Brazing Process Improvement in Condensing Unit Assembly Line

SUBASH BOSE

ROADMAP

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

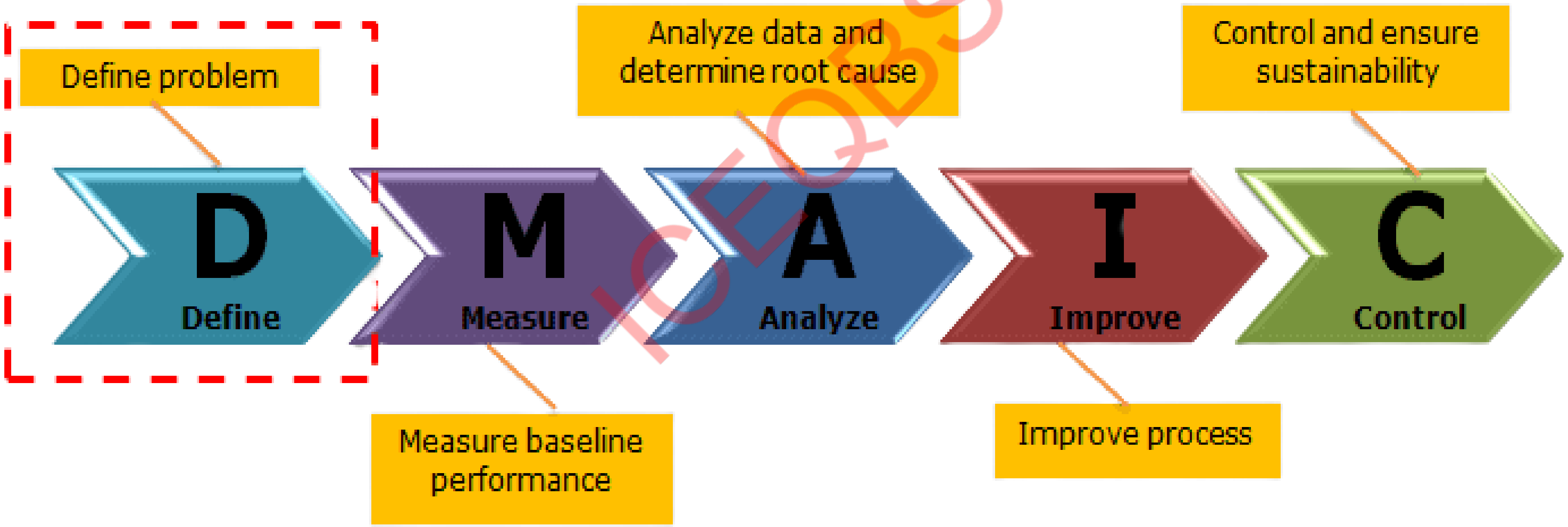
OVERVIEW

Background

The brazing process in the condensing unit assembly line currently exhibits an average defect rate of 13.9%, with significant monthly variation between 9% and 18%, making it one of the largest contributors to assembly quality losses. Pareto analysis indicates that brazing defects account for approximately 47% of total assembly defects, driven mainly by joint leakage, poor filler flow, and oxidation.

These defects result in frequent rework, increased production costs, and reduced line throughput, leading to an estimated annual Cost of Poor Quality (COPQ) of ₹12 lakhs, primarily due to rework effort and leak-related failures. In addition, leak defects negatively impact product reliability, increasing customer complaints and warranty exposure.

DEFINE PHASE

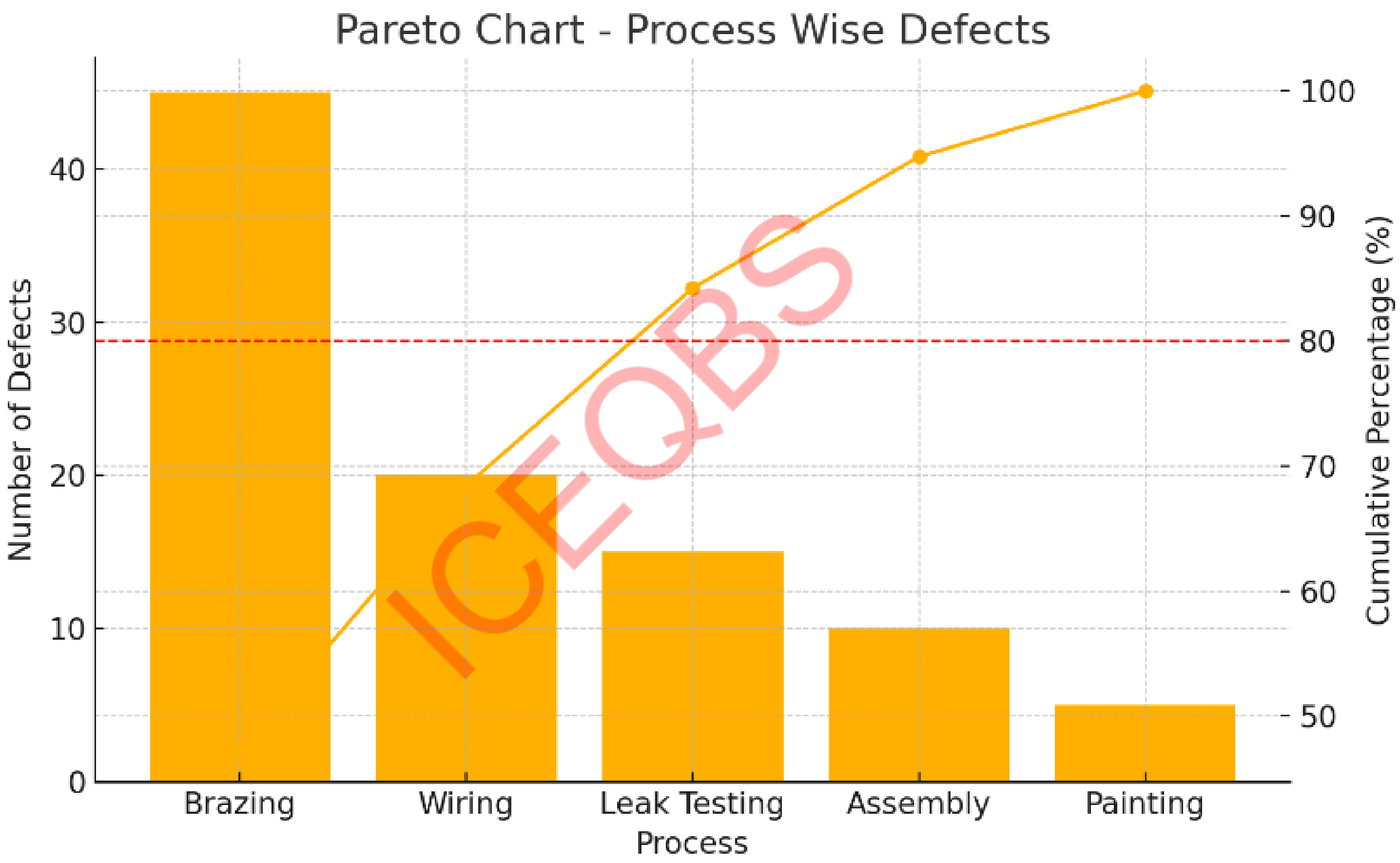


VOC & CTQ

CTQ Tree :

Voice of customer	Critical to X	Primary Metric for improvement
"Customers expect leak-free, reliable condensing units that perform consistently without rework or early failure."	CTQ (Critical to Quality) → First Pass Yield (FPY) in Brazing Process	**Primary Metric -** Defect Rate (%) = Total Joints Inspected / No. of Defective Joints×100 **Secondary Metric -** Productivity

Pareto chart



Inference :

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

Project Charter

Project Title: **Brazing Process Improvement – Condensing Unit Assembly Line**

Project Leader

Subash Bose

Project Team Members:

Ms. Priya Nair
Mr. Arvind Patel
Mr. Suresh Iyer
Ms. Kavita Singh

Champion/Sponsors:

Mr. Ramesh Kumar

Key Stake Holders

Leak Testing Team
Quality Inspection Team
Final Assembly / Testing Section
OEM / Distributor / Dealer

Problem Statement:

Over the past 9 months, the brazing process in the condensing unit assembly line has shown an **average defect rate of 13.9%**, with monthly variation ranging from **9% to 18%**.

