

Reduce the scrap rate in steel fabrication

ICEOBS

Libu Varghese

ROADMAP



OVERVIEW

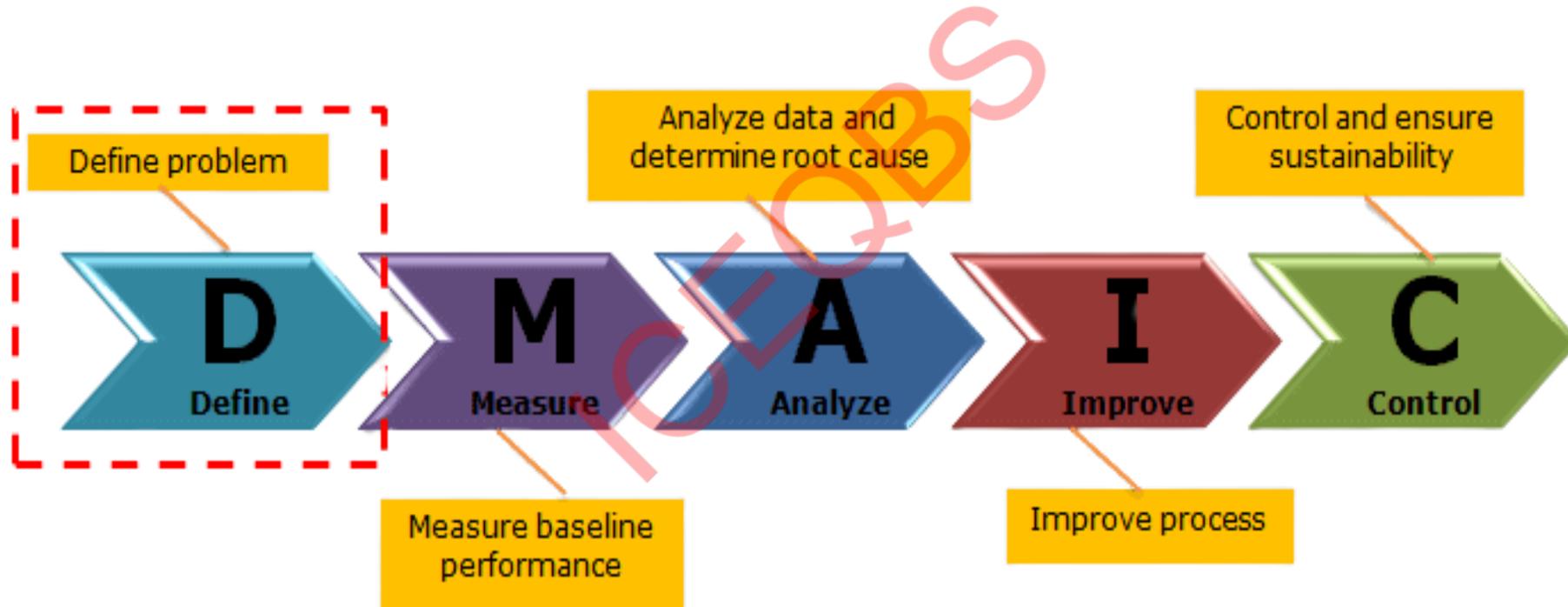


Background

The steel fabrication process currently has a scrap rate of 6% due to dimensional inaccuracies, welding defects, and improper assembly. This results in increased material wastage, higher rework costs, delayed deliveries, and reduced productivity. Reducing scrap will lower the cost of poor quality, improve resource utilization, ensure on-time delivery, and strengthen customer confidence while aligning with ISO and industry quality standards.

ICEQBS

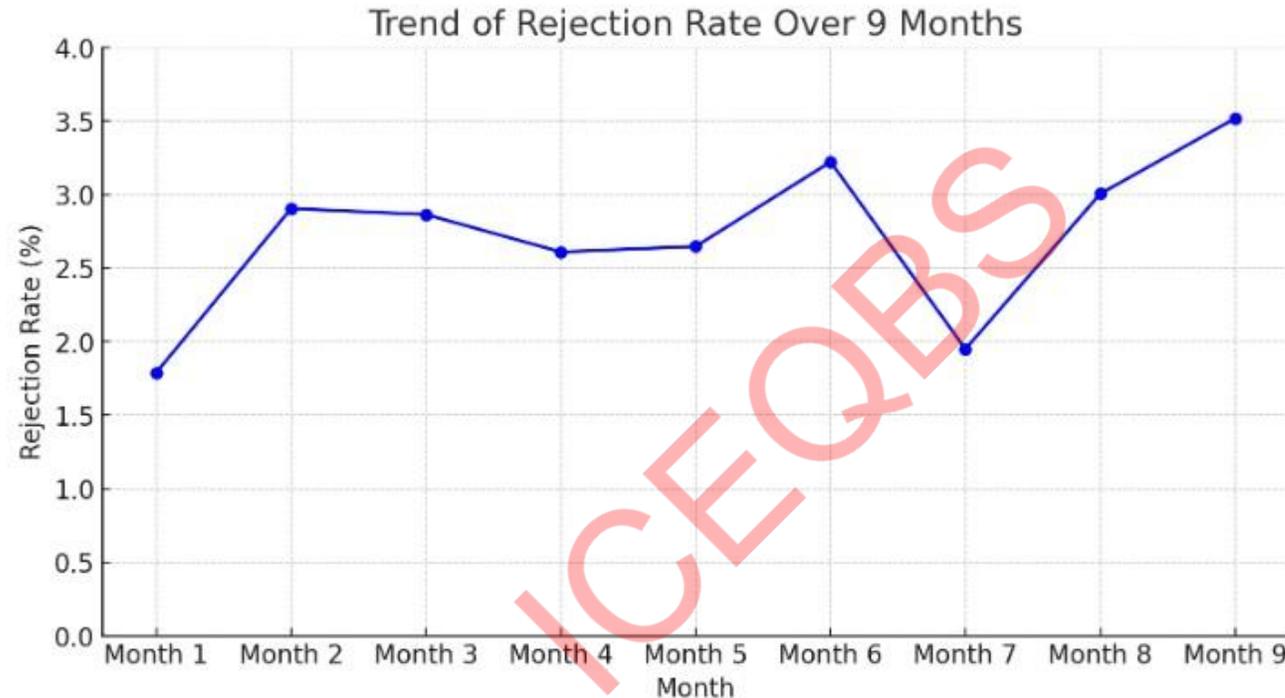
DEFINE PHASE



CTQ Tree :

Voice of customer	Critical to X	Primary Metric for improvement
<i>“All components must meet design specifications and standards.”</i>	CTQ = Rejection Rate (%)	Primary Metric - Y = Rejection Rate (%) Secondary Metric - Productivity

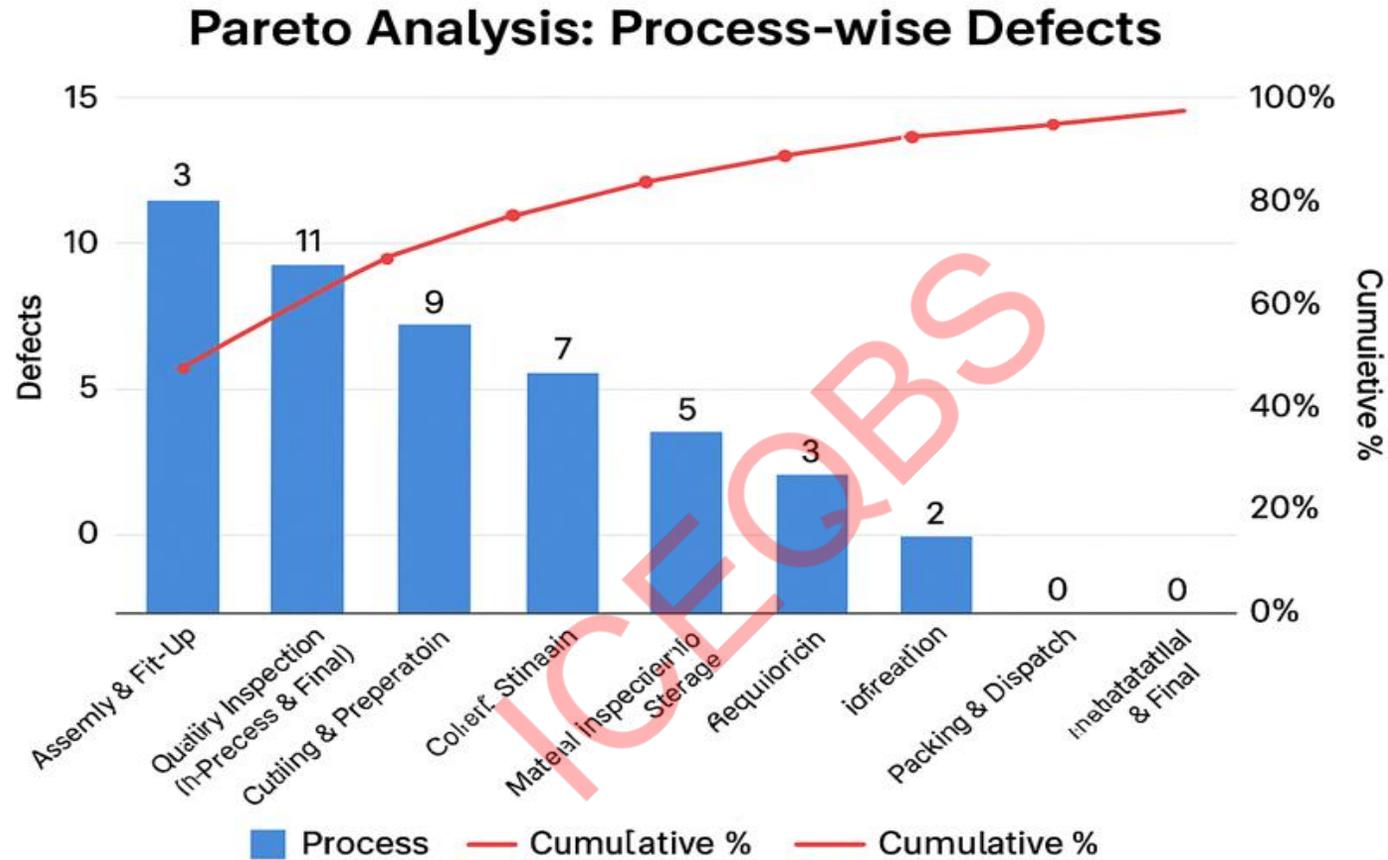
Baseline Performance of Primary Metric (9 months data as Line chart)



