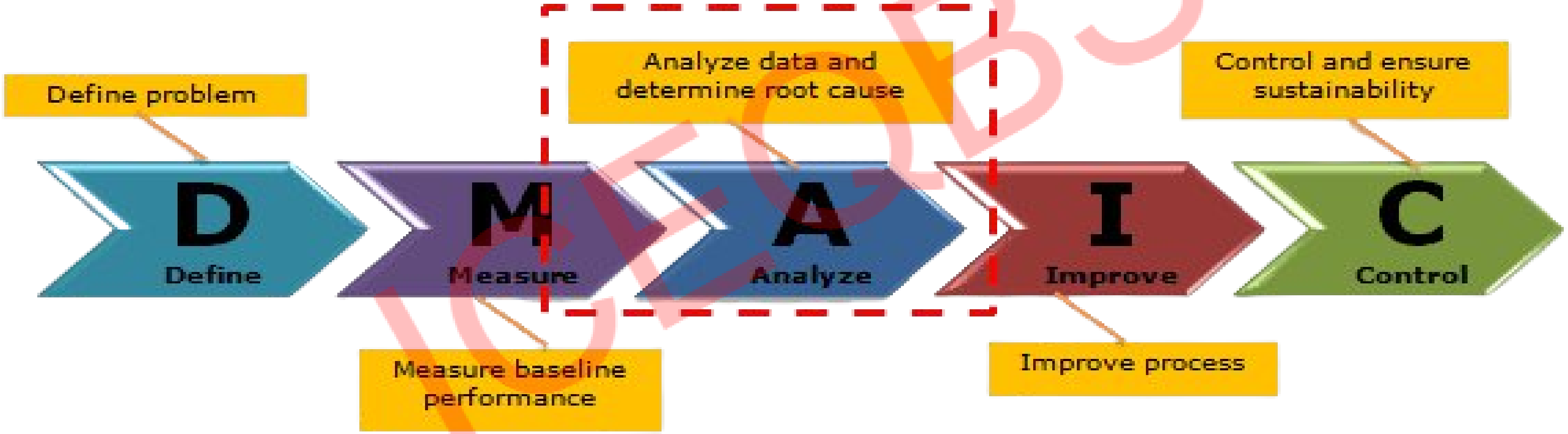
Key Process Outputs (CTQs

Output / CTQ	Operational Definition	Measurement Method
Leak-free joints	% of coils passing leak test	Leak test under pressure
Joint strength	Pull test force on brazed joint	Tensile testing machine
Cycle time	Time to complete one brazing operation	Stopwatch / timer
Visual joint quality	No visible porosity, under fill, or excessive flux residue	Visual inspection checklist
Rework rate	% of joints re-brazed or repaired	Production records

Data Collection Plan

No.	Input Variable (X)	Operational Definition	Data Type	Measurement Method / Tool
1	Gas pressure variation	Variation in brazing torch gas pressure	Continuous	Pressure gauge reading
2	Operator brazing skill	Level of operator performance based on qualification & audit score	Discrete	Skill assessment form
3	Joint gap consistency	Gap distance between tube & fin before brazing	Continuous	Feeler gauge / micrometer
4	Heating time control	Time torch is applied per joint	Continuous	Stopwatch / timer
5	Fixture alignment accuracy	Alignment tolerance of coil during brazing	Continuous	Dial gauge / fixture check
6	Equipment maintenance frequency	Number of preventive maintenance tasks completed as scheduled	Attribute	Maintenance log
7	Gas flow regulator calibration	Calibration status and deviation in flow	Continuous	Calibration report
8	Flux quality (moisture content)	Moisture % in flux	Continuous	Moisture meter / lab test
9	Flux application amount	Quantity of flux applied per joint	Continuous	Weight before/after application
10	SOP availability / standardization	Presence and use of SOP at workstation	Attribute	Checklist audit
11	Copper tube cleanliness	Presence of oil or oxidation film	Attribute	Surface cleanliness test
12	Ambient humidity	Humidity level in brazing area	Continuous	Hygrometer

ANALYSE PHASE



Analyse – Hypothesis testing

Regression Equation

Scrap_Percentage = 8.821 - 0.04829 Operator_Brazing_Skill_Score + 5.395 Joint_Gap_Consistency_mm + 0.0797 Heating_Time_Control_sec

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	8.821	0.709	12.43	0.000	
Operator_Brazing_Skill_Score	-0.04829	0.00551	-8.77	0.000	1.00
Joint_Gap_Consistency_mm	5.395	0.571	9.45	0.000	1.05
Heating_Time_Control_sec	0.0797	0.0198	4.03	0.000	1.05

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.506726	86.84%	85.57%	82.30%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	52.525	17.5083	68.19	0.000
Operator_Brazing_Skill_Score	1	19.743	19.7432	76.89	0.000
Joint_Gap_Consistency_mm	1	22.947	22.9475	89.37	0.000
Heating_Time_Control_sec	1	4.165	4.1645	16.22	0.000
Error	31	7.960	0.2568		
Total	34	60.485			