Goal Statement:

To **reduce the brazing defect rate from 13.9% to below 8%** within **6 months (by March 2026)**

Secondary Metric

Productivity

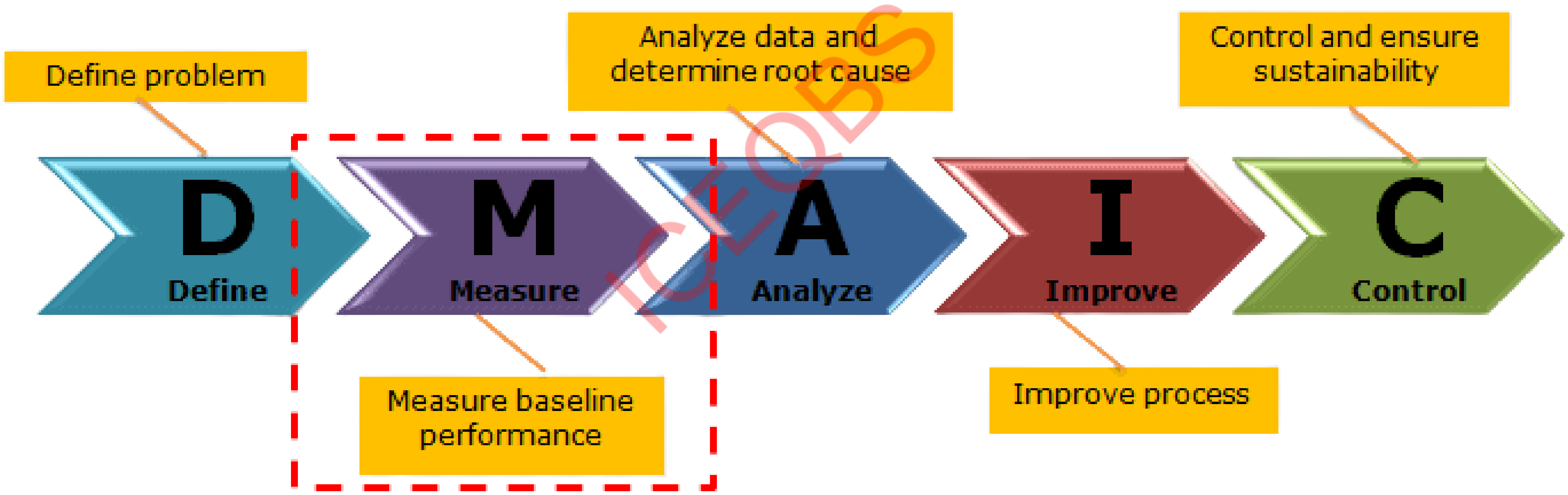
Assumptions Made:

Brazing parameters, materials, and joint designs remain unchanged during the improvement period.
Operators and maintenance teams are available for training and process standardization.

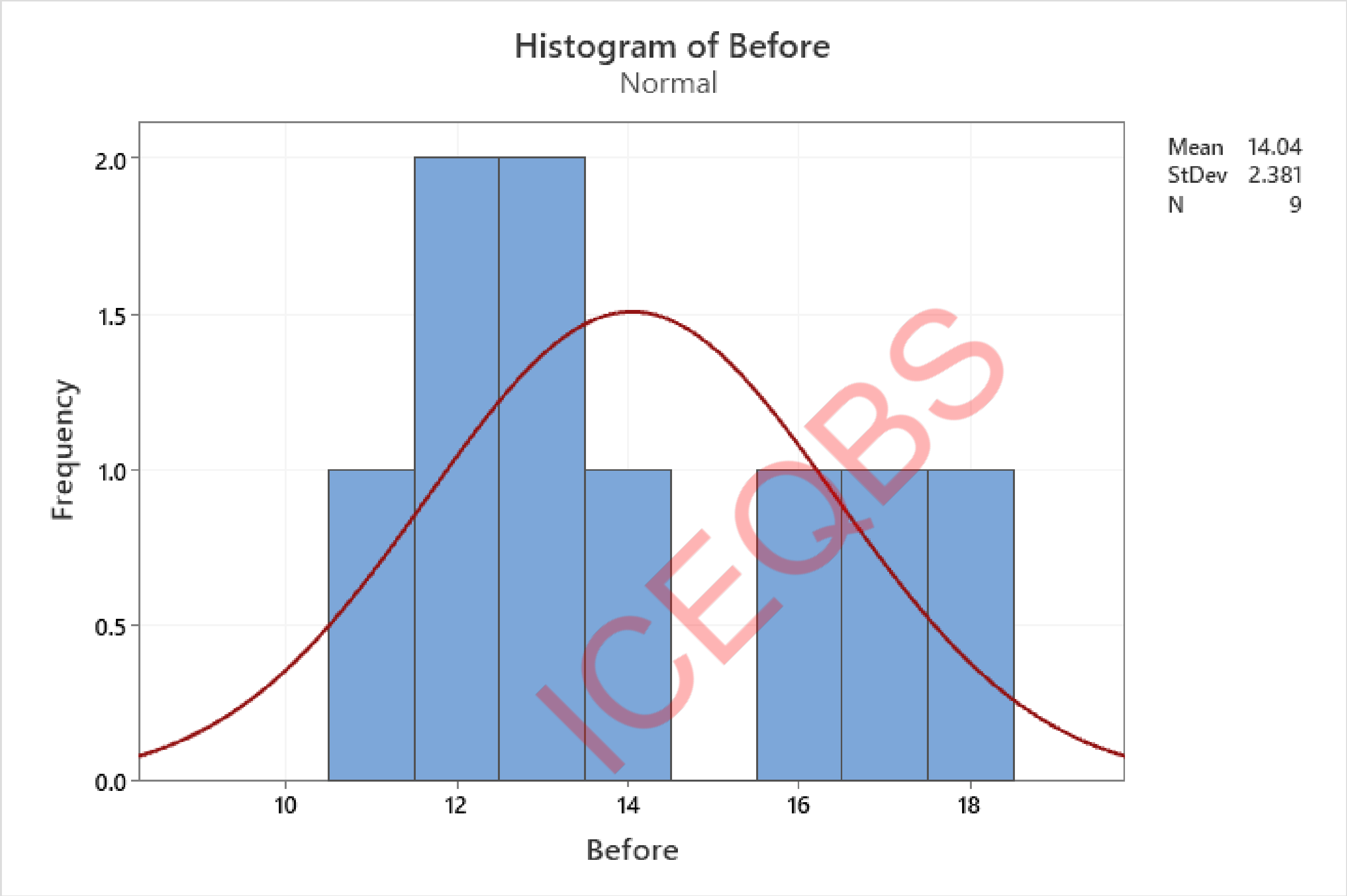
Project Charter

Tangible and Intangible Benefits:	Risk to Success:
Reduction in COPQ by **₹4–5 lakhs annually** through lower rework and scrap. **15% improvement in FPY**, increasing effective line throughput. Improved customer confidence due to enhanced product reliability.	Variation in operator skill or adherence to standard brazing practices. Equipment condition or inconsistent temperature control impacting brazing quality.
In Scope:	**Out of Scope:**
Machining and material removal operations (turning, milling, drilling, grinding) within aerospace component manufacturing	Casting, forging, heat treatment, coating, and assembly processes
Signatories:	**Project Timeline:**
Mr. Ramesh Kumar	6 months

