QUALITY ENGINEERING IN PLASTIC BOTTLE MANUFACTURING

Group 2

Team Members:

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PROJECT OBJECTIVE

This project focuses on reducing defects caused by air pressure in blow-molded plastic bottles by applying Lean Six Sigma methodology to stabilize the process, improve First Pass Yield, and enhance capability

OVERVIEW

PROJECT OVERVIEW

Plastic bottle manufacturing is a high-volume process where even minor deviations in air pressure result in leakage, deformation, customer complaints, and loss of material. The current process is experiencing an average defect rate of 3%, which directly impacts cost, throughput, and customer satisfaction.

This project aims to analyze the causes of air pressure variation, identify statistically valid root causes, implement improvements, and achieve stable and capable process performance with defects reduced to 1% or lower.

BACKGROUND

Our plant manufactures 1,00,000 blow-molded plastic bottles per month.
Over the past several months, the defect rate due to uneven Air pressure has averaged around 3%, with fluctuations ranging from 1.9% to 3.7%. These defects lead to leakage failures and structural weakness of the bottle, especially during transport or filling operations.
The major business problems observed include:

- High scrap and rework
- Increased machine downtime
- Higher customer complaint rates
- Reduced FPY

The management has set a goal to reduce the defect rate to 1%, enabling improved quality, cost reduction, and enhanced customer reliability.

DEFINE

VOICE OF CUSTOMER & CTQ

Voice of Customer (VOC):
Customers - primarily FMCG, beverage companies, and third-party bottlers - expect bottles with less defects, consistent wall thickness to ensure no leakage, no deformation, and proper durability during filling, transportation, and end-use.

Critical to Quality (CTQ):
Air pressure Uniformity (variation must be within the allowed tolerance range)
Metric Definition:
% Defective Bottles = (Number of bottles rejected due to Air pressure variation ÷ Total bottles produced) × 100

BASELINE PERFORMANCE (LAST 9 MONTHS)

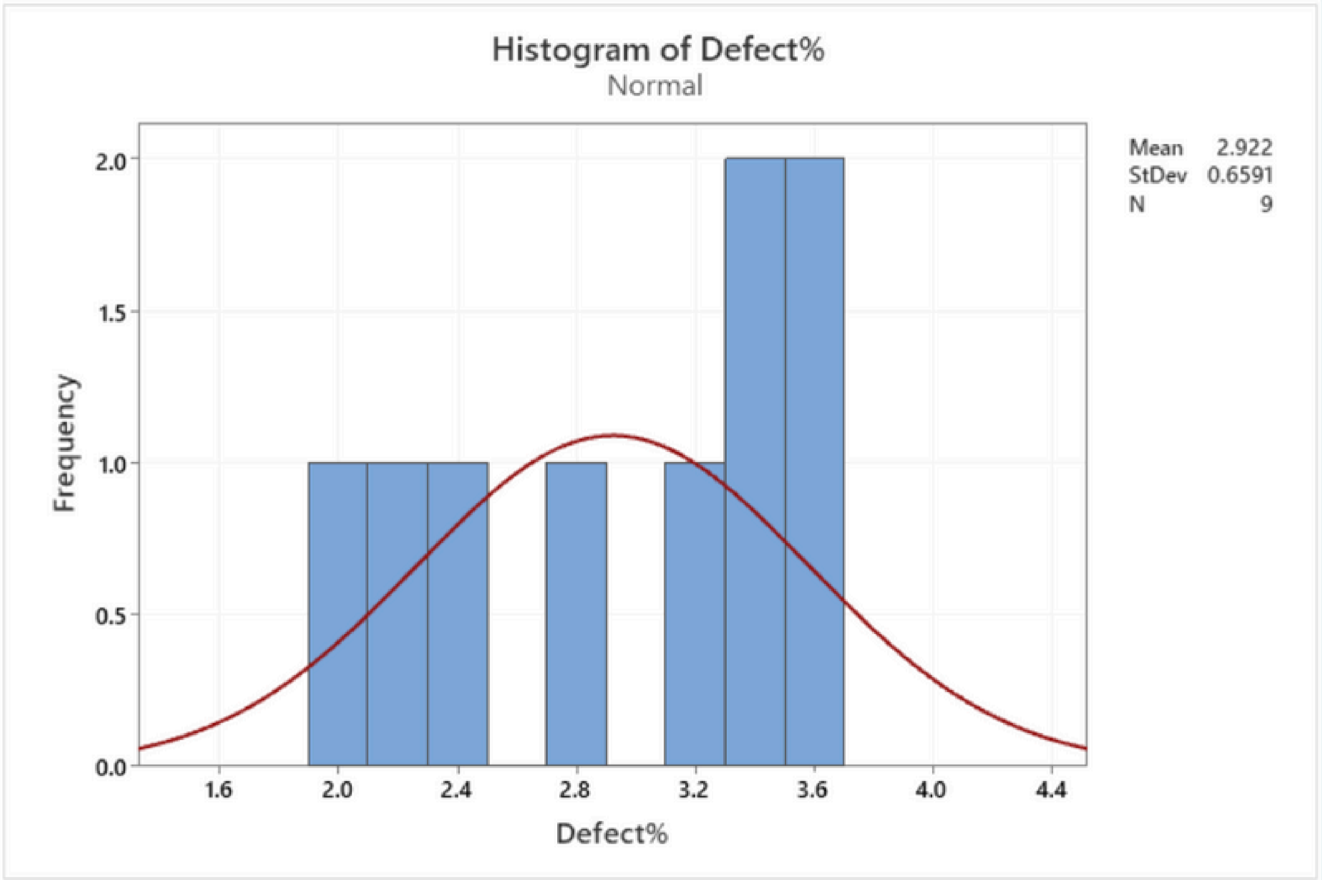
Month	% Defective
Jan	2.40%
Feb	3.10%
Mar	3.30%
Apr	2.10%
May	3.60%
Jun	2.80%
Jul	3.40%
Aug	1.90%
Sep	3.70%

Descriptive Statistics: Defect%

Statistics

Variable	Mean	StDev	Variance	Median	Range	IQR
Defect%	2.922	0.659	0.434	3.100	1.800	1.250

Histogram of Defect%



Although the average is 3%, the wide month-to-month variation indicates a process with low stability and multiple influencing factors. Such unstable processes are ideal candidates for Six Sigma improvement.

GOAL STATEMENT & BUSINESS CASE

Goal Statement

The goal of this project is to reduce the defect rate from 3% to 1% within a period of four months (October 2025 to January 2026) in the blow-molding operation

Business Case

Currently, 3% of bottles (3,000 per month) are rejected due to Air pressure and other issues.

Given the unit cost of approximately ₹5 per bottle, the monthly financial loss is ₹15,000, and annual loss is ₹1.8 lakhs.

By reducing the defect rate from 3% to 1%, we can save:

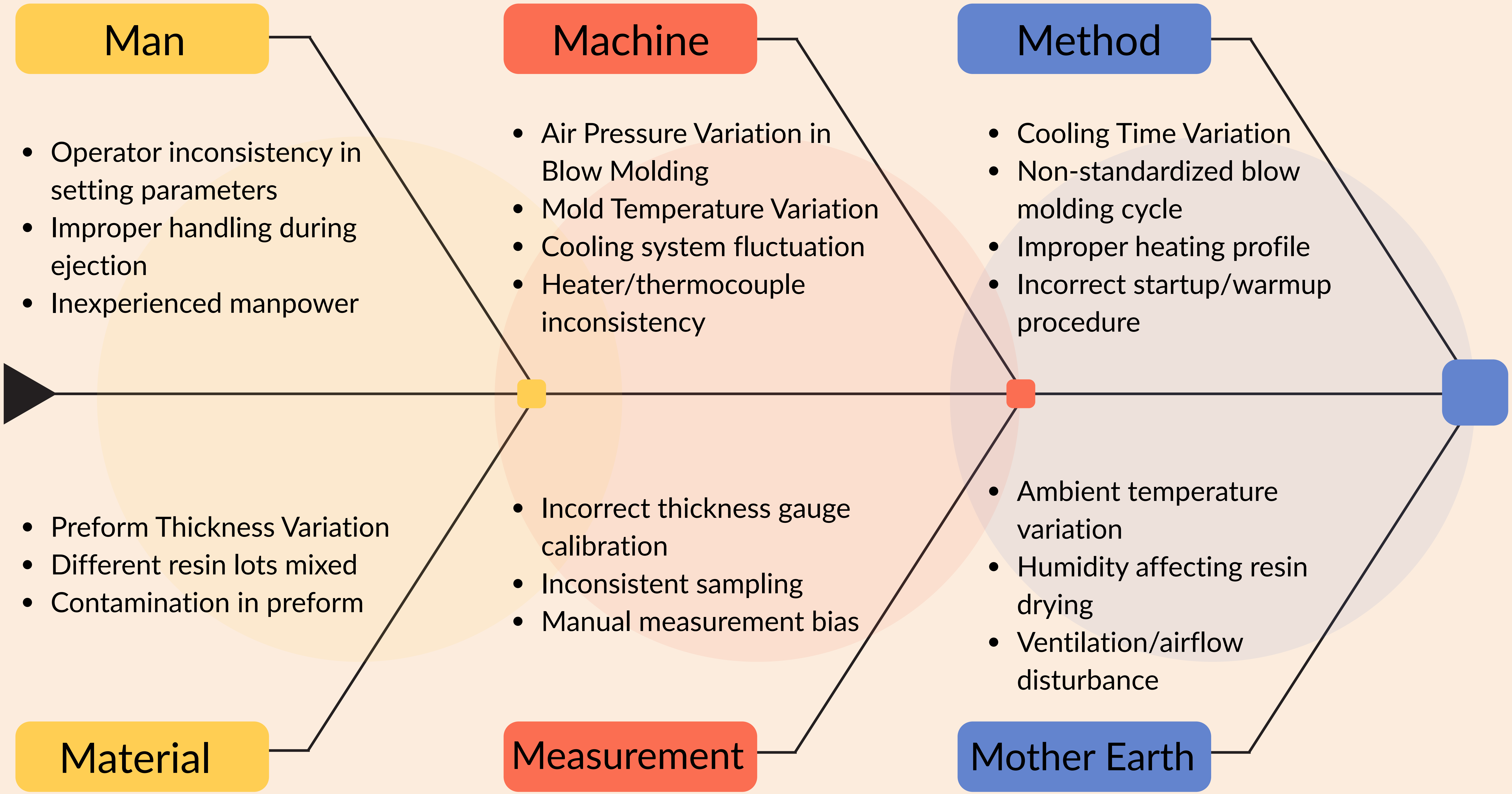
- ₹10,000 per month
- ₹1.2 lakhs annually

Additional intangible benefits include:

- Improved customer satisfaction
- Reduced complaints
- Higher production reliability
- Reduced material wastage
- Increased throughput

MEASURE

FISH BONE ANALYSIS



CAUSE AND EFFECT MATRIX (X-Y DIAGRAM)

Output Priorities	Functional strength	Scrap reduction	Leakage / failure rate	Visual quality
Rating	9	9	8	7