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 :

- Assembly & Fit-up contributes substantially for the scrap and included in the scope of the project

Project Charter

Project Title:	Reduce the scrap rate in steel fabrication		
Project Leader	Libu Varghese	Project Team Members:	
Champion/Sponsors:	Plant Head – Production	Key Stake Holders	
		End Clients/Owners	
		Quality Control Team	
		Contractors/Subcontractors	
Problem Statement:	Goal Statement:		
The current scrap rate in the steel fabrication process is 6%, based on the analysis on last 6 months data. This leads to increased material costs, delayed deliveries, and reduced overall productivity.	Reduce the scrap rate in steel fabrication from 6% to 2% or less within 6 months, while maintaining or improving daily output levels.		
Secondary Metric	Productivity	Assumptions Made:	
		Scrap data is accurate, consistently recorded, and properly classified.	
		Product design, drawings, and customer specifications will remain unchanged during the project period.	

Project Charter

Tangible and Intangible Benefits:

Reduction in **material wastage and scrap cost** (estimated savings ~\$15,000/month).
Improved **productivity and machine/labor utilization**.

Risk to Success:

Incorrect root cause identification due to mixed defect types (dimension, welding, assembly).
Resistance to new welding or assembly practices from shop-floor teams.

In Scope:

Cutting, preparation, welding, assembly, and inspection of steel components.

Out of Scope:

Procurement of raw material, transportation, and on-site installation.

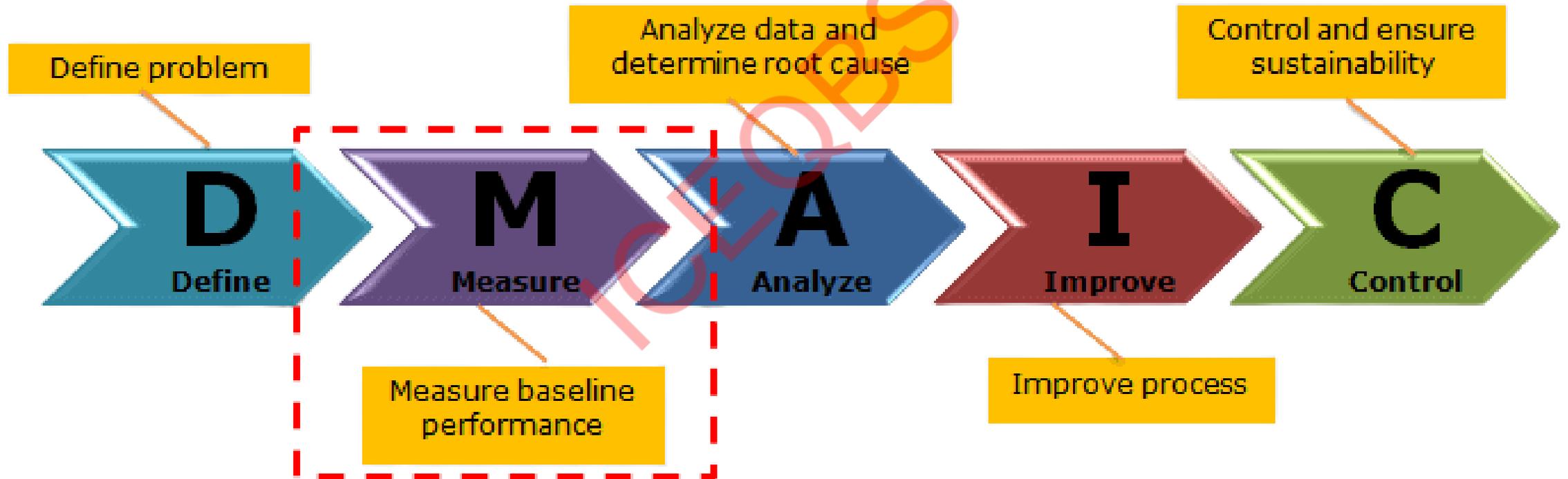
Signatories:

Plant Head – Production

Project Timeline:

6 Months

MEASURE PHASE



Suppliers (S)	Inputs (I)	Process (P)	Outputs (O)	Customers (C)
Raw material suppliers	Steel plates and sections	1. Receive and inspect raw materials	Accepted fabricated steel components	Internal QC department
Welding electrode suppliers	Welding electrodes and consumables	2. Cut and prepare steel components	Scrap / rejected components	Assembly / installation team
Maintenance team	Fabrication drawings	3. Assemble components	Production reports	End customers
Production planning	Work instructions	4. Welding and joining	Inspection reports	Management
	Skilled operators	5. Inspect fabricated components		
		6. Rectify minor defects		
		7. Segregate defective and accepted components		

Data collection – Histogram (Before improvement)

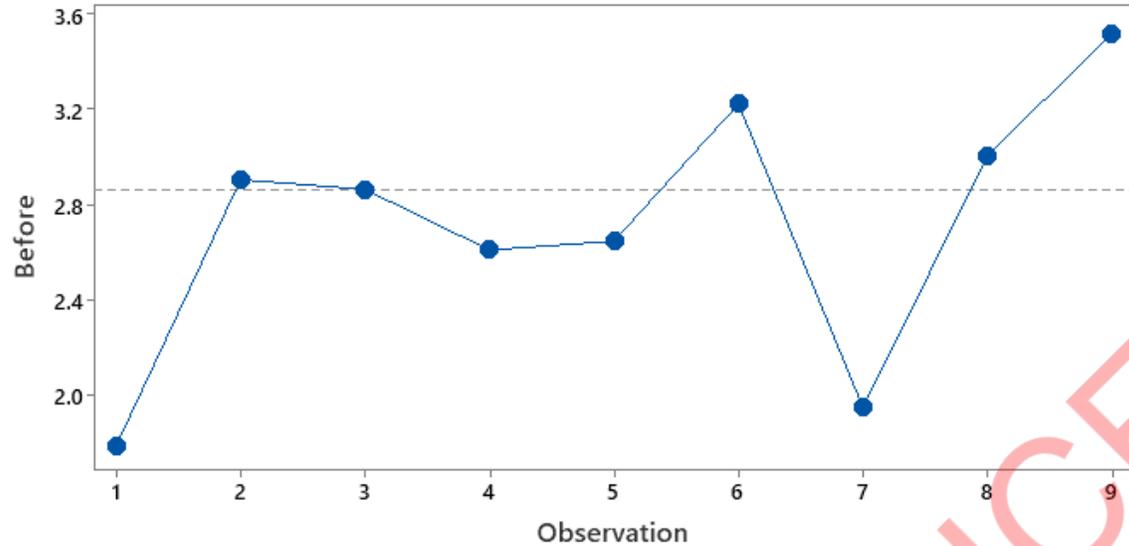


Inference :

- Data is normally distributed over the mean

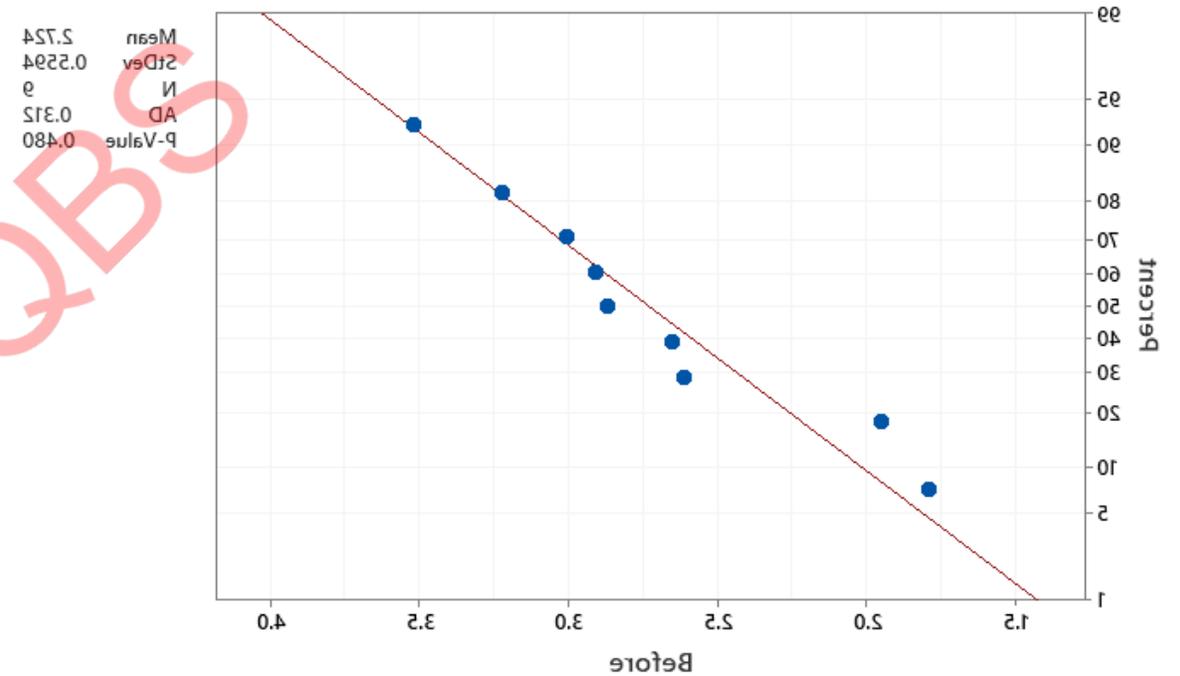
Data collection – Run Chart (Before improvement)