MEASURE PHASE



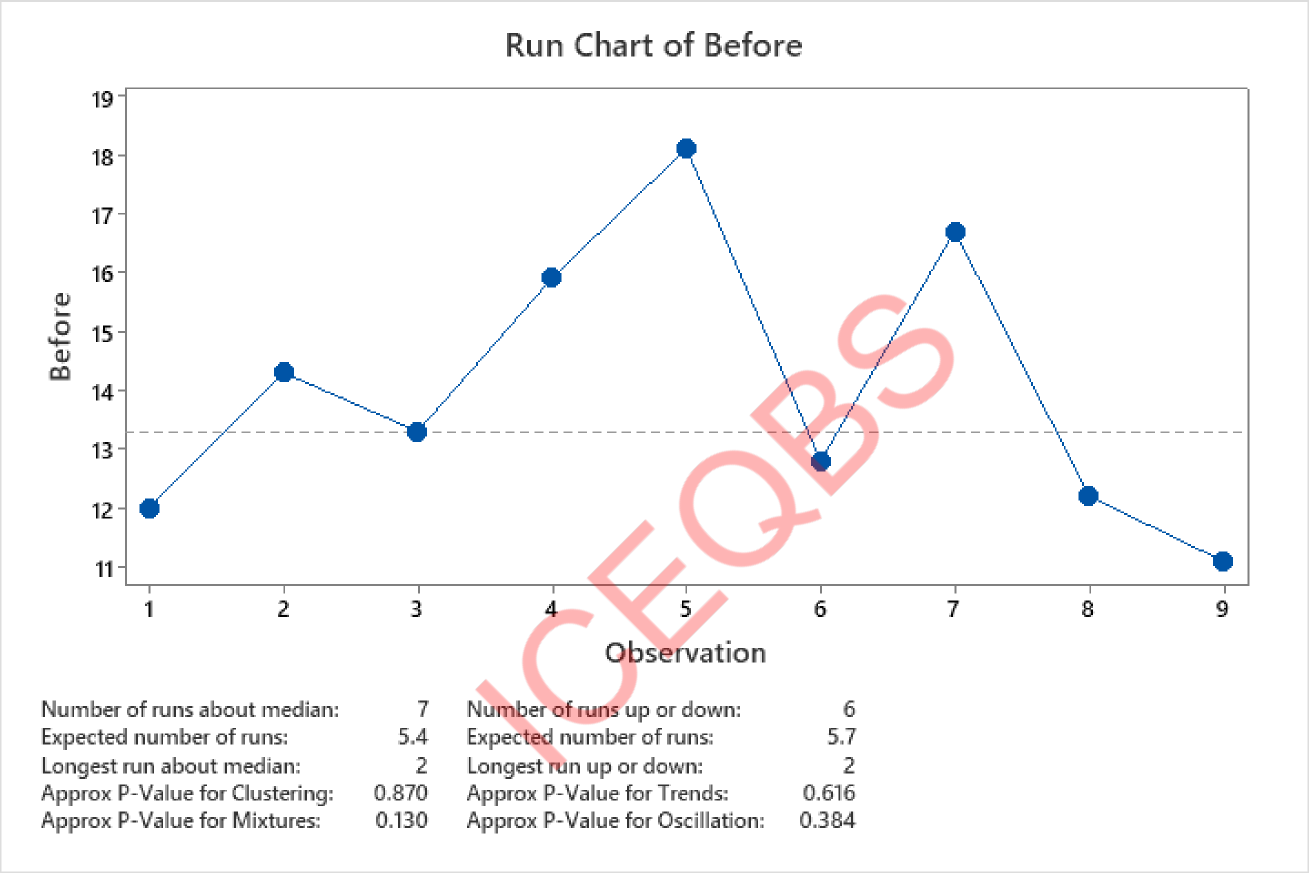
Data collection – Histogram (Before improvement)



Inference :

- Data is normally distributed over the mean

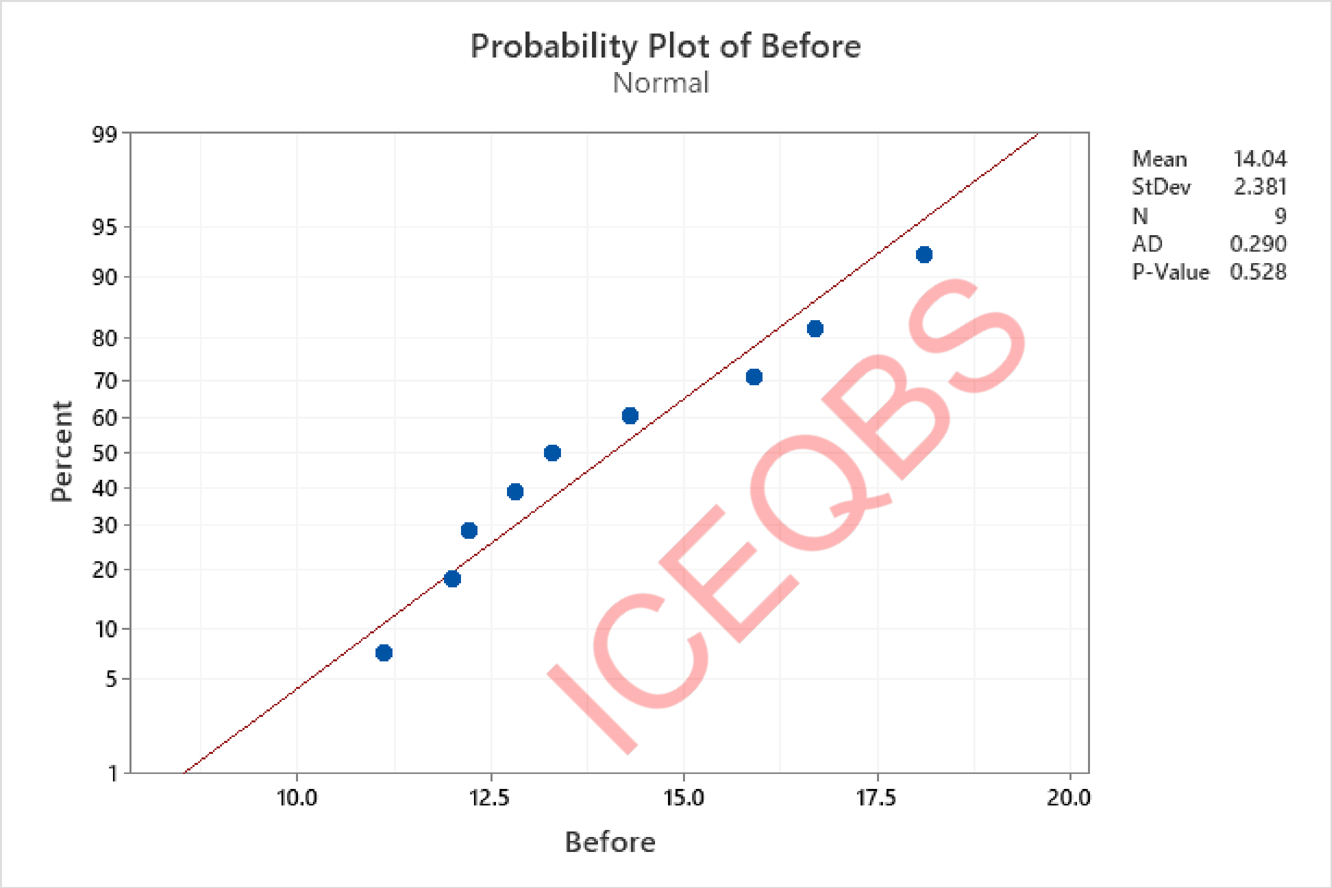
Data collection – Run Chart (Before improvement)



Inference :

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

Data collection – Normality plot (Before improvement)



Inference :

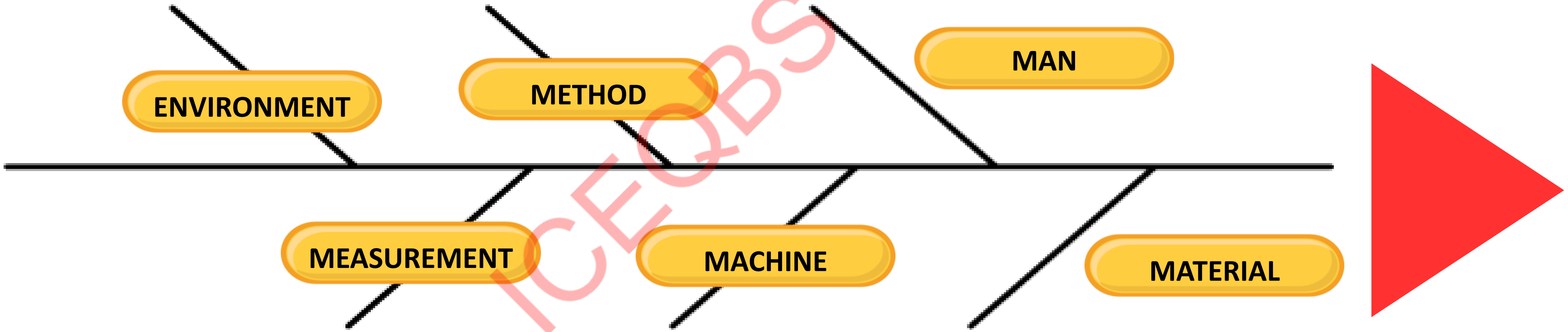
- P > 0.05 in all scenarios, thus all the data is normally distributed

Fish Bone Diagram

1. Poor ventilation near brazing area
2. Dust or oil contamination in workplace
3. High humidity levels
4. Poor lighting at workstations
5. Temperature fluctuations in work area

1. Non-standard heating time
2. Incorrect joint clearance
3. Improper cleaning sequence
4. Random torch movement
5. No defined temperature control

1. Unskilled or newly trained operators
2. Fatigue or lack of focus
3. Non-adherence to SOPs
4. Inadequate supervision
5. No skill certification system



1. No temperature monitoring
2. Inconsistent leak test pressure
3. Inaccurate defect recording
4. Lack of process capability study (Cp, Cpk)
5. Poor calibration of gauges and meters

