Reduction of Wiring Defect Rate in Electrical Panel Boards

Sajeev

ROADMAP

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

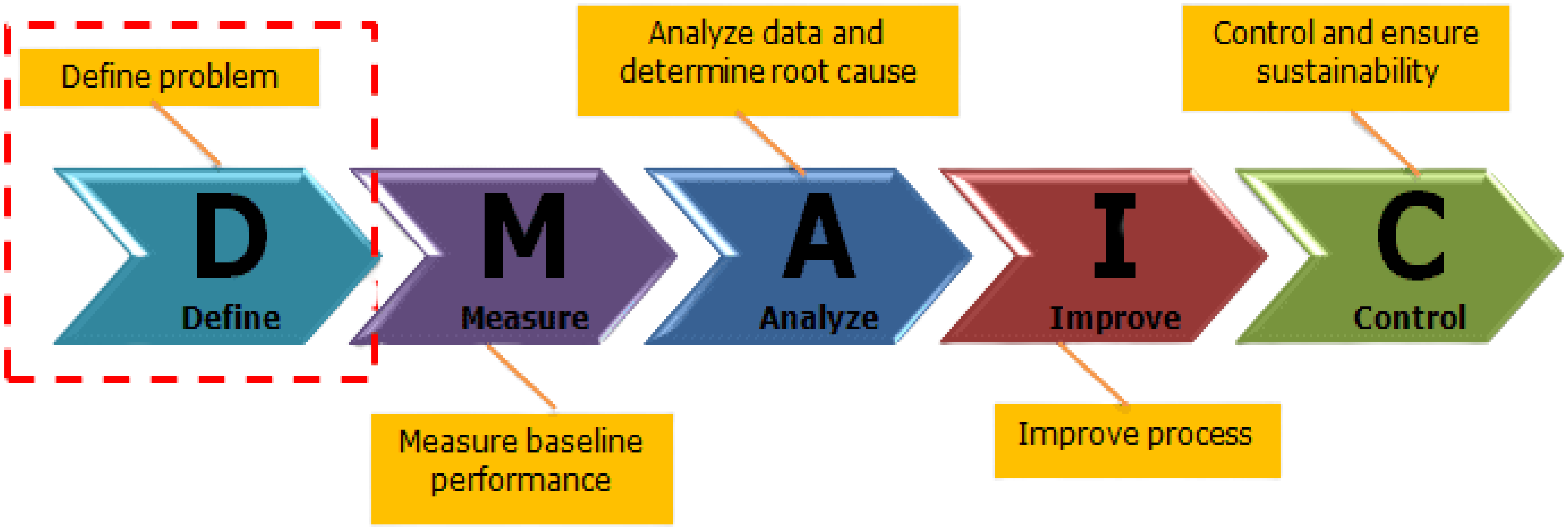
OVERVIEW

Background

The Electrical Panel Boards assembly process currently experiences a wiring defect rate of 3.2%, which exceeds the organization's acceptable quality limits. These defects result in rework, scrap, extended assembly time, and delayed deliveries, leading to increased manufacturing costs and reduced operational efficiency.

High defect levels also impact customer satisfaction and brand reputation, as wiring errors can affect product reliability, safety, and compliance with electrical standards. Continued operation at the current defect rate places pressure on production resources, increases cost per unit, and limits the organization's ability to meet delivery commitments consistently.

DEFINE PHASE

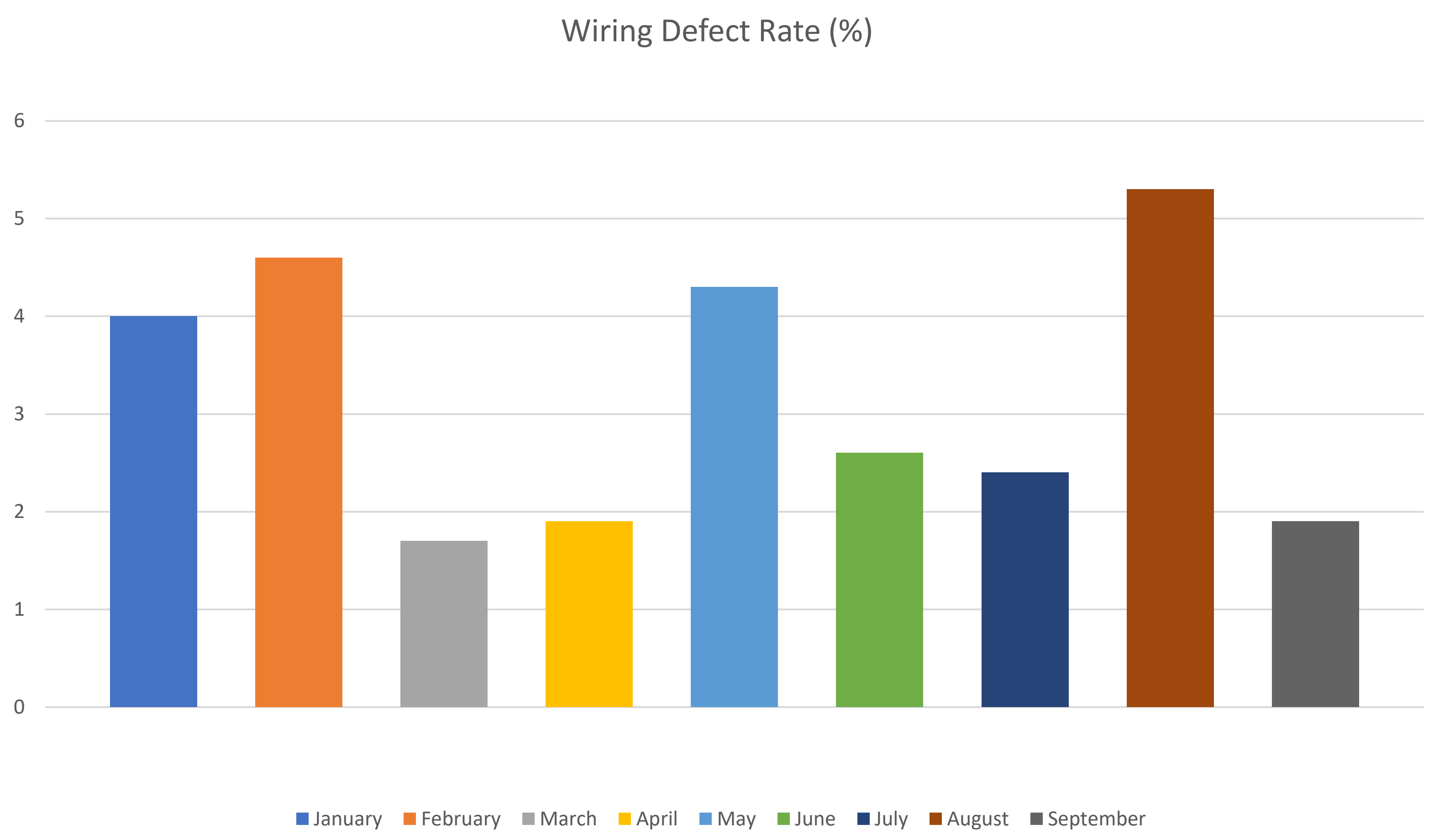


VOC & CTQ

CTQ Tree :

Voice of customer	Critical to X	Primary Metric for improvement
Customers expect defect-free, safe, and reliable electrical panel boards delivered on time, without the need for rework or corrections.	CTC – Defect Rate	**Primary Metric -** Y = Wiring Defect Rate (%) **Secondary Metric -** First Pass Yield (FPY)

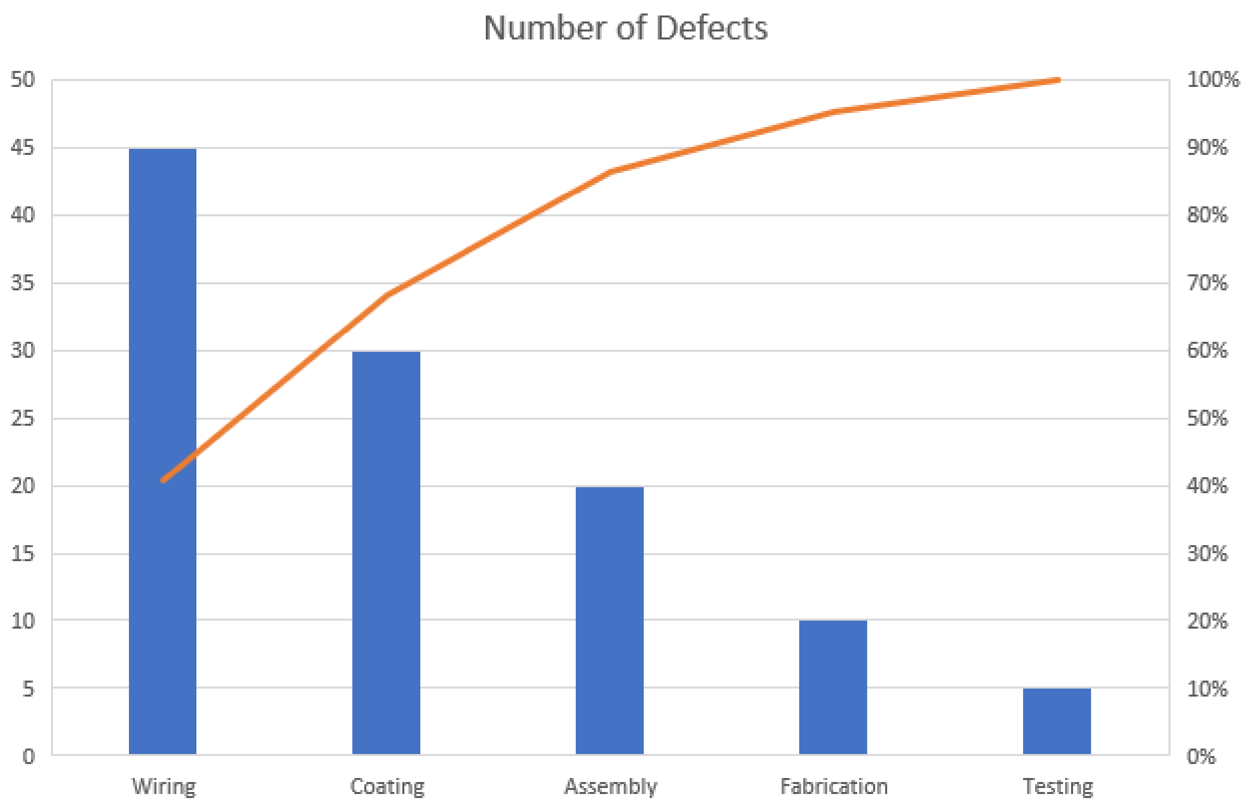
Baseline Performance of Primary Metric (9 months data as Line chart)



