Scrap Reduction in Steel Bellows Manufacturing Process

Maheshwaran

ROADMAP

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

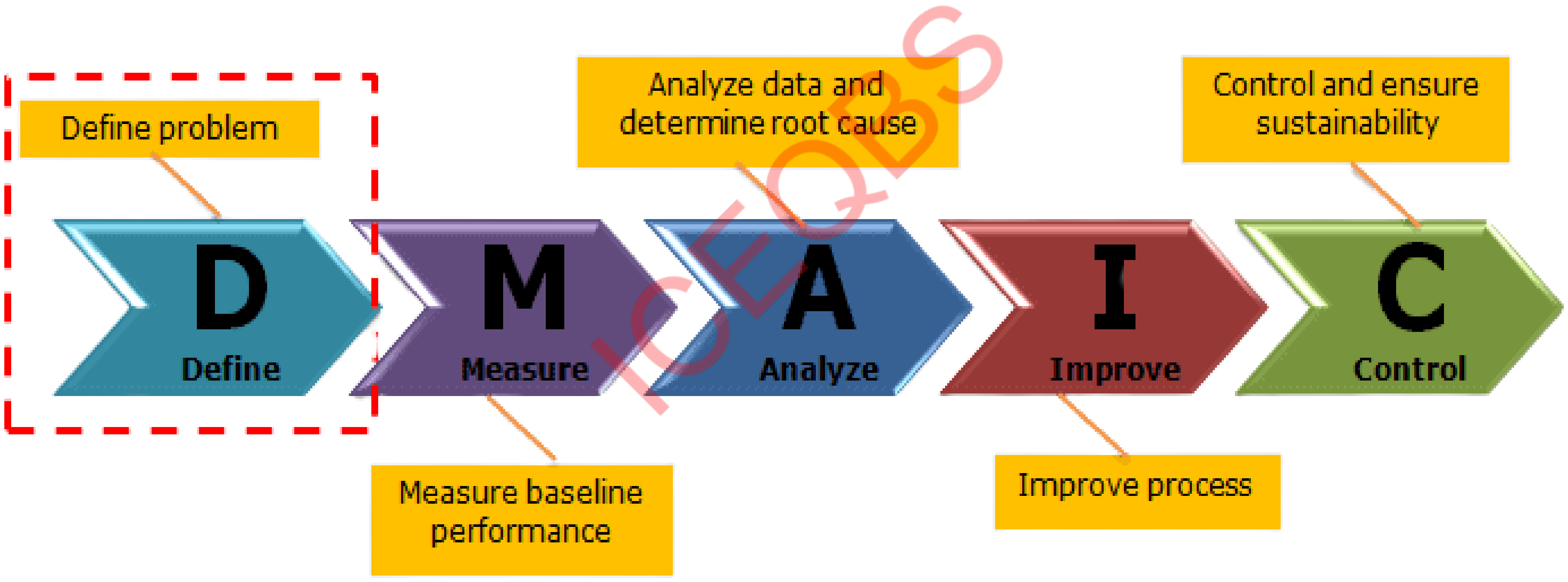
OVERVIEW

Background

The steel bellows manufacturing process currently operates at an average scrap level of 3.0% (Apr–Sep 2025), primarily driven by welding defects (42%), forming cracks (28%), and leak test failures (18%). This level of scrap results in significant material loss, increased rework, and an estimated monthly cost impact of ₹4.8 lakh, adversely affecting production efficiency and delivery consistency.

Reducing scrap is a critical opportunity to improve operational performance and cost efficiency. Achieving a scrap level of 1.0% or less by Q2–2026 will lower the cost of poor quality, reduce rework cycle time, and stabilize delivery performance. The project is expected to generate monthly savings of at least ₹3 lakh, while strengthening product quality, customer satisfaction, and alignment with the organization's Lean Manufacturing and Zero Defect initiatives.

DEFINE PHASE

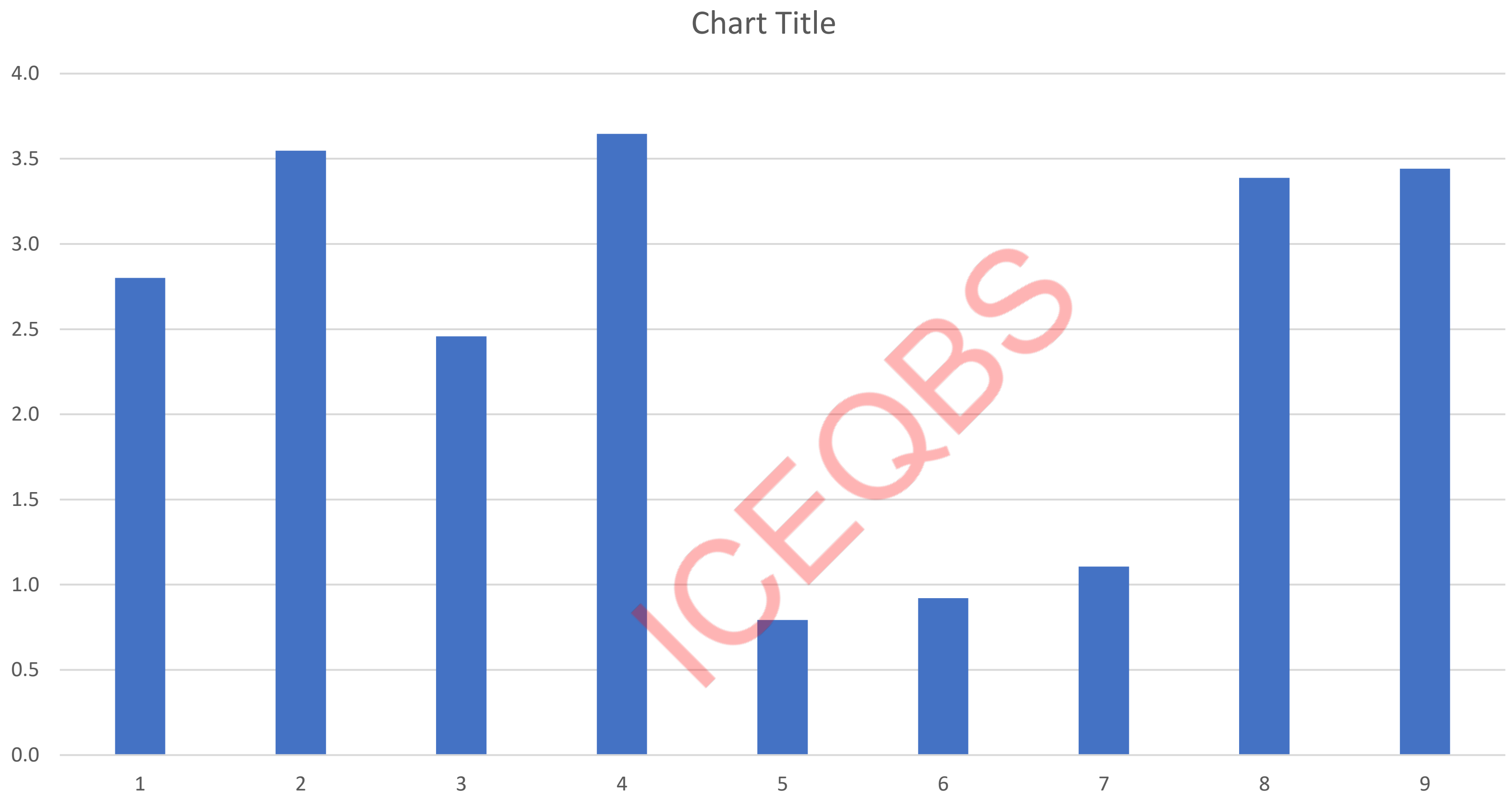


VOC & CTQ

CTQ Tree :

Voice of customer	Critical to X	Primary Metric for improvement
Defect-free bellows	CTQ: % Scrap	**Primary Metric -** % Scrap **Secondary Metric -** Productivity

Baseline Performance of Primary Metric (9 months data)



Inference :