1. Torch pressure fluctuations
2. Worn-out torch nozzles
3. Gas supply inconsistency
4. Leaky hoses or fittings
5. Lack of preventive maintenance

1. Oxidized or dirty copper tubes
2. Poor-quality brazing rods
3. Incorrect filler alloy selection
4. Contaminated flux or absence of flux
5. Damaged fittings / connectors

Common and Special causes

Common Causes:

- Operator skill variation
- Fatigue or lack of focus
- Torch pressure fluctuations
- Worn-out torch nozzles
- Oxidized copper tubes
- Poor-quality brazing rods
- Non-standard heating time
- Improper cleaning sequence
- Inaccurate defect recording
- Poor ventilation near brazing area

Special Causes:

- New or untrained operator
- Gas supply inconsistency
- Leaky hoses or fittings
- Contaminated flux or absence of flux
- Incorrect filler alloy selection
- Damaged fittings/connectors
- No temperature monitoring
- Poor calibration of gauges
- High humidity levels
- Temperature fluctuations in work area

3M Analysis for Waste

MUDA

1. Rework on Leaking Joints
2. Excess Movement of Operators
3. Waiting Time

Mura

1. Variation in Brazing Temperature or Heating Time
2. Uneven Workload Between Operators
3. Irregular Material Supply

Muri

1. Overheating Torch Use Without Cooldown
2. Operator Handling Multiple Torches/Stations
3. Lack of Proper Jigs or Fixtures

8 Wastes Analysis

Type of Waste	Examples in Brazing Process
1. Defects	• Leaking brazed joints
	• Incomplete filler penetration
2. Overproduction	• Brazing more coils than daily schedule
	• Pre-brazing subassemblies before downstream demand
3. Waiting	• Waiting for gas cylinder change or torch repair
	• Waiting for quality inspection clearance
4. Non-Utilized Talent	• Skilled operators not involved in problem-solving
	• Lack of suggestion system for process improvements
5. Transportation	• Moving coils long distances between brazing and testing
	• Carrying cylinders manually across workstations
6. Inventory	• Storing too many copper tubes near workstation
	• Accumulation of half-finished brazed joints
7. Motion	• Frequent walking to pick up rods or tools
	• Awkward bending or stretching to reach joints
8. Extra Processing	• Applying excess filler material
	• Double-heating joints due to poor first pass technique

Action Plan for Low Hanging Fruits

Observed Issue / Cause	Lean Tool / Approach	Action to be Taken	Expected Benefit (Low Hanging Fruit)
Gas pressure fluctuation and leaky hoses (Special Cause)	Jidoka / TPM (Total Productive Maintenance)	Replace worn hoses, introduce daily torch pressure check sheet	Stable flame, consistent brazing temperature
Untrained or newly rotated operators (Special Cause)	Standard Work / Skill Matrix	Conduct brazing certification and skill-based job allocation	Reduced operator variation, improved quality
Excess walking to get rods and torches (Muda – Motion Waste)	5S & Layout Optimization	Place tool racks and rod holders near each workstation	Reduced motion, 10% cycle time saving
Uneven workload across brazing stations (Mura)	Line Balancing / Yamazumi Chart	Reassign work content evenly among operators	Smoother flow, higher productivity
Overheating torches without cooldown (Muri)	TPM / Visual Controls	Implement visual “Torch Rest” boards and cooling schedule	Longer equipment life, fewer defects

Action Plan for Low Hanging Fruits

Observed Issue / Cause	Lean Tool / Approach	Action to be Taken	Expected Benefit (Low Hanging Fruit)
High humidity and poor ventilation (Special Cause)	5S / Environmental Control	Install exhaust fans, control humidity using dehumidifiers	Stable brazing quality, fewer oxidation defects
Excess filler usage (Muda – Overprocessing)	Standard Work / SOP Revision	Define optimal filler rod length and application standard	Material savings, reduced rework
Waiting during gas changeover (Muda – Waiting)	SMED / Quick Changeover	Introduce dual-cylinder manifold system	Reduced downtime, smoother flow
Inventory pile-up near brazing area (Muda – Inventory)	Kanban System / FIFO	Introduce visual WIP limit and Kanban replenishment	Controlled WIP, reduced clutter
Leak failures in testing (Special Cause)	Poka-Yoke / Quality at Source	Install visual heat indicators or color change flux	Early defect detection, improved FPY

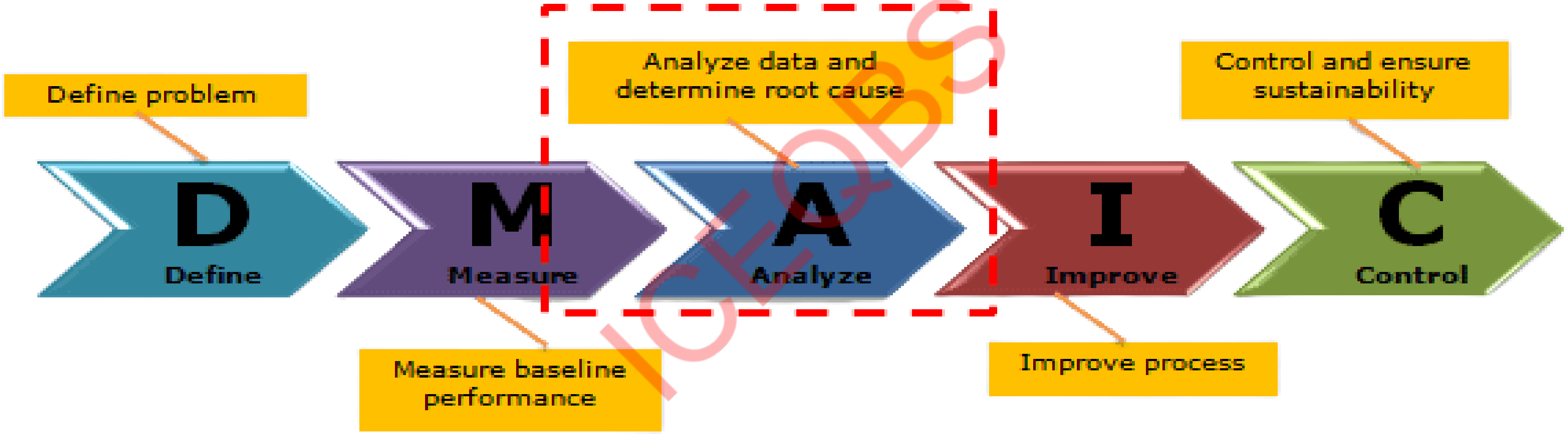
Top 12 Prioritized Root Causes (Based on Net Score)

Root Cause	Score
Operator Skill Level	267
Torch Angle / Technique	257
Fixture / Jig Design	256
Joint Cleanliness	245
Surface Preparation	244
Flux Quality / Application	243
Filler Rod Quality	242
Torch Pressure Stability	217
Torch Tip Condition	215
Gas Flow Rate	201
Operator Fatigue	203
Inspection Method	205

Data Collection Plan

Root Cause / Factor to Measure	Data to be Collected	Measurement Method / Source
Operator Skill Level	Skill rating, Training record	Observation / Skill test
Torch Angle / Technique	Torch angle (°), Technique rating	Visual check / Protractor
Fixture / Jig Design	Fixture condition, Fit gap (mm)	Visual / Caliper
Joint Cleanliness	Clean or Dirty (Y/N)	Visual inspection
Surface Preparation	Cleaning method used	Checklist verification
Flux Quality / Application	Flux batch, Application quantity	Weight / Visual check
Filler Rod Quality	Batch number, Rod diameter	Incoming inspection
Torch Pressure Stability	Gas pressure (psi)	Pressure gauge reading
Torch Tip Condition	Tip wear / damage	Visual inspection
Gas Flow Rate	Flow rate (L/min)	Flowmeter reading
Operator Fatigue	Hours worked, Breaks taken	Observation / Logbook
Inspection Method	Leak test pressure, Pass/Fail	Leak test record

ANALYSE PHASE



Analyse – Hypothesis testing

Regression Equation

Defect_Rate_pct = 24.919 - 0.08435 Operator_Skill_Score_0_100
- 1.4198 Joint_Cleanliness_Score_0_10 + 0.4408 Pressure_Stability_CV_pct

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	24.919	0.627	39.73	0.000	
Operator_Skill_Score_0_100	-0.08435	0.00791	-10.67	0.000	1.03
Joint_Cleanliness_Score_0_10	-1.4198	0.0558	-25.45	0.000	1.03
Pressure_Stability_CV_pct	0.4408	0.0353	12.49	0.000	1.00