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 :

- Wiring defects contributes substantially for the scrap and included in the scope of the project

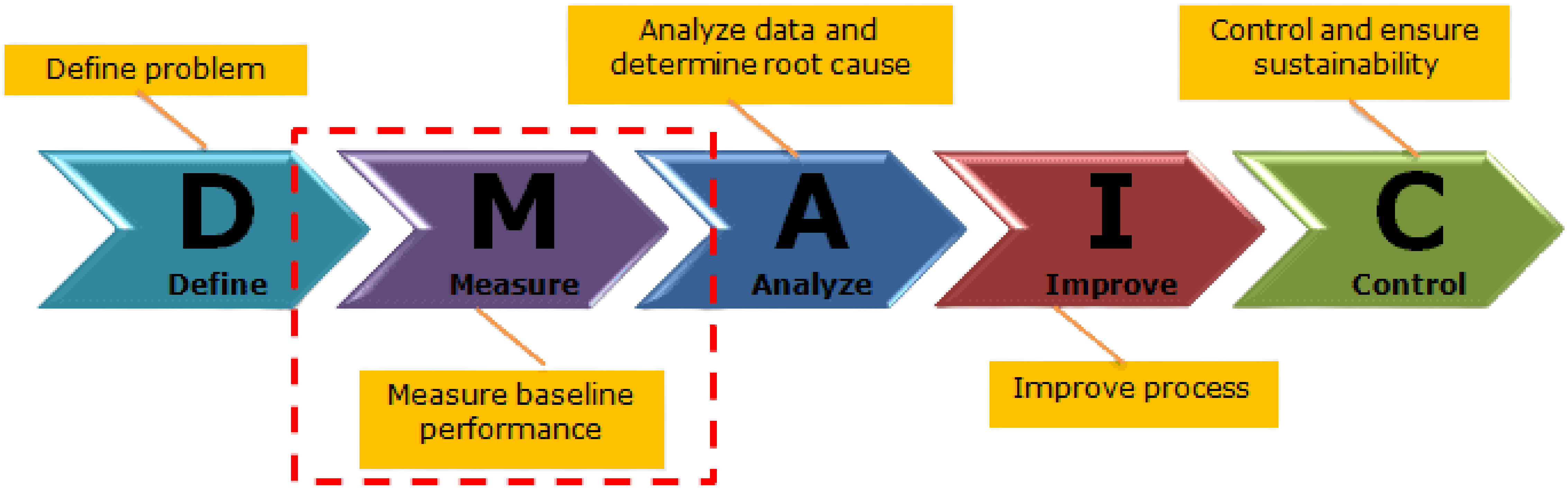
Project Charter

Project Title:	**Reduction of Wiring Defect Rate in Electrical Panel Boards**
Project Leader	**Project Team Members:**
Mr. Sajeev Sadasivan	Mr. Manjunath Mr. Sunil Ms. Fathima
Champion/Sponsors:	
Mr. Sajeev Sadasivan	
Problem Statement:	**Goal Statement:**
wiring defect rate in Electrical Panel Boards assembly is 3.2%, leading to increased rework, delayed deliveries, higher costs, and customer dissatisfaction based on the last 6 months data.	Reduce the wiring defect rate from 3.2% to 1% or less within 6 months while maintaining on-time delivery and reducing rework time by 50%.
Secondary Metric	**Assumptions Made:**
First Pass Yield (FPY)	Wiring defect data is **accurate and consistently recorded**. No **design or specification changes** during the project.

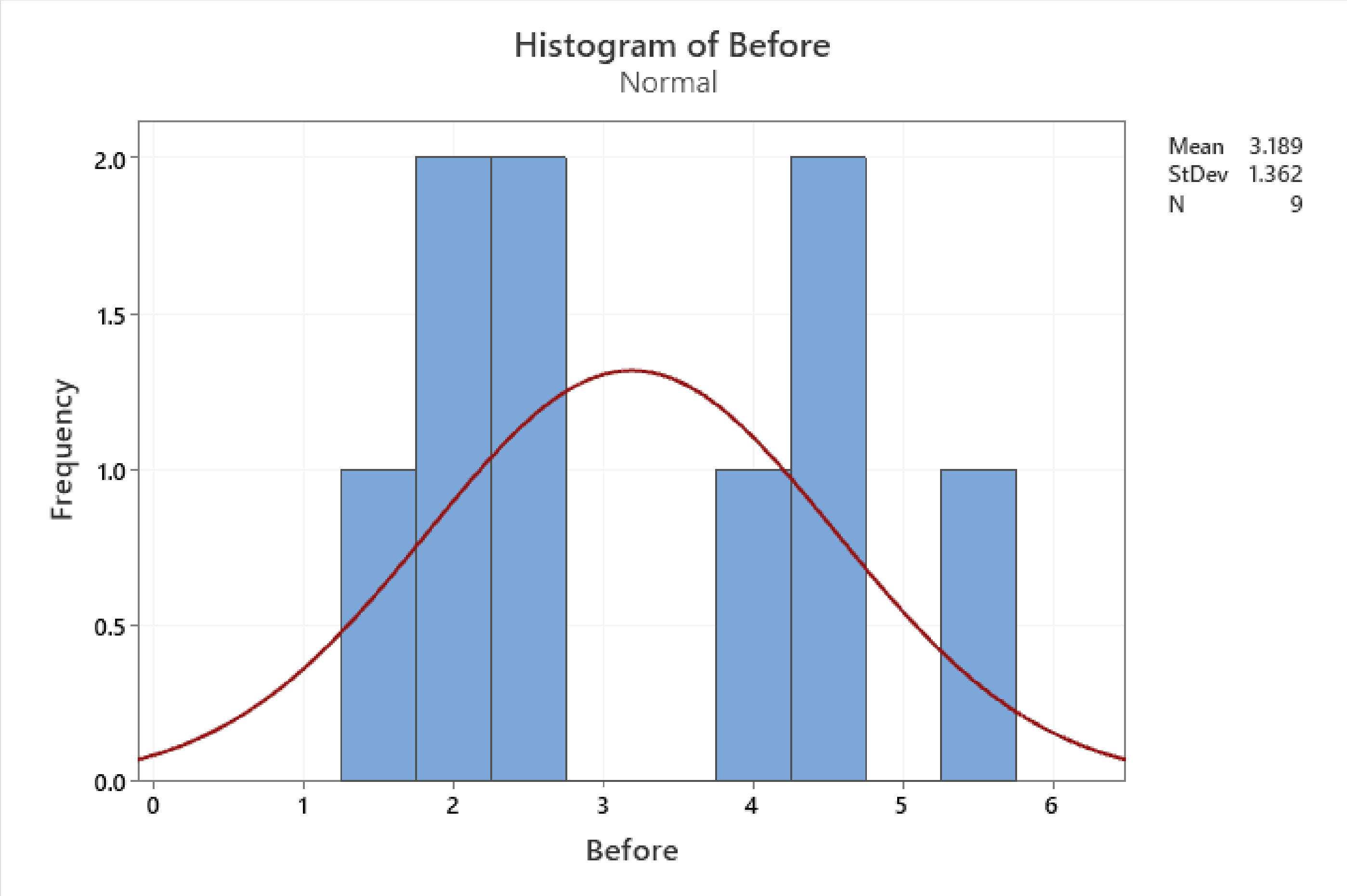
Project Charter

Tangible and Intangible Benefits:	Risk to Success:
Reduced **rework and scrap cost**. Improved **first-pass yield and productivity**. Higher **customer confidence and satisfaction**. Improved **operator skill and quality awareness**.	**Incorrect defect classification** affecting root cause analysis. **Resistance to change** in wiring practices.
In Scope:	**Out of Scope:**
Wiring & Termination process of Electrical Panel Boards Defect detection, inspection, and rework activities related to wiring	Procurement of raw materials Final assembly and testing beyond wiring defects
Signatories:	**Project Timeline:**
Project sponsor and leader	6 months