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

Project Charter

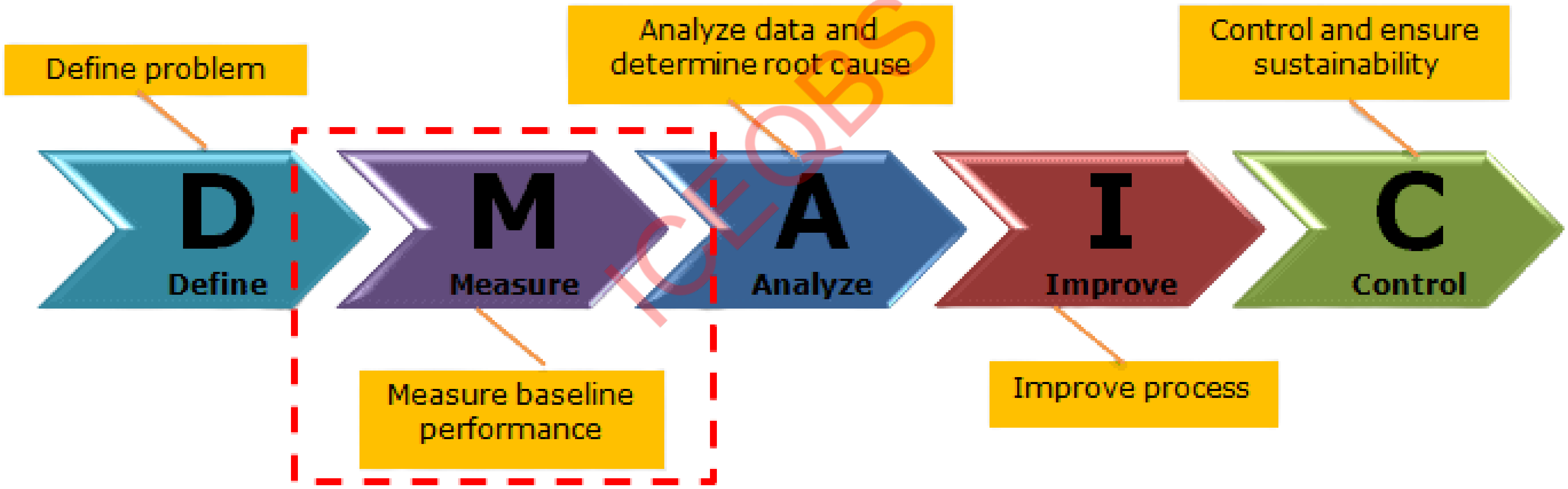
Project Title:	Scrap Reduction in Steel Bellows Manufacturing Process

Project Leader	**Project Team Members:**
Maheshwaran	Mr. K. Singh Mr. S. Maheshwaran Mr. D. Verma
Champion/Sponsors:	**Key Stake Holders**
Mr. R. Sharma (Plant Head)	Production / Manufacturing Head Quality Assurance Team Welding & Forming Operations Team Maintenance / Engineering Team
Problem Statement:	**Goal Statement:**
Scrap in machining process is very high (@ 3 %) based on the data for the last 9 months	Reduce the overall scrap percentage from 3.0% to 1.0% or less by the end of Q2–2026, while maintaining production output, quality, and delivery schedules.
Secondary Metric	**Assumptions Made:**
Productivity	Production volume, product mix, and customer demand remain stable during the project period. Accurate scrap and defect data are available for analysis and validation.

Project Charter

Tangible and Intangible Benefits:	Risk to Success:
Reduction in scrap from 3.0% to ≤1.0%, delivering **₹3 lakh/month cost savings**. Lower material wastage, rework costs, and leak test failures	Inconsistent welding and forming practices across shifts may limit scrap reduction. Variation in raw material quality and delayed corrective maintenance can affect process stability.
In Scope:	**Out of Scope:**
Steel bellows manufacturing processes: forming, trimming, welding, leak testing, inspection Process parameters, tooling, fixture design, operator training	Other product lines (flexible hoses, expansion joints) Design changes in bellows geometry
Signatories:	**Project Timeline:**
R. Sharma P. Mehta (Operations Head)	6 months

MEASURE PHASE



SIPOC

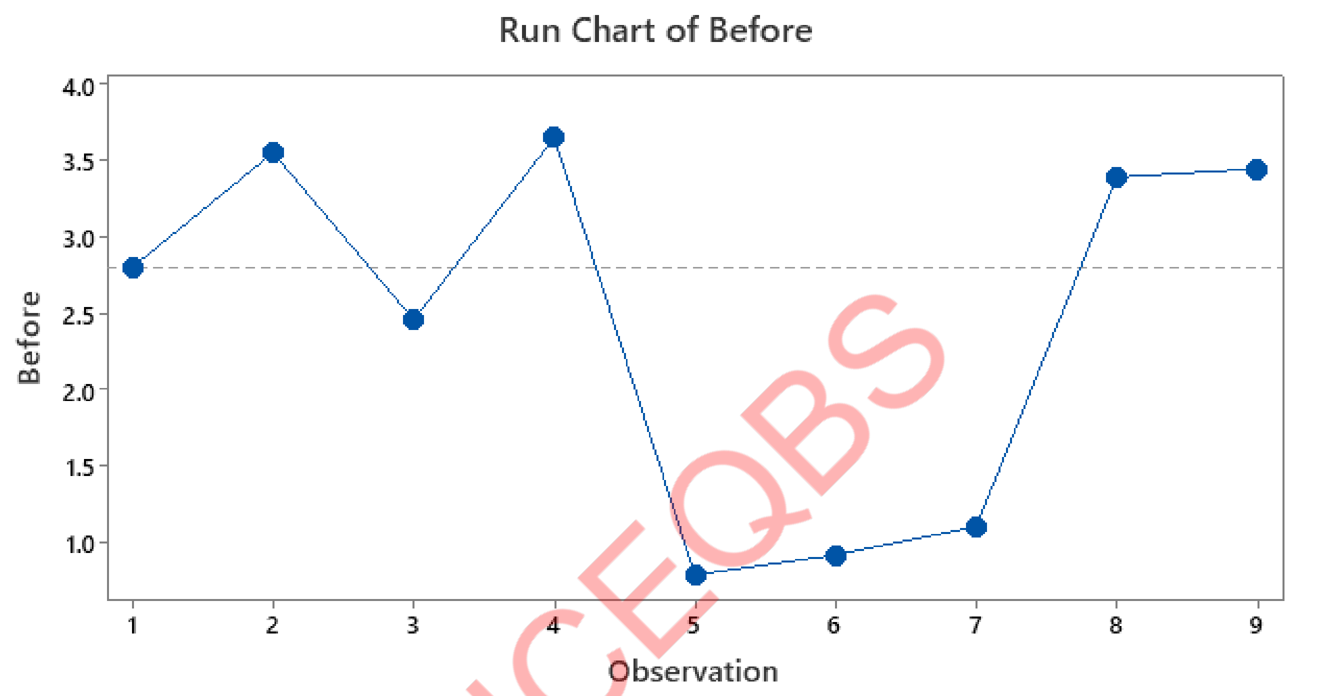
– Suppliers	I – Inputs	P – Process (High-Level Steps)	O – Outputs	C – Customers
Raw Material Vendors	Stainless steel sheets / tubes	Material Preparation – Cutting & cleaning of SS sheets/tubes	Cut blanks / cleaned material	Production Line
Tooling Suppliers	Forming dies, welding jigs, trimming tools	Forming / Hydroforming – Shape bellows using dies or hydraulic forming	Formed bellows	In-process inspection
Maintenance Department	Machines, lubrication, maintenance support	Trimming & Sizing – Trim edges and achieve dimensional accuracy	Trimmed, dimensionally accurate bellows	Welding team
Welding Consumables Supplier	Argon gas, filler rods, welding wire	Welding (TIG/Laser) – Join bellows ends or assemblies	Welded bellows	Leak testing cell
Calibration & Quality Team	Gauges, NDT equipment, pressure testers	Leak Testing / Pressure Testing – Check for leaks and weld integrity	Leak-free verified bellows	Final inspection
Operators & Production Staff	Work instructions, skill, training	Final Inspection & Cleaning – Visual, dimensional, surface inspection	Accepted final bellows	Customers / Assembly line
Packaging Supplier	Packaging material	Packaging & Dispatch – Pack, label, and ship products	Packed finished bellows	OEM / End customers

Data collection – Histogram (Before improvement)

Inference :

- Data is normally distributed over the mean

Data collection – Run Chart (Before improvement)