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	983.3	327.760	333.55	0.000
Operator_Skill_Score_0_100	1	111.8	111.812	113.79	0.000
Joint_Cleanliness_Score_0_10	1	636.6	636.637	647.87	0.000
Pressure_Stability_CV_pct	1	153.3	153.278	155.98	0.000
Error	116	114.0	0.983		
Total	119	1097.3			

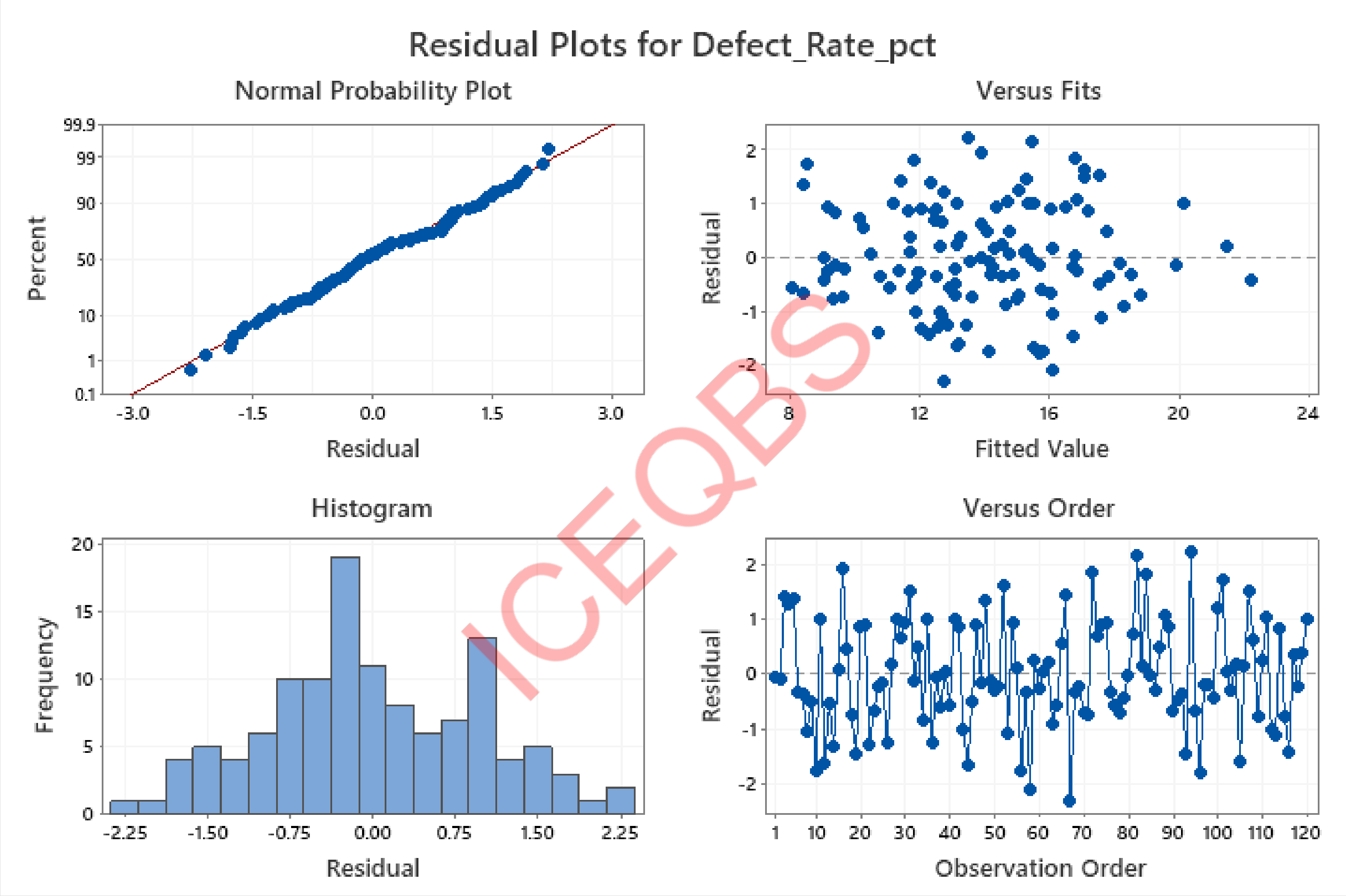
Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.991289	89.61%	89.34%	88.94%

Inference :

- operator skill, joint cleanliness, and pressure stability are the critical root causes driving brazing defects and must be addressed in the Improve phase.

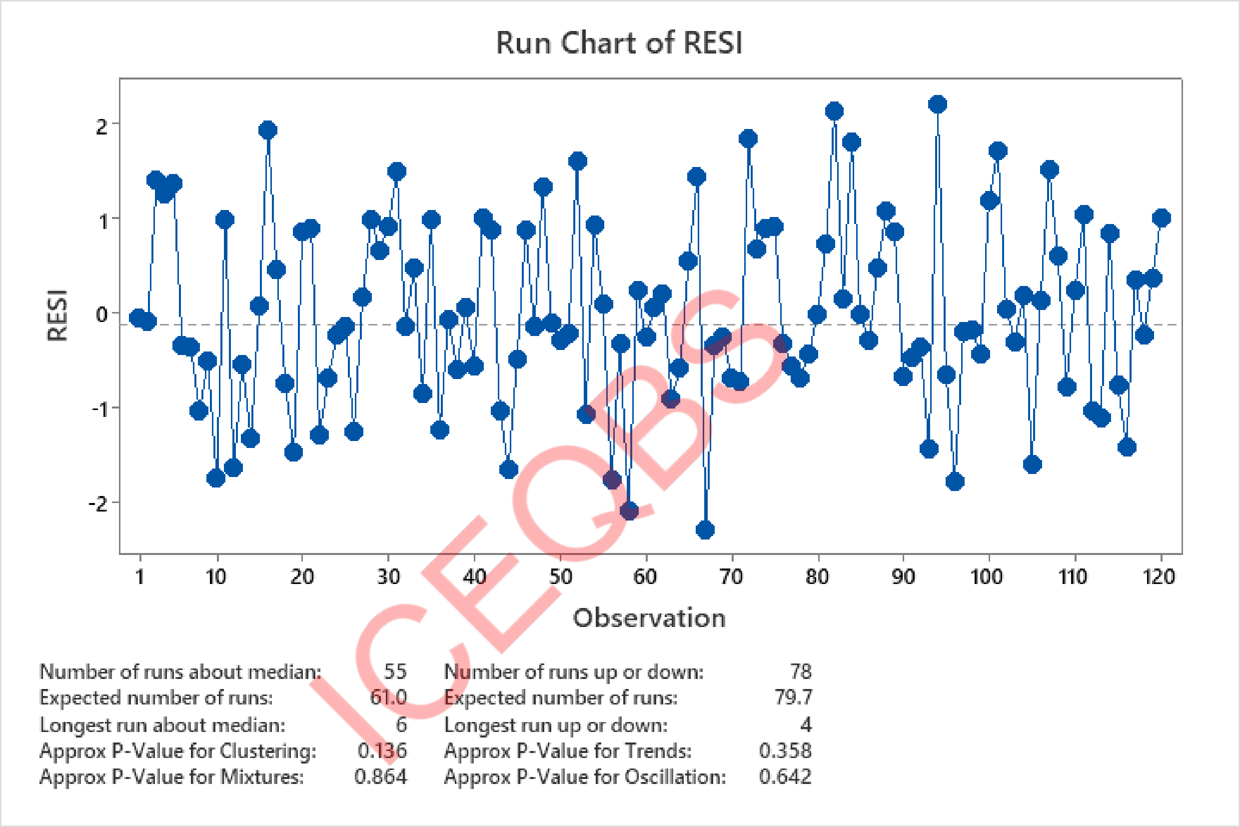
Analyse – Hypothesis testing



Inference :

- Analysis confirms the regression model assumptions are met (normal, random, and independent errors), validating the identified root causes in the Analyze phase.