MEASURE PHASE



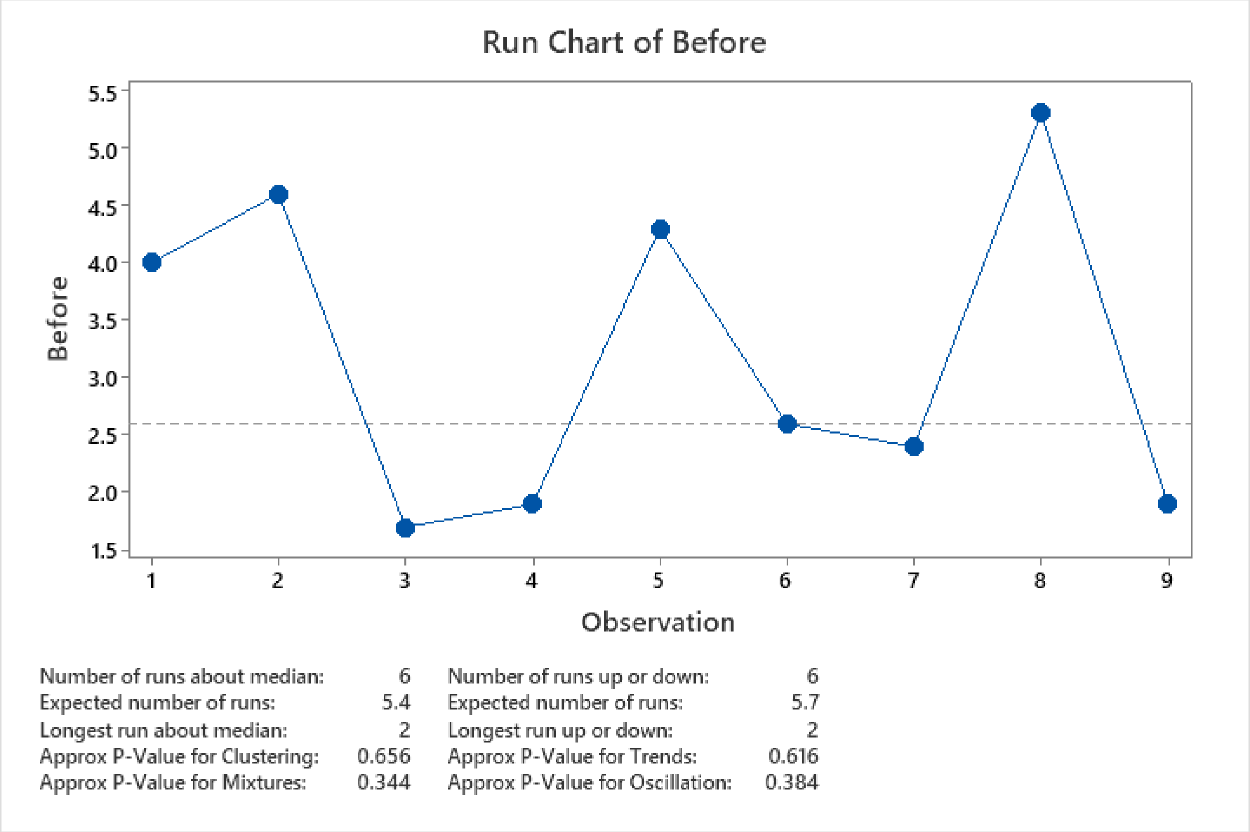
Data collection – Histogram (Before improvement)

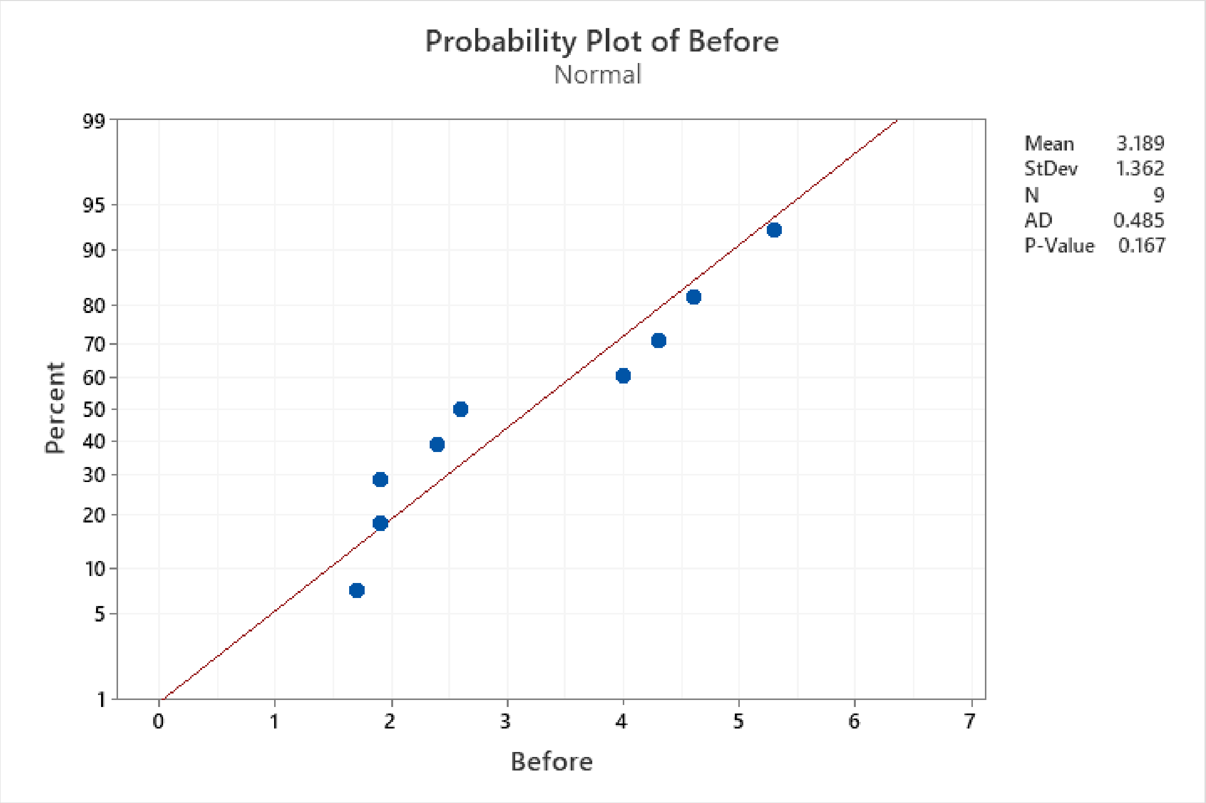


Inference :

- Data is normally distributed over the mean

Data collection – Run Chart (Before improvement)

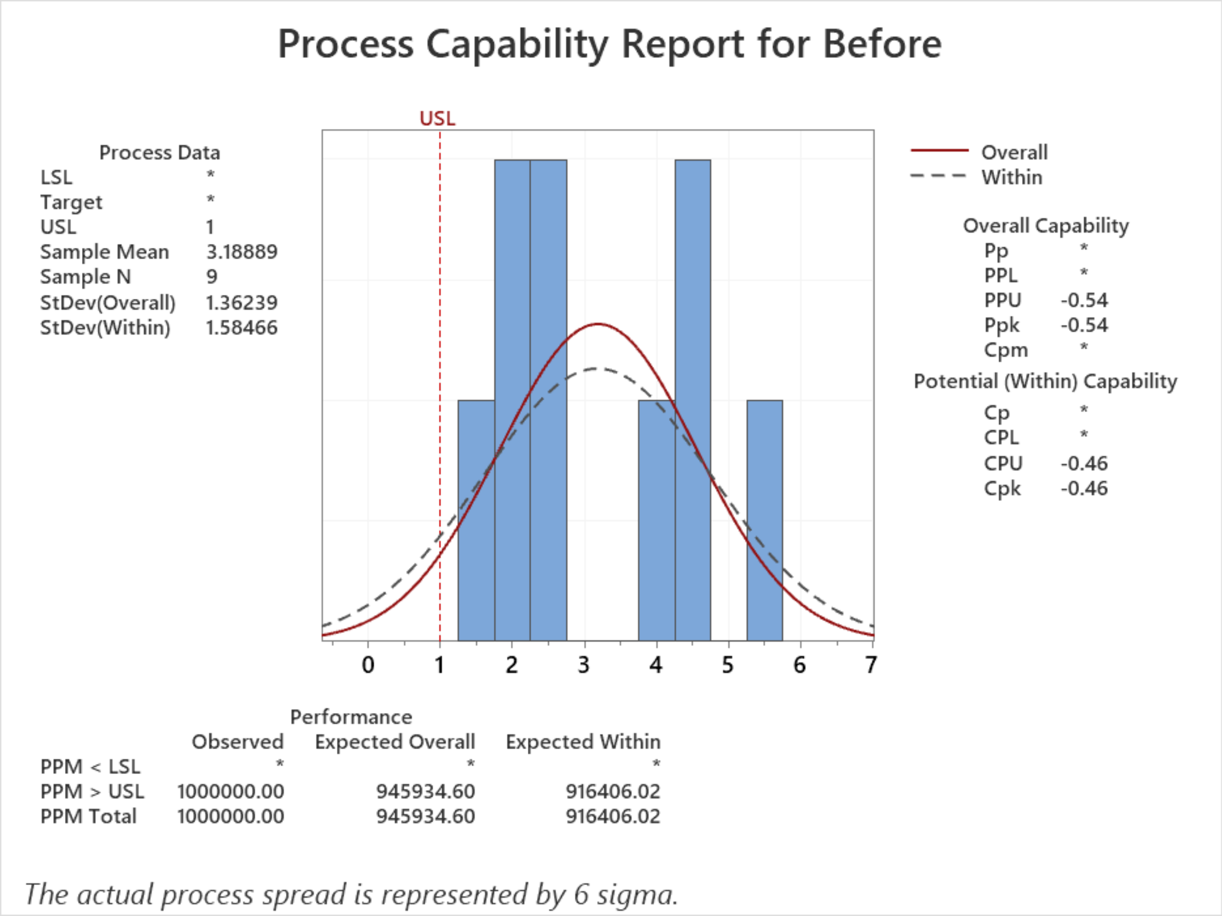




Inference :

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

Data collection – Normality plot (Before improvement)



Inference :

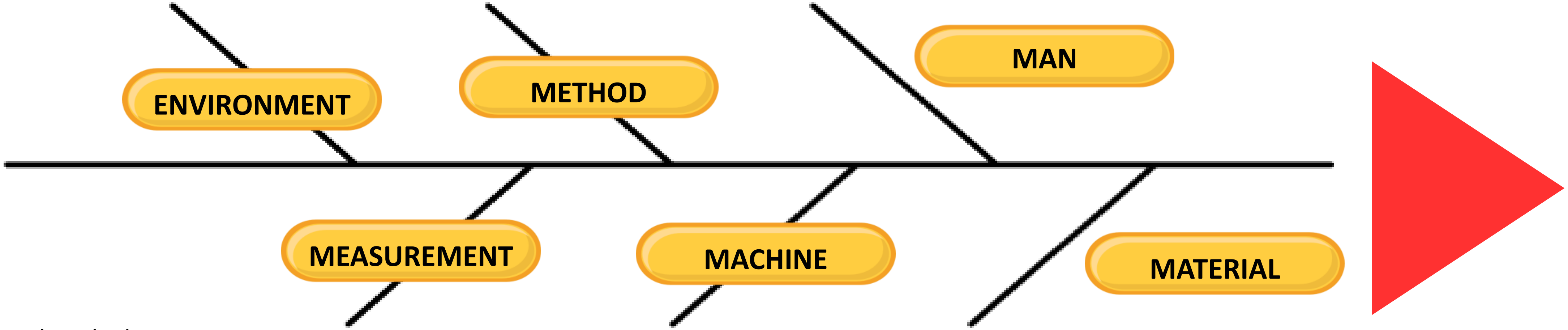
- P > 0.05 in all scenarios, thus all the data is normally distributed