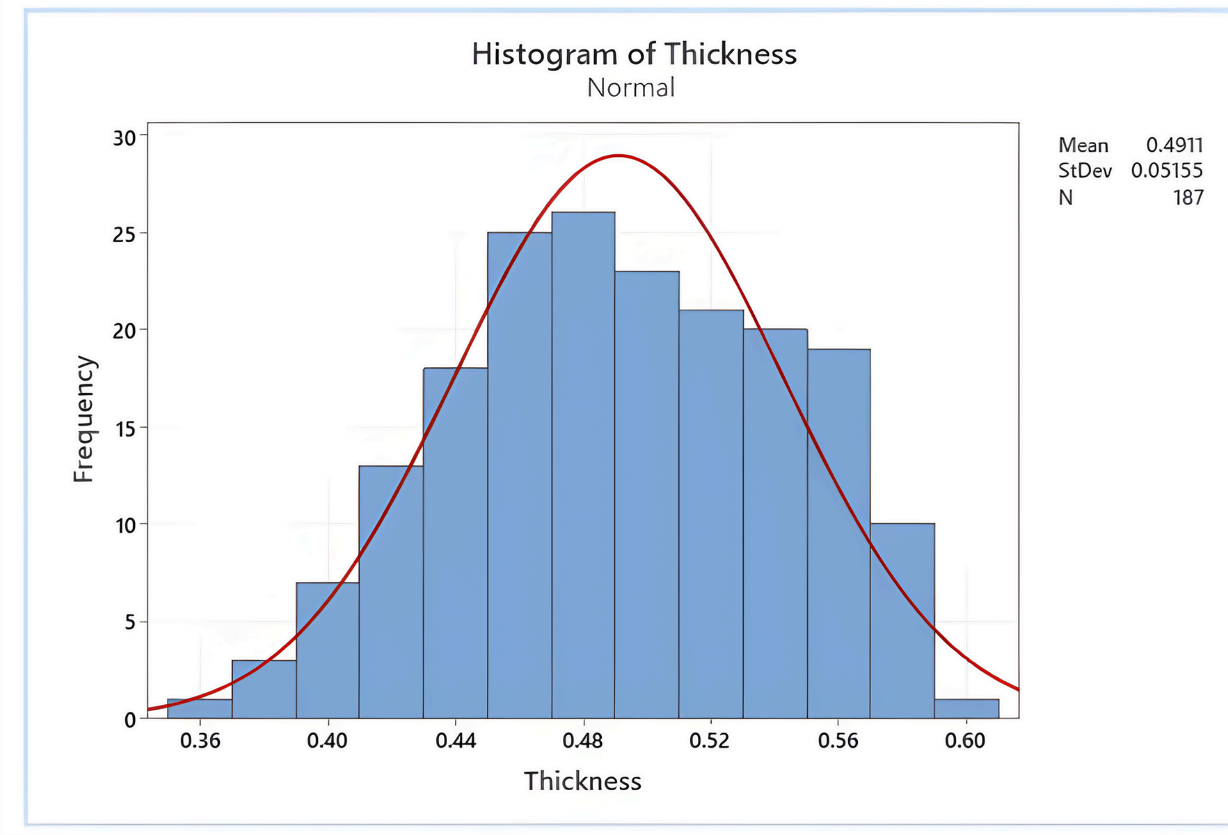
Input Variable	Strength (9)	Scrap (9)	Leakage (8)	Visual (7)	Net Score
Air Pressure Variation in Blow Molding	9	9	9	7	283
Mold Temperature Variation	9	9	8	7	275
Preform Thickness Variation	9	8	9	7	274
Cooling Time Variation	8	8	8	6	250
Resin Moisture Fluctuation	6	6	6	5	191
Operator inconsistency	4	5	4	3	134
Heater/Thermocouple inconsistency	5	6	5	4	167
Ambient temperature variation	2	3	2	2	75

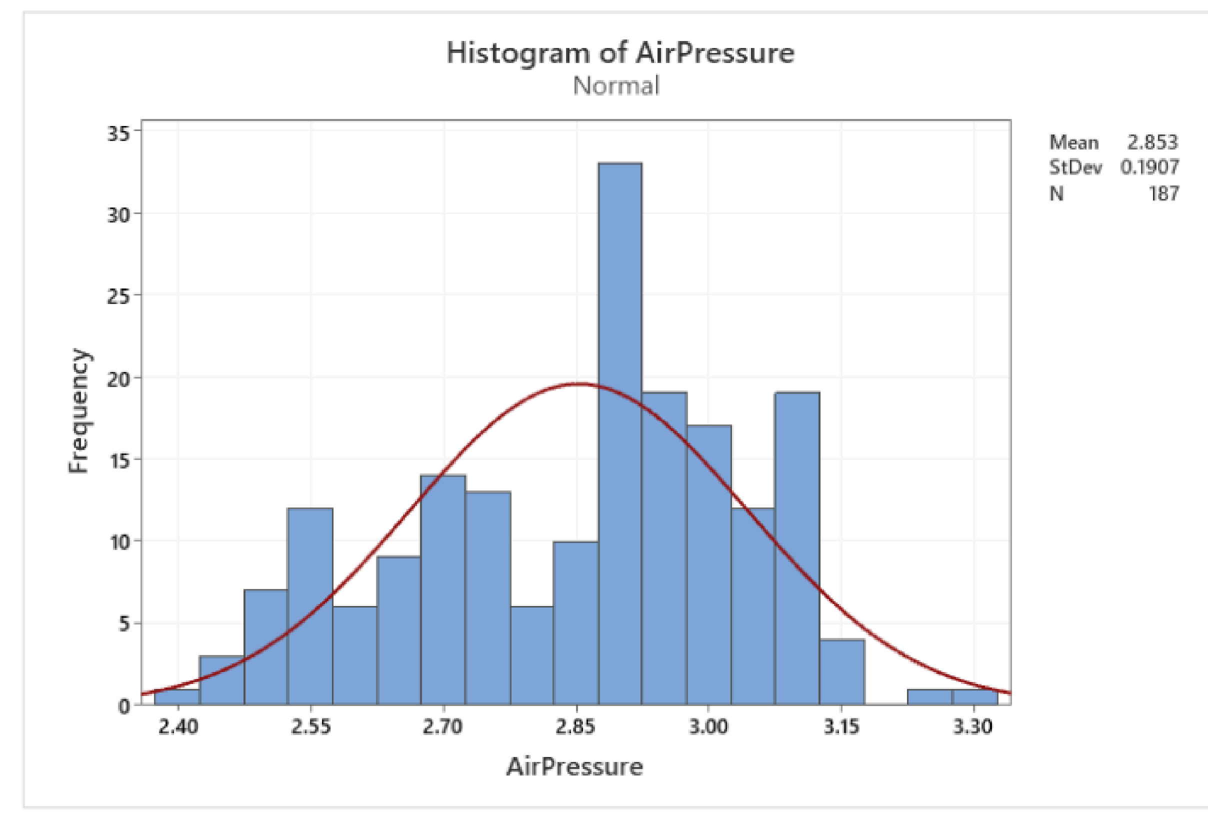
- Based on the X–Y prioritization, **Air Pressure Variation, Mold Temperature Variation, Preform Thickness Variation, and Cooling Time Variation** were identified as the most critical X-factors affecting Wall Thickness Variation.
- These inputs directly correspond to the causes listed in the Fishbone Diagram and therefore were selected for detailed data collection, process capability analysis, regression, and improvement.

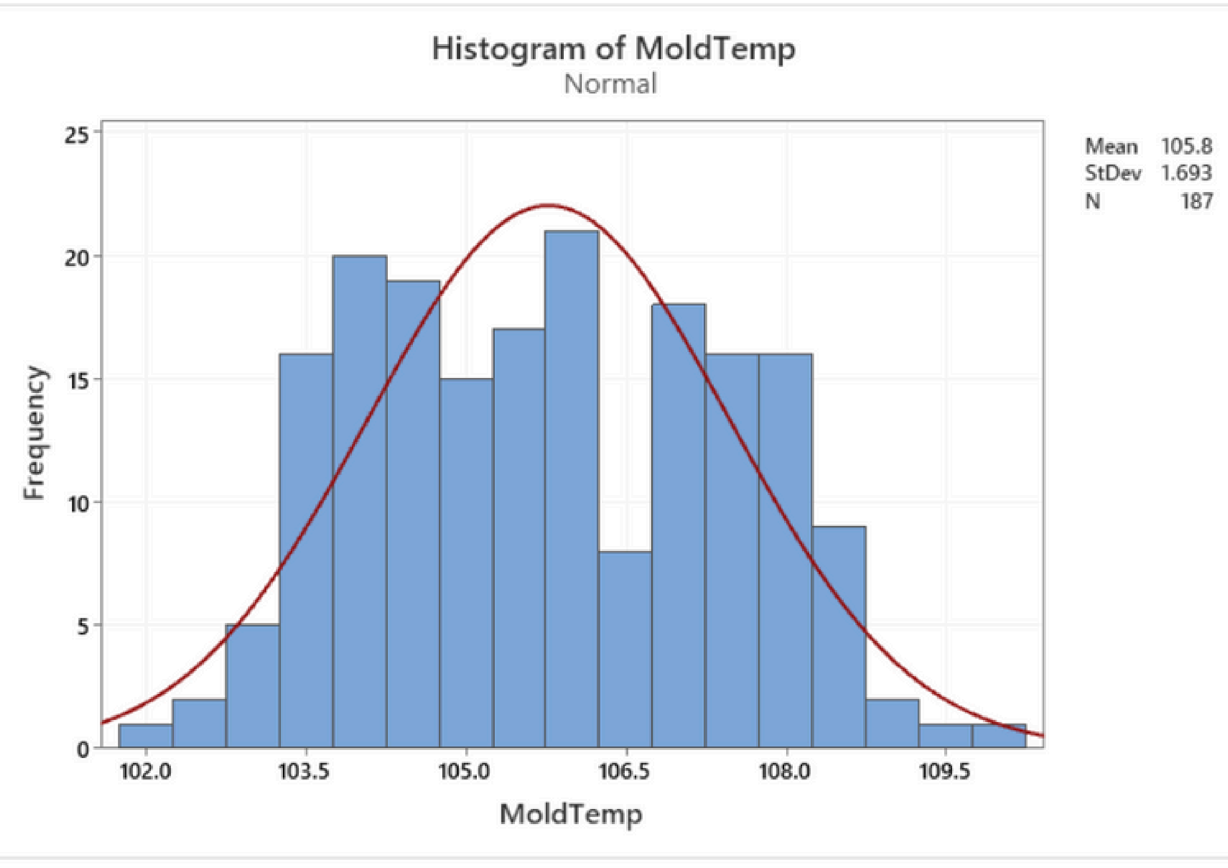
DATA COLLECTION – DESCRIPTIVE STATISTICS (BEFORE IMPROVEMENT)