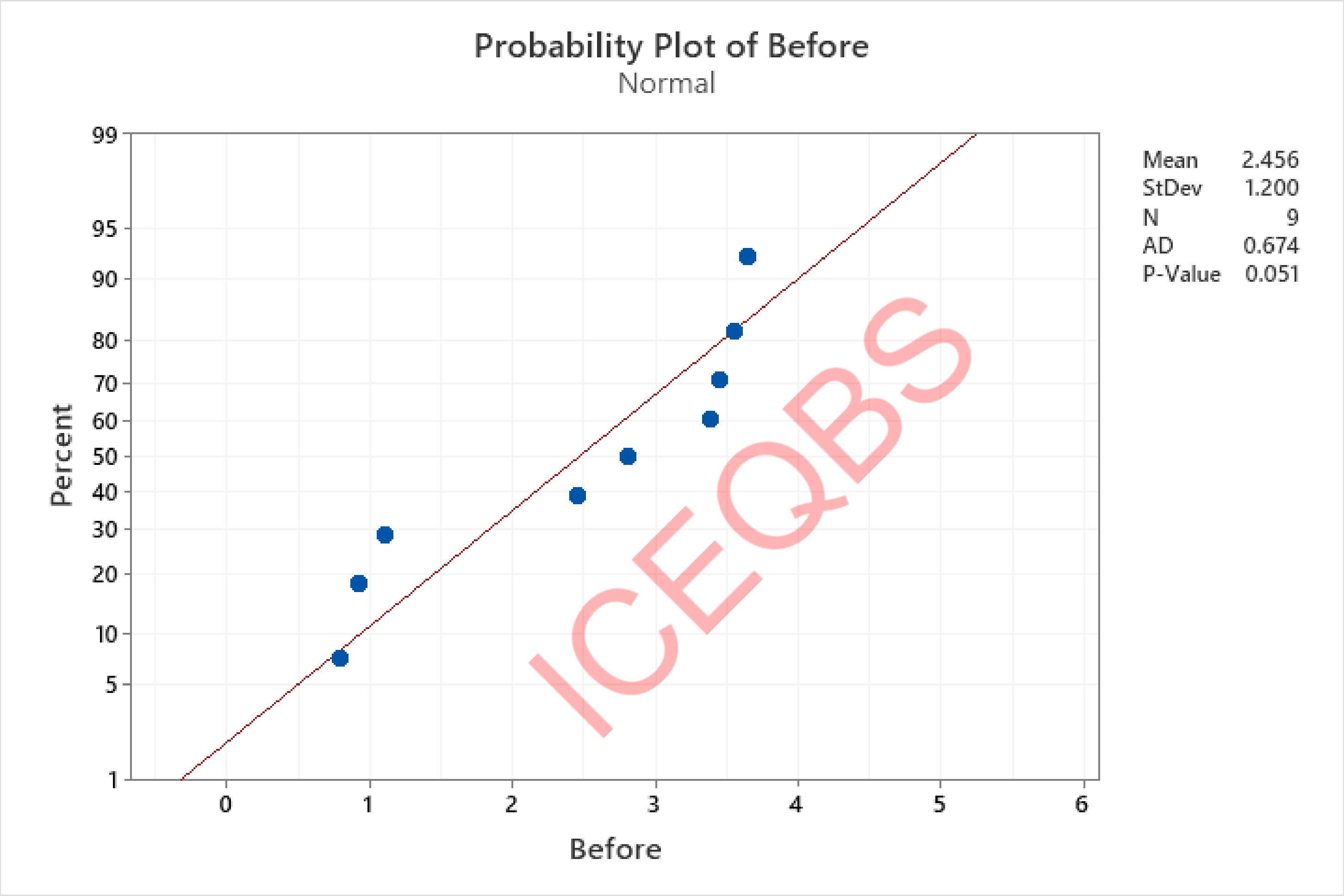


Number of runs about median:	6	Number of runs up or down:	5
Expected number of runs:	5.4	Expected number of runs:	5.7
Longest run about median:	3	Longest run up or down:	4
Approx P-Value for Clustering:	0.656	Approx P-Value for Trends:	0.278
Approx P-Value for Mixtures:	0.344	Approx P-Value for Oscillation:	0.722

Inference :

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

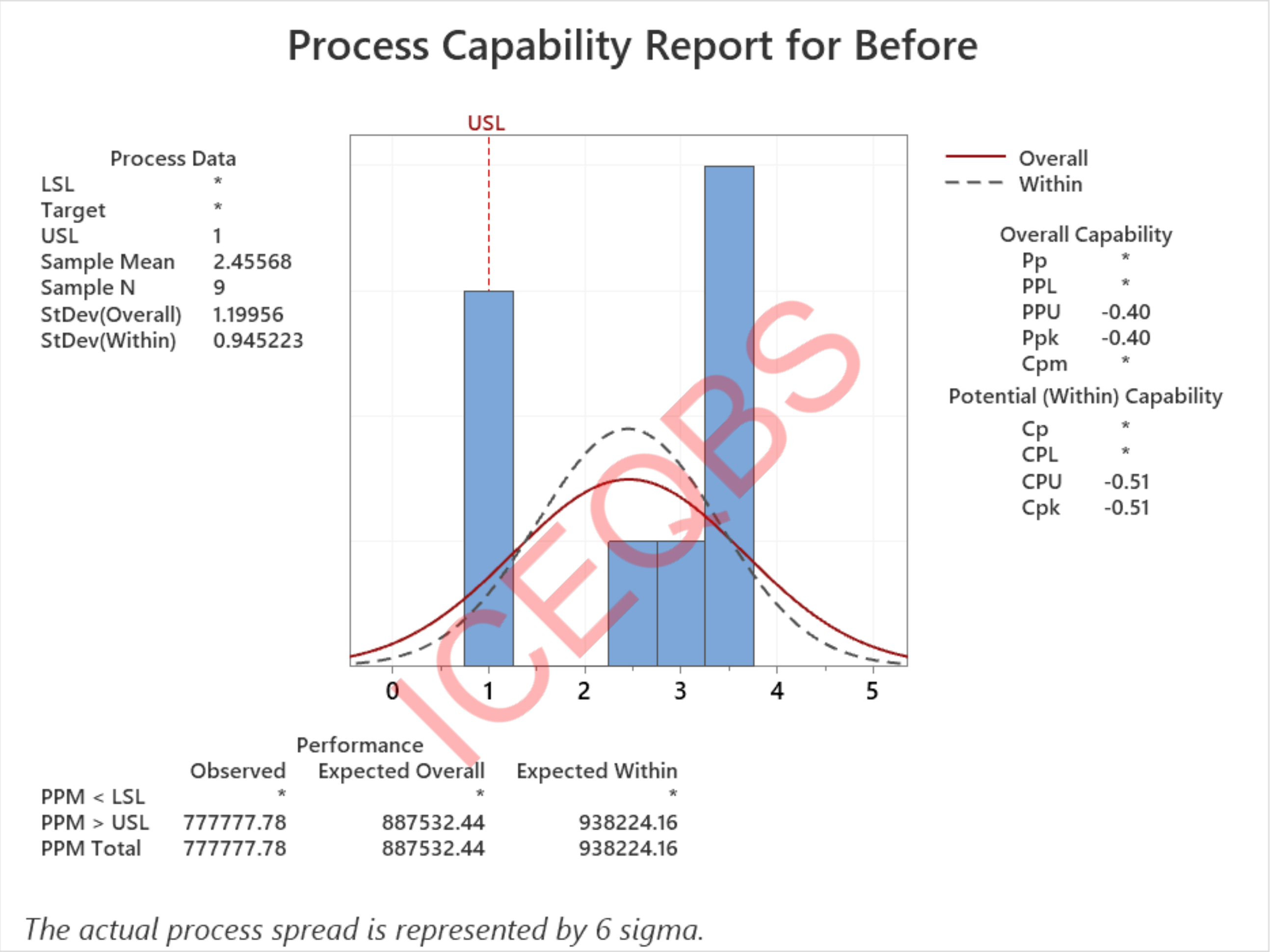
Data collection – Normality plot (Before improvement)



Inference :

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

Process Capability (Before improvement)



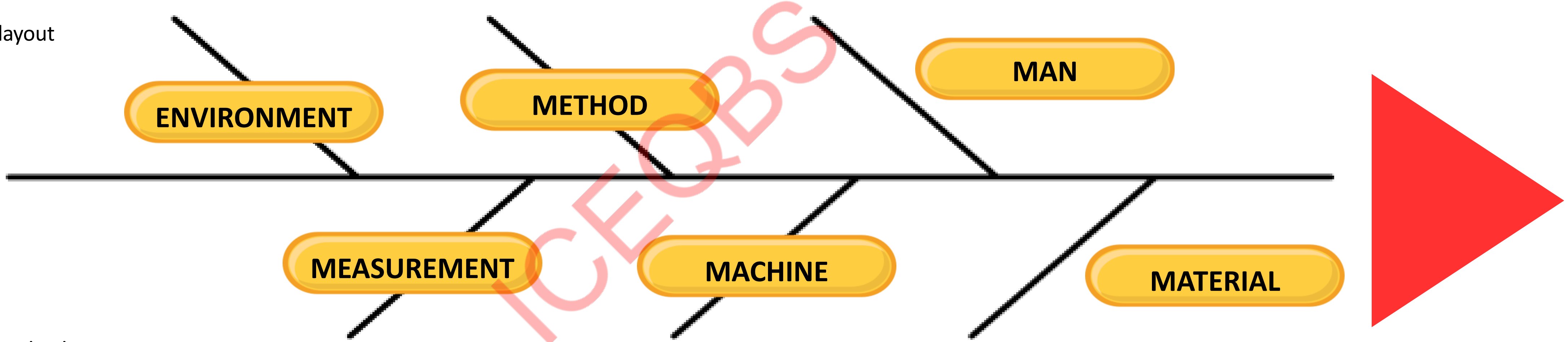
Inference :
Before improvement, the process is highly incapable, with the mean (~2.46) exceeding the USL of 1, negative Cpk/Ppk values, and extremely high nonconformance, indicating severe performance gaps.