Fish Bone Diagram

1. Poor lighting in assembly area
2. High humidity affecting insulation
3. Dust or contaminants on wires
4. Excessive heat affecting worker comfort and wire flexibility

1. Wiring procedure not standardized
2. Steps skipped due to time pressure
3. Incorrect wire routing or termination
4. Improper sequencing of wiring steps

1. Inexperienced assembly staff
2. Lack of training on wiring standards
3. Fatigue due to long shifts
4. Miscommunication of wiring diagrams



1. Inconsistent inspection criteria
2. Delayed or infrequent testing
3. QC instruments not calibrated
4. Human error in defect identification

1. Worn-out wire stripping tools
2. Loose or poorly calibrated screwdrivers
3. Faulty crimping tools
4. Inconsistent labeling machines for wires
5. Poorly maintained assembly jigs or fixtures

1. Wrong wire gauge supplied
2. Poor-quality terminals/connectors
3. Inconsistent insulation on wires
4. Damaged wires during transport

Common and Special causes

Common Causes

- Inexperienced assembly staff
- Lack of training on wiring standards
- Fatigue due to long shifts
- Miscommunication of wiring diagrams
- Wiring procedure not standardized
- Steps skipped due to time pressure
- Lack of checklist for QC before testing

Special Causes

- Worn-out wire stripping tools
- Loose or poorly calibrated screwdrivers
- Faulty crimping tools
- Poorly maintained assembly jigs or fixtures
- Inconsistent insulation on wires
- Inconsistent inspection criteria
- Human error in defect identification
- No real-time defect tracking system

3M Analysis for Waste

MUDA

- Rework panels due to wiring defects
- Excess motion of operators searching for tools or wires
- Waiting time for QC inspection before proceeding to next step

Mura

- Variability in wiring defect rate between shifts (some shifts have more errors)
- Inconsistent wire lengths or improper terminations across panels
- Fluctuating time taken to complete wiring of each panel

Muri

- Operators working overtime to meet tight deadlines
- Machines or crimping tools being overused without maintenance
- Assembly staff handling multiple panels at once, increasing fatigue and errors

8 Wastes Analysis

Waste	Examples
Defects	• Panels failing QC due to loose connections • Wrong wire connections requiring rework
Overproduction	• Wiring panels faster than QC can inspect them • Producing extra panels “just in case” for future orders
Waiting	• Operators waiting for wire or components to arrive • Panels waiting in queue for QC inspection
Non-Utilized Talent	• Operators not involved in problem-solving or improvement discussions. • Lack of training opportunities to enhance skill in precision machining.
Transportation	• Moving panels back and forth between assembly and QC • Carrying wires or tools across long distances on the shop floor
Inventory	• Overstock of wires, terminals, or connectors • Panels stored for long periods before inspection
Motion	• Operators walking repeatedly to fetch gauges or tools. • Manual handling of heavy parts without fixtures or trolleys.
Overprocessing	• Re-doing wiring multiple times due to improper termination • Excessive labeling or double-checking that adds no real value

Action Plan for Low Hanging Fruits

Area	Identified Issue / Root Cause	Lean Tool / Approach	Action Steps (Low-Hanging Fruits)	Expected Benefit	Owner / Responsible	Timeline
Special Causes	Worn-out or poorly calibrated tools	5S / TPM	Inspect all tools, replace or calibrate worn-out ones, label tools	Reduce wiring defects, less rework	Maintenance / Production Lead	2 weeks
	Wrong wire gauge / poor-quality terminals	Supplier Management / Standard Work	Verify incoming material quality, implement a quick check at goods-in	Reduce defects due to wrong material	QC / Procurement	1 week
	Inconsistent inspection criteria	Standard Work / Visual Mangement	Create visual QC checklist for wiring, train operators	Fewer missed defects, consistent quality	QC Team	2 weeks
Man (People)	Fatigue / improper training	Standard Work / Kaizen	Short refresher training on wiring standards, rotate shifts to reduce fatigue	Increase accuracy and morale	Production Supervisor	1 week
	Miscommunication of diagrams	Visual Management	Post wiring diagrams at workstations, color-coded labels	Reduce wiring errors	Engineering Liaison	1 week
Machine	Faulty crimping tools	TPM / 5S	Clean, lubricate, and calibrate crimping tools; implement daily tool check	Prevent loose connections	Maintenance	2 weeks
Material	Mismatched wires / damaged components	Supplier Management / 5S	Implement incoming inspection, segregate rejected items	Reduce material-related defects	QC / Warehouse	1 week

Action Plan for Low Hanging Fruits

Area	Identified Issue / Root Cause	Lean Tool / Approach	Action Steps (Low-Hanging Fruits)	Expected Benefit	Owner / Responsible	Timeline
Overproduction (Waste)	Panels wired ahead of QC capacity	Kanban / Pull System	Implement pull-based workflow, only wire as per schedule	Reduce rework and storage	Production Planner	2 weeks
Waiting (Waste)	Operators waiting for components	5S / Standard Work	Organize components near workstations, maintain small buffer	Reduce idle time	Production Lead	1 week
Transport (Waste)	Excessive movement of panels	5S / Layout Optimization	Reorganize assembly and QC layout for minimal movement	Reduce handling time	Production / Layout Team	2 weeks
Overprocessing (Waste)	Excessive rework	Standard Work / Poka-Yoke	Introduce mistake-proofing: wire guides, color-coded terminals	Reduce rework	Production Lead	2 weeks
Inventory (Waste)	Overstock of wires / terminals	5S / Kanban	Maintain minimum stock levels, implement visual Kanban	Reduce storage cost, ensure material availability	Warehouse / Procurement	1 week
Motion (Waste)	Unnecessary bending / reaching	5S / Ergonomics	Arrange tools and wires within arm's reach	Reduce fatigue, improve efficiency	Production Lead	1 week
Defects (Waste)	Panels failing QC	Poka-Yoke / Standard Work	Introduce wire termination jigs, visual inspection aids	Reduce defect rate from 8% → 2%	Production & QC	3 weeks

Action Plan for Low Hanging Fruits

Muda (Waste)

Waste Type	Lean Tool	Action Plan	Benefit
Rework due to defects	Poka-Yoke	Error-proof clamping and tool offset checks	Lower rework hours
Waiting for inspection	Point-of-Use Inspection	Provide in-line gauges / go-no-go tools at CNC	Reduced waiting time

Mura (Unevenness)

Issue	Lean Tool	Action Plan	Benefit
Variation in cycle times	Standard Work + SMED	Standardize CNC setup parameters and quick-change tooling	Consistent productivity
Inconsistent finish quality	SPC Control Charts	Monitor process stability and provide operator feedback	Stable surface quality

Muri (Overburden)

Issue	Lean Tool	Action Plan	Benefit
Overused cutting tools	Kanban for Tool Change	Visual tool life tracking and Kanban cards	Prevents tool breakage, reduces scrap
Operators overloaded	Work Balancing / Line Balancing	Redistribute machine responsibilities	Reduced errors, improved focus

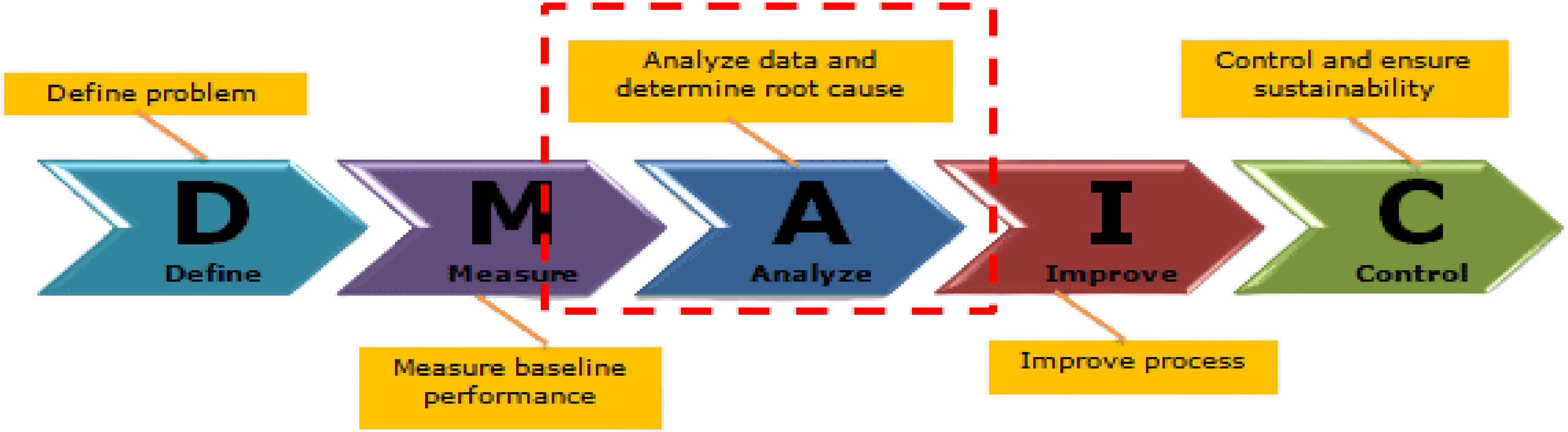
Top 12 Prioritized Root Causes (Based on Net Score)