Run Chart of Before



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:	2
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

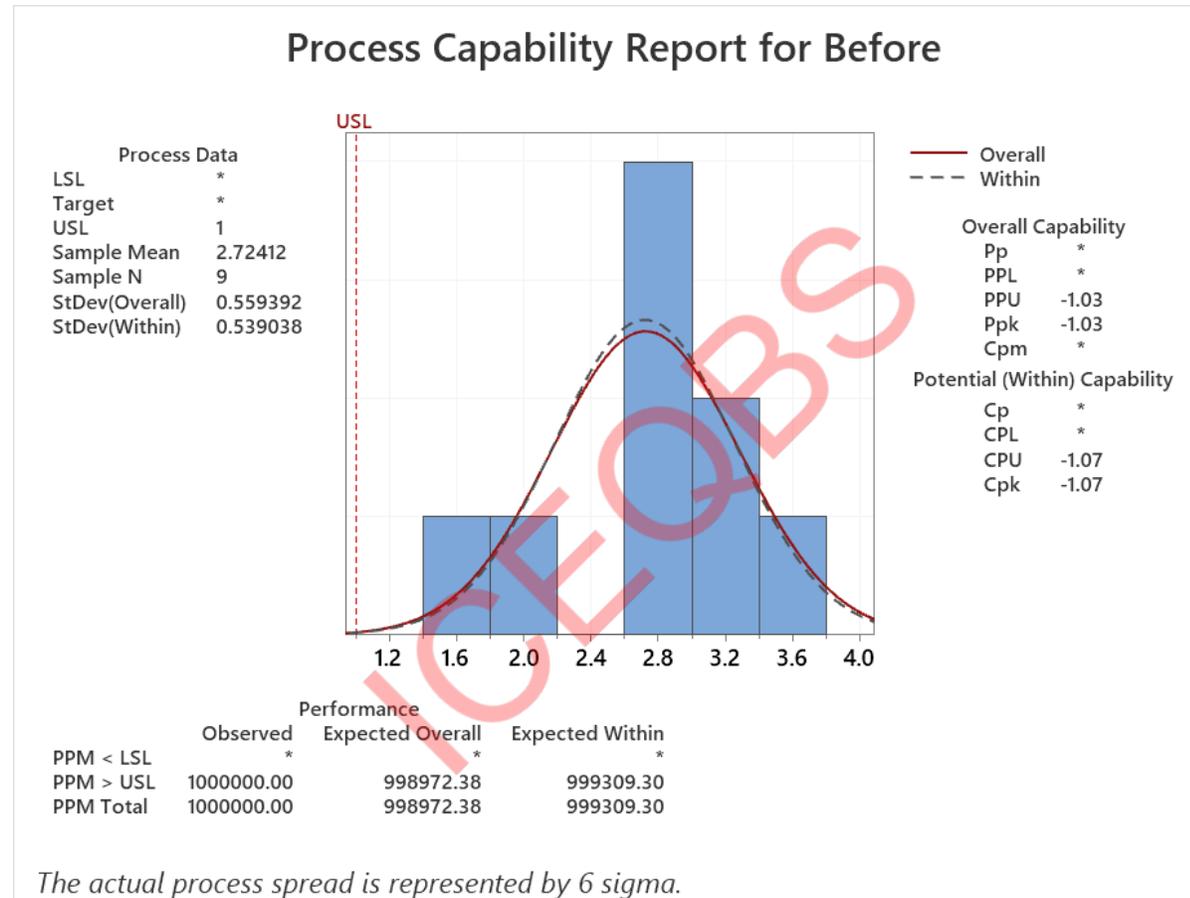
Probability Plot of Before



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

3M Analysis for Waste

MUDA

- Excess inventory of raw materials in storage.
- Waiting time due to delayed material delivery.
- Rework of fabricated parts due to dimensional errors

Mura

- Fluctuating daily output of fabricated components.
- Irregular workload on welding operators.
- Inconsistent inspection schedules causing bottlenecks.

Muri

- Operators handling multiple heavy parts simultaneously.
- Machines running continuously without preventive maintenance.
- Quality inspectors checking too many items in a short time.

Common and Special causes

Common Causes:

- Design & Drawing Review delays
- Material Requisition & Procurement issues
- Material Inspection & Storage inefficiencies
- Cutting & Preparation variability
- Fabrication & Welding minor inconsistencies
- Quality Inspection (In-Process & Final) routine deviations

Special Causes:

- Equipment breakdowns
- Operator errors
- Material defects from supplier
- Unexpected rework due to design changes
- Safety incidents causing stoppages

Action Plan for Low Hanging Fruits

Area/Issue	Observed Problem	Lean Tool / Approach	Action to Take	Expected Benefit
Special Cause: Equipment Breakdown	Frequent machine stoppages	TPM (Total Productive Maintenance)	Schedule preventive maintenance and daily equipment checks	Reduced downtime, improved productivity
Special Cause: Operator Errors	Mistakes in fabrication & welding	Standard Work & Poka-Yoke	Implement standard operating procedures and error-proofing jigs	Fewer defects, reduced rework
Special Cause: Material Defects from Supplier	Poor quality steel leading to scrap	Supplier Collaboration / 5S	Identify key suppliers, implement incoming material inspection	Lower scrap rate, better quality

Action Plan for Low Hanging Fruits

Area/Issue	Observed Problem	Lean Tool / Approach	Action to Take	Expected Benefit
Muda (Waste – Overproduction)	Excess fabrication before demand	Kanban / Just-in-Time	Implement pull system for production	Reduced inventory, storage cost savings
Muda (Waste – Waiting)	Delays due to material shortage	5S & Visual Management	Organize storage, implement material readiness board	Less downtime, smoother workflow
Mura (Unevenness – Fluctuating Workload)	Irregular welding schedules	Heijunka (Leveling)	Balance workload among teams and shifts	Stable output, less stress on operators
Muri (Overburden – Operators)	Handling multiple heavy parts	Workload Balancing / Kaizen	Reassign tasks, use mechanical aids	Reduced fatigue, fewer errors

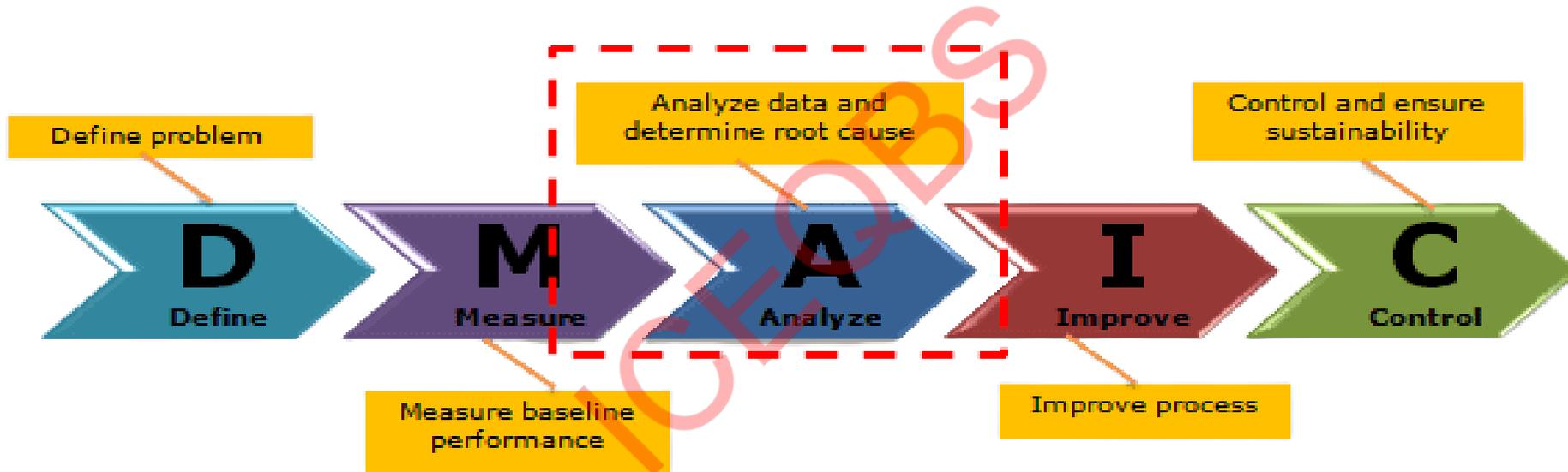
Action Plan for Low Hanging Fruits

Area/Issue	Observed Problem	Lean Tool / Approach	Action to Take	Expected Benefit
Defects (8 Wastes)	Scrap, rework	Kaizen / Poka-Yoke	Implement error-proofing, checklists, and quality checks	Lower scrap, higher first-pass yield
Over-processing (8 Wastes)	Extra steps in cutting/prep	Value Stream Mapping (VSM)	Identify non-value steps and eliminate	Faster throughput
Transport (8 Wastes)	Excess movement of parts	5S / Layout Optimization	Optimize workshop layout	Reduced material handling time
Inventory (8 Wastes)	Excess raw material & WIP	Kanban / JIT	Reduce buffer stocks, produce based on demand	Lower carrying costs
Motion (8 Wastes)	Excess walking of operators	5S / Standard Work	Organize tools & materials closer to workstations	Less operator fatigue, faster process
Waiting (8 Wastes)	Delays in inspection & approval	Visual Management / Standard Work	Implement inspection schedule boards	Less idle time
Underutilized Talent (8 Wastes)	Operators not contributing to improvement	Kaizen / Suggestion System	Encourage participation in improvement ideas	Increased engagement, continuous improvement culture