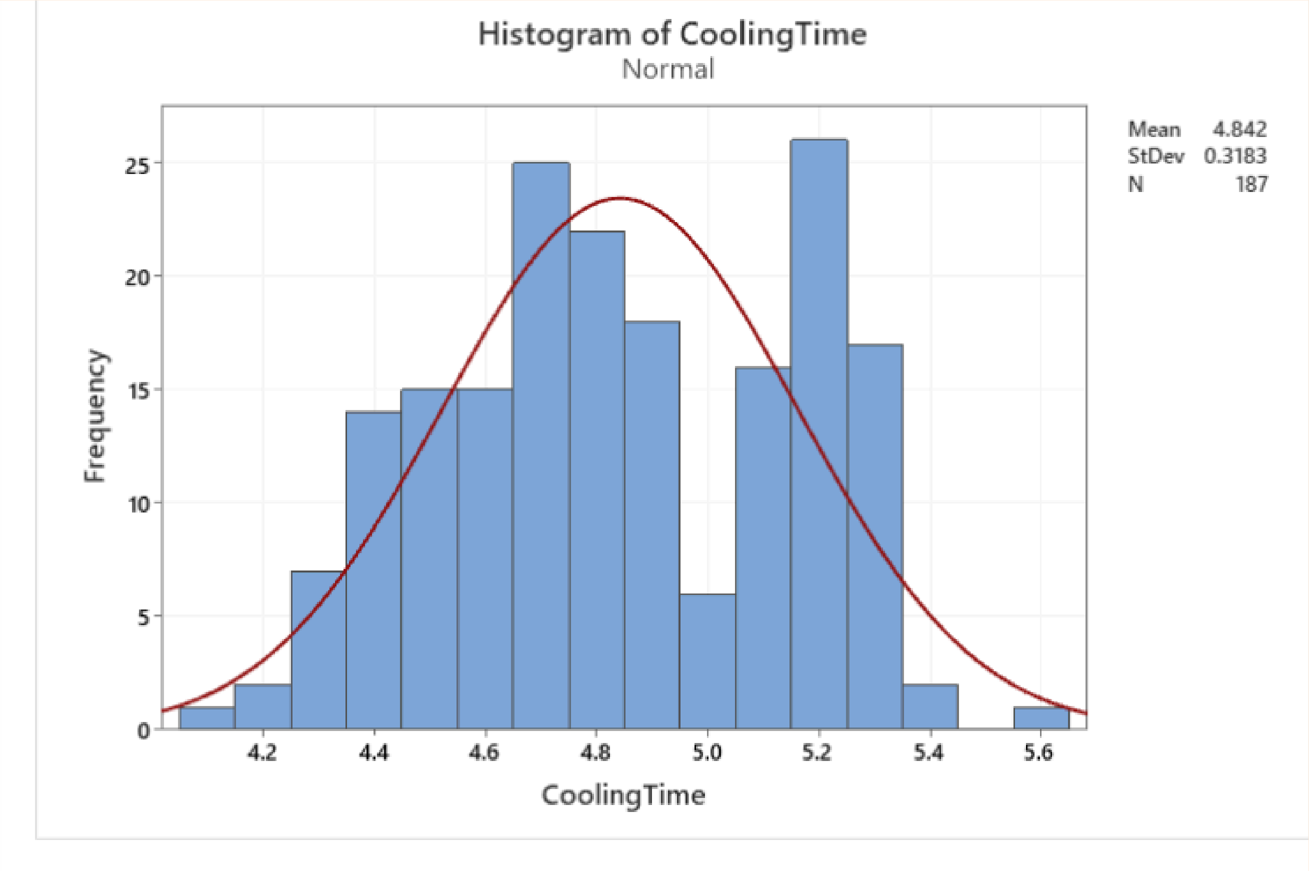
Variable	Mean	StDev	Variance	Median	Range	IQR	Percentage Deviation
Thickness	0.49107	0.05155	0.00266	0.4906	0.2392	0.0803	0.104974851
AirPressure	2.8529	0.1907	0.0364	2.897	0.866	0.303	0.066844264
MoldTemp	105.77	1.69	2.87	105.74	7.73	2.82	0.015978066
CoolingTime	4.842	0.3183	0.1013	4.818	1.49	0.547	0.065737299

BEFORE-IMPROVEMENT DATA ANALYSIS

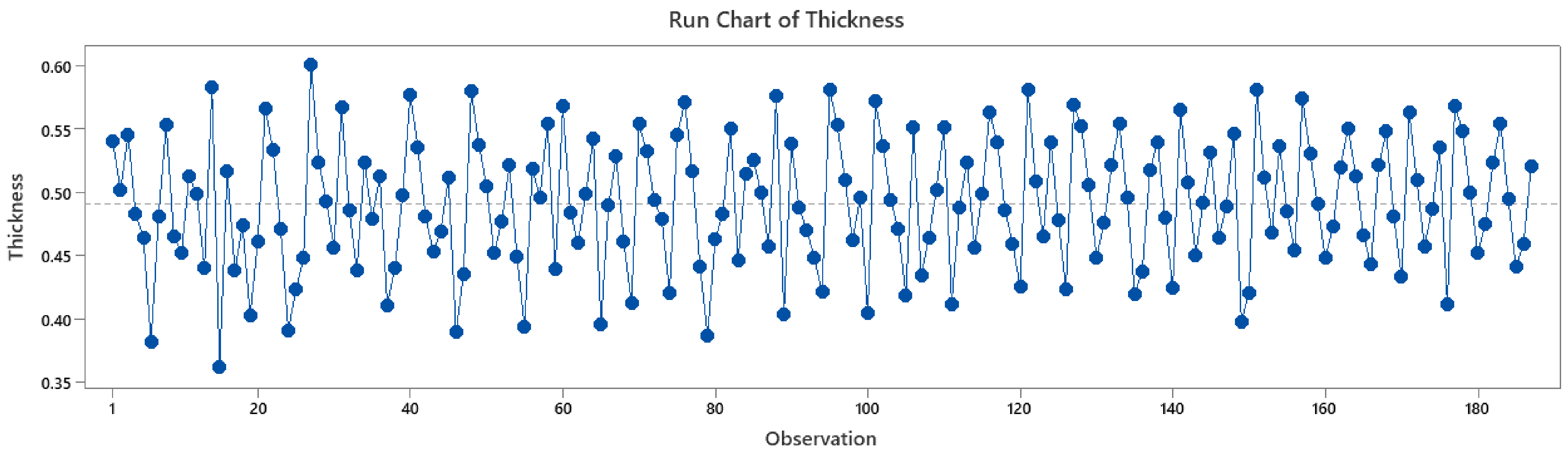




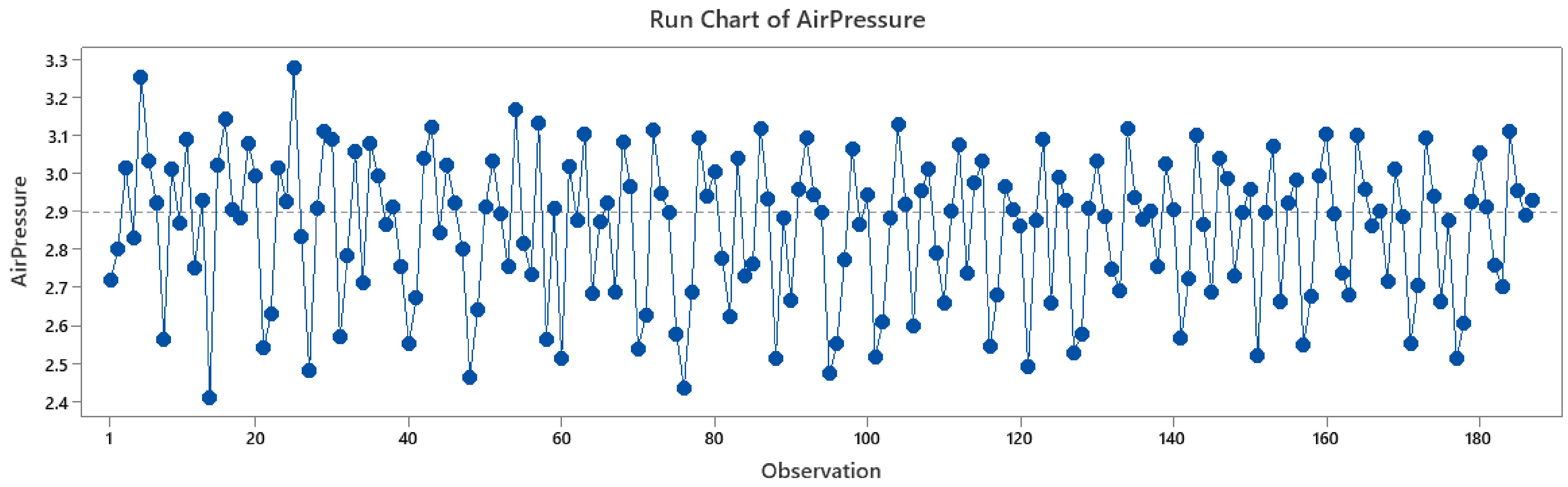




TO CHECK SPECIAL CAUSES IN THE PROCESS

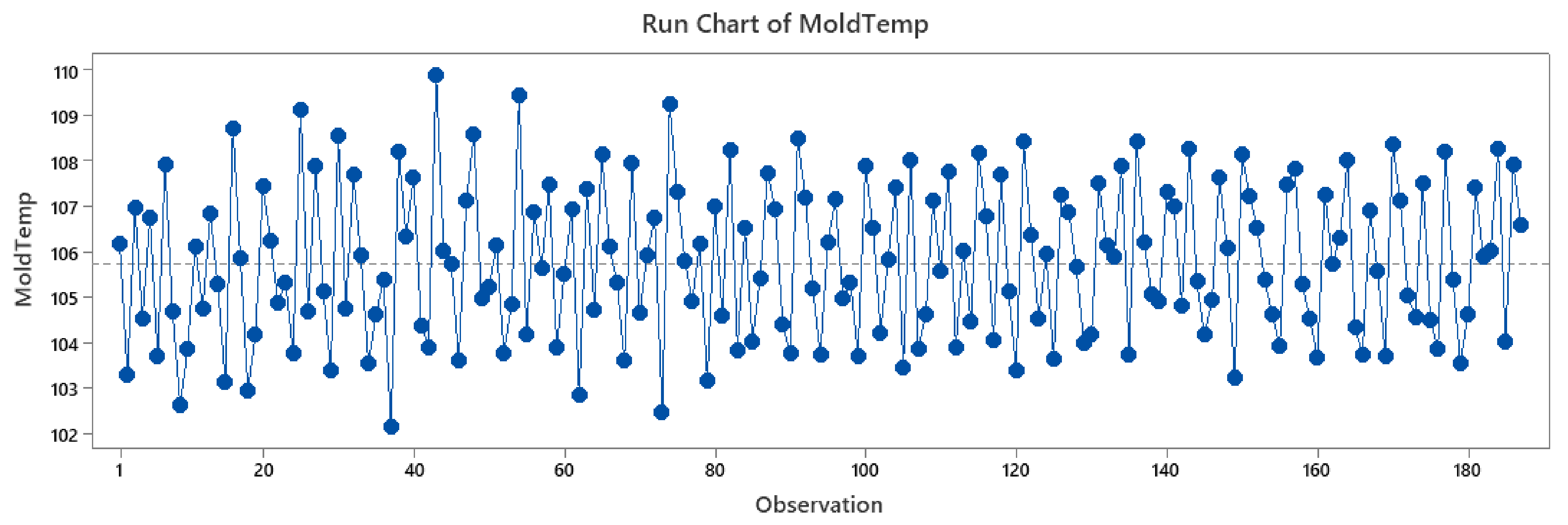


Number of runs about median:	97	Number of runs up or down:	102
Expected number of runs:	94.5	Expected number of runs:	124.3
Longest run about median:	4	Longest run up or down:	4
Approx P-Value for Clustering:	0.643	Approx P-Value for Trends:	0.000
Approx P-Value for Mixtures:	0.357	Approx P-Value for Oscillation:	1.000