1. Worn-out stripping tools – 162
2. Faulty crimping tools – 162
3. Poor-quality wires / terminals – 162
4. Wrong wire gauge – 162
5. Mismatched color coding – 162
6. Improper routing / sequencing – 162
7. Lack of checklist / Standard Work – 162
8. Inconsistent QC criteria – 162
9. Inexperienced staff – 148
10. Lack of training – 148
11. Excessive panel handling – 84
12. Miscommunication of diagrams – 72

Data Collection Plan

Sn.	Root Cause/ Input	Data to be Collected	Measurement Unit	Method / Tool
1	Worn-out stripping tools	Tool condition, number of defective crimps	Defective crimps per 100 crimps	Visual inspection, checklist
2	Faulty crimping tools	Tool calibration status, defective connections	Defects per 50 crimps	Calibration log, visual inspection
3	Poor-quality wires / terminals	Wire insulation defects, terminal integrity	Defective wires per batch	Incoming inspection, random sampling
4	Wrong wire gauge	Wire gauge measurement	Gauge mismatch count	Vernier caliper / Gauge tool
5	Mismatched color coding	Color code mismatch, wiring errors	Count per panel	Visual inspection
6	Improper routing / sequencing	Wire path deviation, skipped connections	Number of errors per panel	Visual inspection, checklist
7	Lack of checklist / Standard Work	Checklist adherence, missing steps	% compliance per panel	Observation, checklist
8	Inconsistent QC criteria	QC inspection variance, missed defects	# of missed defects per panel	QC double-check, audit
9	Inexperienced staff	Operator skill level, error frequency	Defects per operator	Observation, skill matrix
10	Lack of training	Training completion, wiring errors	% trained operators	Training log, observation

ANALYSE PHASE



Analyse – Hypothesis testing

Regression Analysis: Scrap_% versus Wornout_Stripping_Tool_Usag

Regression Equation

Scrap_% = -0.848 + 0.01583 Wornout_Stripping_Tool_Usage_Ho
+ 9.84 Crimping_Tool_Calibration_Error - 0.03688 Wire_Terminal_Quality_Score
+ 0.8086 Improper_Routing_Defects_per_Ba

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	-0.848	0.977	-0.87	0.394	
Wornout_Stripping_Tool_Usage_Ho	0.01583	0.00203	7.80	0.000	1.06
Crimping_Tool_Calibration_Error	9.84	1.15	8.55	0.000	1.07
Wire_Terminal_Quality_Score	-0.03688	0.00991	-3.72	0.001	1.04
Improper_Routing_Defects_per_Ba	0.8086	0.0925	8.74	0.000	1.07

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.665586	91.36%	89.98%	87.29%

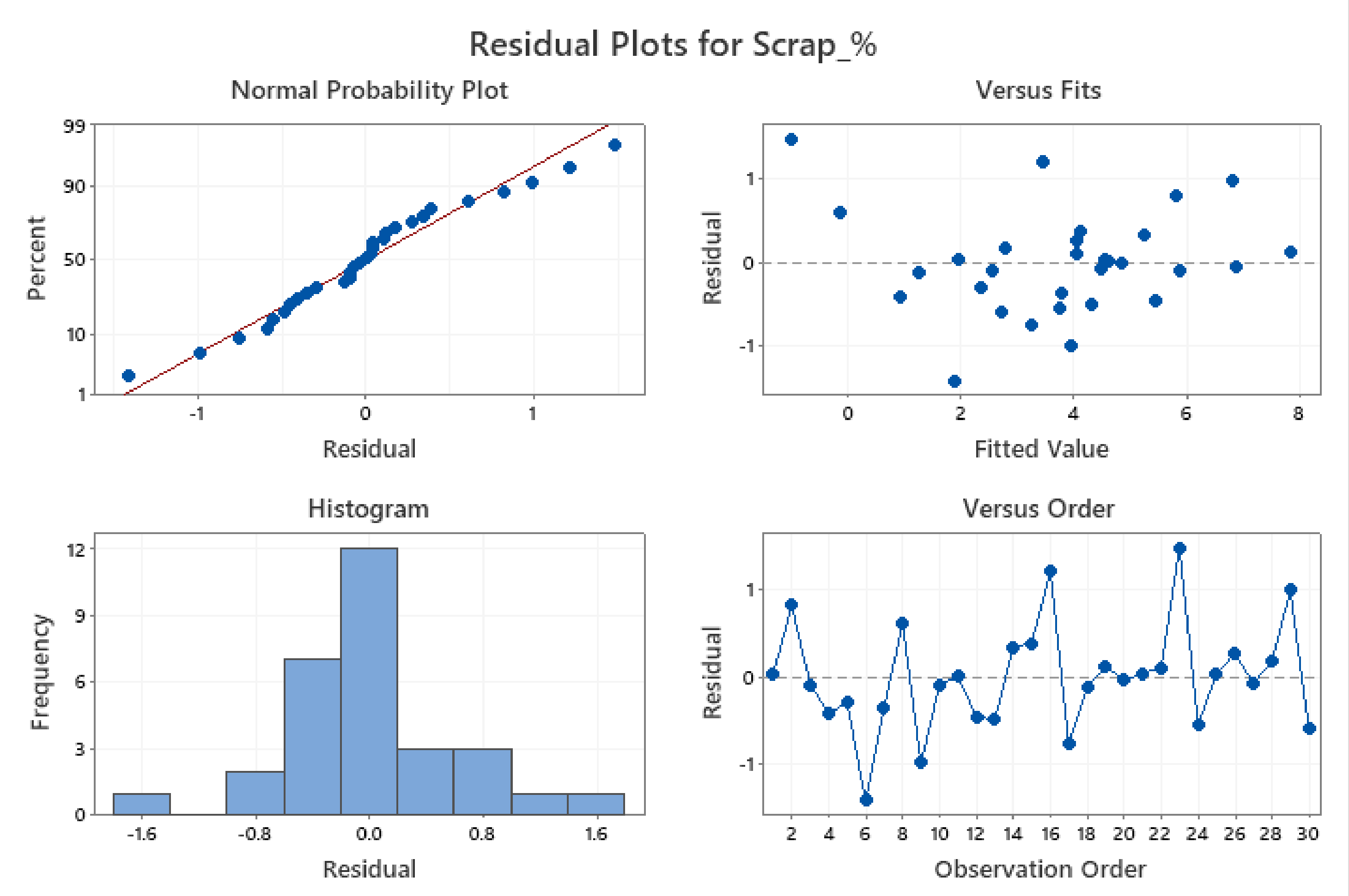
Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	4	117.154	29.2884	66.11	0.000
Wornout_Stripping_Tool_Usage_Ho	1	26.947	26.9471	60.83	0.000
Crimping_Tool_Calibration_Error	1	32.360	32.3598	73.05	0.000
Wire_Terminal_Quality_Score	1	6.143	6.1426	13.87	0.001
Improper_Routing_Defects_per_Ba	1	33.864	33.8638	76.44	0.000
Error	25	11.075	0.4430		
Total	29	128.229			

Inference :