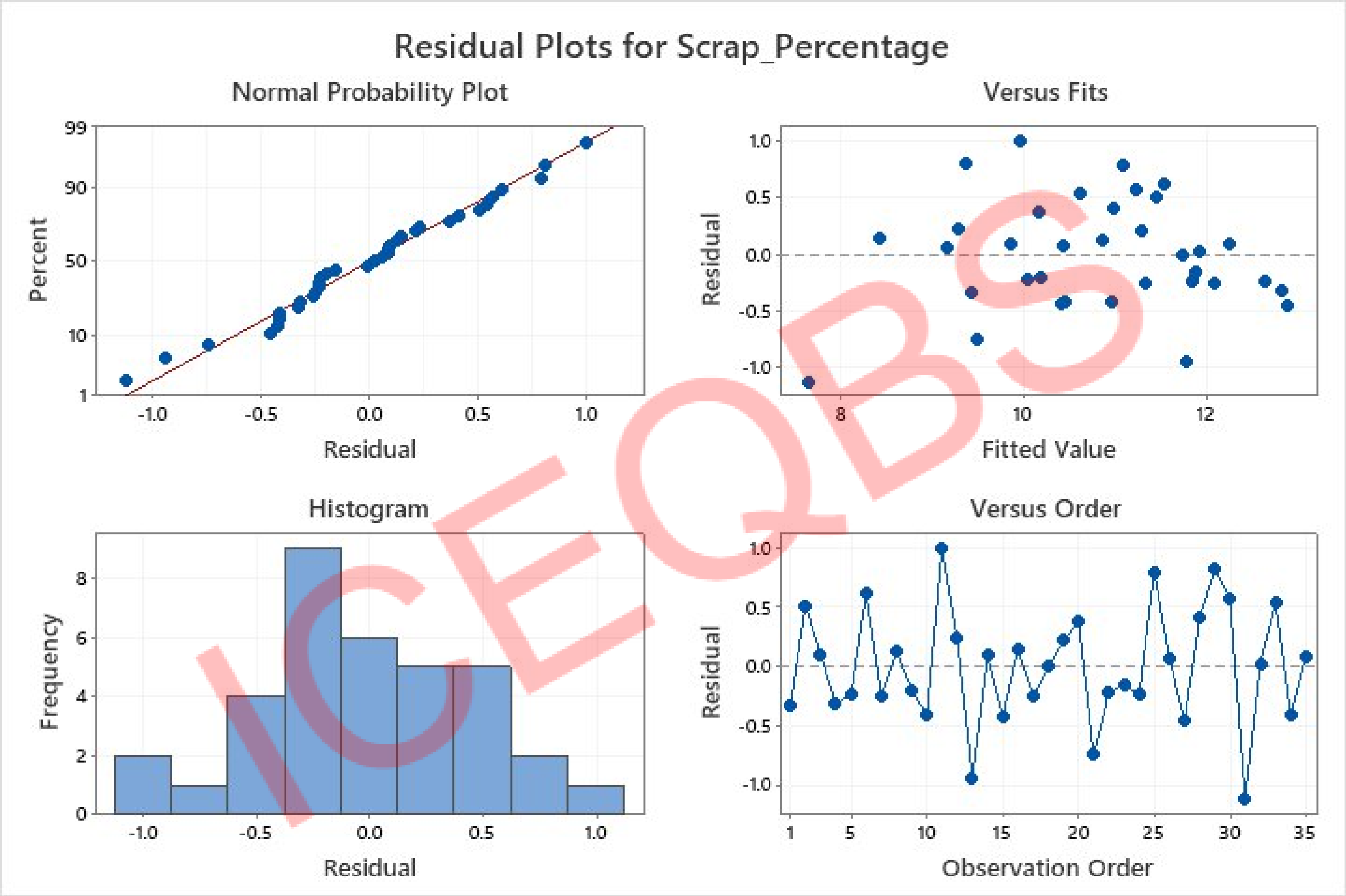
Fits and Diagnostics for Unusual Observations

Obs	Scrap_Percentage	Fit	Resid	Std Resid	
11	10.958	9.962	0.996	2.04	R
31	6.526	7.644	-1.118	-2.50	R

Inference :

- All three factors significantly affect scrap percentage, with high R^2 (86%) showing the model strongly explains scrap, and operator skill and joint gap consistency being the strongest contributors.

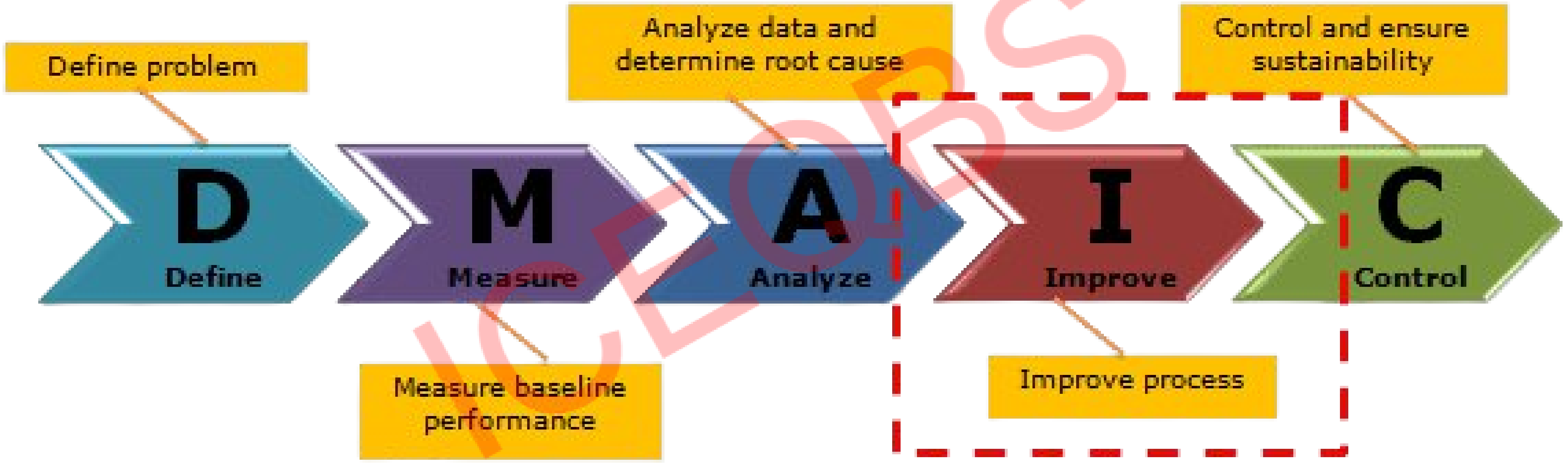
Analyse – Hypothesis testing



Inference :

The residual plots show a good model fit, with residuals appearing random, approximately normal, and showing no patterns or trends—indicating the regression model is valid