Data Collection Plan

Output / Input	Type of Data	Measurement Method	Unit	Frequency	Responsibility
% Scrap (Primary Y)	Continuous	Scrap count vs total production log	%	Daily	Production Engineer
Welding defect rate	Continuous	Visual inspection & defect log	%	Daily	Quality Inspector
Dimensional deviation	Continuous	Vernier / measuring gauge check	mm	Per batch	Quality Inspector
Rework quantity	Discrete	Rework register	Nos	Daily	Production Supervisor
Assembly mismatch defects	Discrete	Inspection checklist	Nos	Daily	QC Inspector
Material grade variation	Discrete	Incoming inspection report	Pass / Fail	Per lot	Stores / Quality
Welding parameter settings	Continuous	Welding machine parameter log	Amp / Volt	Per setup	Welding Supervisor
Machine downtime	Continuous	Equipment downtime log	Minutes	Shift-wise	Maintenance Engineer

ANALYSE PHASE



Analyse – Hypothesis testing

Regression Analysis: Scrap Rate (%) versus Drawing Review Time (hrs), Proc

Regression Equation

Scrap Rate (%) = 0.009 + 0.423 Cutting Precision Deviation (mm)
+ 0.3351 Welding Defect Rate (per 100 un)
+ 0.2259 Inspection Deviations per Batch

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	0.009	0.118	0.08	0.937	
Cutting Precision Deviation (mm)	0.423	0.154	2.75	0.009	1.04
Welding Defect Rate (per 100 un)	0.3351	0.0298	11.25	0.000	1.01
Inspection Deviations per Batch	0.2259	0.0591	3.82	0.000	1.04

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.208447	77.33%	75.85%	73.21%

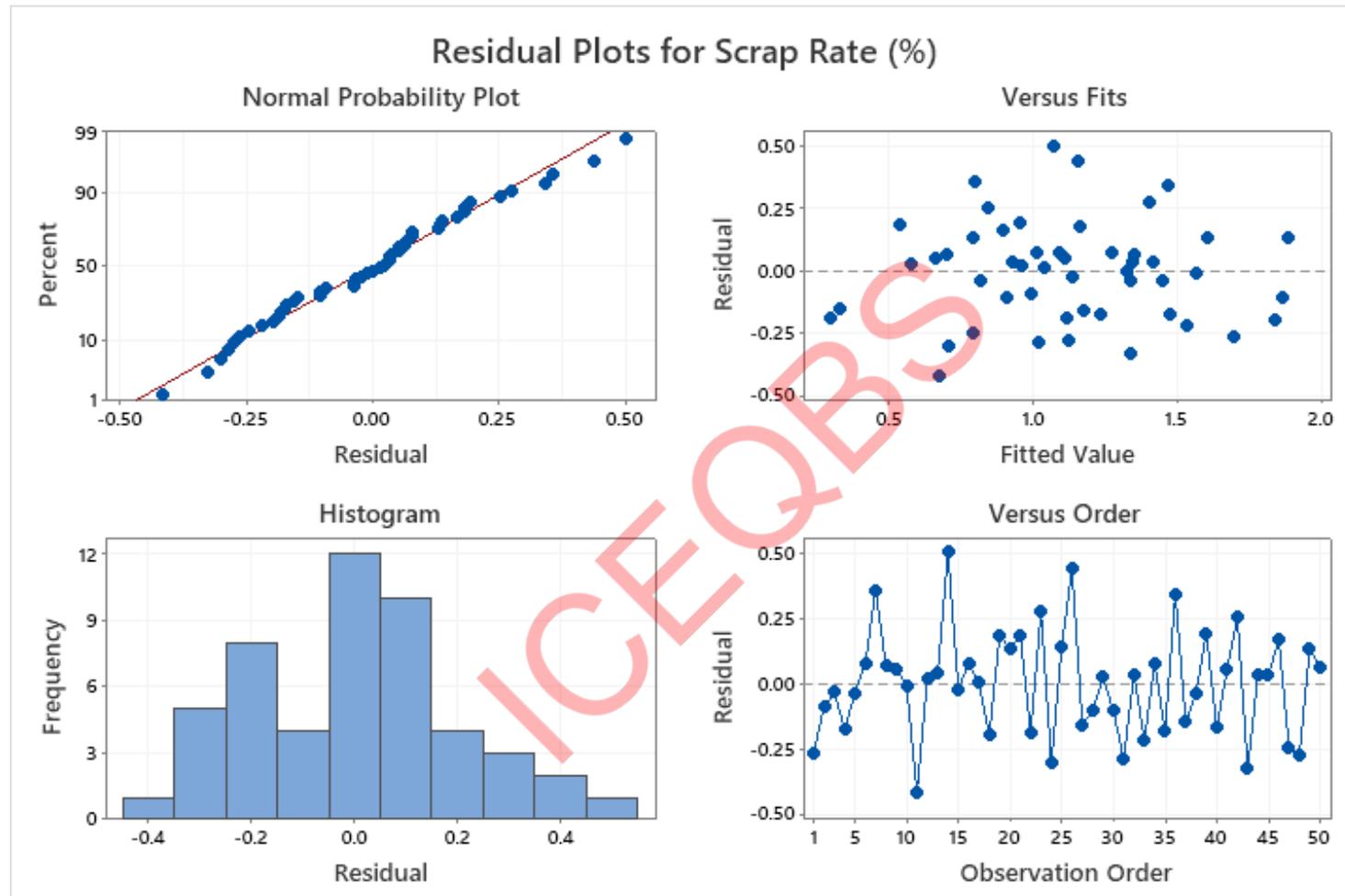
Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	6.8168	2.27227	52.30	0.000
Cutting Precision Deviation (mm)	1	0.3281	0.32811	7.55	0.009
Welding Defect Rate (per 100 un)	1	5.5014	5.50143	126.62	0.000
Inspection Deviations per Batch	1	0.6340	0.63395	14.59	0.000
Error	46	1.9987	0.04345		
Total	49	8.8155			

Inference :