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

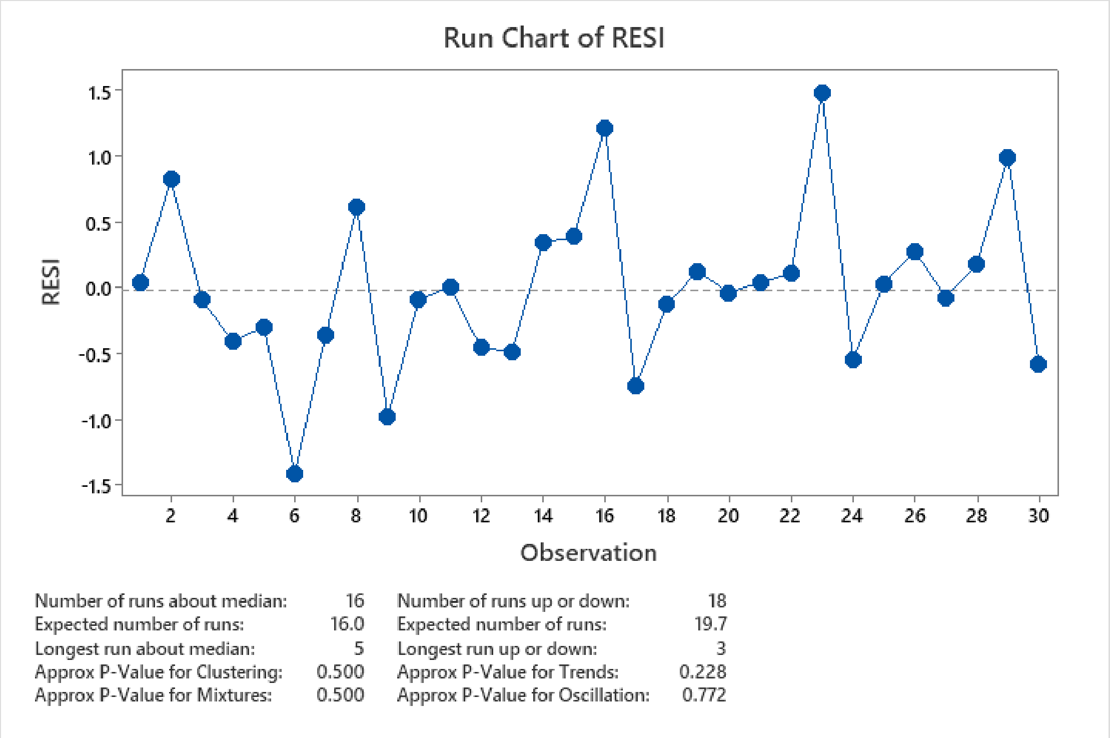
Analyse – Hypothesis testing

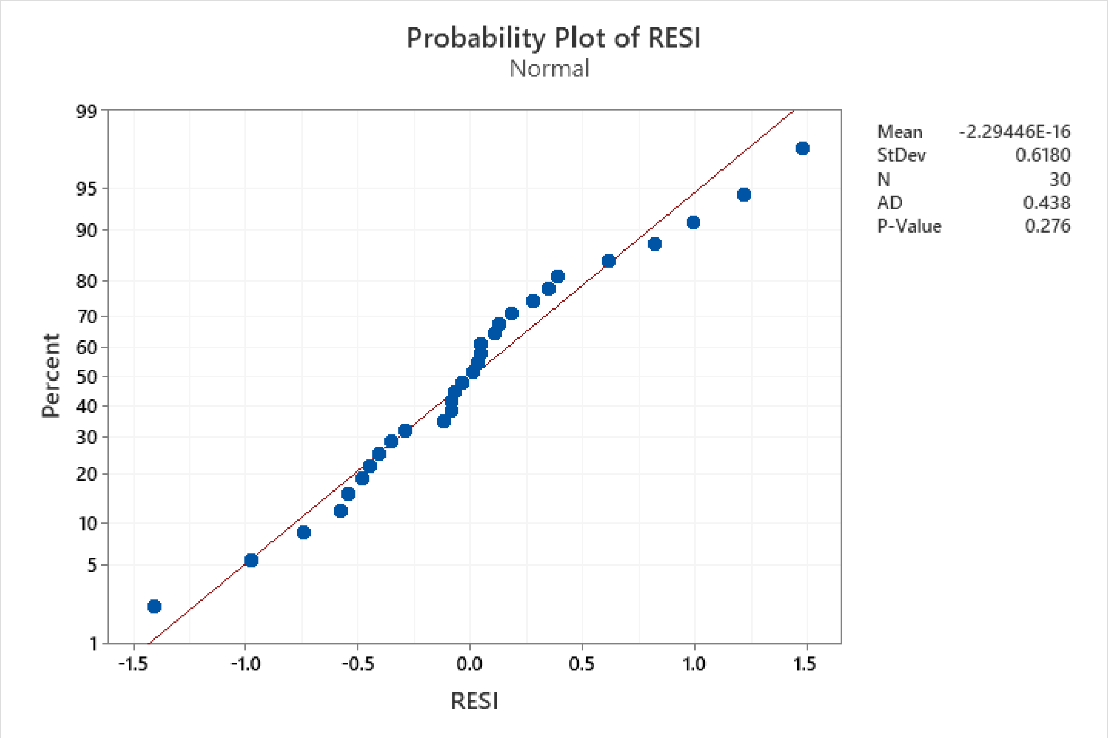


Inference :

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

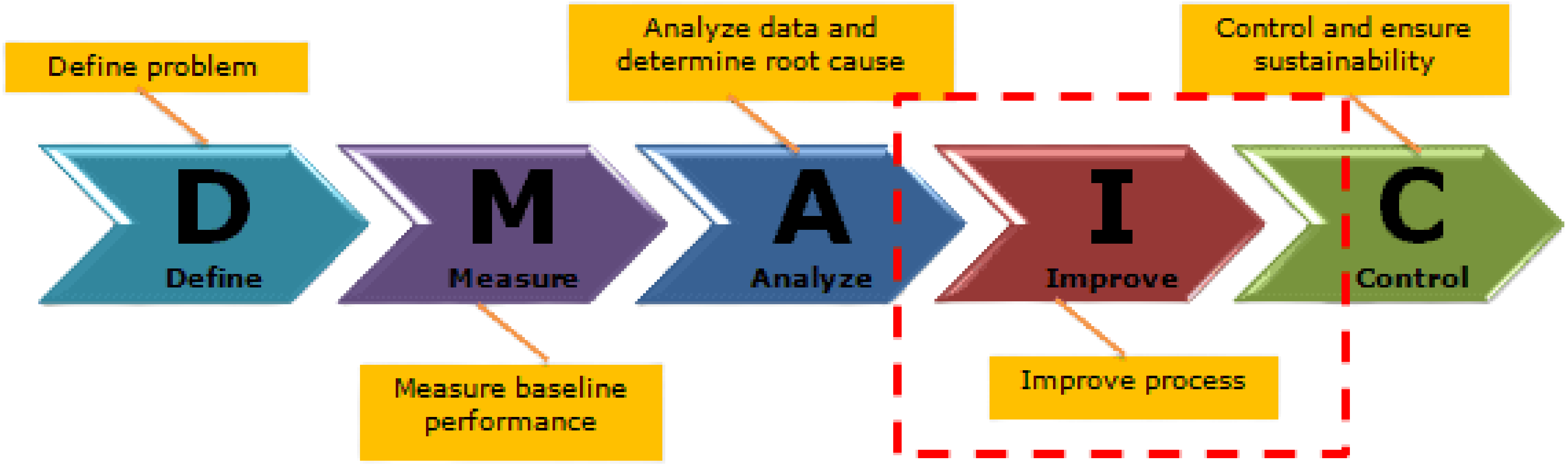
Summary of Statistically validated Root causes



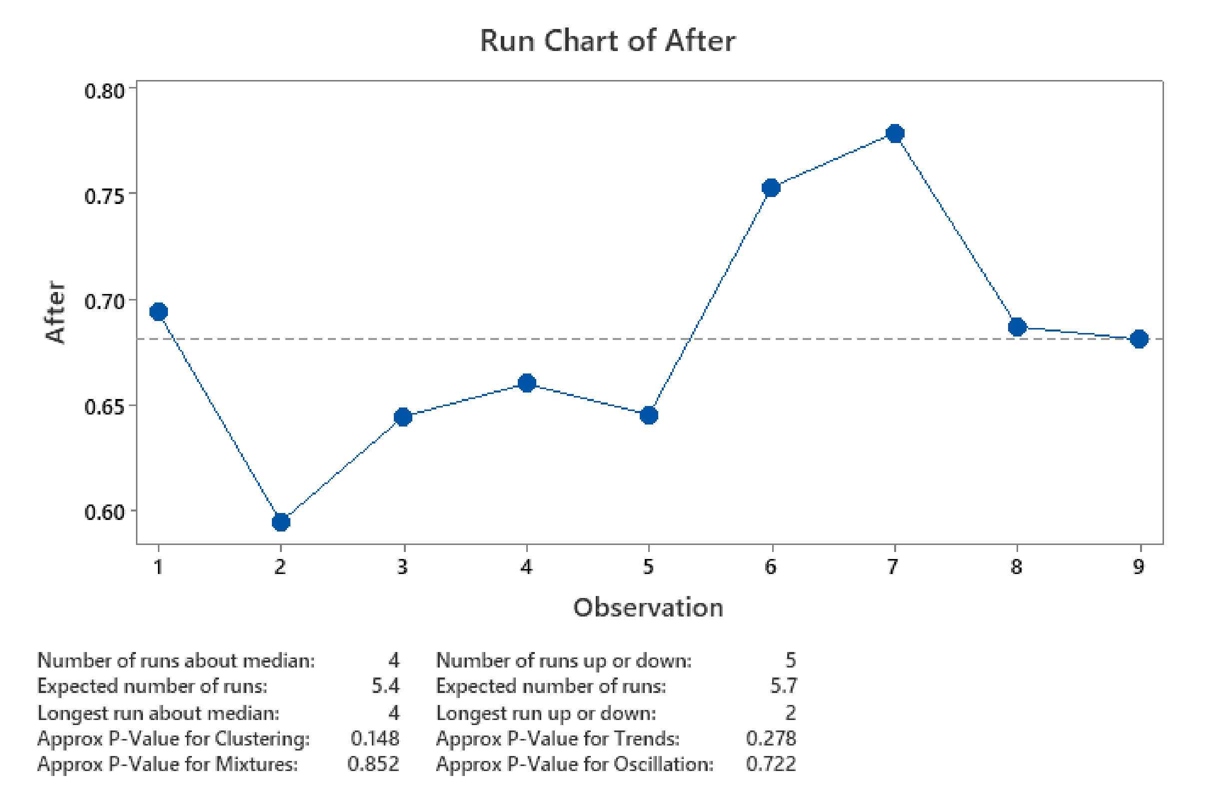


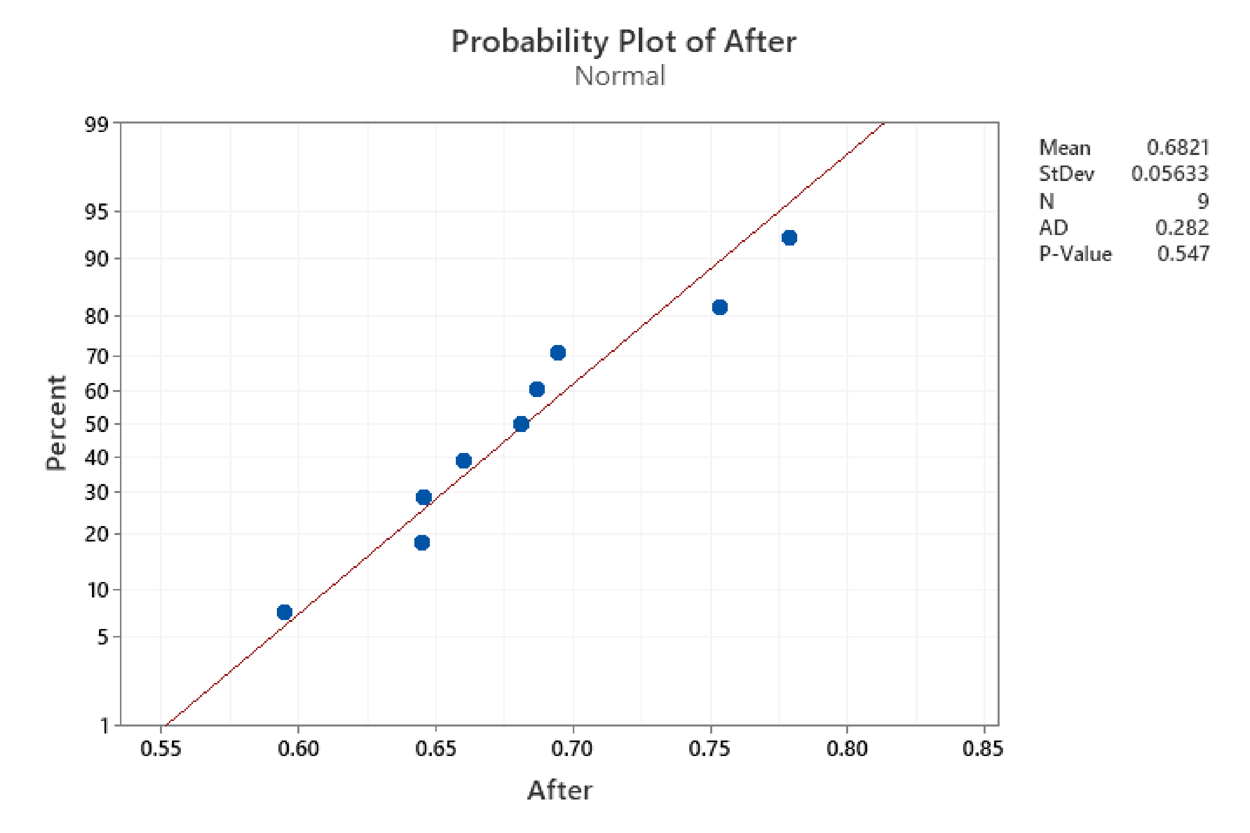
Residuals are randomly distributed with no visible trends, indicating a stable process.• Probability plot shows residuals follow normal distribution (p-value > 0.05), validating model assumptions.