IMPROVE PHASE



Improve Design of Experiment

RunOrder	CenterPt	Blocks	Brazing skill	Joint gap consistency	Heating time	% scrap	FITS1	RESI1
1	0	1	82.5	0.55	29	2.74	2.60	0.13
2	1	1	95	0.7	32	3.31	3.22	0.09
3	1	1	95	0.4	32	1.45	1.54	-0.09
4	1	1	70	0.7	26	3.57	3.66	-0.09
5	1	1	70	0.7	32	4.30	4.30	-0.01
6	0	1	82.5	0.55	29	2.60	2.60	0.00
7	1	1	95	0.7	26	2.49	2.58	-0.08
8	1	1	70	0.4	26	2.07	1.98	0.09
9	1	1	95	0.4	26	0.89	0.90	0.00
10	1	1	70	0.4	32	2.54	2.62	-0.08
11	0	1	82.5	0.55	29	2.65	2.60	0.05

Improve

Factorial Regression: % scrap versus Brazing skill, Joint gap consistency, Heating time, CenterPt

Backward Elimination of Terms

α to remove = 0.05

Coded Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		2.6006	0.0296	87.90	0.000	
Brazing skill	-1.0845	-0.5423	0.0347	-15.63	0.000	1.00
Joint gap consistency	1.6805	0.8402	0.0347	24.22	0.000	1.00
Heating time	0.6430	0.3215	0.0347	9.27	0.000	1.00

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0981250	99.24%	98.92%	97.87%

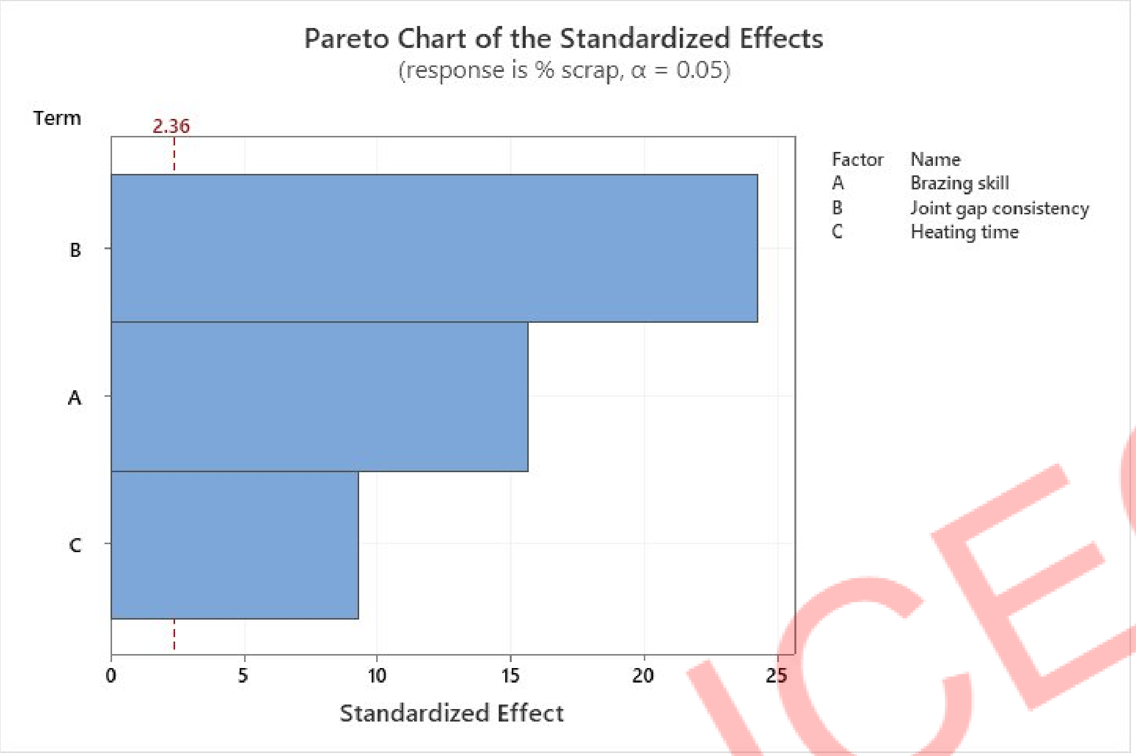
Improve

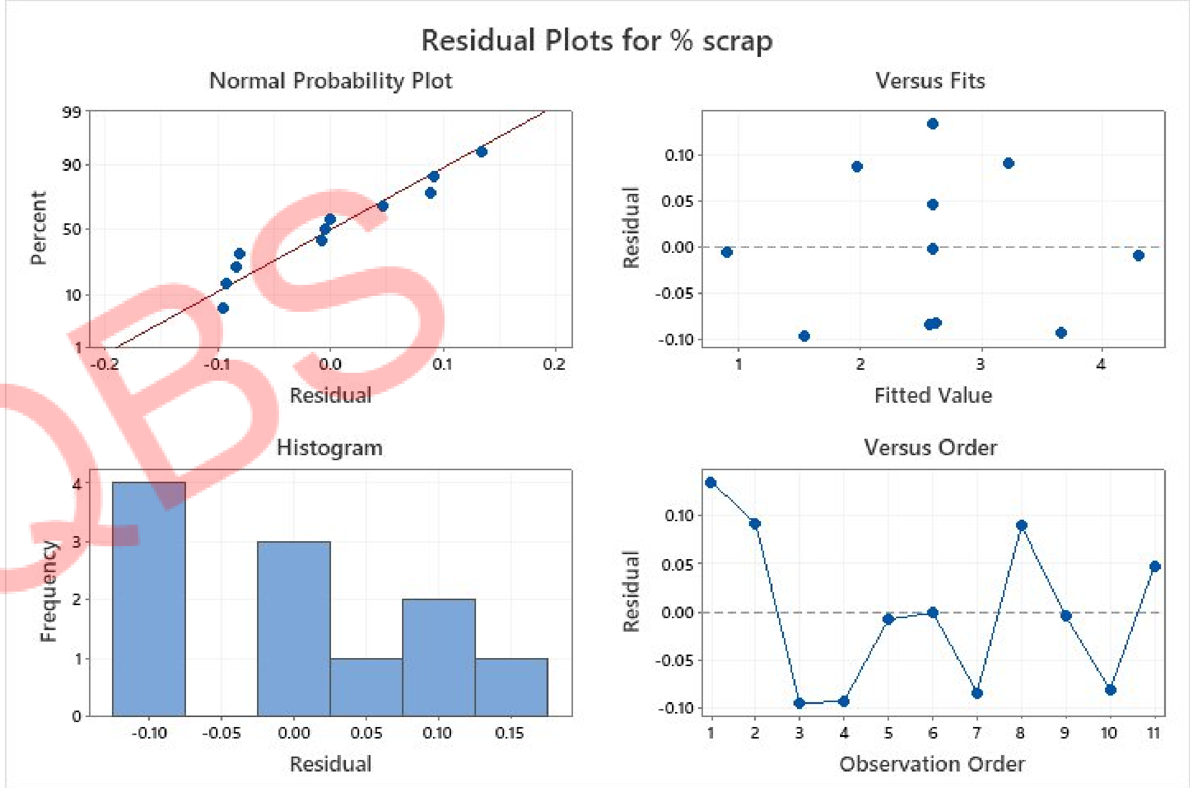
Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	3	8.82734	2.94245	305.60	0.000
Linear	3	8.82734	2.94245	305.60	0.000
Brazing skill	1	2.35228	2.35228	244.30	0.000
Joint gap consistency	1	5.64816	5.64816	586.61	0.000
Heating time	1	0.82690	0.82690	85.88	0.000
Error	7	0.06740	0.00963		
Curvature	1	0.01503	0.01503	1.72	0.237
Lack-of-Fit	4	0.04300	0.01075	2.30	0.326
Pure Error	2	0.00937	0.00468		
Total	10	8.89474			