Fish Bone Diagram

1. Poor lighting / visibility
2. Uncontrolled temperature / humidity
3. Dust / contamination in welding area
4. Inadequate ventilation
5. Poor workstation layout

1. Incorrect forming pressure / parameters
2. Non-standardized welding procedure
3. Lack of pre-cleaning before welding
4. Inadequate process control (no SPC)Absence of Poka-Yoke in assembly

1. Inadequate operator training
2. Inconsistent skill levels
3. Poor handling practices
4. Lack of process ownership
5. Fatigue / lack of supervision



1. Inaccurate measuring instruments
2. Inconsistent inspection method
3. Lack of real-time data monitoring
4. Incomplete traceability

1. Worn forming dies
2. Welding machine instability
3. Inadequate tool maintenance
4. Leak test equipment calibration drift
5. Improper alignment jigs

1. Variation in SS sheet thickness
2. Surface contamination (oil, rust)Inconsistent hardness or temper
3. Poor-quality filler wire or gas
4. Non-conforming supplied batches

8 Wastes Analysis

Type of Waste	Description	Example 1	Example 2
1. Overproduction	Making more than what is needed or before it is needed	Producing extra bellows to “fill capacity” even without customer orders	Manufacturing multiple prototypes before finalizing customer specs
2. Waiting	Idle time when materials, machines, or approvals are delayed	Operators waiting for welding machine setup or maintenance	Waiting for quality inspector approval before moving to the next process
3. Transport	Unnecessary movement of materials or products	Moving semi-finished bellows long distances between forming and welding areas	Transporting finished parts multiple times for inspection or storage
4. Overprocessing	Performing more work or using more precision than required	Using a higher welding grade or filler metal than the design demands	Polishing surfaces beyond customer requirements
5. Inventory	Excess raw materials, WIP, or finished goods not yet sold	Stocking large quantities of stainless steel sheets “just in case”	Accumulating finished bellows waiting for shipment or inspection
6. Motion	Unnecessary movement of people or tools	Operators walking back and forth to get tools, clamps, or gauges	Poor workstation layout causing excess reaching or bending
7. Defects / Rework	Products not meeting specifications requiring rework or scrap	Bellows leaking during pressure testing due to welding defects	Wrong material batch used, requiring rework or scrap
8. Unused Talent	Not utilizing workers’ skills, ideas, and experience	Ignoring operators’ suggestions for fixture improvements	Assigning skilled welders to simple loading tasks instead of training others

Action Plan for Low Hanging Fruits

Special Causes (sudden failures / abnormalities)

SNO	Area / Station	Observation (What is happening)	Waste / 3M Category	Proposed Low-Hanging Fruit Action
1	Raw material storage (incoming strip)	Large stacks of material awaiting processing; operators walking long distances to retrieve	Inventory waste (Muda) + Motion waste + Mura (uneven flow)	Relocate material closer to forming line; introduce Kanban signaling for restocking; mark storage zones (5S)
2	Tube forming line (first forming step)	Machine downtime frequent due to unplanned tool changeovers; resulting in idle time & waiting	Waiting waste + Muri (overburden of machine and setup) + Special cause (tool change failures)	Standardize tool changeover, create SMED quick-change kit, train operator
3	Bellows convolution forming station	Excessive walking by operator fetching gauges, measuring devices from central area	Motion waste + Muda	Place measurement tools at workstation using shadow-board; 5S implement
4	Weld / seam station	Weld rejects relatively high (rework required) → defects	Defects waste + special cause (inconsistent weld quality)	Introduce visual weld-quality checklist; two-minute inspection after each batch; retrain welder; post weld immediate feedback
5	Intermediate buffer between forming & trimming	Large inventory buffer, items wait a long time → waiting & inventory waste	Inventory waste + Waiting waste + Mura (uneven flow)	Reduce buffer size; implement pull system (Kanban) for trimming station; visual WIP limit board
6	Trimming station	Operator overloaded, frequent overtime; machine often runs overtime to keep up	Muri (overburden) + Over-processing waste (excess trimming due to inconsistent parts)	Balance workload: cross-train second operator; smooth production schedule; review trimming step for any unnecessary rework

Action Plan for Low Hanging Fruits

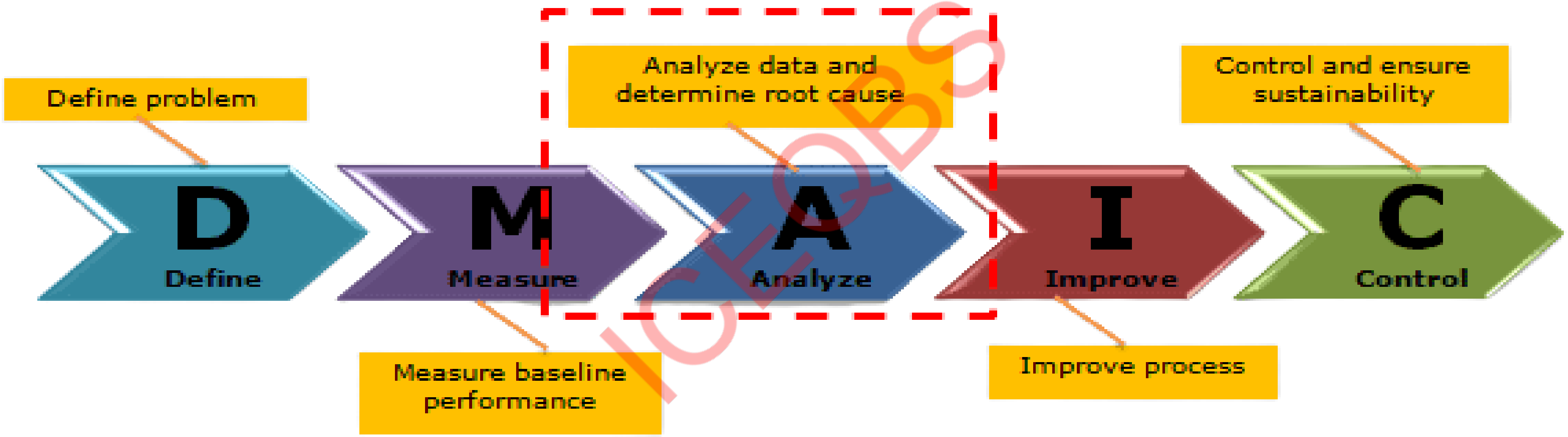
Special Causes (sudden failures / abnormalities)

SNO	Area / Station	Observation (What is happening)	Waste / 3M Category	Proposed Low-Hanging Fruit Action
7	Final inspection & packaging	Inspection paperwork duplicated, multiple forms for same part; slow handover → over-processing waste	Over-processing waste + Unused talent waste (inspectors doing redundant work)	Merge forms into single digital check-list; incorporate inspector suggestions; deploy tablet or mobile device if possible
8	Transport of parts between stations (forming → weld → trim)	Frequent non-value-adding transport of parts across floor; trolleys move long distances	Transport waste + Motion waste	Re-layout transport path: shorten distance, mark floor paths; implement “one-piece flow” where possible
9	Daily downtime data / machine breakdown log	Machine breakdowns not systematically logged/analysed; cause recurrence of special-cause events	Special cause + Mura (variation)	Start simple daily downtime log board; root cause quick review in morning stand-up; assign team to trending
10	Operator suggestion system	Very few suggestions coming from operators → unused talent waste	Unused talent waste	Launch “quick kaizen suggestion” board; reward small improvements; monthly review meeting