IMPROVE PHASE



Improve





The run chart indicates a stable process after improvement with no abnormal trends or shifts.
The probability plot confirms the data is normally distributed (p-value > 0.05), indicating consistent and predictable 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	3.19	1.36	0.45
After	9	0.6821	0.0563	0.019

Estimation for Difference

Difference	95% CI for Difference
2.507	(1.459, 3.555)

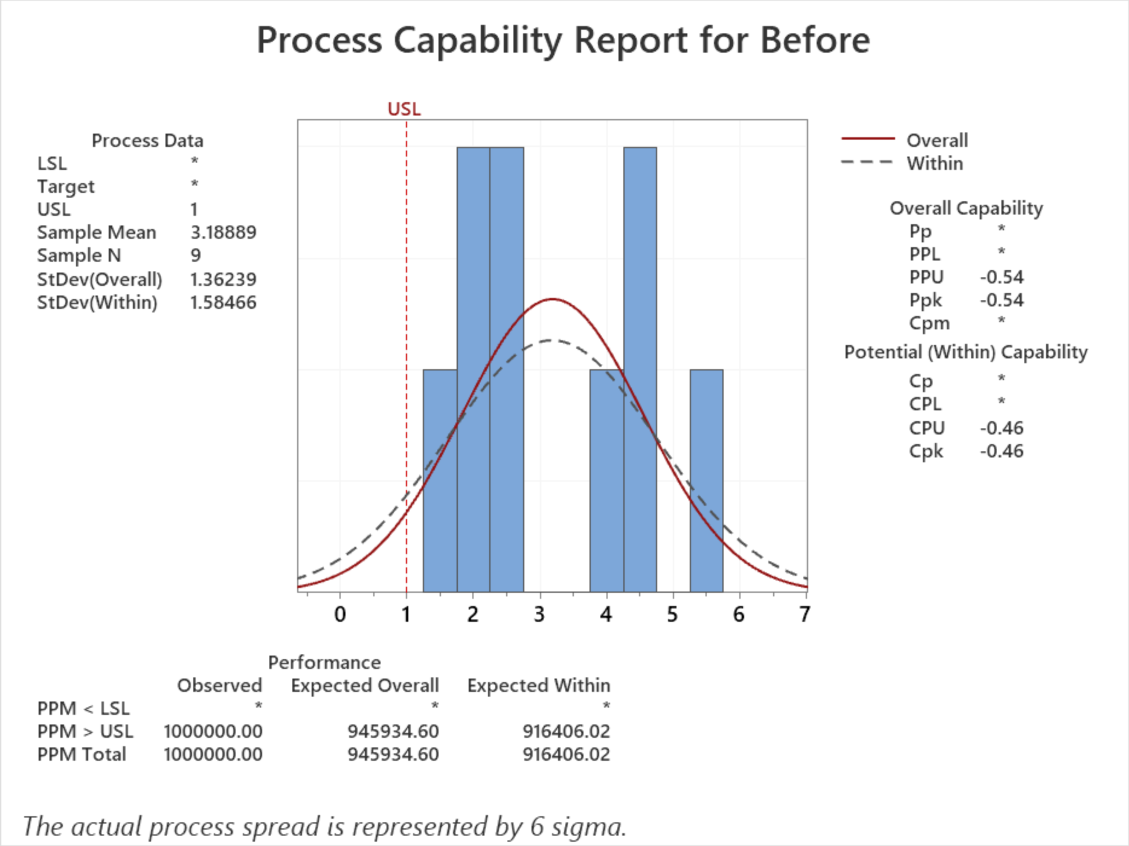
Test

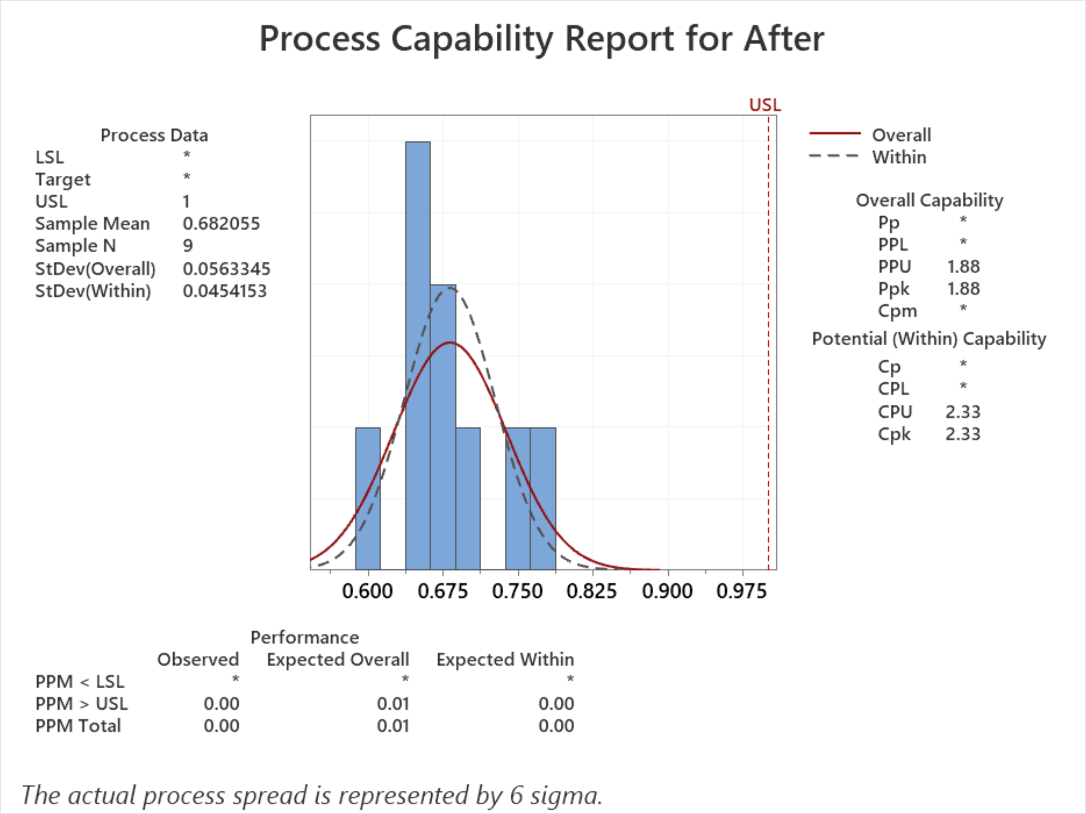
Null hypothesis $H_0: \mu_1 - \mu_2 = 0$
Alternative hypothesis $H_1: \mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
5.52	8	0.001

The run chart indicates a stable process after improvement with no abnormal trends or shifts.
The probability plot confirms the data is normally distributed (p-value > 0.05), indicating consistent and predictable performance after improvement.

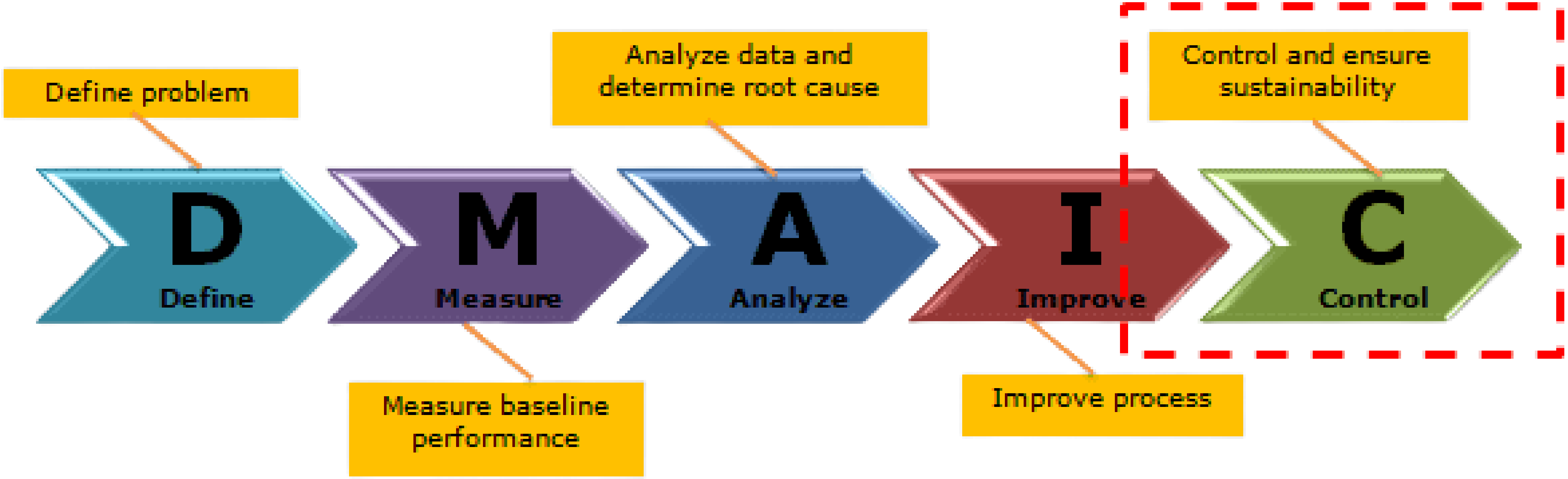
Improve – Process capability – Before & After Improvement