Inference :
All three factors—brazing skill, joint gap consistency, and heating time—are highly significant and explain almost all variation in scrap ($R^2 \approx 99\%$), confirming a strong, reliable factorial model with no lack-of-fit issues.

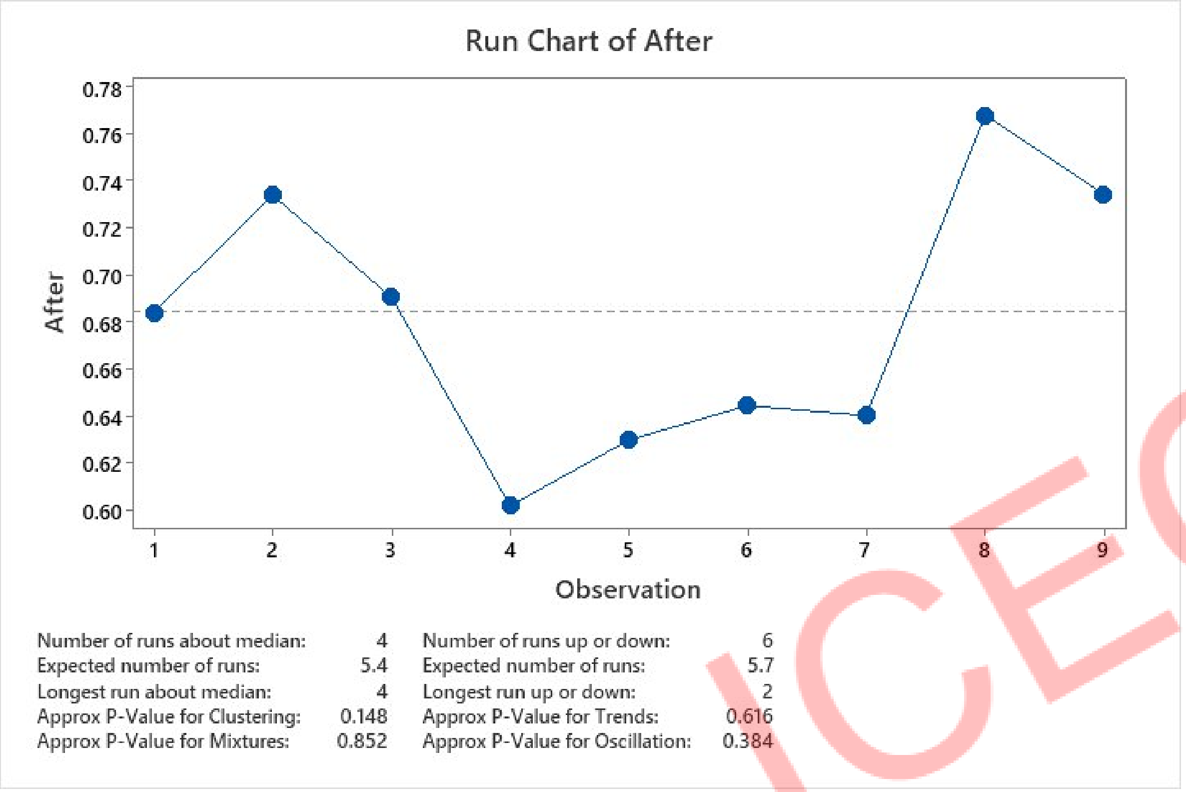
Improve

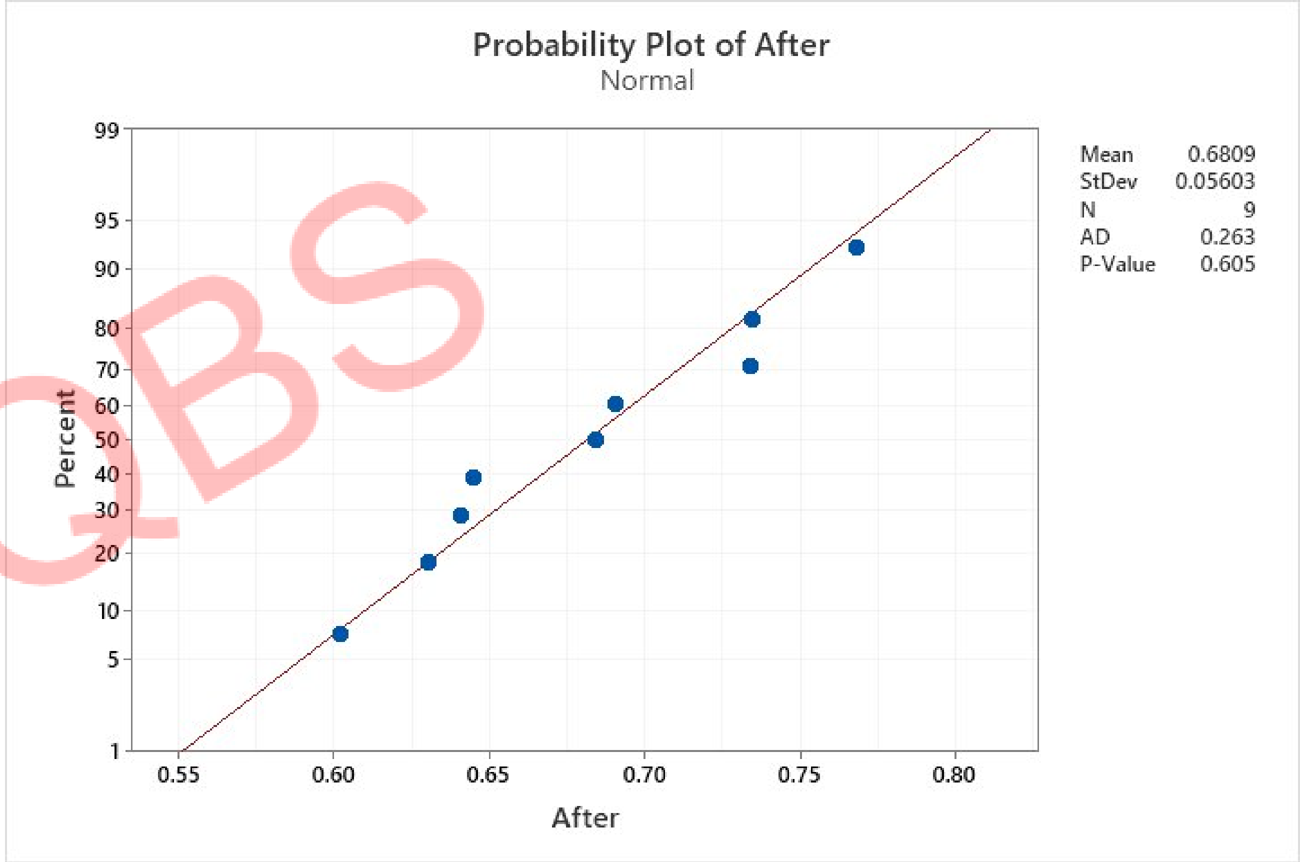




The Pareto chart shows that **Joint Gap Consistency (B)** has the strongest impact on scrap, followed by **Brazing Skill (A)** and **Heating Time (C)**, and the residual plots confirm the model is valid with no major violations.

Improve – Run chart and Normality Test (After Improvement)