Top 12 Prioritized Root Causes (Based on Net Score)

S. No.	Issue / Cause Description	Count
1	Variation in sheet / material thickness & quality	135
2	Machine downtime / changeover delays	123
3	Poor material supplier consistency	105
4	Inspection batch size / scheduling imbalance	103
5	Long tool / fixture changeover time (SMED opportunity)	101
6	Electrode wear / welding consumable condition	98
7	Lack of standard welding setup & operator method	98
8	Operator walking / inefficient layout	97
9	Excess WIP buffer / over-production policy	87
10	Delay in maintenance approvals / maintenance scheduling	85
11	Over-processing in inspection / redundant checks	83
12	Unused operator suggestions / low engagement	70

ANALYSE PHASE



Analyse – Hypothesis testing

Regression Analysis: Scrap_Percent versus Sheet_Thickness_Deviation_mm,

Regression Equation

Scrap_Percent = 13.683 + 24.96 Sheet_Thickness_Deviation_mm - 0.07080 Electrode_Wear_Score - 0.07973 Welding_Setup_Std_Score

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	13.683	0.335	40.89	0.000	
Sheet_Thickness_Deviation_mm	24.96	1.17	21.36	0.000	1.02
Electrode_Wear_Score	-0.07080	0.00365	-19.37	0.000	1.04
Welding_Setup_Std_Score	-0.07973	0.00311	-25.62	0.000	1.03

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.322338	96.72%	96.54%	96.23%

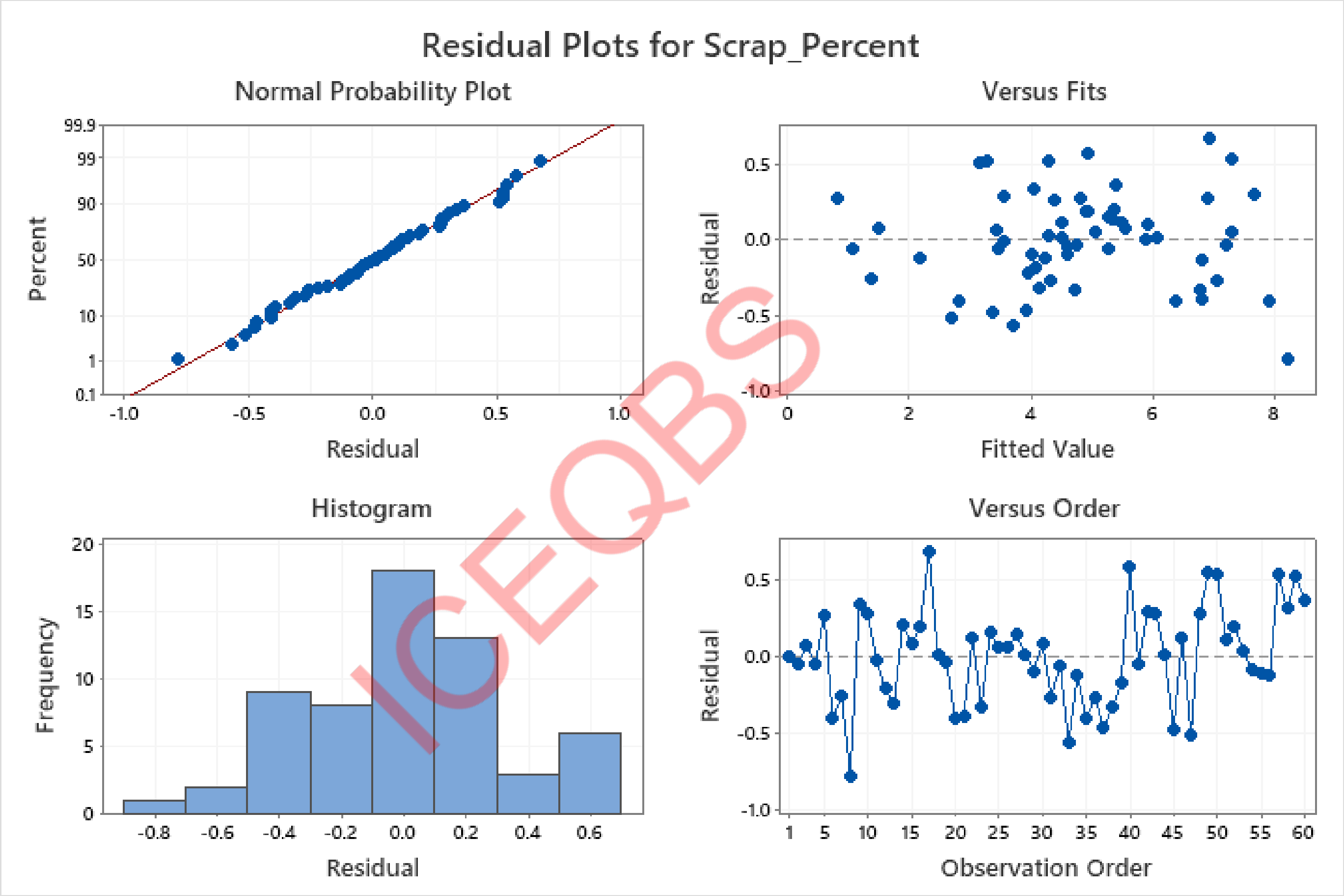
Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	171.503	57.1675	550.21	0.000
Sheet_Thickness_Deviation_mm	1	47.421	47.4212	456.40	0.000
Electrode_Wear_Score	1	38.998	38.9981	375.34	0.000
Welding_Setup_Std_Score	1	68.174	68.1742	656.14	0.000
Error	56	5.818	0.1039		
Total	59	177.321			

Inference :

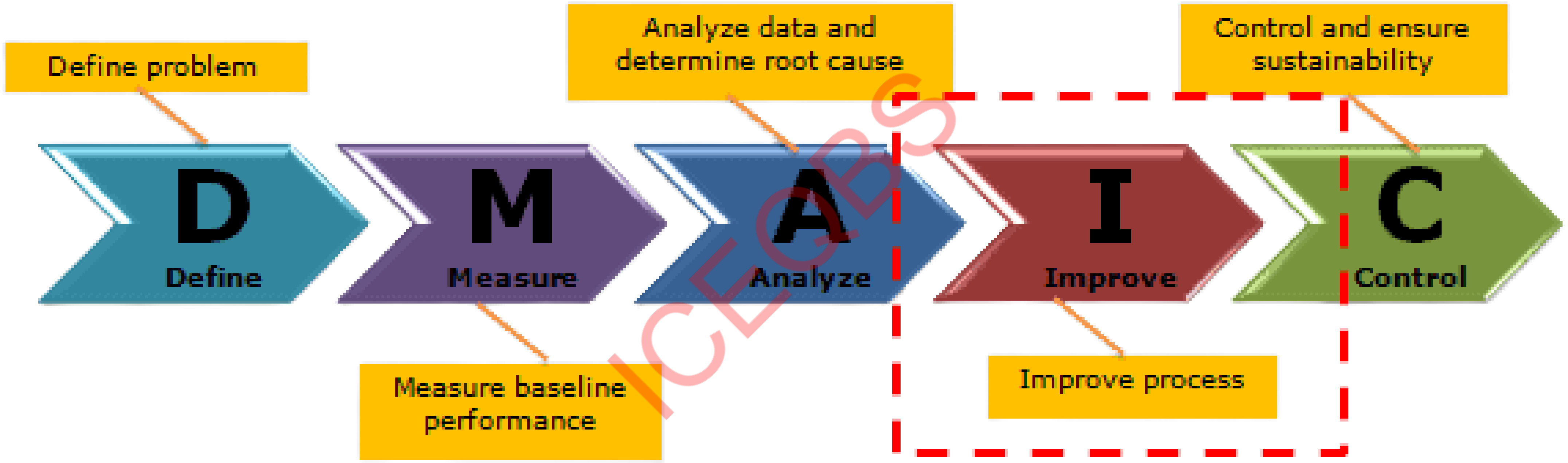
- Scrap is mainly driven by sheet thickness deviation, electrode wear, and welding setup issues, and these factors explain almost all the variation in scrap.

Analyse – Hypothesis testing



Inference :
The residual plots show normal, random, and pattern-free residuals, confirming the regression model is valid and reliable for explaining scrap behavior.