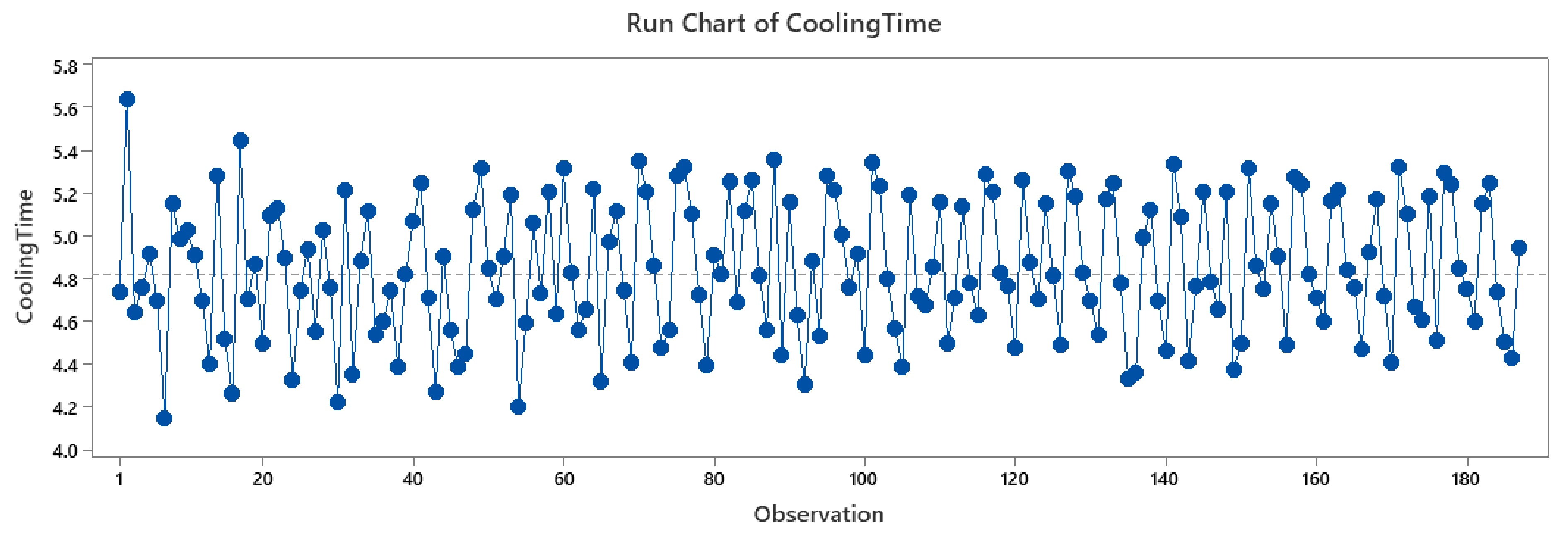


Number of runs about median:	106	Number of runs up or down:	113
Expected number of runs:	94.5	Expected number of runs:	124.3
Longest run about median:	4	Longest run up or down:	4
Approx P-Value for Clustering:	0.954	Approx P-Value for Trends:	0.024
Approx P-Value for Mixtures:	0.046	Approx P-Value for Oscillation:	0.976

BEFORE-IMPROVEMENT DATA ANALYSIS



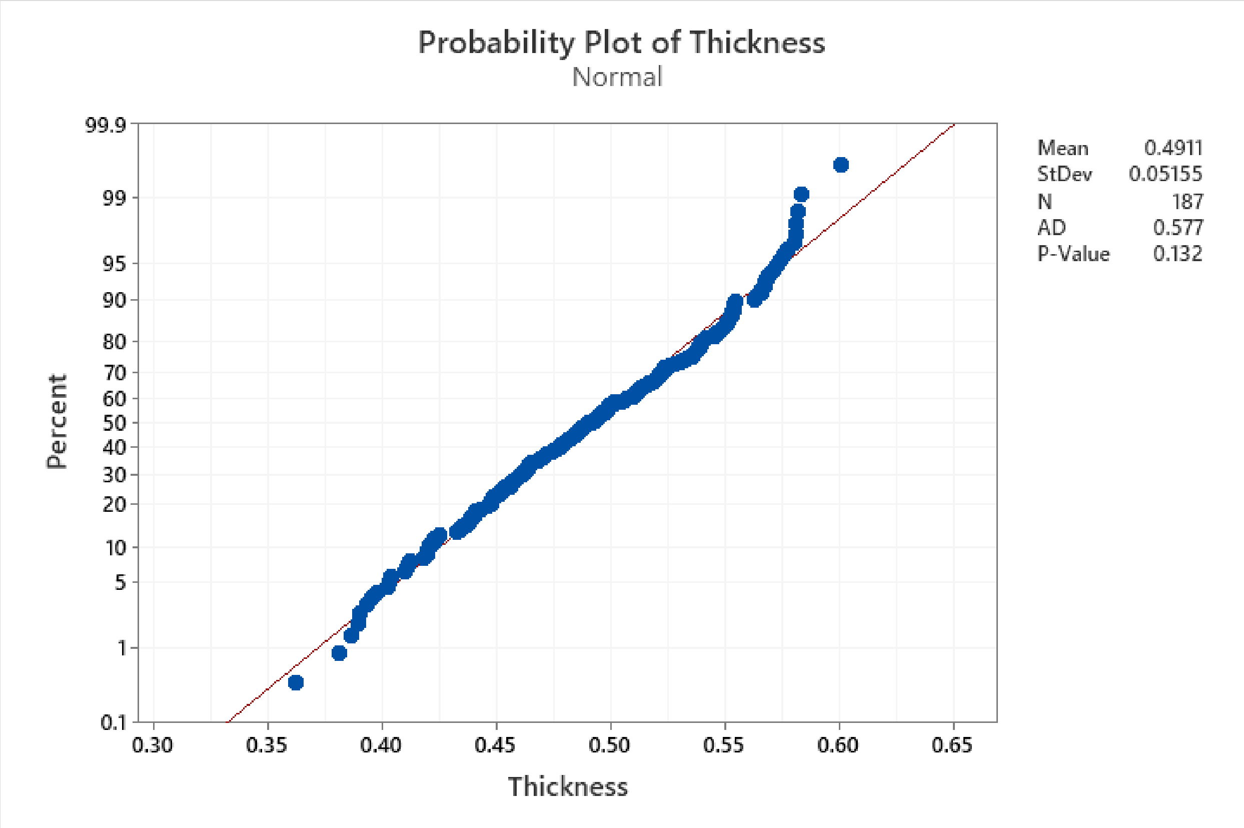
Number of runs about median:	115	Number of runs up or down:	127
Expected number of runs:	94.5	Expected number of runs:	124.3
Longest run about median:	4	Longest run up or down:	5
Approx P-Value for Clustering:	0.999	Approx P-Value for Trends:	0.679
Approx P-Value for Mixtures:	0.001	Approx P-Value for Oscillation:	0.321

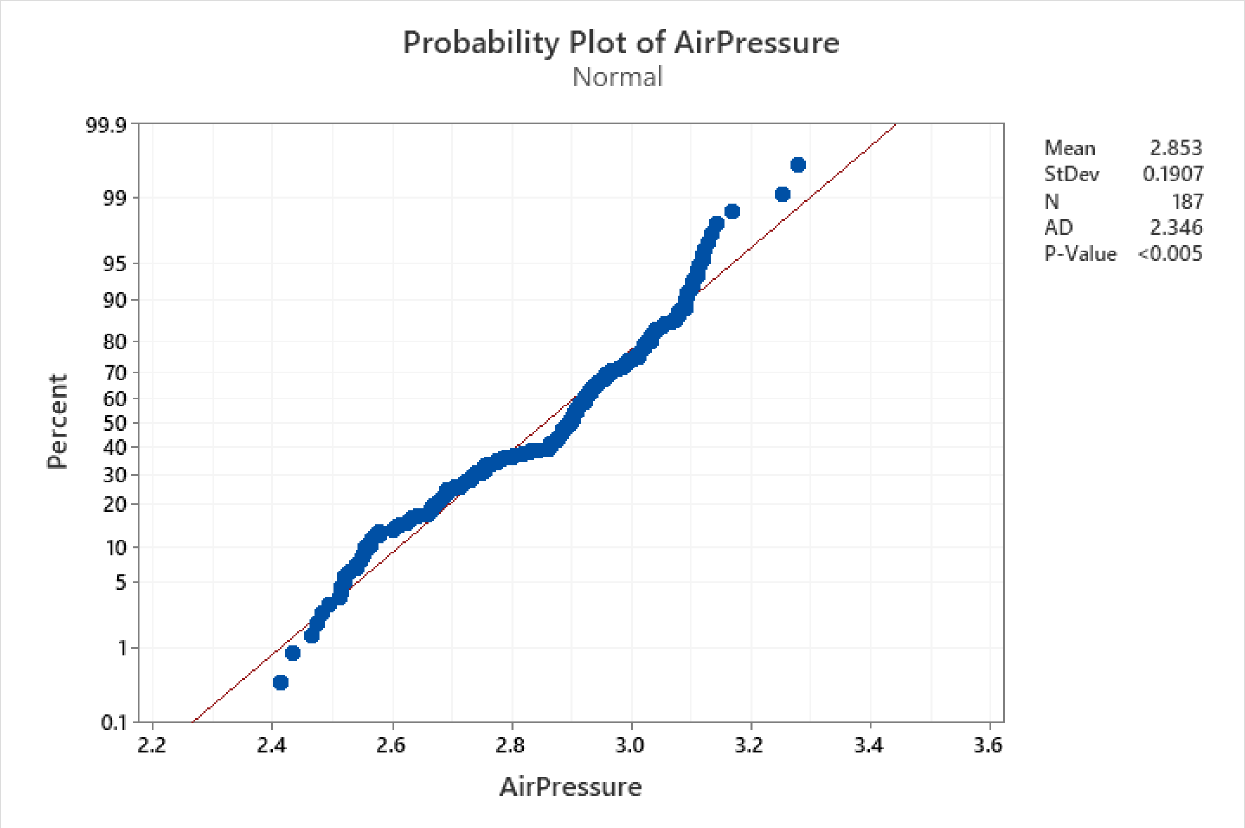


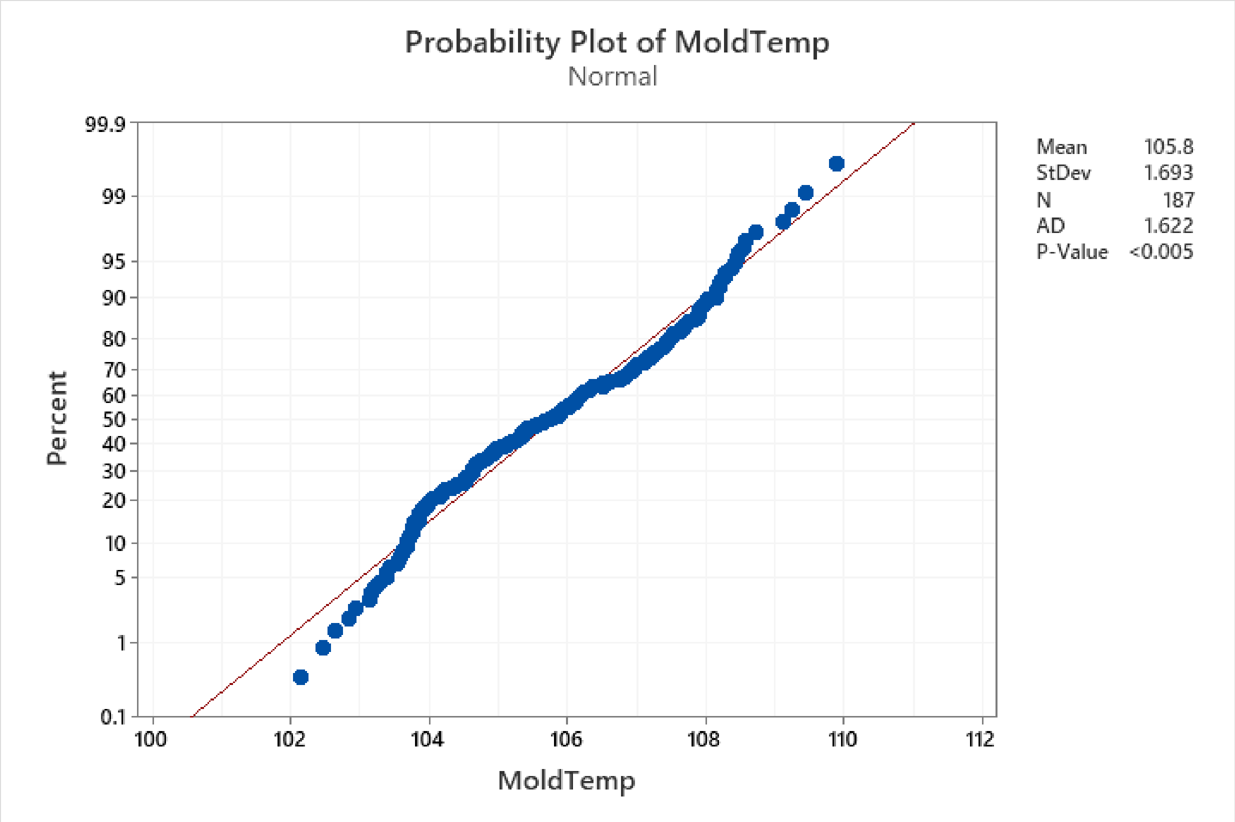
Number of runs about median:	106	Number of runs up or down:	109
Expected number of runs:	94.5	Expected number of runs:	124.3
Longest run about median:	4	Longest run up or down:	4
Approx P-Value for Clustering:	0.954	Approx P-Value for Trends:	0.004
Approx P-Value for Mixtures:	0.046	Approx P-Value for Oscillation:	0.996