Analyse – Hypothesis testing



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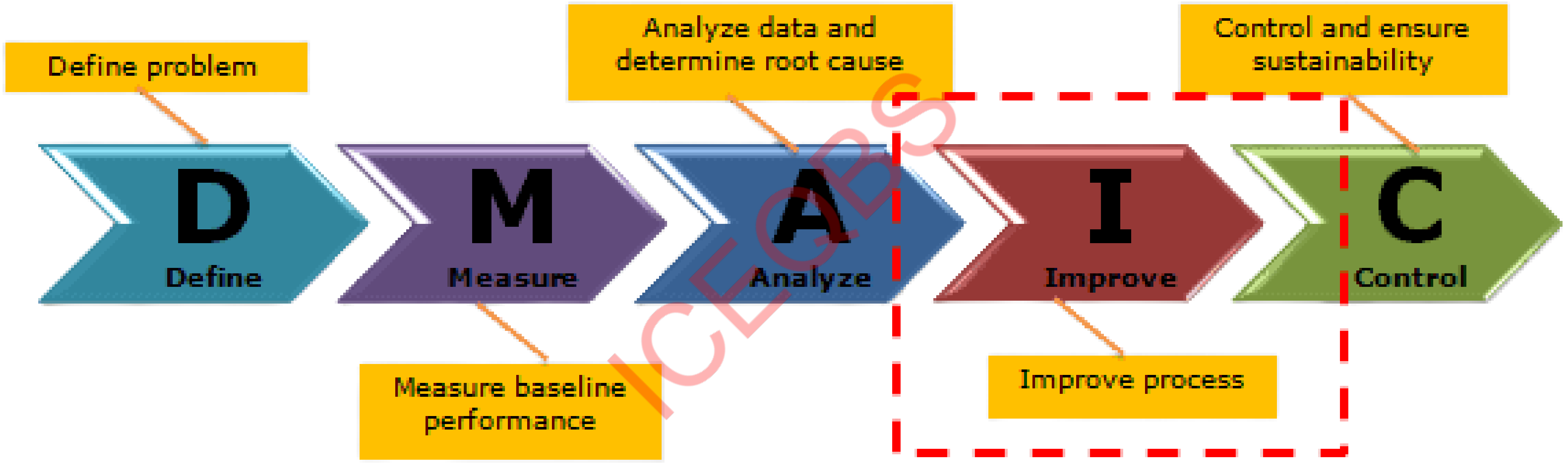
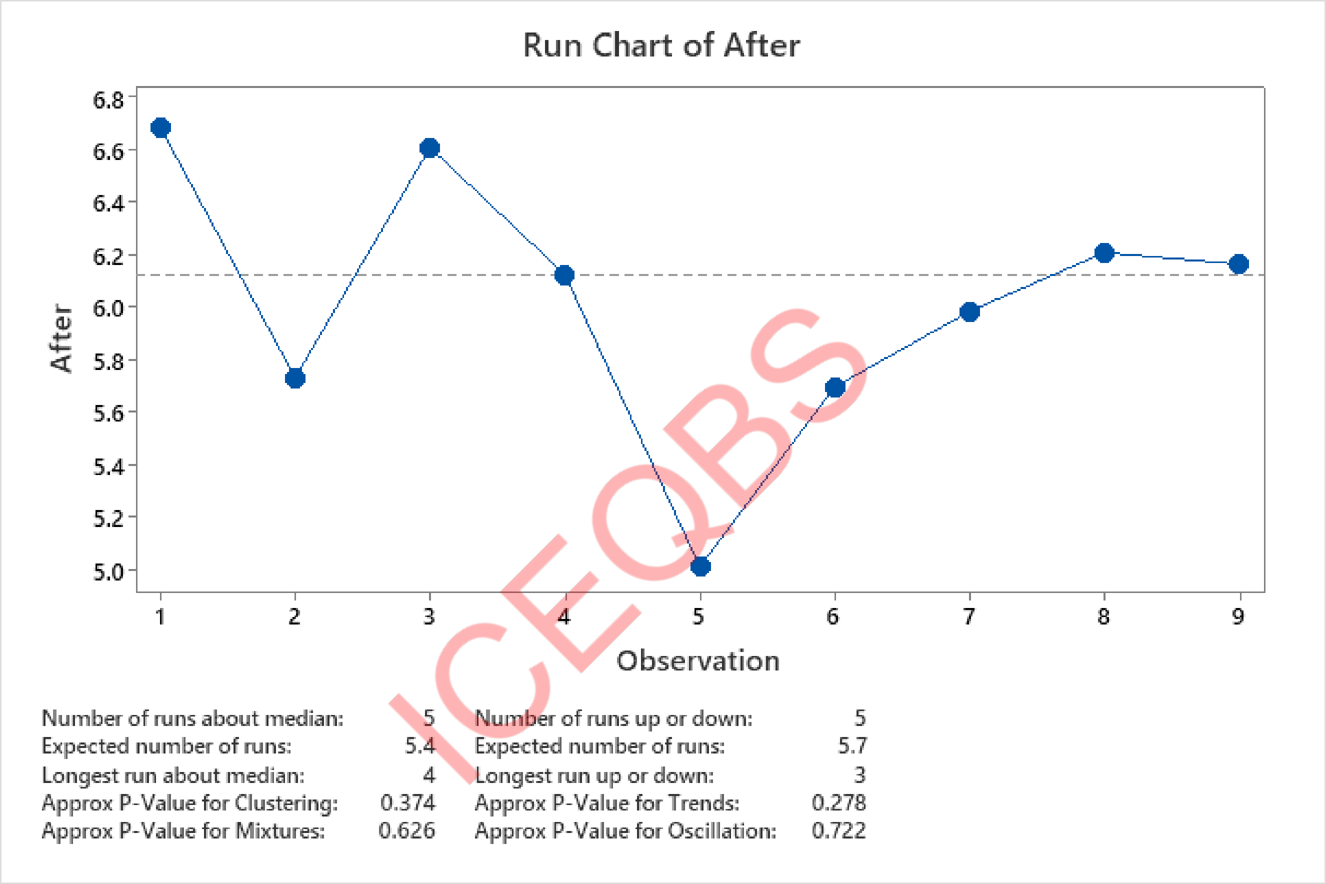
IMPROVE PHASE



Improve

#	Critical Root Cause	Action	How to Implement (Simple Steps)
1	Operator Skill Score	Standardize the brazing method (WIS + visual standards)	Create 1-page Work Instruction Sheet with photos: torch distance, dwell time, filler feed, joint coverage; define "good vs bad" examples; display at station
2	Operator Skill Score	Skill certification & coaching loop	Skill matrix; certify operators on a test coupon; daily 10-minute coaching for low scorers; re-test weekly until minimum score met
3	Joint Cleanliness Score	Pre-brazing cleaning standard + verification	Define cleaning method (solvent wipe + abrasion + dry); set max "time from clean to braze"; add a simple cleanliness checklist + random checks
4	Joint Cleanliness Score	Poka-yoke for surface prep compliance	Introduce color-tag / stamp after cleaning; no tag = no brazing; provide dedicated "clean zone" tray to prevent re-contamination
5	Pressure Stability CV (%)	Stabilize torch pressure using PM + monitoring	Install inline regulator/gauge; define acceptable CV% range; daily leak check; weekly hose/regulator inspection; replace torch tip/nozzle on trigger limits

Improve



- **The post-improvement results indicate a stable, controlled process with consistent performance, confirming that the implemented improvements are effective and sustainable.**

Improve

•**The probability plot confirms the post-improvement data follows a normal distribution (p > 0.05) with a stable mean, indicating consistent and predictable process performance after improvement.**

Improve

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	14.04	2.38	0.79
After	9	6.024	0.507	0.17

Estimation for Difference

Difference	95% CI for Difference
8.021	(6.149, 9.892)