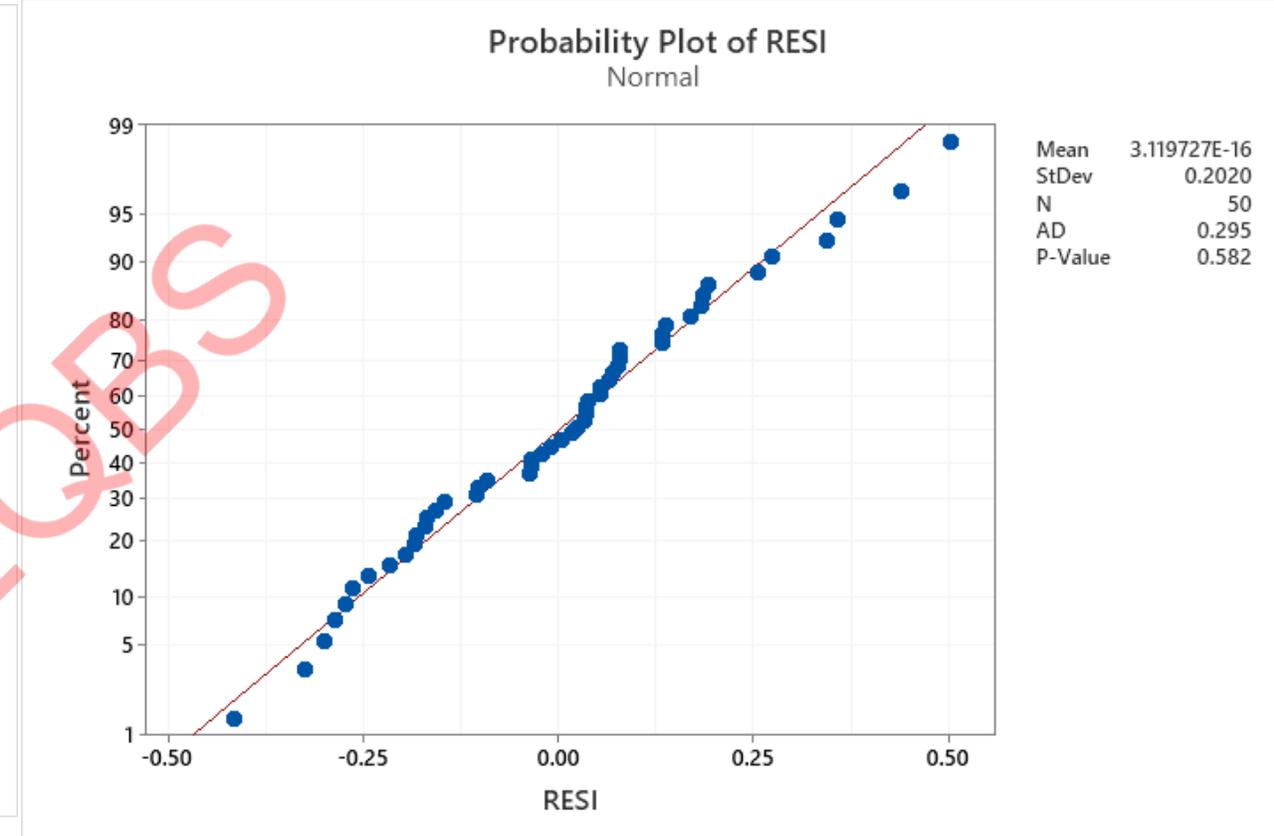
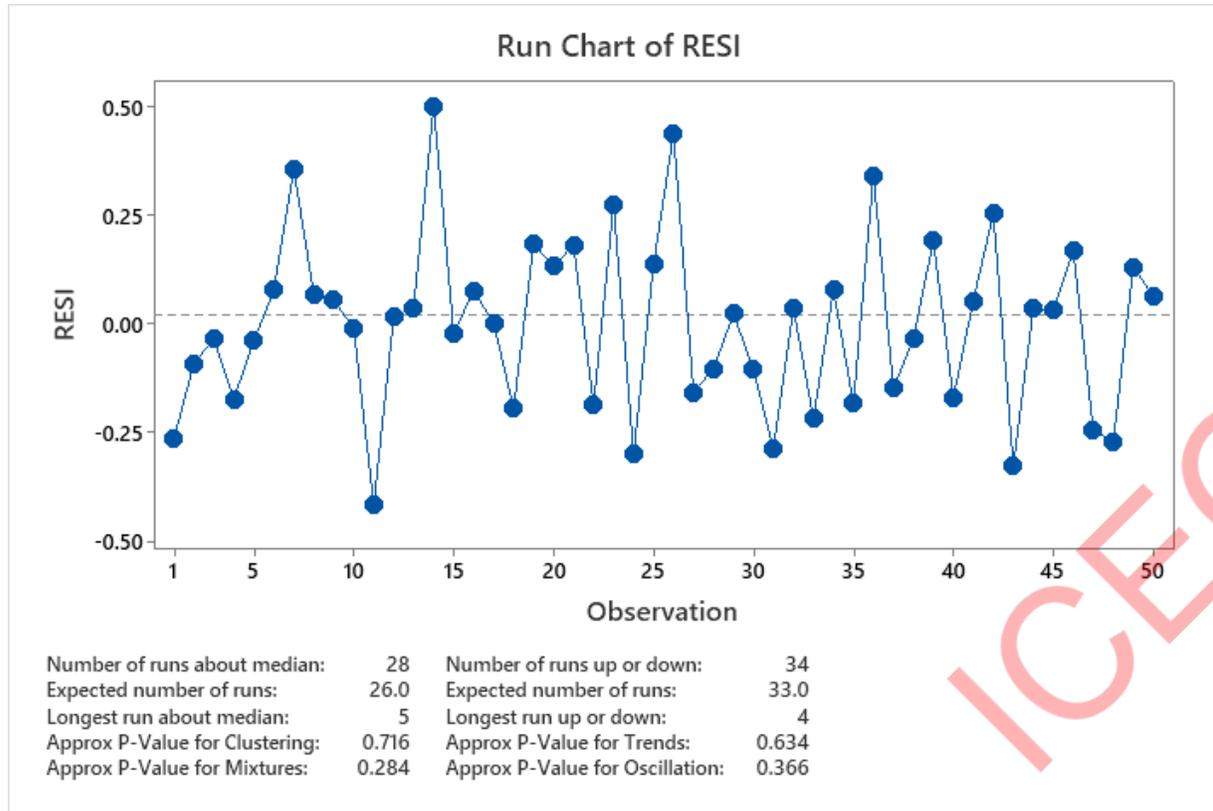
- Since $p < 0.05$, thus not all means are equal

Analyse – Hypothesis testing



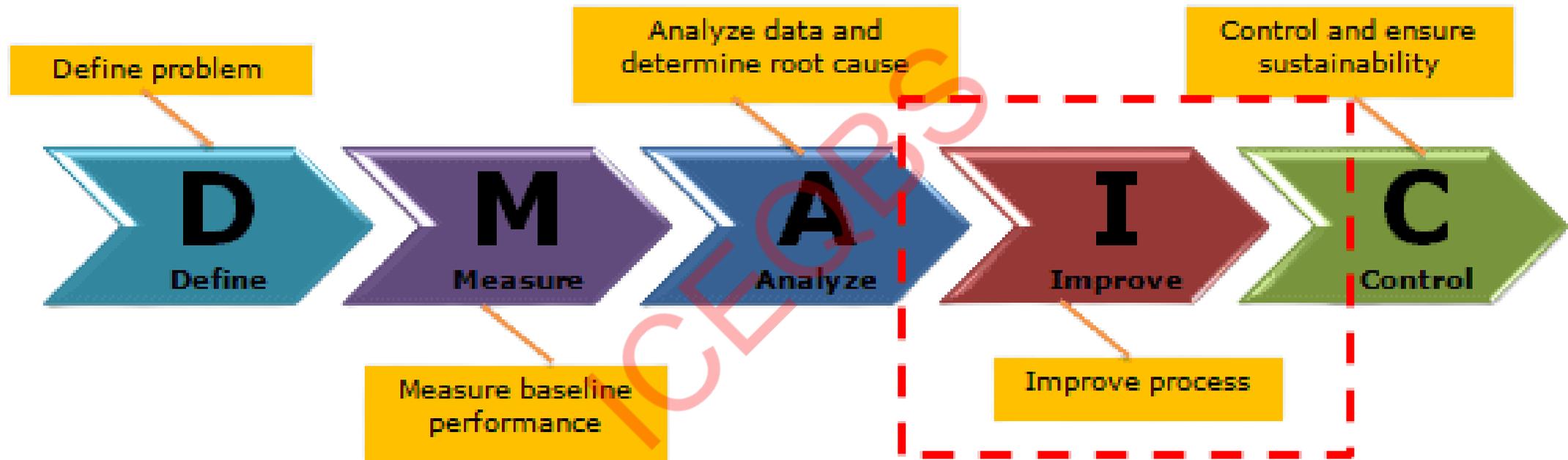
Data are normally distributed. This confirms that the requirements are met and the scrap rate model is stable and reliable for decision-making.

Summary of Statistically validated Root causes



- Residuals show random variation with no trends or patterns, indicating a stable process.
- Probability plot confirms residuals follow a normal distribution (p-value > 0.05), validating the model assumptions.

IMPROVE PHASE



Factorial Regression: % SCRAP versus CUTTING, WELDING, INSPECTION, CenterPt

Coded Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		0.87610	0.00507	172.86	0.000	
CUTTING	0.08727	0.04364	0.00507	8.61	0.001	1.00
WELDING	0.24781	0.12390	0.00507	24.45	0.000	1.00
INSPECTION	0.13861	0.06930	0.00507	13.67	0.000	1.00
CUTTING*WELDING	-0.08727	-0.04364	0.00507	-8.61	0.001	1.00
WELDING*INSPECTION	-0.13861	-0.06930	0.00507	-13.67	0.000	1.00
Ct Pt		0.12071	0.00970	12.44	0.000	1.00

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0143352	99.69%	99.22%	95.31%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	6	0.261924	0.043654	212.43	0.000
Linear	3	0.176474	0.058825	286.26	0.000
CUTTING	1	0.015233	0.015233	74.13	0.001
WELDING	1	0.122817	0.122817	597.66	0.000
INSPECTION	1	0.038424	0.038424	186.98	0.000
2-Way Interactions	2	0.053657	0.026829	130.55	0.000
CUTTING*WELDING	1	0.015233	0.015233	74.13	0.001
WELDING*INSPECTION	1	0.038424	0.038424	186.98	0.000
Curvature	1	0.031793	0.031793	154.71	0.000
Error	4	0.000822	0.000205		
Lack-of-Fit	2	0.000761	0.000380	12.46	0.074
Pure Error	2	0.000061	0.000031		
Total	10	0.262746			

- Cutting, welding, and inspection significantly influence % scrap, with notable interaction effects, and the model shows an excellent fit.

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	2.724	0.559	0.19
After	9	0.5930	0.0564	0.019

Estimation for Difference

Difference	95% CI for Difference
2.131	(1.699, 2.563)