IMPROVE PHASE



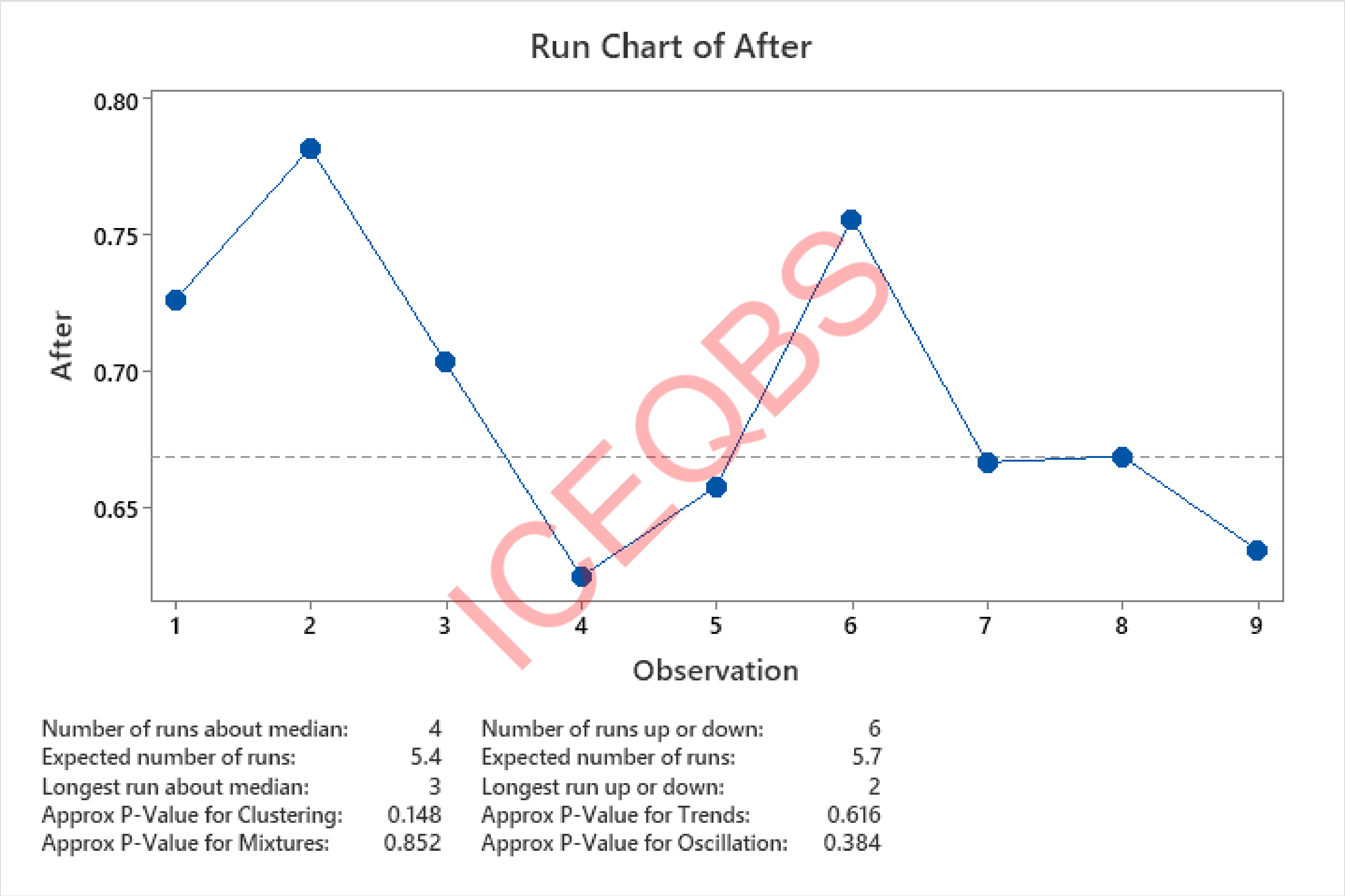
Improve

#	Critical root cause addressed	Improvement action	How to implement (key steps)	KPI / Target
1	Sheet/material thickness variation	Tighten incoming material control + supplier capability program	Define CTQs (thickness, hardness, coating, surface defects); update supplier spec & inspection plan; introduce COA requirement; run supplier capability (Cp/Cpk) for thickness; implement supplier scorecard and escalation for lots outside spec	Incoming thickness deviation reduced by ≥40%; supplier lot rejection ≤1%
2	Sheet/material thickness variation	Incoming inspection upgrade with “smart sampling” + segregation system	Move from fixed batch size to risk-based sampling (new supplier/grade = higher sampling); add simple measurement SOP (calibrated micrometer / thickness gauge); color-tagging for accepted/hold/reject; quarantine area with disposition cycle time SLA	100% traceability; “Hold” disposition closed <24 hrs; zero mixed-lot use

Improve

#	Critical root cause addressed	Improvement action	How to implement (key steps)	KPI / Target
3	Electrode wear / consumable condition	Consumable life management + storage/handling controls	Define electrode life limits by weld length/parts count; create “electrode health” checklist per shift; implement FIFO, humidity control, baking/drying where applicable; introduce change trigger rules (arc stability/visual wear thresholds) and log usage	Electrode change compliance ≥95%; weld defect-driven scrap reduced by ≥30%
4	Welding setup & operator method variation	Standard welding recipe + setup validation (WPS + golden parameters)	Create “golden setup” for each bellow type (current/voltage/travel speed, fit-up, tack sequence); first-piece approval checklist; poka-yoke settings (lockable knobs / parameter password); visual standard work at station; method training + certification	First-pass yield ↑; setup adherence ≥95%; operator skill matrix 100% current
5	Welding setup & consumable condition (system control)	Layered Process Audits + real-time process monitoring	Daily LPA: thickness check, electrode status, setup checklist, calibration status; weekly audit on WPS adherence; add simple SPC/control charts on key CTQs (thickness deviation, electrode wear score, setup score); trigger corrective actions based on thresholds	Scrap sustained ≤ target; audit closure <48 hrs; control chart violations acted on same shift

Improve



The after run chart shows stable, random variation around the median with no significant trends or patterns, indicating the improved process is under control.

Improve

The after probability plot confirms the data is normally distributed (p = 0.567) with a lower mean (~0.69), validating stable and improved process performance.

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	2.46	1.20	0.40
After	9	0.6910	0.0543	0.018

Estimation for Difference

Difference	95% CI for Difference
1.765	(0.842, 2.688)