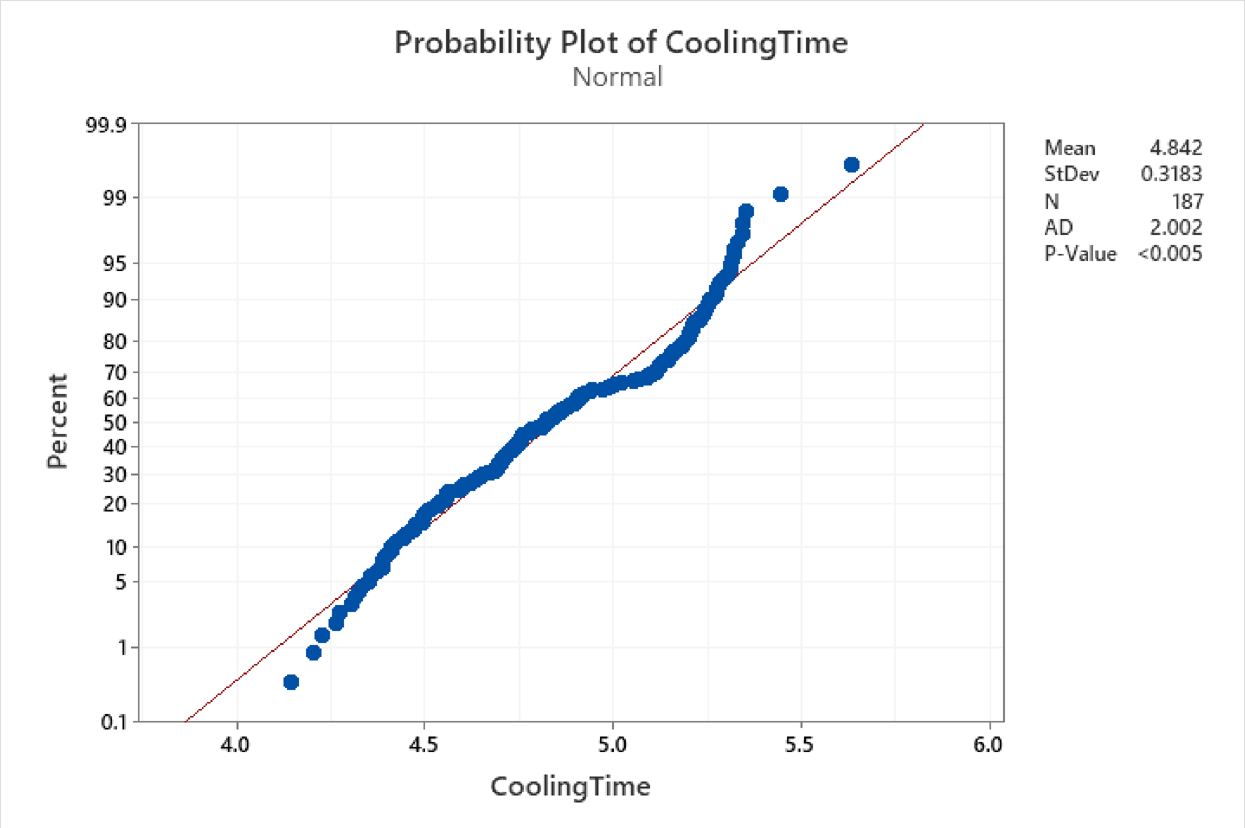
- P > 0.05 – No special causes in the process
- P < 0.05 – special causes are there in the process and the data cannot be used for the future analysis
- All data points should be randomly distributed in above and below line

DATA COLLECTION (NORMALITY PLOT)





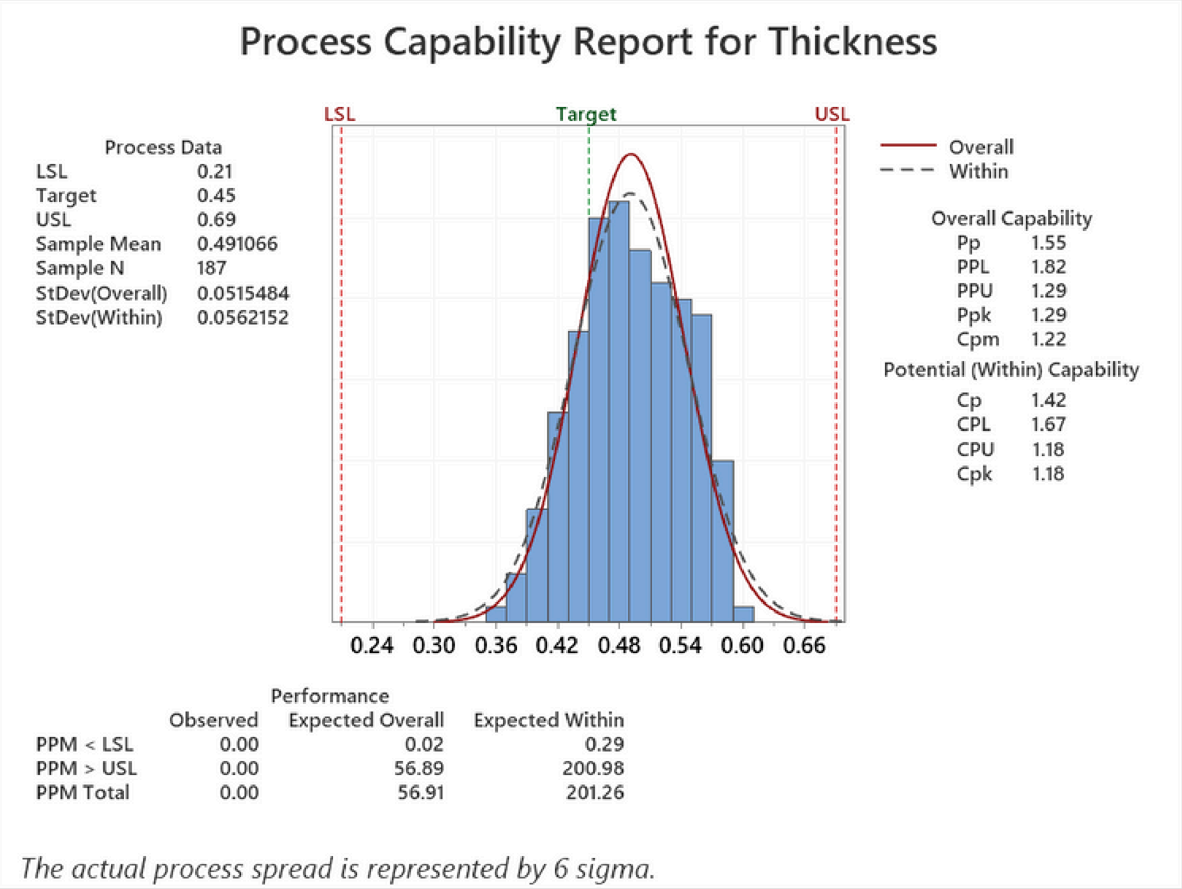


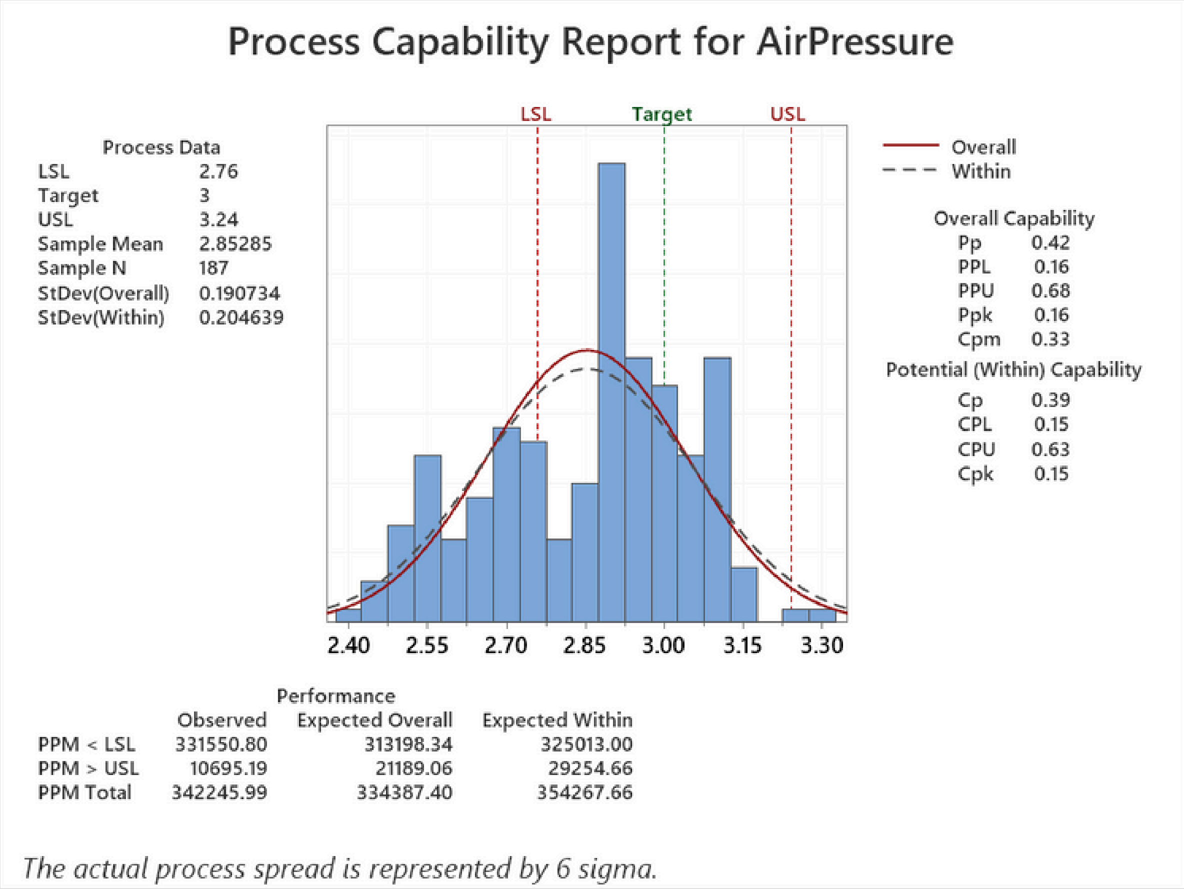


Inference :