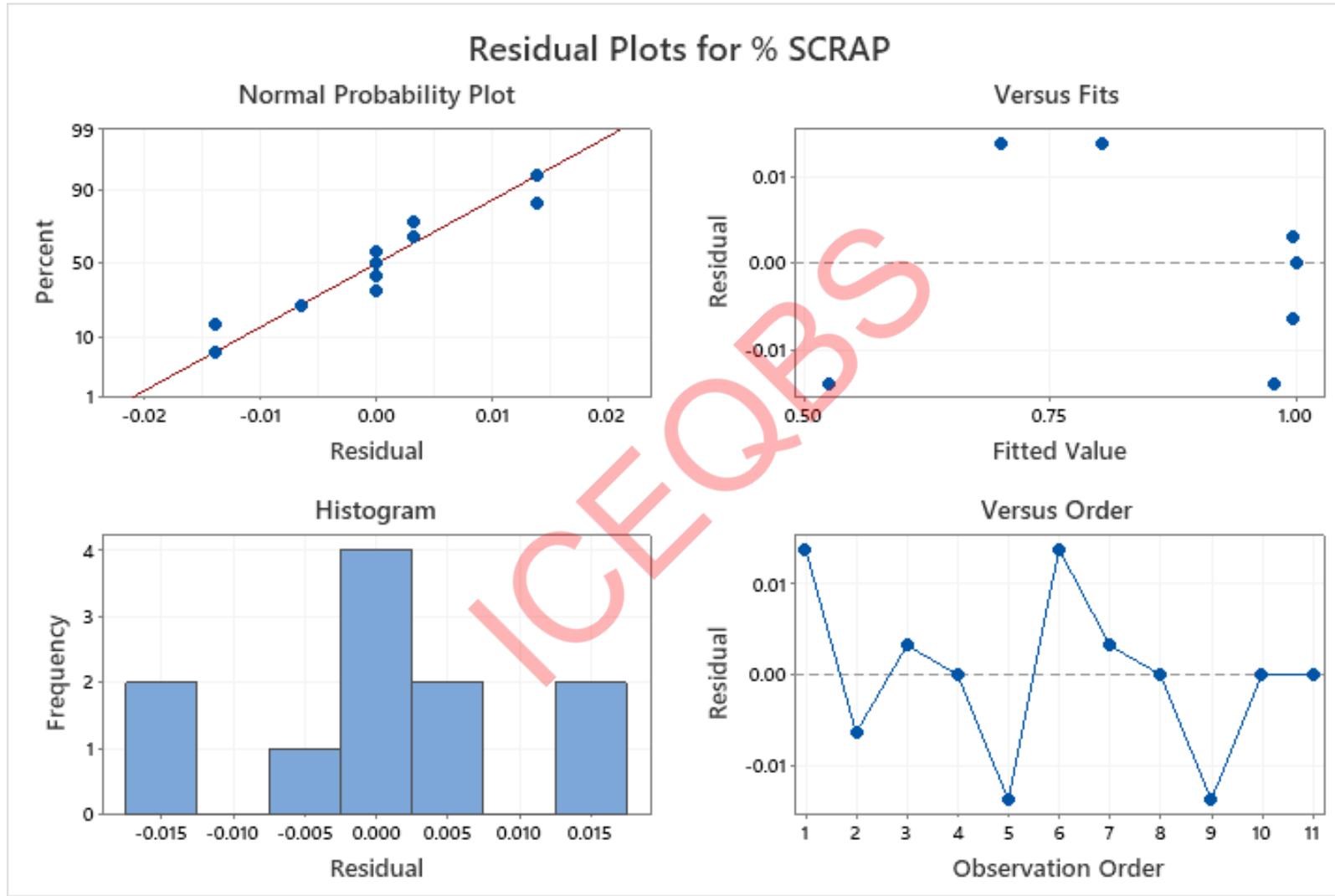
Test

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

T-Value	DF	P-Value
11.37	8	0.000

The two-sample t-test shows a statistically significant reduction after improvement ($p < 0.05$), confirming that the implemented changes led to a meaningful performance improvement.

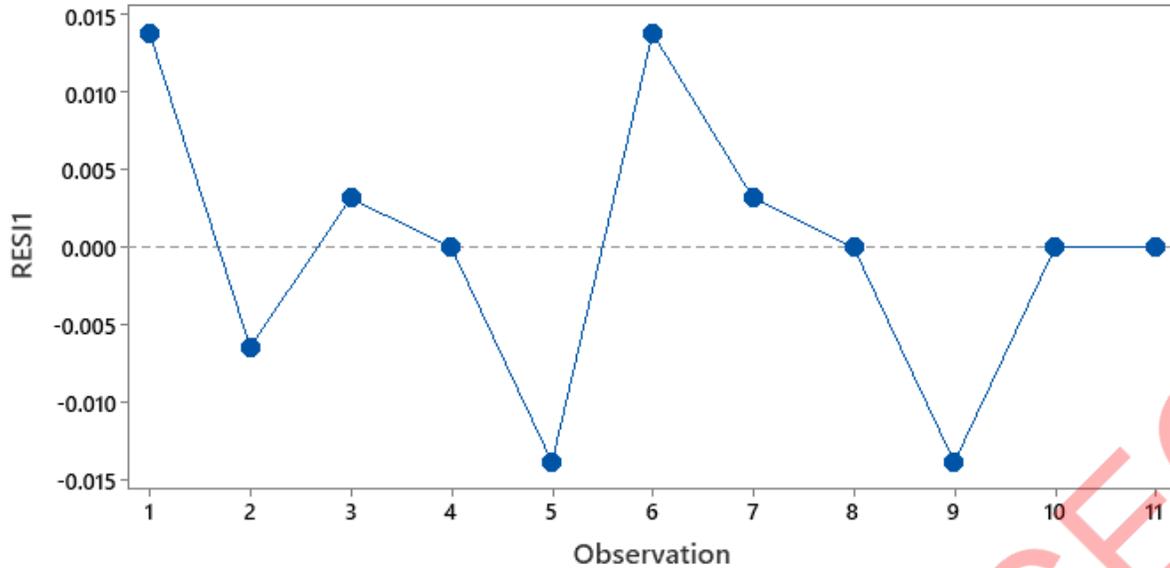
Improve



Residuals are normally distributed and randomly scattered with no patterns, confirming model adequacy and stable scrap behavior.

Improve – Run chart and Normality Test (After Improvement)

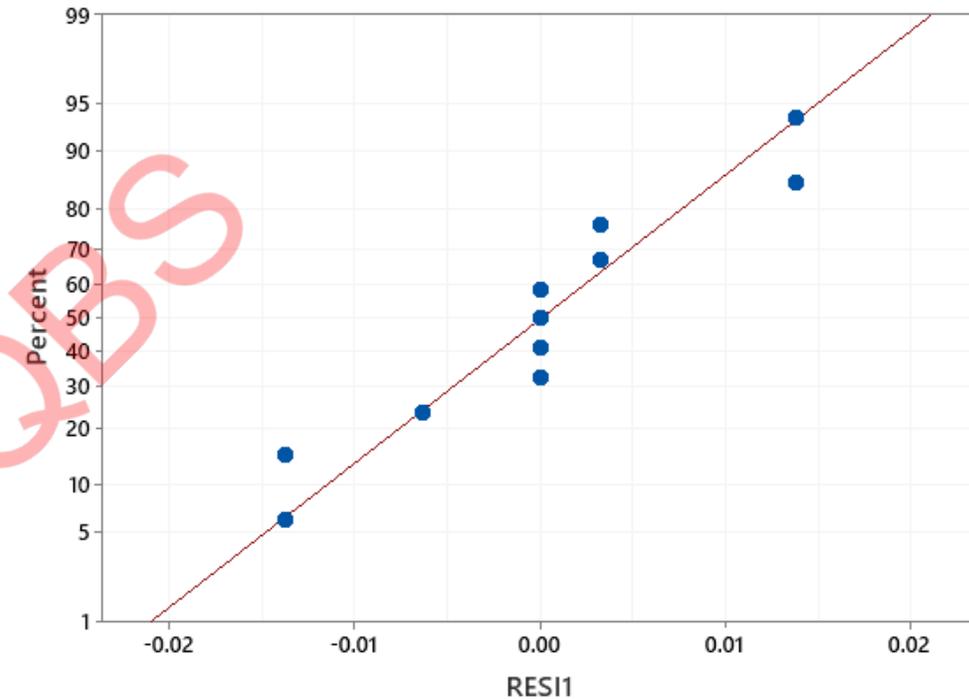
Run Chart of RESI1



Number of runs about median:	8	Number of runs up or down:	7
Expected number of runs:	6.5	Expected number of runs:	7.0
Longest run about median:	2	Longest run up or down:	3
Approx P-Value for Clustering:	0.839	Approx P-Value for Trends:	0.500
Approx P-Value for Mixtures:	0.161	Approx P-Value for Oscillation:	0.500

Probability Plot of RESI1

Normal

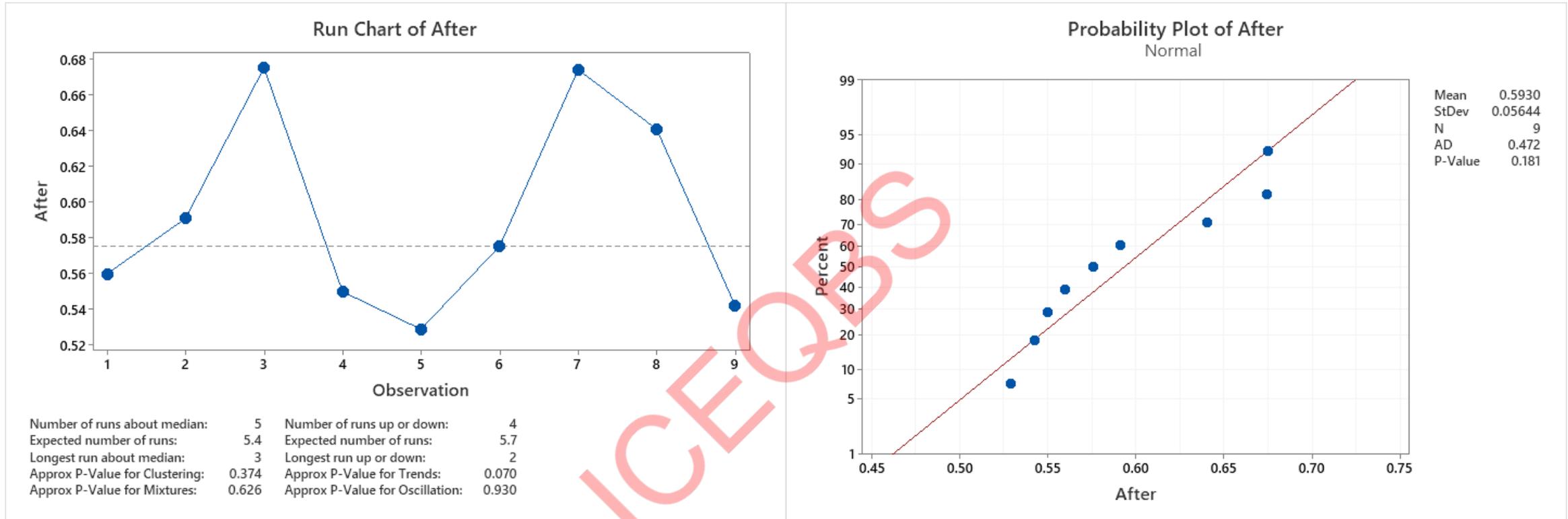


Mean	0
StDev	0.009066
N	11
AD	0.515
P-Value	0.149

Inference:

- The probability plot confirms normal distribution ($p > 0.05$), indicating a stable process and valid model assumptions.