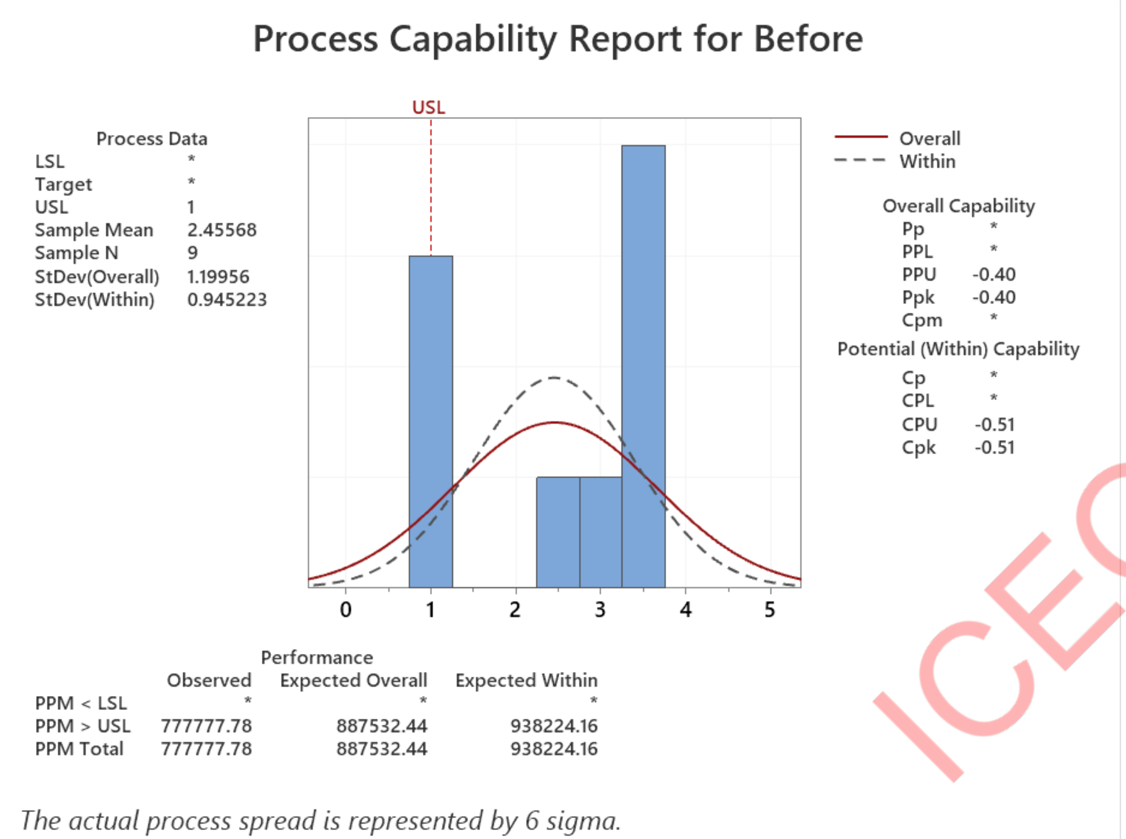
Test

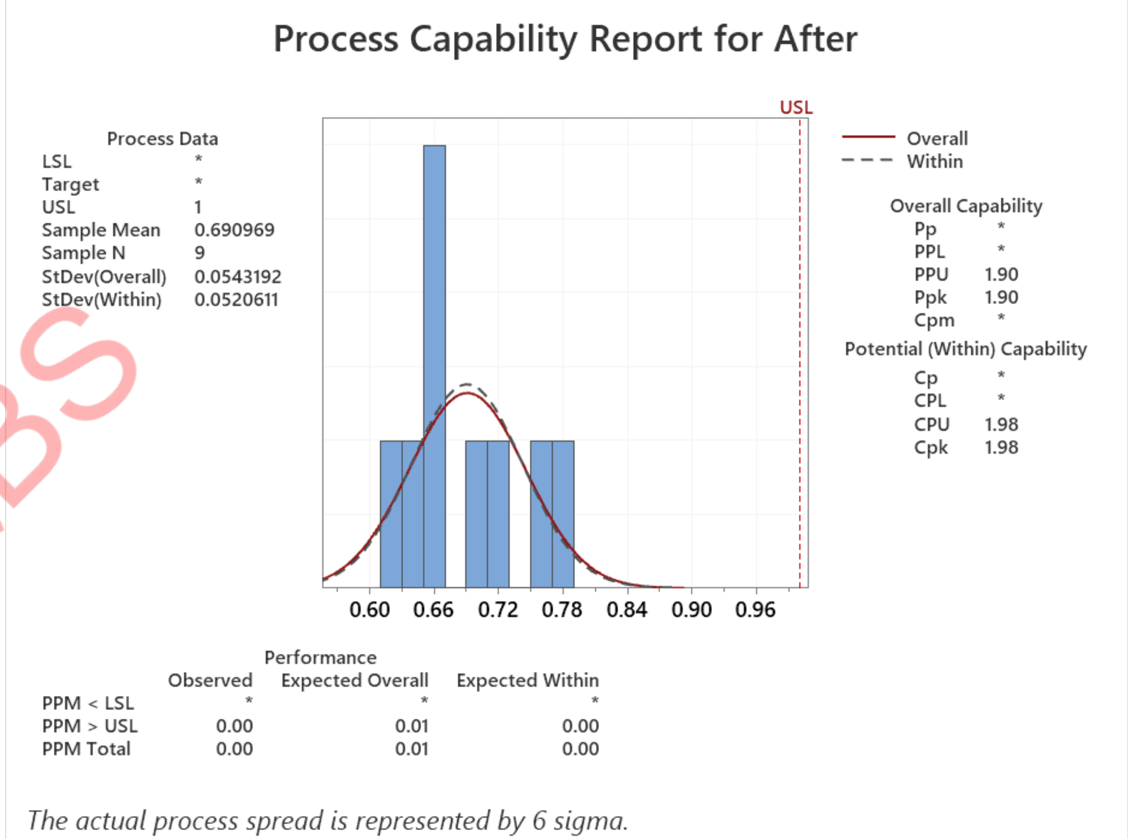
Null hypothesis $H_0: \mu_1 - \mu_2 = 0$
Alternative hypothesis $H_1: \mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
4.41	8	0.002

The two-sample t-test confirms a statistically significant reduction after improvement (mean reduced from ~2.46 to ~0.69, p = 0.002), demonstrating the improvement is effective.

Improve – Process capability – Before & After Improvement

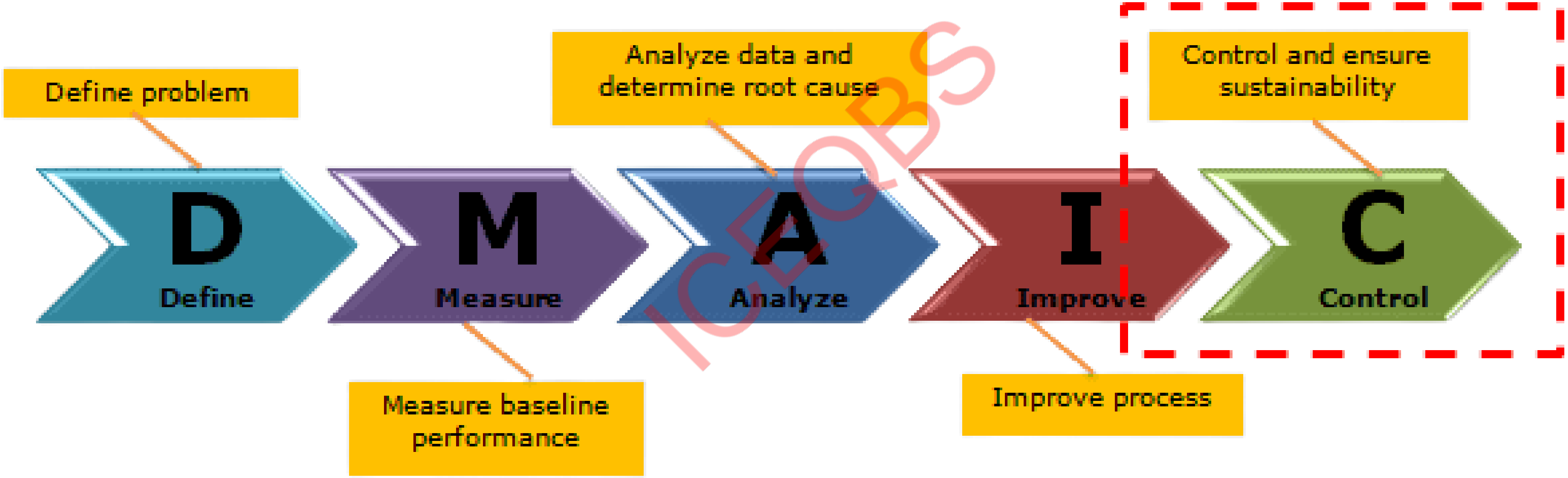




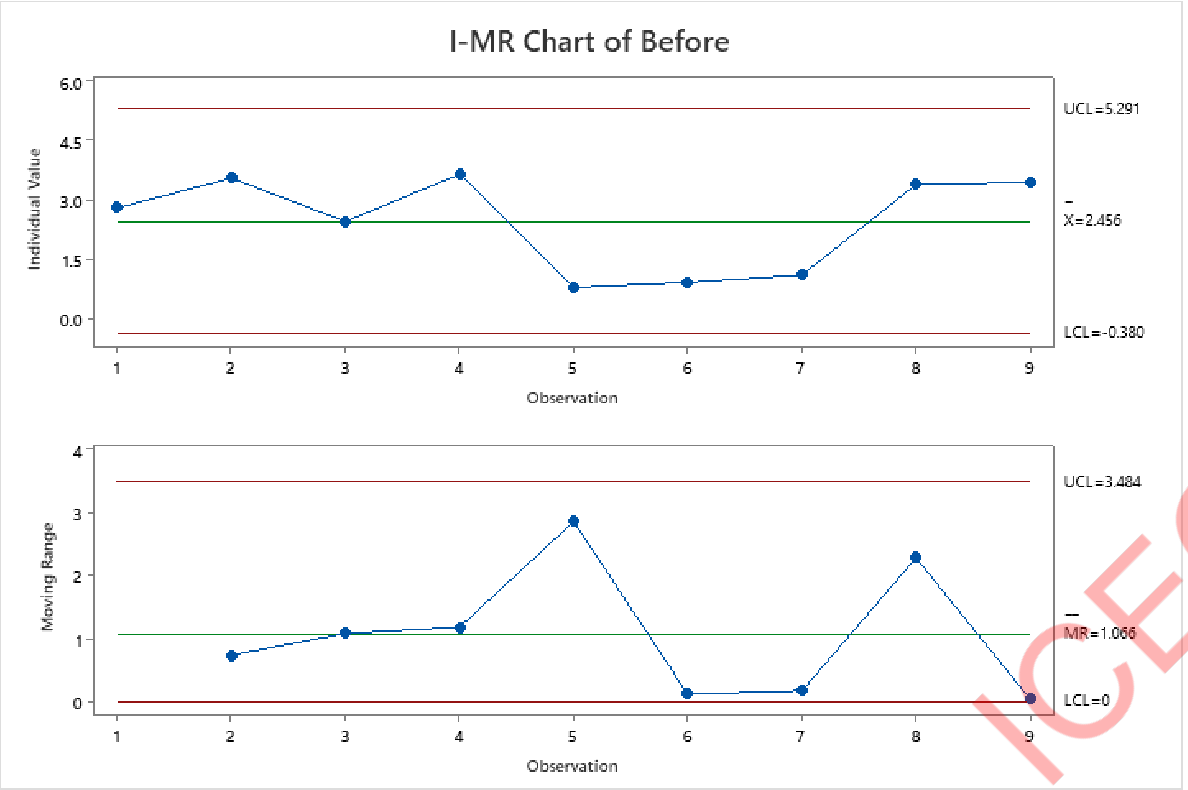
Inference :