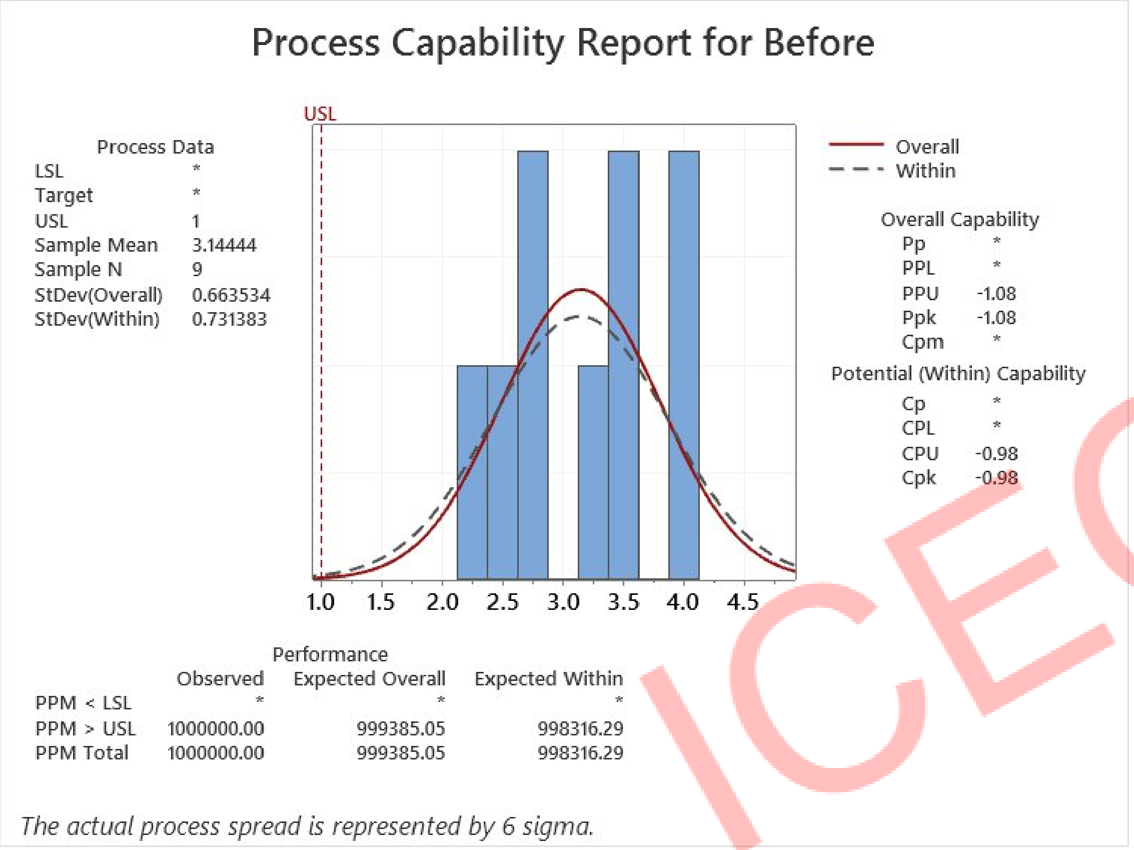


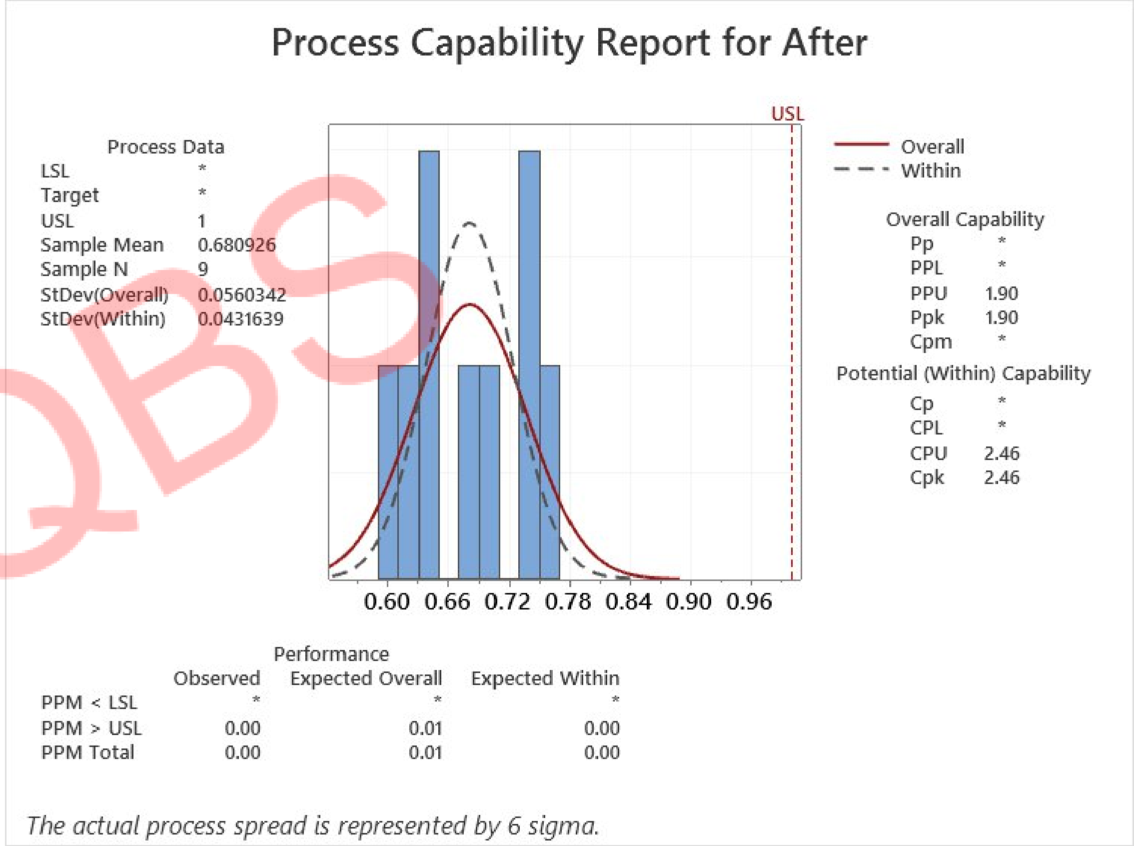


Inference:

•The run chart and probability plot show that the improved process is stable (no special-cause patterns) and normally distributed, confirming the process remains in control after improvements.