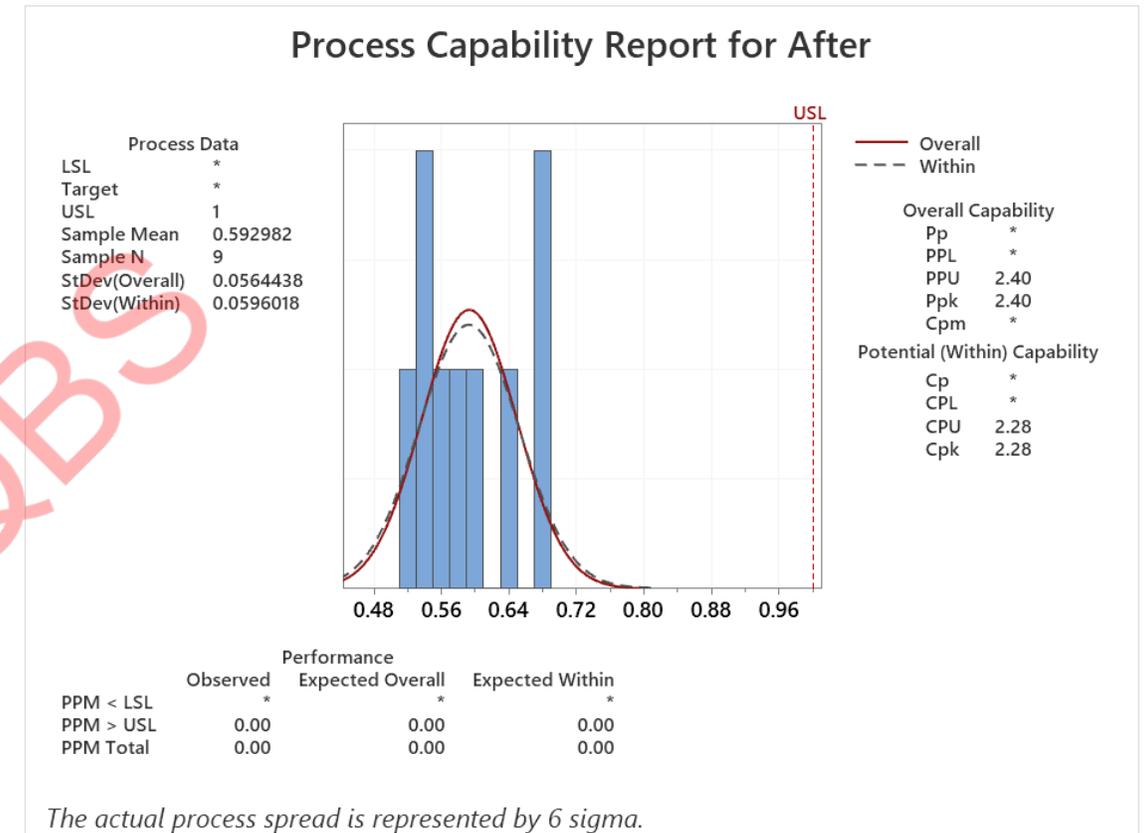
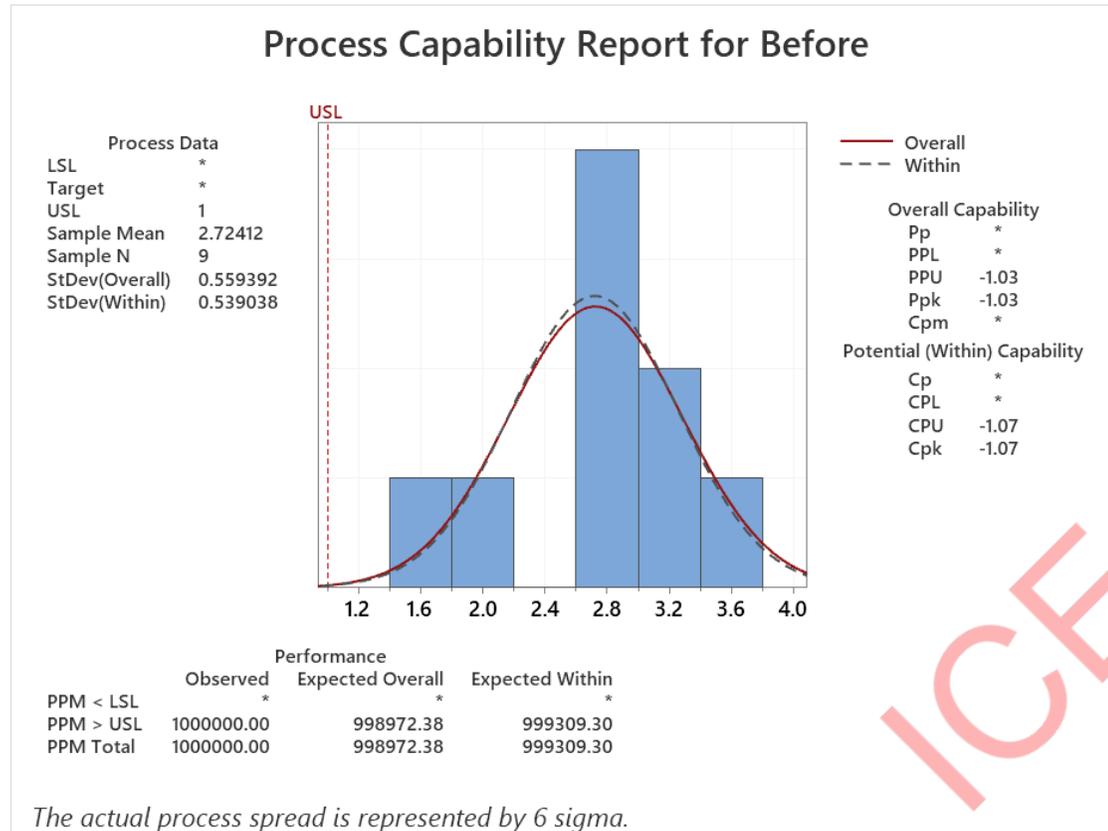
Improve – Run chart and Normality Test (After Improvement)



Inference:

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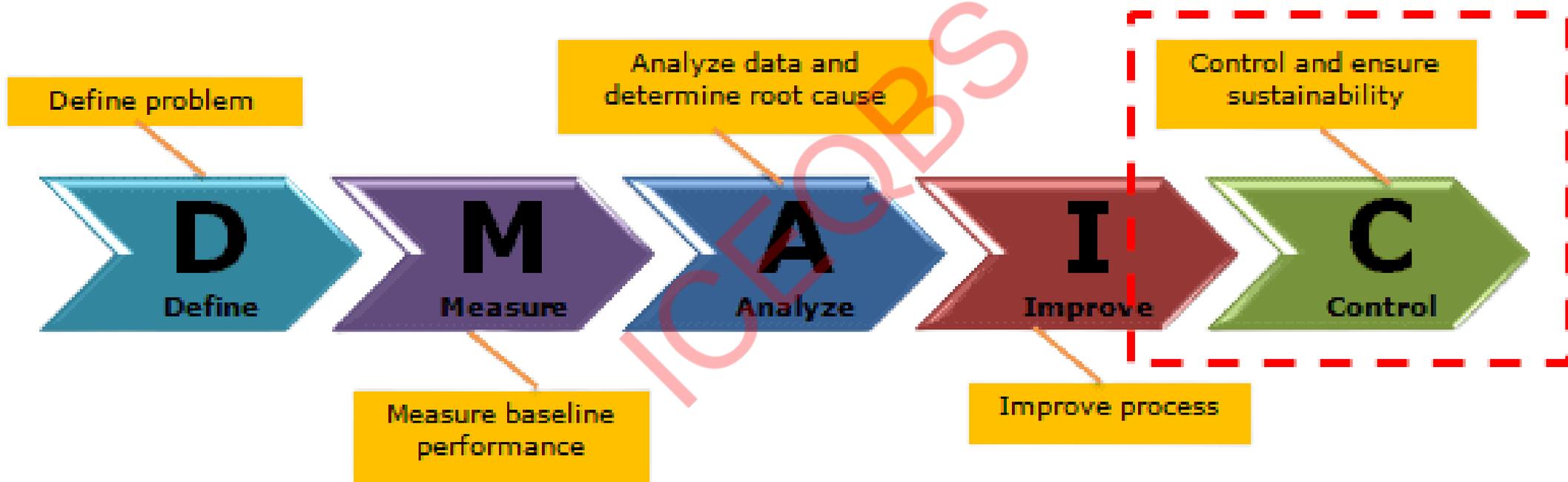
Improve – Run chart and Normality Test (After Improvement)