Test

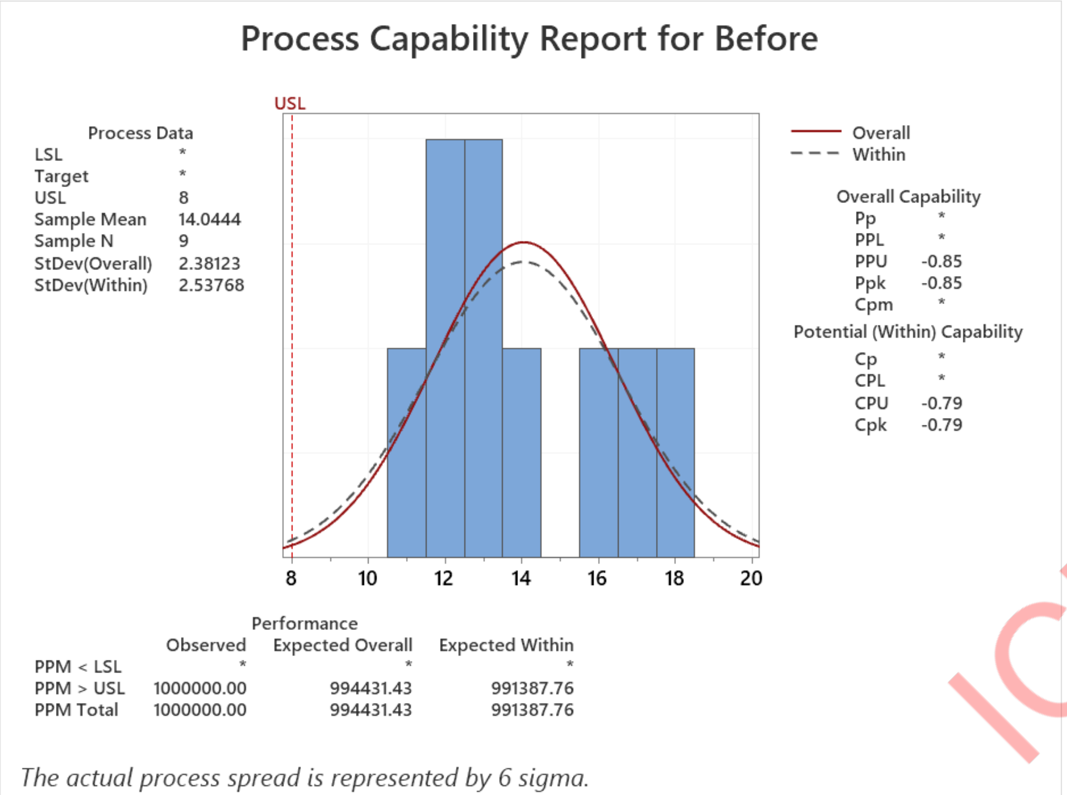
Null hypothesis $H_0: \mu_1 - \mu_2 = 0$
Alternative hypothesis $H_1: \mu_1 - \mu_2 \neq 0$

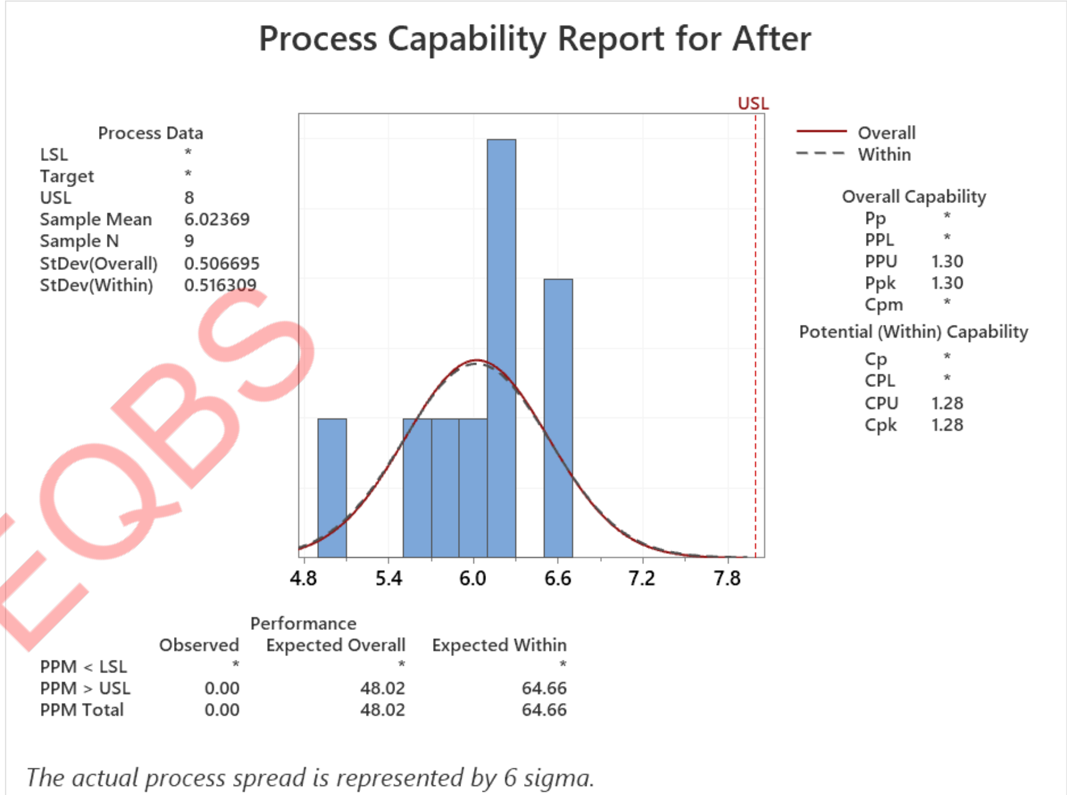
T-Value	DF	P-Value
9.88	8	0.000

Inference:

- The two-sample t-test confirms a statistically significant reduction after improvement, with the mean dropping from ~14.0 to ~6.0 ($p < 0.001$), demonstrating that the improvement actions were highly effective.

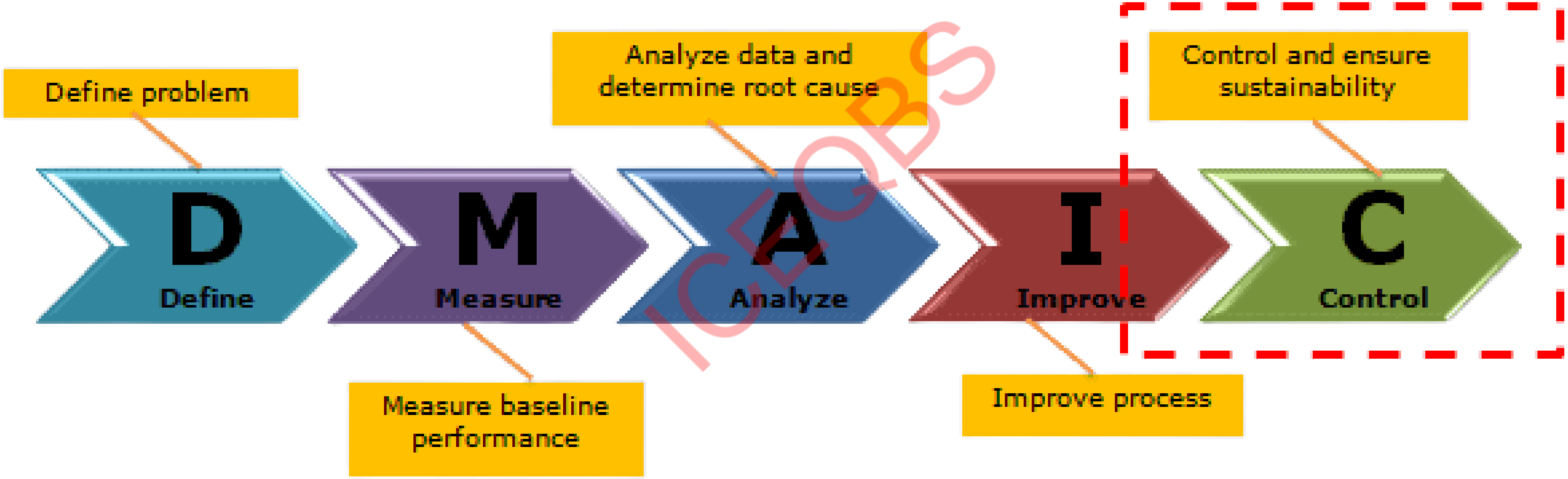
Improve – Process capability – Before & After Improvement