Improve – Process capability – Before & After Improvement

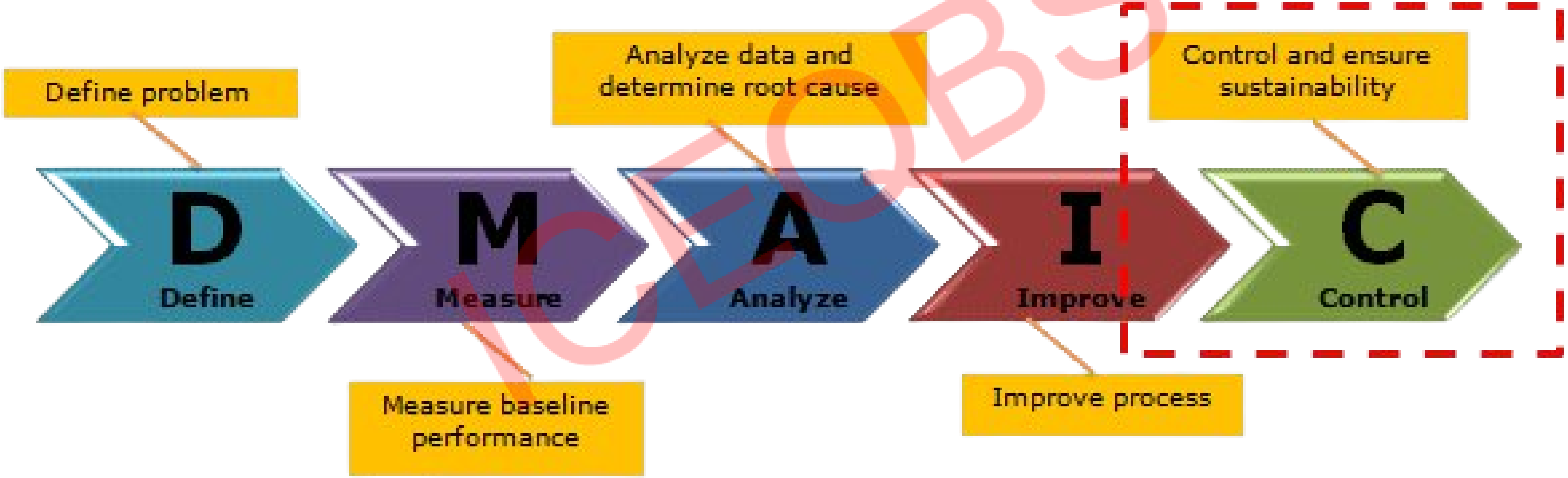




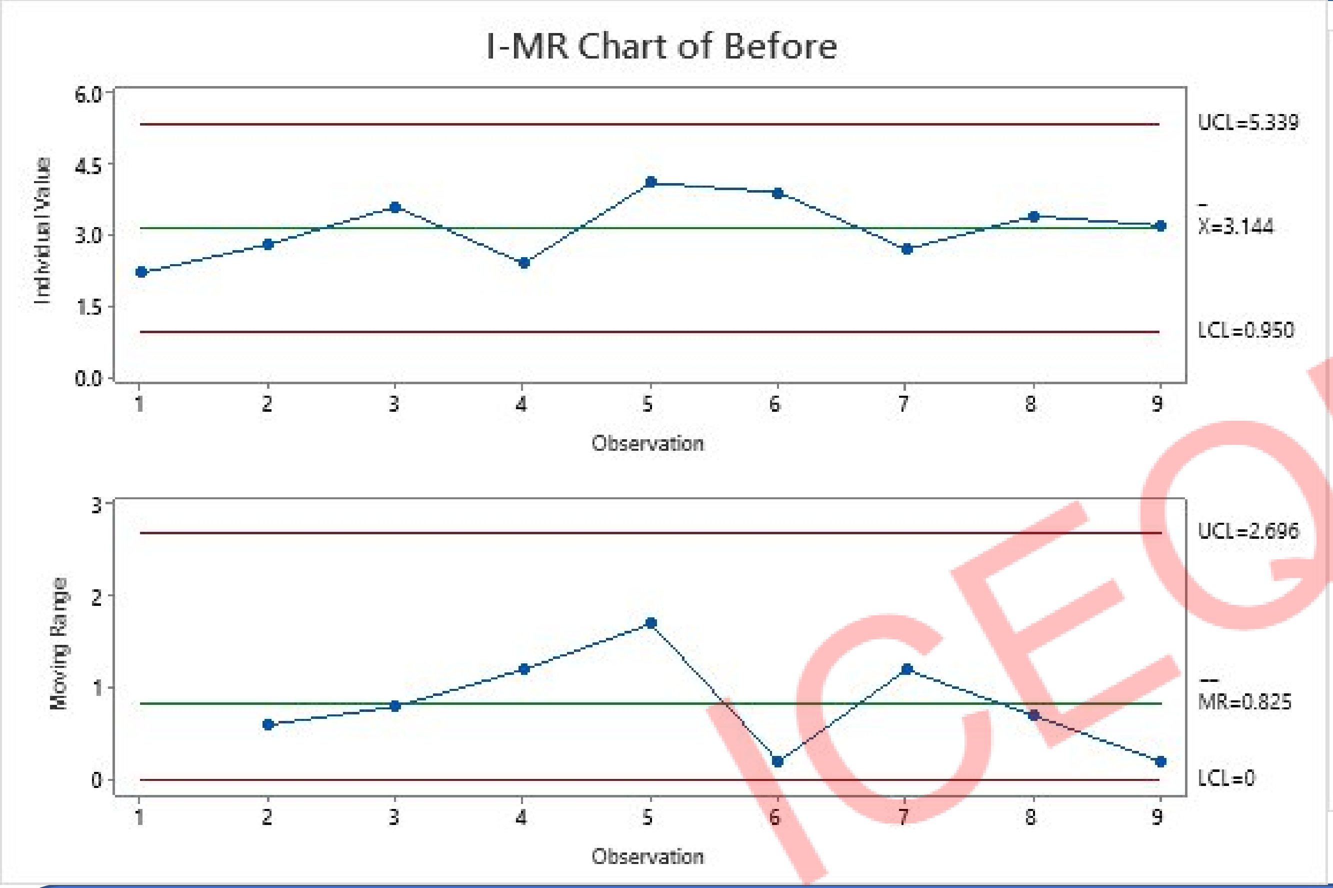
Inference :

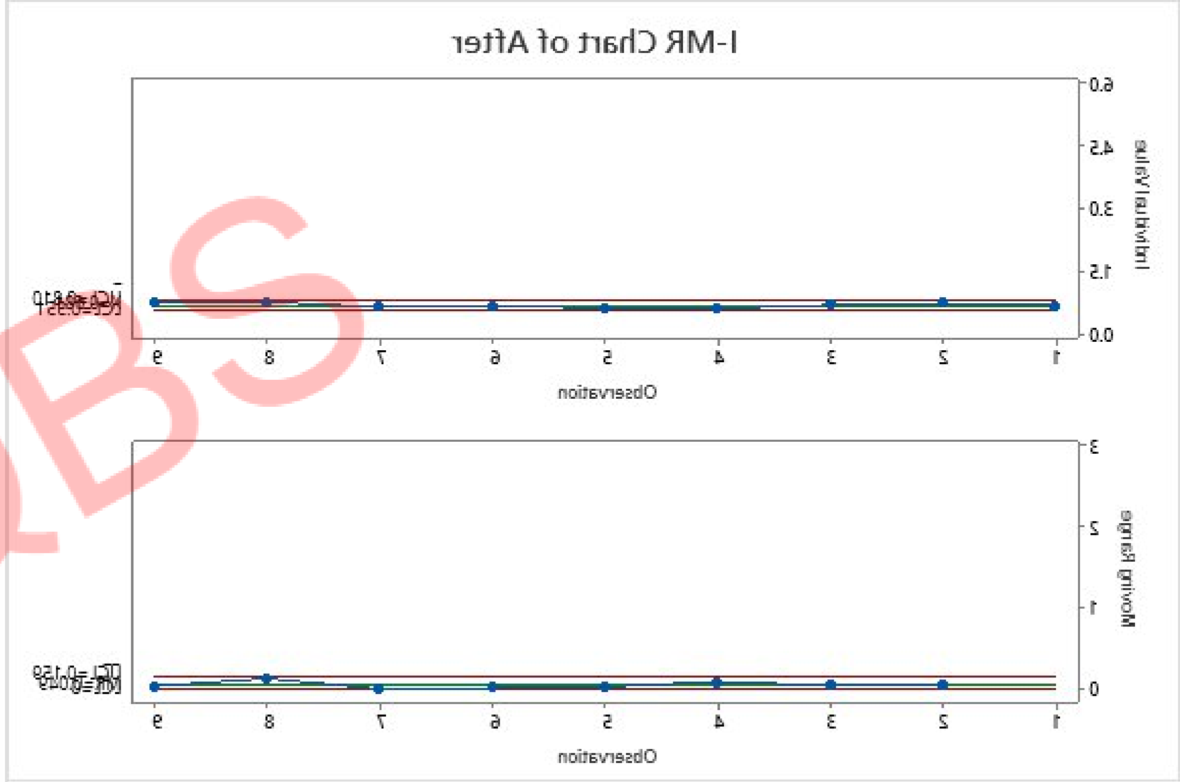
- The process capability improved dramatically after improvements, shifting from a non-capable process (Cpk ≈ −0.98) to a highly capable and stable process (Cpk ≈ 2.46).