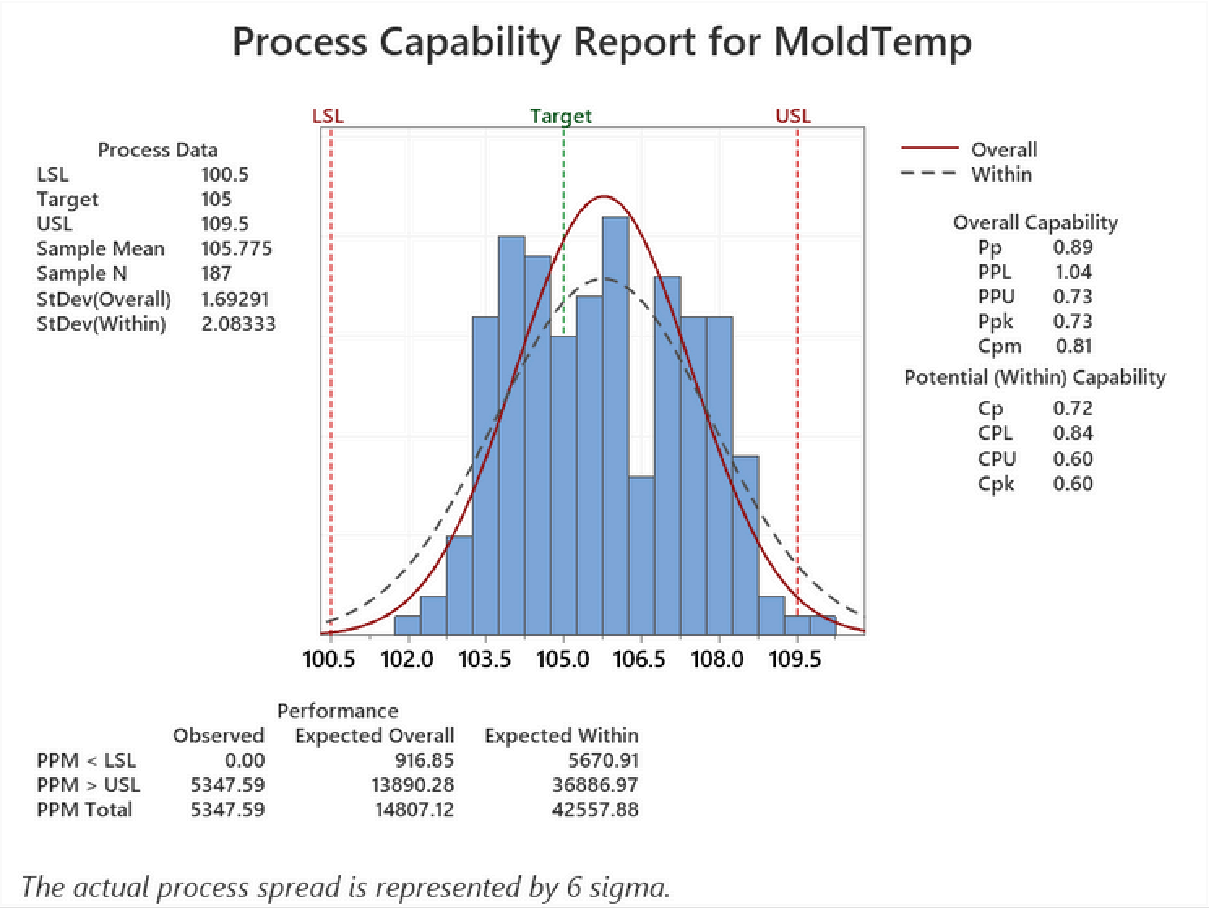
P > 0.05 in all oven thus all the data is normally distributed

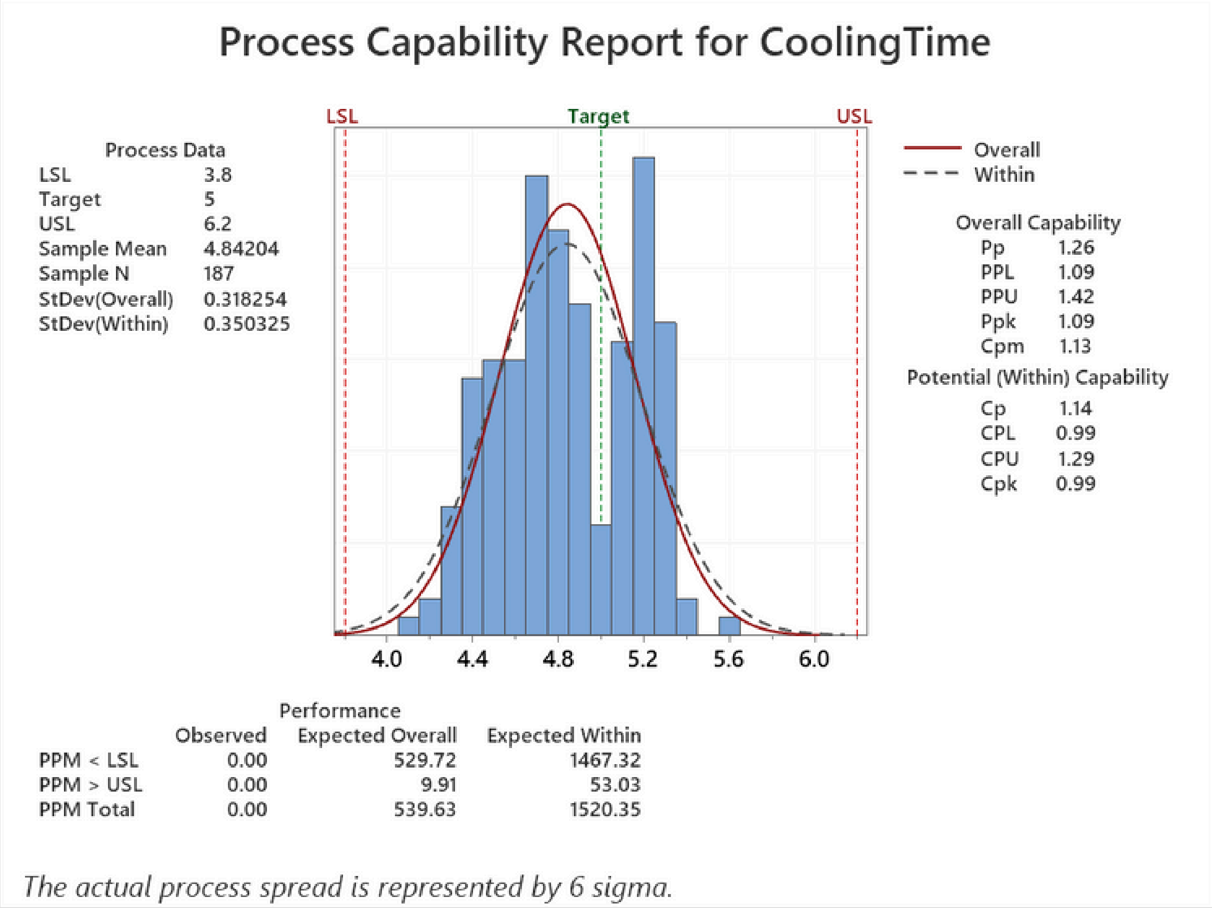
DATA COLLECTION PROCESS CAPABILITY (BEFORE IMPROVEMENT)





Parameter	Nominal Value	Allowed Variation (±3σ)	LSL	USL
Thickness (mm)	**0.45 mm**	±0.24 mm	0.21	0.69
Air Pressure (bar)	**3.00 bar**	±0.24 bar	2.76	3.24
Mold Temperature (°C)	**105°C**	±4.5°C	100.5	109.5
Cooling Time (s)	**5.0 s**	±1.2 s	3.8	6.2





Air Pressure: Cpk value is very less in comparison to other factors and most of the collected data is near to upper specified limit, which indicates Air Pressure needs improvement.

ANALYZE

REGRESSION ANALYSIS

WORKSHEET 5

Regression Analysis: AirPressure versus CompressorTemp, ValveOpening, FilterClogIndex

Backward Elimination of Terms

α to remove = 0.05

Regression Equation

AirPressure = 2.8750 - 0.01982 CompressorTemp + 0.013883 ValveOpening

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	2.8750	0.0528	54.50	0.000	
CompressorTemp	-0.01982	0.00104	-19.11	0.000	1.19
ValveOpening	0.013883	0.000425	32.66	0.000	1.19

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0107416	99.37%	99.19%	98.54%

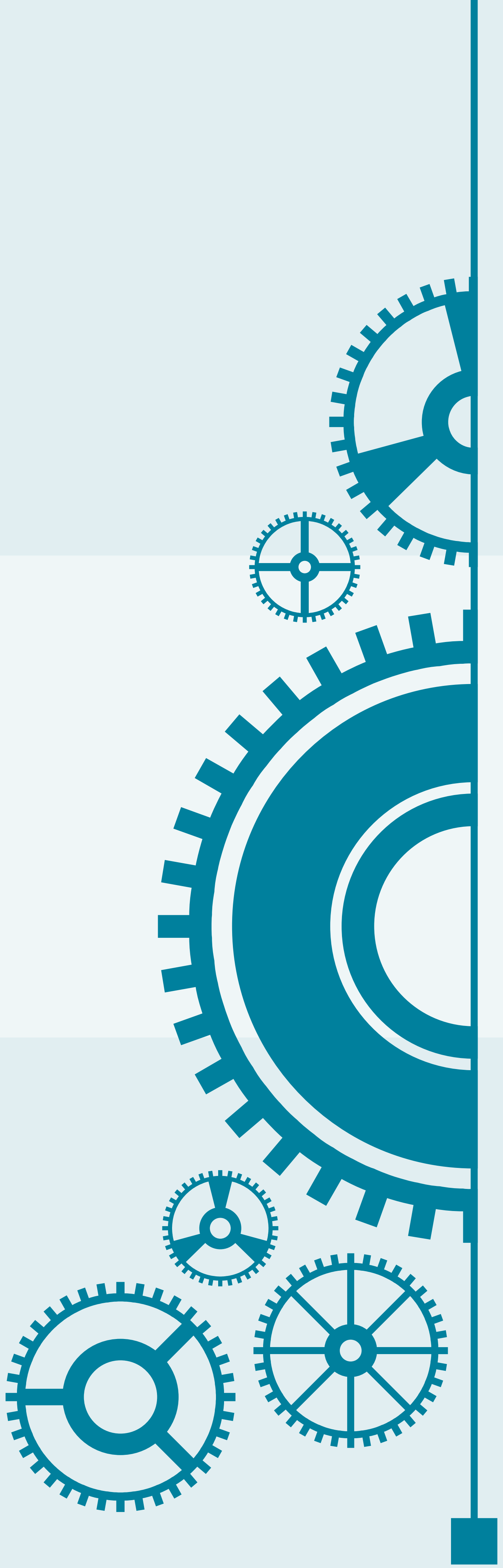
Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	2	0.127928	0.063964	554.37	0.000
CompressorTemp	1	0.042154	0.042154	365.34	0.000
ValveOpening	1	0.123043	0.123043	1066.39	0.000
Error	7	0.000808	0.000115		
Total	9	0.128736			

CompressorTemp	ValveOpening	FilterClogIndex	AirPressure
50	70	0.12	2.86
52	65	0.55	2.74
55	80	0.33	2.885
58	75	0.8	2.775
60	85	0.05	2.855
49	60	0.27	2.735
53	90	0.69	3.085
57	72	0.44	2.76
59	68	0.11	2.65
54	78	0.9	2.878

Compressor Temperature and Valve opening are critically important for Air Pressure

IMPROVE



DESIGN OF EXPERIMENT

StdOrder	RunOrder	CenterPt	Blocks	CompressorTemp	ValveOpening (%)	Air Pressure
3	1	1	1	-1	-1	2.5
5	2	0	1	0	0	2.85
6	3	0	1	0	0	2.89
4	4	1	1	1	1	3.1
1	5	1	1	-1	1	2.65
2	6	1	1	1	-1	3.2
7	7	1	1	1	-1	3.18
8	8	1	1	-1	1	2.68
9	9	0	1	0	0	2.84
10	10	1	1	-1	-1	2.55