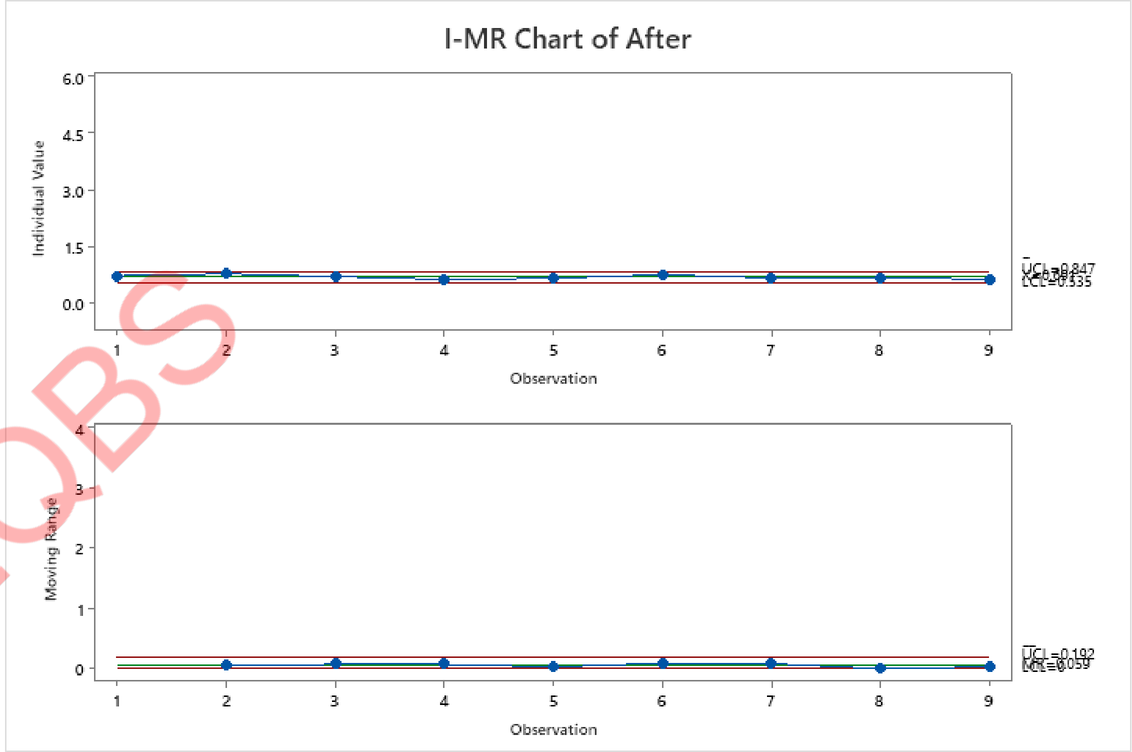
- The before–after capability comparison shows the process moved from completely incapable (negative Cpk) to capable (Cpk ≈ 1.98), with the mean well below the USL and near-zero defects after improvement.

CONTROL PHASE



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





Inference:

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

Control Plan

#	Area / Root Cause	5S Mechanism (Visual / Workplace Control)	Poka-Yoke (Error-Proofing)	How it prevents scrap
1	Sheet thickness variation	Shadow board & labeled rack for material grades/thickness (Sort + Set in Order)	Physical go/no-go thickness gauge at line entry – material cannot be issued unless it passes	Prevents wrong thickness sheet entering forming/welding
2	Material mix-up / supplier lot variation	Color-coded lot identification & FIFO lanes (Set in Order + Standardize)	Barcode / QR scan mandatory before material issue; mismatch triggers stop	Eliminates mixed lots and unapproved supplier material usage
3	Electrode wear / consumable condition	Electrode life bin with max-use marking (Shine + Standardize)	Wear indicator tag or punch-card system – electrode locked out after defined usage	Prevents welding with worn or degraded electrodes
4	Welding setup variation	Visual WPS board at each station with photo of correct setup (Standardize)	Preset parameter lock / password protection on welding machine	Prevents incorrect current, voltage, or sequence settings
5	Operator method inconsistency	Standard Work display + tool positioning fixtures (Sustain)	Asymmetric fixtures / locator pins – part fits only in correct orientation	Eliminates wrong fit-up and inconsistent welding sequence

Control Plan

#	Implementation step	Potential failure mode	Effect of failure	S (1–10)	Potential cause	O (1–10)	Current controls	D (1–10)	RPN	Proactive action (recommended)
1	Material spec + supplier control rollout	Supplier continues shipping thickness outside tightened spec	High scrap, rework, line stoppage	9	Supplier capability not assessed; no enforcement mechanism	5	Incoming inspection; supplier feedback	6	270	Supplier capability & containment plan: run initial Cp/Cpk on thickness; require COA; define escalation (hold lot, SCAR, approved deviation only); dual-source for critical thickness
2	Incoming inspection + segregation	Wrong thickness/grade issued to production (mix-up)	Defects propagate through forming/welding; scrap spikes	9	Similar-looking sheets; poor identification; rush to issue	4	Visual tagging	6	216	Poka-yoke issue control: barcode/QR scan at material issue + ERP/Excel validation; physical FIFO lanes; quarantine cage for “HOLD” lots; issue only against work order
3	Electrode life management	Worn electrode used beyond limit	Weld defects, leak failures, rework/scrap	8	No clear life limit; operators bypass change; poor storage	6	Operator judgement	5	240	Electrode governance system: define life-by-weld-length/parts; “change trigger” checklist; controlled storage (humidity/FIFO); issue log; supervisor verification once/shift
4	Standard welding setup + WPS	Wrong machine parameters / setup not followed	Inconsistent weld quality; high variation and scrap	9	Multiple variants; settings changed; inadequate training	5	WPS available, not enforced	5	225	Lock + certify: create “golden recipe” per bellow type; parameter lock/password; first-piece approval checklist; operator certification + re-cert every 6 months

Control Plan

#	Process step	CTQ / Risk controlled	Control method	Specification / Standard	Reaction plan
1	Incoming material receipt	Sheet thickness deviation	Incoming inspection + supplier COA verification	Thickness within approved spec (per drawing/WPS); approved supplier only	Stop issue → quarantine lot → inform SCM & supplier → SCAR → use alternate lot/supplier
2	Material storage & issue	Wrong thickness / mixed lot usage	FIFO lanes, color coding, barcode/QR verification before issue	Material issued only against WO & matching spec	Block issue → segregate → correct identification → retrain store operator
3	Welding consumable usage	Electrode wear / degradation	Electrode life log, FIFO storage, humidity control	Electrode within defined life limit; storage per SOP	Replace electrode → record deviation → supervisor verification → analyze repeat cases
4	Welding setup & execution	Setup variation / wrong parameters	Standard WPS display, parameter lock, first-piece approval	“Golden setup” parameters adhered; first piece approved	Stop welding → reset parameters → re-approve first piece → re-certify operator if repeated
5	Process sustainment	Control drift / loss of discipline	Layered Process Audit (LPA) + SPC on key CTQs	Scrap % ≤ target; no control chart violations	Immediate containment → root cause → corrective action → update SOP / training

Conclusion

Results after improvement

- **This project successfully transformed an unstable, high-scrap process into a stable and capable operation, delivering sustained scrap reduction, improved FPY, and measurable cost savings.**