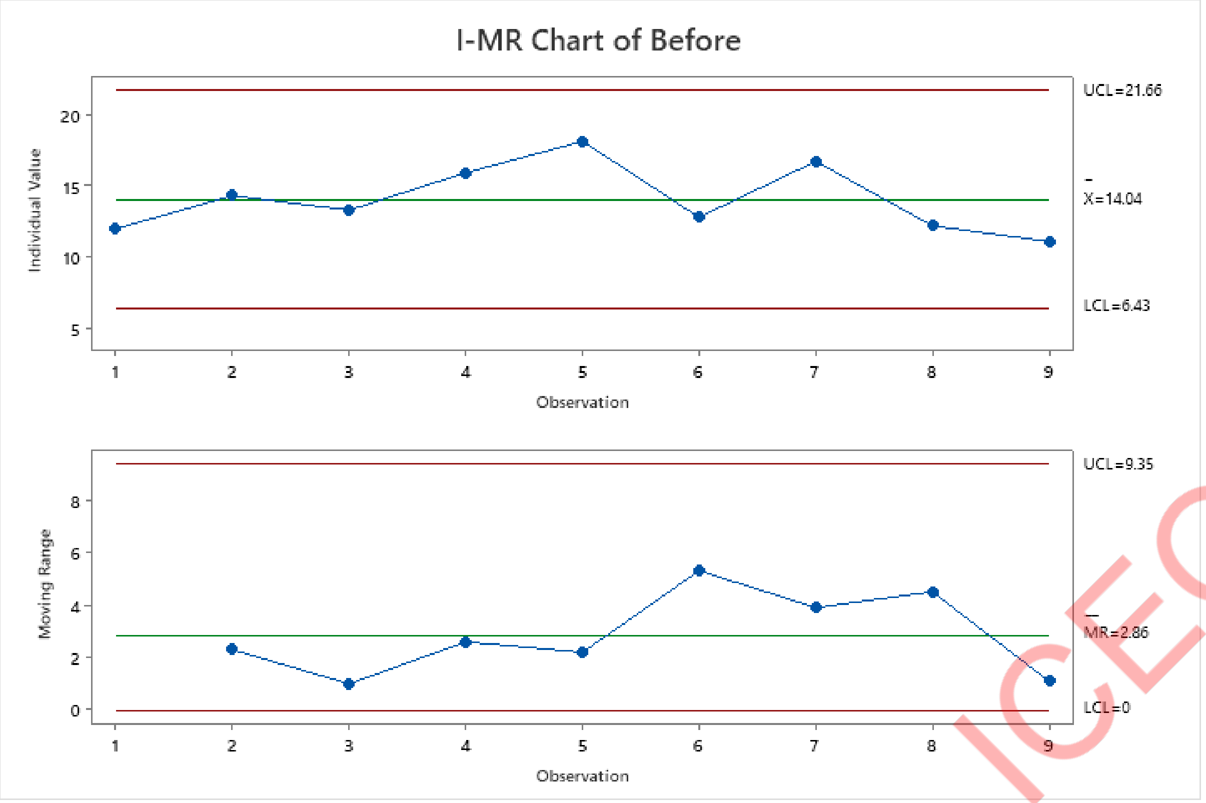


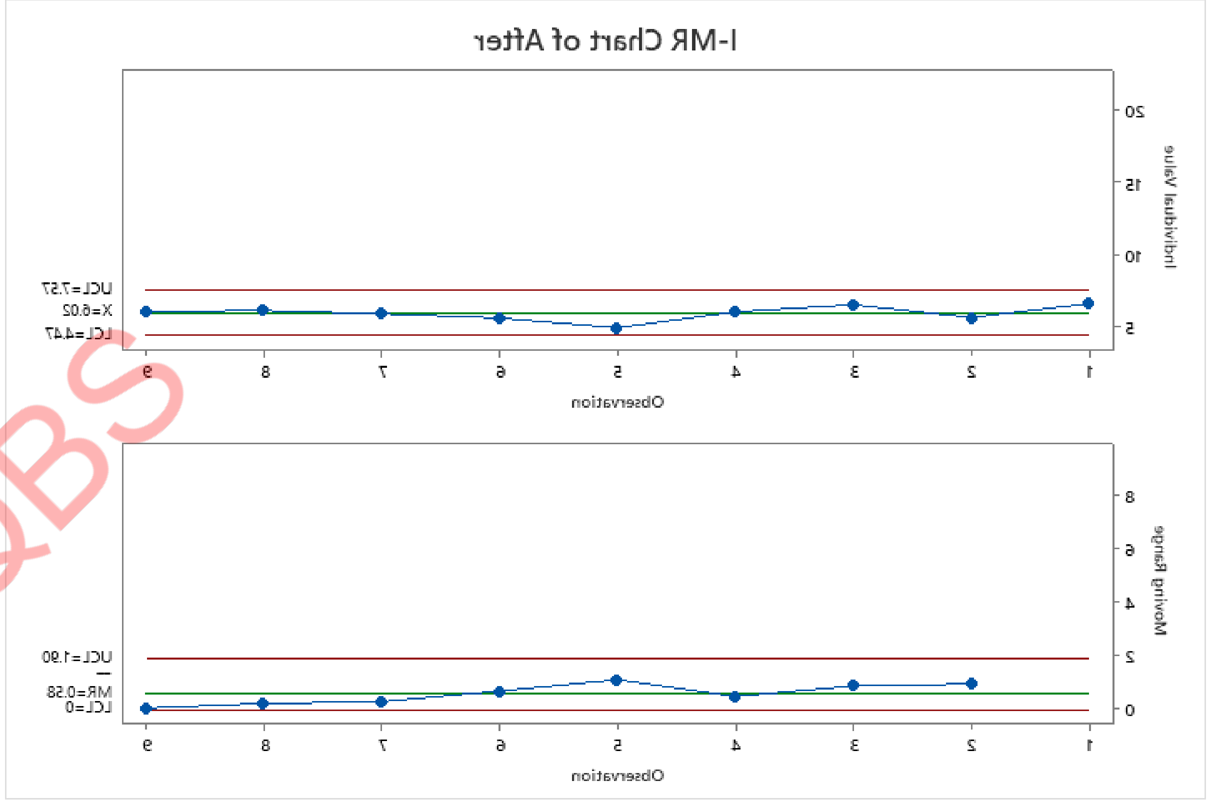
Inference :
The capability comparison shows the process improved from incapable (negative Cpk) to capable after improvement (Cpk > 1), with the mean well within specification and a drastic reduction in defects.

CONTROL PHASE



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





Inference:

- The I-MR charts show that the process shifted to a lower mean with significantly reduced variation after improvement, and all points remain within control limits, confirming a stable and controlled process.

Control Plan

#	Category	Mechanism	What It Prevents	How It Sustains the Gain
1	5S – Standardize	Visual brazing standard board at workstation (ideal torch angle, joint appearance, filler flow)	Variation due to operator interpretation	Operators follow the same "one best way"; skill variation reduces
2	5S – Set in Order	Dedicated, color-coded cleaning kit (brush, cloth, solvent) kept only at brazing station	Skipping or inconsistent joint cleaning	Makes cleaning the default behavior; no searching, no excuses
3	Poka-Yoke	Cleaned-joint tag / marker (joint must be marked after cleaning before brazing)	Brazing without proper surface preparation	Physical/visual gate ensures only cleaned joints are brazed
4	Poka-Yoke	Pressure OK / NOT-OK indicator on torch regulator (green–red band or digital limit)	Brazing with unstable or incorrect gas pressure	Operator cannot start brazing unless pressure is within limits
5	5S – Sustain	Daily 5-minute self-check checklist (Skill posture, Cleanliness done, Pressure OK)	Process drift over time	Builds discipline and ownership; early detection of deviation

Control Plan

#	Process Step / Improvement Area	Potential Failure Mode	Potential Effect of Failure	Potential Cause	S (1–10)	O (1–10)	D (1–10)	RPN	Proactive Action (Improvement Control)	Responsible
1	Operator skill standardization	Operator does not follow standardized brazing method	Inconsistent brazing → leaks / rework	Lack of clarity, habits from old method	8	5	5	200	Mandatory skill certification + visual work instruction at station	Production / Quality
2	Operator training & certification	Skill level deteriorates over time	Gradual increase in defects	No refresher training or monitoring	7	4	5	140	Quarterly skill audit + retraining trigger if score < target	HR / Line Supervisor
3	Joint cleanliness process	Brazing done without proper cleaning	Poor wetting → weak joint	Operator skips cleaning step under pressure	9	4	4	144	Poka-yoke: cleaning tag/marker required before brazing	Quality / Production
4	Pressure stability control	Torch pressure fluctuates during brazing	Incomplete fusion, oxidation defects	Regulator wear, gas leakage	8	3	4	96	Preventive maintenance checklist + pressure OK/NOT-OK indicator	Maintenance
5	Control & monitoring	Deviations not detected early	Sustained increase in defect rate	No daily monitoring / ownership	8	3	5	120	Daily control checklist + weekly defect trend review	Line Leader

Control Plan

#	Process / CTQ	Control Method	Monitoring Frequency	Reaction Plan	Responsibility
1	Operator Skill Score	Skill audit checklist + certification record	Monthly (or on operator change)	Retrain operator and restrict brazing activity until score ≥ target	Production Supervisor / HR
2	Joint Cleanliness Score	Pre-brazing cleanliness checklist + random audits	Daily (spot check)	Stop brazing, re-clean joint, counsel operator	Quality Inspector
3	Pressure Stability (CV %)	Regulator gauge check / pressure log	Shift-wise	Stop operation, repair regulator or hose, resume after verification	Maintenance
4	Brazing Defect Rate (%)	Run chart / control chart	Daily	Root cause review if trend or point beyond limit	Quality / Line Leader
5	Standard Work Compliance	5S audit + visual standard verification	Weekly	Correct deviation and re-train team	Line Supervisor

Conclusion

Results after improvement

- **This project successfully reduced defects, stabilized the process, and achieved sustained capability improvement, delivering measurable cost savings and enhanced product reliability.**