Regression Equation in Uncoded Units

Air Pressure (Bar) = 2.86681 + 0.27436 CompressorTemp (∘C) + 0.01186 ValveOpening (%) - 0.05814 CompressorTemp (∘C)*ValveOpening (%)

Alias Structure

Factor	Name
A	CompressorTemp (∘C)
B	ValveOpening (%)

Aliases

I
A
B
AB

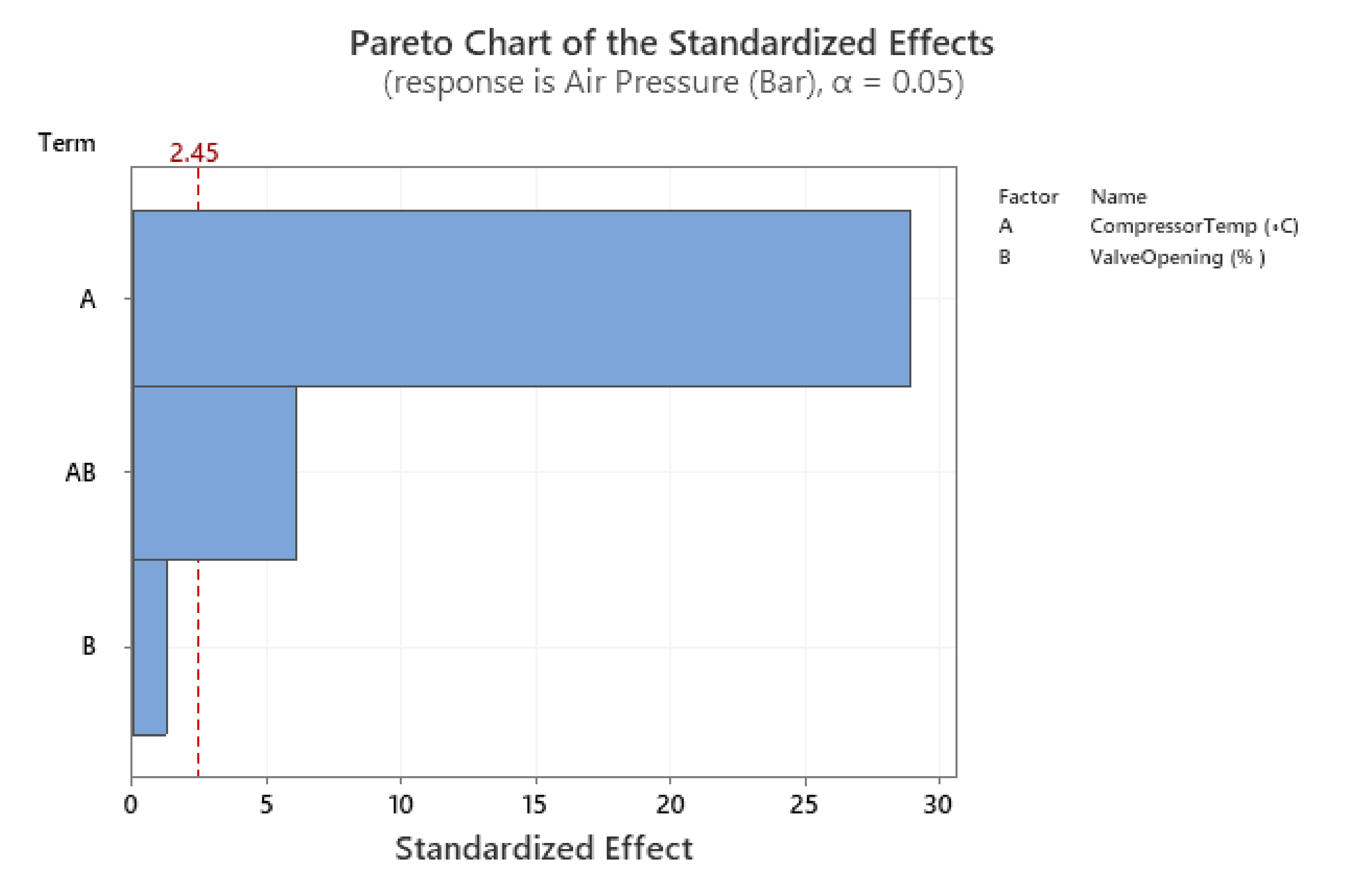
Factorial Regression: Air Pressure (Bar) versus CompressorTemp (∘C), ValveOpening (%)

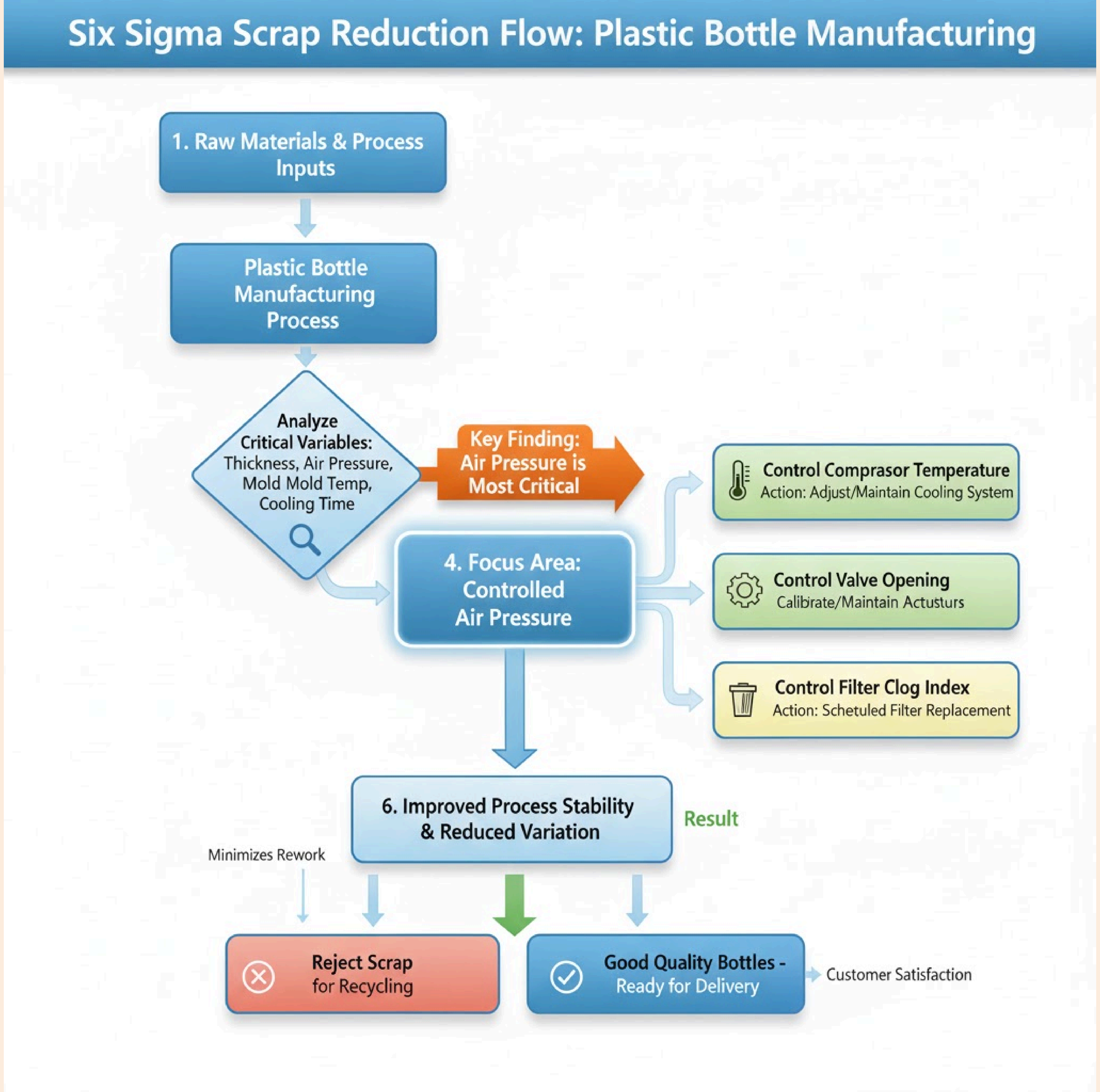
Coded Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		2.86681	0.00788	363.70	0.000	
CompressorTemp (∘C)	0.54872	0.27436	0.00949	28.91	0.000	1.06
ValveOpening (%)	0.02372	0.01186	0.00949	1.25	0.258	1.06
CompressorTemp (∘C)*ValveOpening (%)	-0.11628	-0.05814	0.00949	-6.13	0.001	1.06

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0241670	99.39%	99.09%	98.20%



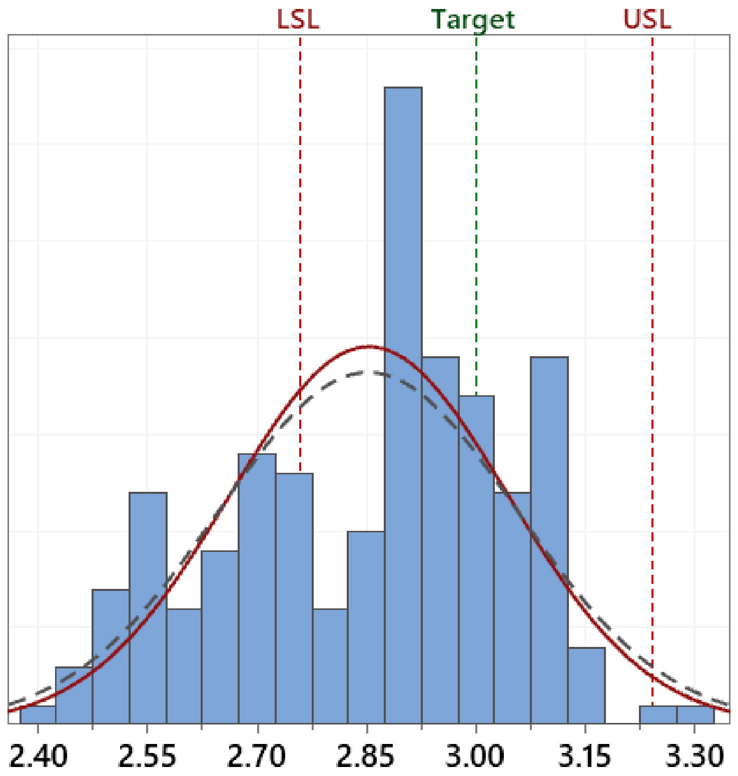

Six Sigma Scrap Reduction Flow: Plastic Bottle Manufacturing
1. Raw Materials & Process Inputs
Plastic Bottle Manufacturing Process
Analyze Critical Variables: Thickness, Air Pressure, Mold Mold Temp, Cooling Time
Key Finding: Air Pressure is Most Critical
4. Focus Area: Controlled Air Pressure
Control Comprasor Temperature
Action: Adjust/Maintain Cooling System
Control Valve Opening
Calibrate/Maintain Actusturs
Control Filter Clog Index
Action: Schetuled Filter Replacement
6. Improved Process Stability & Reduced Variation
Result
Minimizes Rework
Reject Scrap for Recycling
Good Quality Bottles - Ready for Delivery
Customer Satisfaction

IMPROVE – PROCESS CAPABILITY – BEFORE & AFTER IMPROVEMENT

Process Capability Report for AirPressure

Process Data

LSL	2.76
Target	3
USL	3.24
Sample Mean	2.85285
Sample N	187
StDev(Overall)	0.190734
StDev(Within)	0.204639