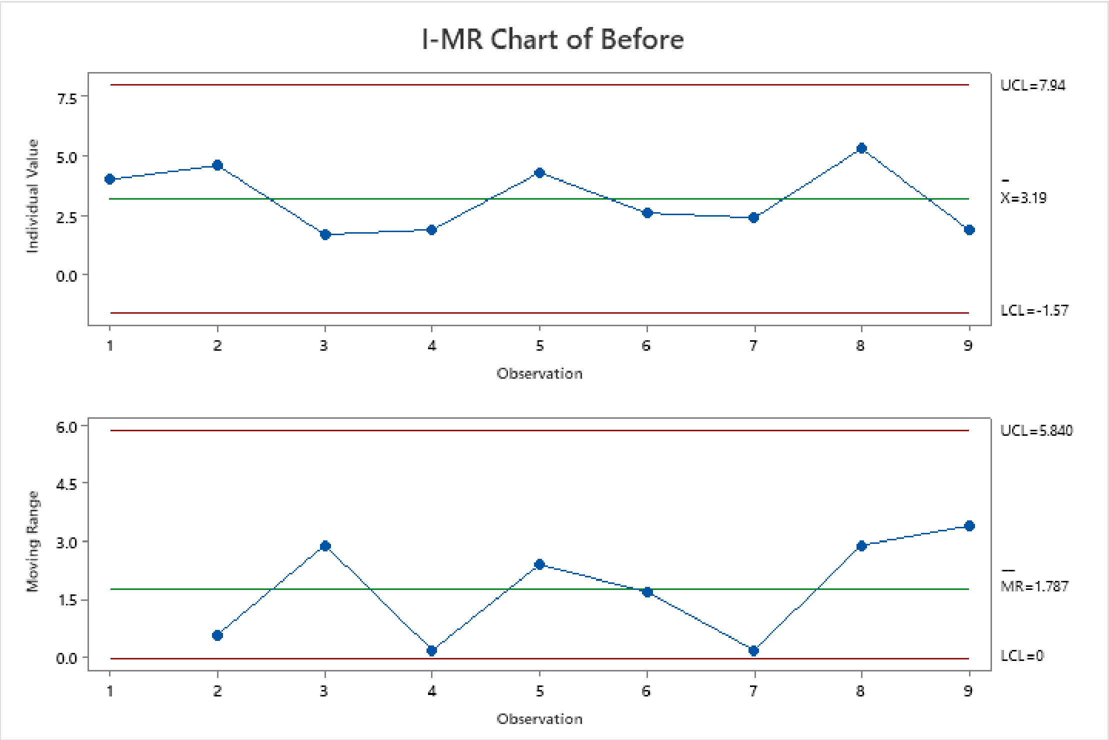


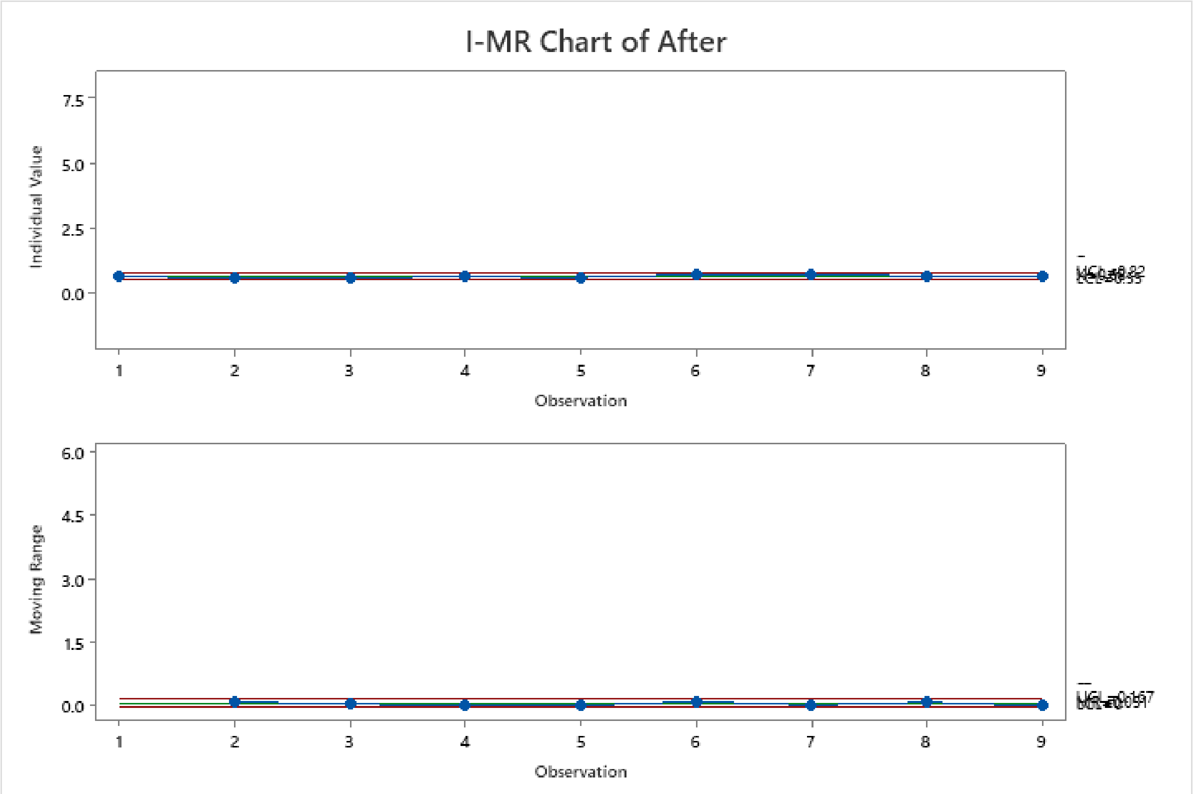
Before improvement, the process is not capable, with Cpk well below acceptable limits and high defect levels observed.
After improvement, the process becomes capable and well-centered within specification limits, with a significant reduction in variation and defects.

CONTROL PHASE



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





• Before improvement, the process shows higher variation with points closer to control limits, indicating limited process control.
• After improvement, variation is significantly reduced and all points remain well within control limits, confirming a stable and controlled process.

Control Plan - 5S and poka yoke mechanism for sustaining the improvement

Key 5S / Poka-Yoke Mechanism	Purpose (What it Prevents)
Tool life control with OK/NOT-OK tagging (stripping & crimping tools)	Prevents defects due to worn or out-of-calibration tools
Shadow boards with color-coded wire & terminal bins	Prevents wrong tool, wrong wire gauge, and wrong terminal usage
Go / No-Go crimp gauge before shift start	Prevents under-crimping or loose connections
Standard routing guides / harness jigs with golden sample	Prevents improper routing and sequencing errors
Mandatory station checklist with visual confirmation	Prevents skipping critical wiring and QC steps

Control Plan

Process Step / Improvement Action	Potential Failure Mode	Potential Effect	Potential Cause	S	O	D	RPN	Recommended Preventive Action
Tool life control for stripping tools	Worn tool used beyond life	Conductor damage, high scrap	No tracking of usage hours	8	5	4	160	Tool life limit defined; OK/NOT-OK tagging; tool issue log
Crimping tool calibration	Tool out of calibration	Loose / weak crimps	Missed calibration schedule	9	4	3	108	Weekly calibration; daily Go/No-Go gauge check
Wire & terminal selection	Wrong wire gauge used	Overheating, rejection	Mixed storage, poor identification	8	4	4	128	Color-coded bins; gauge-specific terminal pockets
Routing & sequencing	Incorrect routing	Panel rejection, rework	No standard routing reference	7	5	4	140	Routing SOP; harness jig; golden sample display
Checklist / standard work usage	Checklist skipped	Defects escape to final QC	Operator bypasses steps	8	3	3	72	Mandatory checklist sign-off; supervisor audit
QC inspection consistency	Subjective inspection	Defects not detected	No clear acceptance criteria	7	3	5	105	Visual standards; sample-based acceptance limits
Operator adherence	Non-compliance to new process	Scrap recurrence	Insufficient training	8	3	4	96	Skill certification; refresher training

Control Plan - to sustain improvements

Process Step	CTQ / Metric	Target / Spec	Control Method	Monitoring Frequency	Reaction Plan	Owner
Wire stripping	Tool usage hours	≤ defined tool life (e.g., 100–150 hrs)	Tool OK/NOT-OK tag; usage log	Daily	Stop work, replace tool, inspect last lot	Production Supervisor
Crimping	Crimp calibration error	Within spec (Go/No-Go = PASS)	Go/No-Go gauge; calibration sticker	Start of each shift	Re-calibrate tool, rework affected crimps	Maintenance / QA
Wire & terminal selection	Wrong gauge incidents	0	Color-coded bins; gauge-specific pockets	Every batch	Segregate batch, correct material, retrain operator	Line Lead
Routing & sequencing	Routing defects / batch	≤ 1	Routing SOP; harness jig; golden sample	Every panel	Correct routing, verify 100%, update SOP if needed	Industrial Engineer
Checklist adherence	Checklist completion %	100%	Mandatory station checklist sign-off	Each shift	Halt next operation, complete checklist	Supervisor
Final outcome	Scrap %	< 1%	Scrap trend chart; daily review	Daily	Root cause analysis; trigger corrective action	Quality Head

Conclusion

Results after improvement

- *This project successfully achieved the targeted reduction in defects through data-driven analysis and sustainable process improvements, resulting in a stable, capable process and laying a strong foundation for continuous improvement.*