CONTROL PHASE



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





Inference:
The I-MR charts show that the process was unstable before improvements but became fully stable and in-control after improvements, with all points well within control limits.

Control Plan

5S Step	What to Do	Why It Helps
1. Sort (Seiri)	Remove all unused tools, files, old versions of work instructions, duplicate spreadsheets, etc. Keep only what is required for current process.	Reduces clutter, prevents returning to old processing habits.
2. Set in Order (Seiton)	Create visual layout of where tools, data input forms, calibration sheets, and measuring instruments must be stored. Use labeled trays / cabinets / digital folders.	Ensures consistent workflow and eliminates searching time.
3. Shine (Seiso)	Schedule weekly cleaning/inspection: check tool condition, machine settings, gauge calibration status.	Keeps equipment accurate and prevents hidden variation.
4. Standardize (Seiketsu)	Create Standard Work Instructions (SOPs), checklists, and criteria for measurement and data entry. Use visual aids and step-by-step sheets near workstations.	Keeps everyone doing the process the same way.
5. Sustain (Shitsuke)	Implement 5S audits with scorecards (weekly → monthly). Rotate responsibility among team members to build ownership.	Prevents backsliding and reinforces discipline.

Control Plan

Type	Example Solution	How It Prevents Error
Control Poka-Yoke	Use physical stops or fixtures so parts can only fit in one orientation.	Prevents assembly errors.
Warning Poka-Yoke	Add a color indicator, alarm, or on-screen prompt if process parameters drift beyond tolerance.	Alerts operator before defective output is produced.
Regulatory/Verification Poka-Yoke	Mandatory checklist fields in software that prevent saving unless all critical inputs are filled.	Prevents missed or skipped process steps.
Sensor-Based	Install auto-calibration reminders or use digital measuring devices that prevent reading outside limits.	Maintains measurement accuracy.
Error-Proofing Data Handling	Use dropdown menus instead of manual typing in digital forms.	Avoids data entry errors and inconsistencies.

FMEA

#	Failure Mode	Effect(s)	Cause(s)	Current Controls	S	O	D	RPN	Recommended Actions (Owner / Target)	New S	New O	New D	New RPN
1	Unauthorized/incorrect machine setting change	Out-of-spec product produced; process drifts back	Operator changes settings; no lockout	Verbal instructions; occasional checks	9	6	5	270	Implement password/role-based lock for settings; physical locks for critical dials; training & change log. (Owner: Maintenance / 2 weeks)	9	2	2	36
2	Measurement device drift / missed calibration	False readings → wrong decisions; hidden defects	No regular calibration reminders; manual log ignored	Manual calibration log (paper)	8	5	6	240	Digital calibration schedule + automated reminders; calibrated digital gauge with auto-logging; calibration accountability. (Metrology / 1 month)	8	2	2	32
3	Operators not following new SOP / skipping steps	Variation returns; inconsistent output	Incomplete training; complexity of steps	SOP posted (text)	7	6	4	168	Mandatory training + signed competency check; laminated step-by-step checklist at station; poka-yoke (step interlocks). (Training / 2 wks)	7	2	2	28
4	Manual data entry errors (records)	Wrong monitoring data; misinterpretation of control charts	Manual typing; multiple formats	Manual spreadsheets	6	5	5	150	Use automatic data capture from gauge to database; enforce dropdowns and validation; restrict manual edit. (IT / 4 wks)	6	1	2	12
5	Wrong tool / material used (mix-up)	Defective product or rework	Similar appearance; no positive ID	Visual checks	8	4	5	160	Color-coding + physical fixtures; barcode/RFID scan before start; poka-yoke tool holders. (Production / 3 wks)	8	1	2	16
6	Supplier material variability (incoming out of spec)	Process upset; increased variation	Weak incoming QC; supplier deviation	Incoming inspection (spot checks)	9	4	6	216	Tighten incoming sampling plans; supplier PPAP/quality agreement; incoming automated inspection and quarantine. (Purchasing / 1 month)	9	2	3	54
	5S deterioration	Waste, longer	No sustainment						Scheduled 5S audits + scorecards; visual indicators;				

Control Plan to sustain improvements

Process Step	What Could Go Wrong (Failure Mode)	Control Characteristic (CTQ / Parameter)	Specification / Target	Reaction Plan if Out of Control
Material / Input Preparation	Wrong material or incorrect batch used	Material Identification	Correct batch + material code	Quarantine lot; notify supervisor; log deviation; investigate supplier
Machine Setup / Configuration	Unauthorized change of settings (process drifts)	Machine Critical Setting (pressure, speed, temp, etc.)	Locked values per SOP	Stop production; re-set settings; retrain if repeated
Process Operation	Variation increases / mean shifts	Key Process Value (Y) (e.g., resolution time, dimension)	Mean ≤ USL with stable trend	If point beyond limits or pattern rules triggered → stop, investigate root cause, adjust; escalate to QE
Measurement System	Measurement device drifts or is inconsistent	Gauge Calibration Status	Must be in calibration	Remove device from use, recalibrate, verify readings before restart
Data Entry / Recording	Wrong values recorded → false decisions	Data capture accuracy	Zero manual input error	Stop trend reporting; correct data entries; review operator training
Work Standardization	Steps skipped or variation in how process is done	SOP / Work Instruction adherence	100% compliance	Retrain operator; update SOP if unclear; document deviation
5S Workplace Management	Clutter returns, tools misplaced → hidden variation	5S Score	≥ 90%	Correct immediately; assign owner; review during daily huddle
Supplier Material Control	Supplier variability impacts process	Incoming Quality Level	Supplier PPM < defined limit	Place supplier on corrective action; re-screen all stock

Conclusion

Results after improvement

- **Project has achieved its intended results after Reduce defects rate in coil brazing process**