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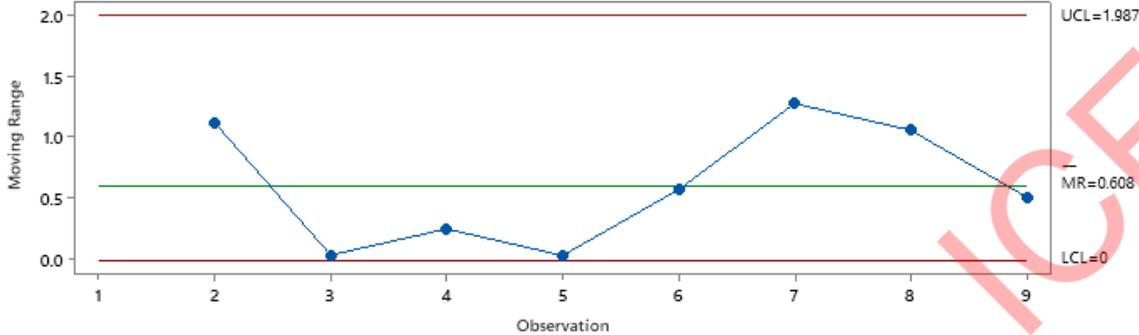
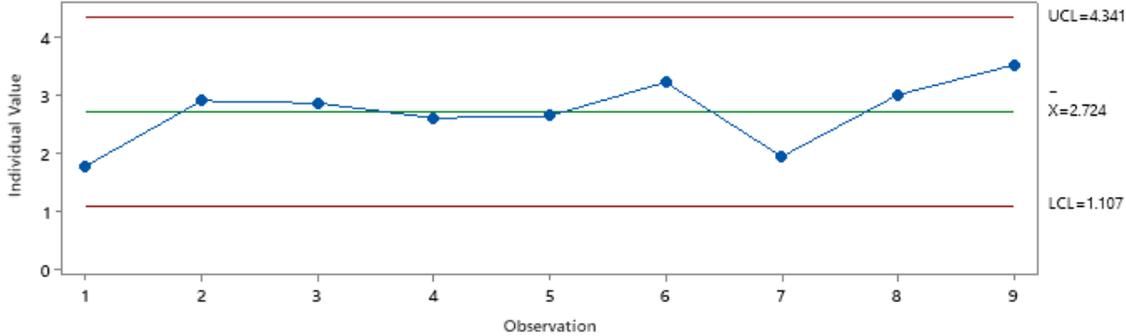
- Before improvement, the process is not capable, with output falling outside specification limits and low Cpk values observed.
- After improvement, the process is well-centered within specifications with a significant increase in Cpk, confirming a capable and stable process.

CONTROL PHASE

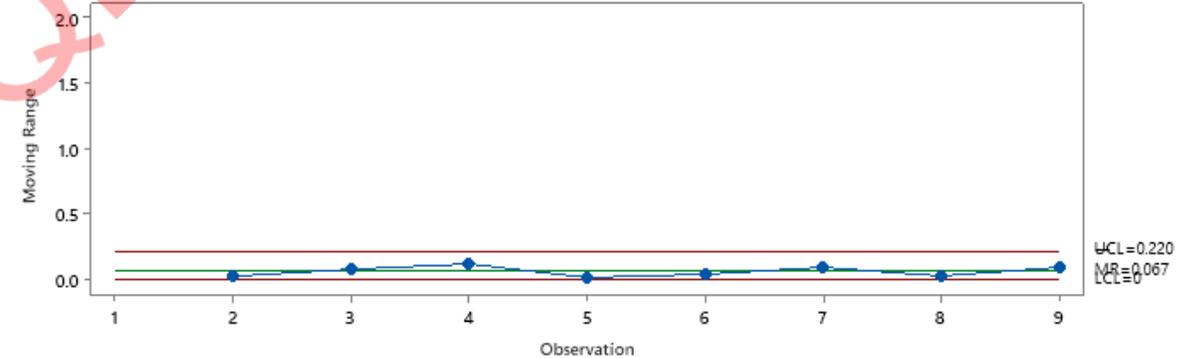
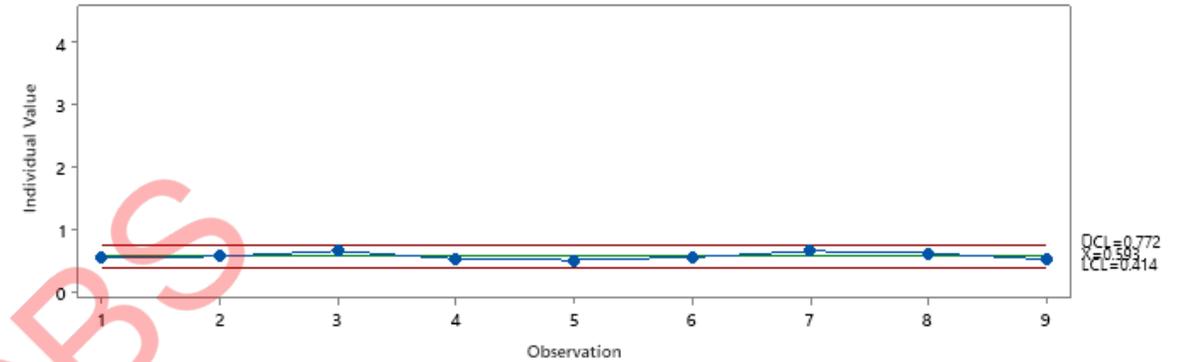


Improve (Statistical validation for Improvement – I-MR Chart)

I-MR Chart of Before



I-MR Chart of After



- Before improvement, the process shows higher variation and limited control.
- After improvement, variation is significantly reduced with all points within control limits, confirming a stable and controlled process.

FMEA

Implementation Step	Potential Failure Mode	Effect on Project (Y: Scrap <1%)	S	Potential Cause	O	Current Controls	D	RPN	Recommended Proactive Action	Owner
Standardize cutting parameters by thickness	Wrong parameter table issued/used	Dimensional errors → scrap/rework	8	Old tables, uncontrolled revisions	5	Work instruction posted	6	240	Version-controlled parameter sheet; single master in QMS; QR to latest version	CNC Programmer
First-off piece approval per shift	First-off check skipped	Defects flow through entire batch	9	Production pressure, unclear accountability	5	Supervisor sign-off	6	270	“No sign-off = no batch start” gate in traveler/ERP; daily audit sample	Fabrication Supervisor
Machine calibration plan	Calibration overdue / not done	Drift in cut accuracy; variability rises	8	No schedule/ownership	4	Maintenance log	6	192	Calibration calendar with due-date tags; escalation if overdue; spare consumables checklist	Maintenance Lead
Implement Go/No-Go checks on critical dims	Wrong gauge used or gauge out of calibration	False accept/reject → scrap or escapes	7	Mixed gau						

Control Plan

Process Step	Critical X	Specification / Target	Monitoring Method	Frequency	Reaction Plan	Owner
Cutting Operation	Cutting Precision Deviation (mm)	$\leq \pm 0.3$ mm	Go/No-Go gauge; I-MR / \bar{X} -R chart	Per shift	Stop batch; recalibrate machine; redo first-off approval	Fabrication Supervisor
Cutting Setup	Cutting Parameter Selection	As per approved parameter table	First-off piece approval checklist	Every job / shift	Hold production; correct parameters; re-approve first-off	CNC Programmer
Machine Readiness	Machine Calibration Status	Calibration within due date	Calibration tag & log review	Weekly	Lock machine; perform calibration before restart	Maintenance Lead
Welding Operation	Welding Defect Rate (defects / 100 welds)	≤ 1	Daily defect log; weekly Pareto	Daily / Weekly	Review top defect; verify WPS; retrain welder if needed	Welding Engineer

Control Plan

Process Step	Critical X	Specification / Target	Monitoring Method	Frequency	Reaction Plan	Owner
Welding Setup	WPS Compliance	100% compliance	WPS checklist; spot audits	Per shift	Stop welding; reset parameters; re-brief welder	QA / Welding Engineer
Fit-Up Process	Fit-Up Conformance	Within WPS limits	Fit-up checklist; gauge	Per joint	Correct fit-up before welding; re-inspect	Production Lead
In-Process Inspection	Inspection Deviations per Batch	≤ 1	In-process inspection records	Per batch	Contain batch; root cause analysis; corrective action	Quality Engineer
Inspection Discipline	Inspection Checklist Completion	100%	Checklist audit	Daily	Re-inspect affected lots; coach inspector	QA Manager
Overall Performance	Scrap Rate (%)	< 1%	Scrap dashboard; trend chart	Monthly	Management review; trigger improvement action	Plant Manager

5S and Poka Yoke mechanism for sustaining the improvement

Area	5S Mechanism	Purpose / Impact
Cutting Station	Color-coded storage for cutting tools, nozzles, and consumables	Prevents wrong tool usage and setup variation
Cutting Station	Shadow boards for templates, gauges, and calibration tools	Ensures availability and correct placement
Welding Bay	Dedicated, labeled racks for electrodes/wire by grade and size	Avoids mix-up leading to weld defects
Welding Bay	Marked zones for WIP, OK parts, and rework parts	Prevents accidental reprocessing or scrap
Inspection Area	Standard inspection kits at each station (gauges, checklists)	Reduces inspection skips and variation
Shop Floor	Visual standards for acceptable cut edge and weld quality	Enables quick operator self-verification
All Areas	Daily 5S checklist with weekly supervisor audit	Sustains discipline and early issue detection



Results after improvement

- *This project successfully achieved its objectives through data-driven analysis and sustainable improvements, resulting in a stable, capable process and a strong foundation for continuous improvement.*