Overall
Within

Overall Capability

Pp	0.42
PPL	0.16
PPU	0.68
Ppk	0.16
Cpm	0.33

Potential (Within) Capability

Cp	0.39
CPL	0.15
CPU	0.63
Cpk	0.15

Performance

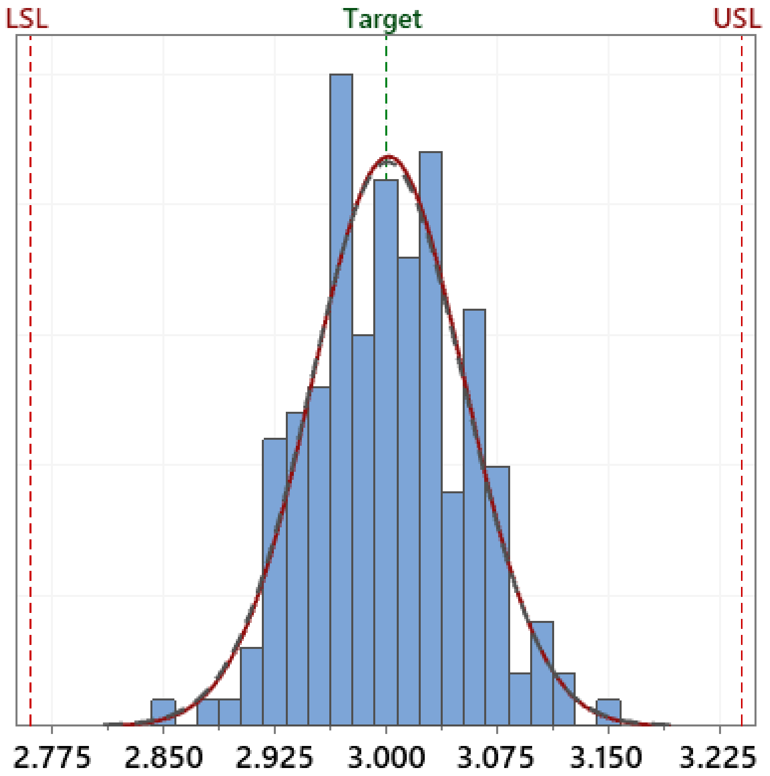
	Observed	Expected Overall	Expected Within
PPM < LSL	331550.80	313198.34	325013.00
PPM > USL	10695.19	21189.06	29254.66
PPM Total	342245.99	334387.40	354267.66

The actual process spread is represented by 6 sigma.

Process Capability Report for Air Pressure (Bar) - After Impr

Process Data

LSL	2.76
Target	3
USL	3.24
Sample Mean	3.00164
Sample N	187
StDev(Overall)	0.0511947
StDev(Within)	0.0516282



Overall
Within

Overall Capability

Pp	1.56
PPL	1.57
PPU	1.55
Ppk	1.55
Cpm	1.57

Potential (Within) Capability

Cp	1.55
CPL	1.56
CPU	1.54
Cpk	1.54

Performance

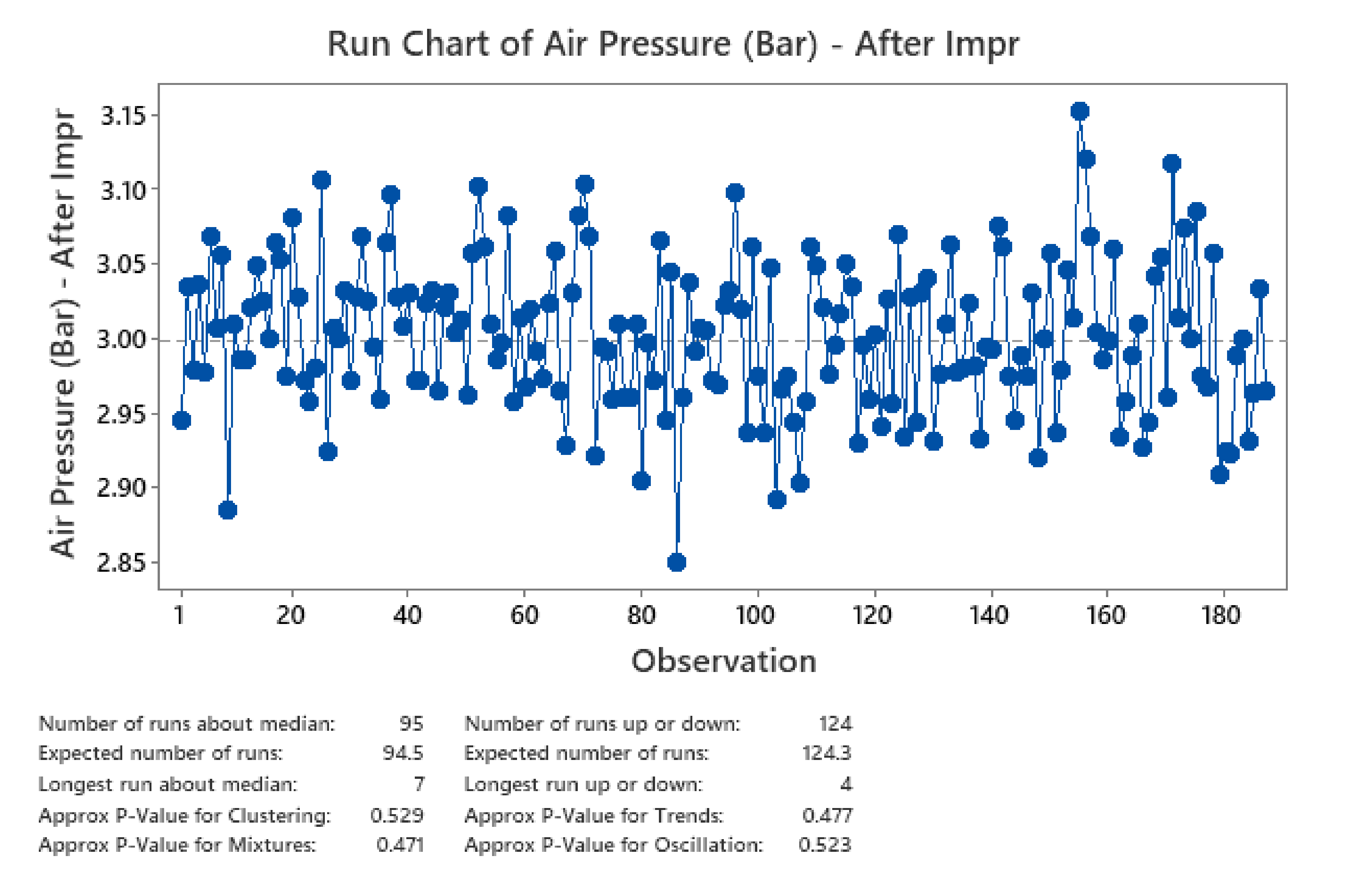
	Observed	Expected Overall	Expected Within
PPM < LSL	0.00	1.18	1.43
PPM > USL	0.00	1.61	1.95
PPM Total	0.00	2.79	3.38

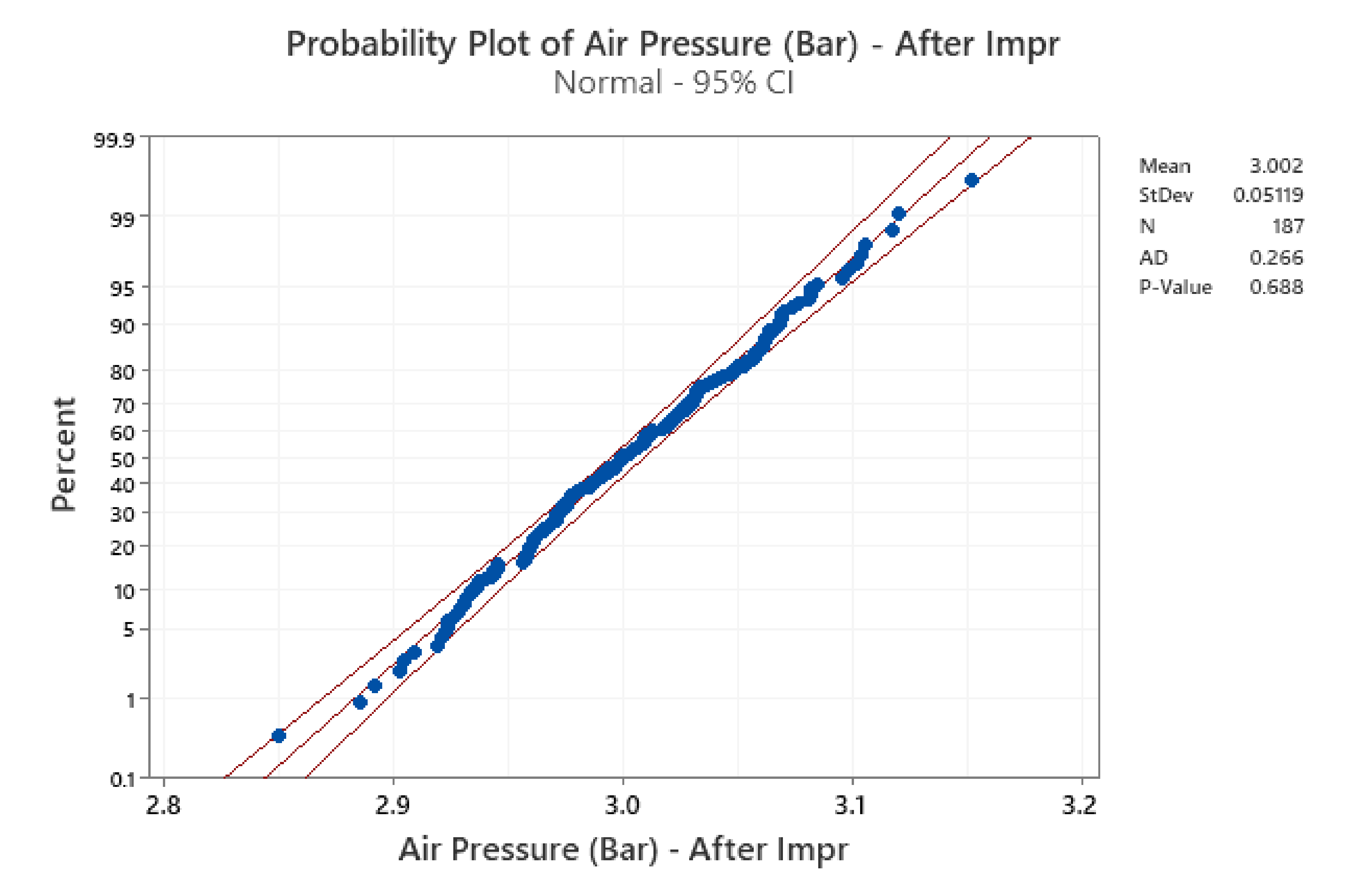
The actual process spread is represented by 6 sigma.

Inference :

- Before Cpk < After Cpk, which shows process is much more capable after improvement
- There is less variability in system since stdev reduced after improvement
- After improvement the data are normally distributed near the target within specified limit

IMPROVE – RUN CHART AND NORMALITY TEST (AFTER IMPROVEMENT)





Inference:

- Run chart – process is stable there is no special causes in the process (p value > 0.05)

Inference:

- Normality test – Data are normally distribut ed

TWO-SAMPLE T-TEST

WORKSHEET 11

Two-Sample T-Test and CI: AirPressure before, AirPressure after

Method

μ_1: population mean of AirPressure before
μ_2: population mean of AirPressure after
Difference: $\mu_1 - \mu_2$

Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
AirPressure before	187	2.853	0.191	0.014
AirPressure after	187	3.0016	0.0512	0.0037

Estimation for Difference

Difference	95% CI for Difference
-0.1488	(-0.1773, -0.1203)

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
-10.30	212	0.000

Inference:

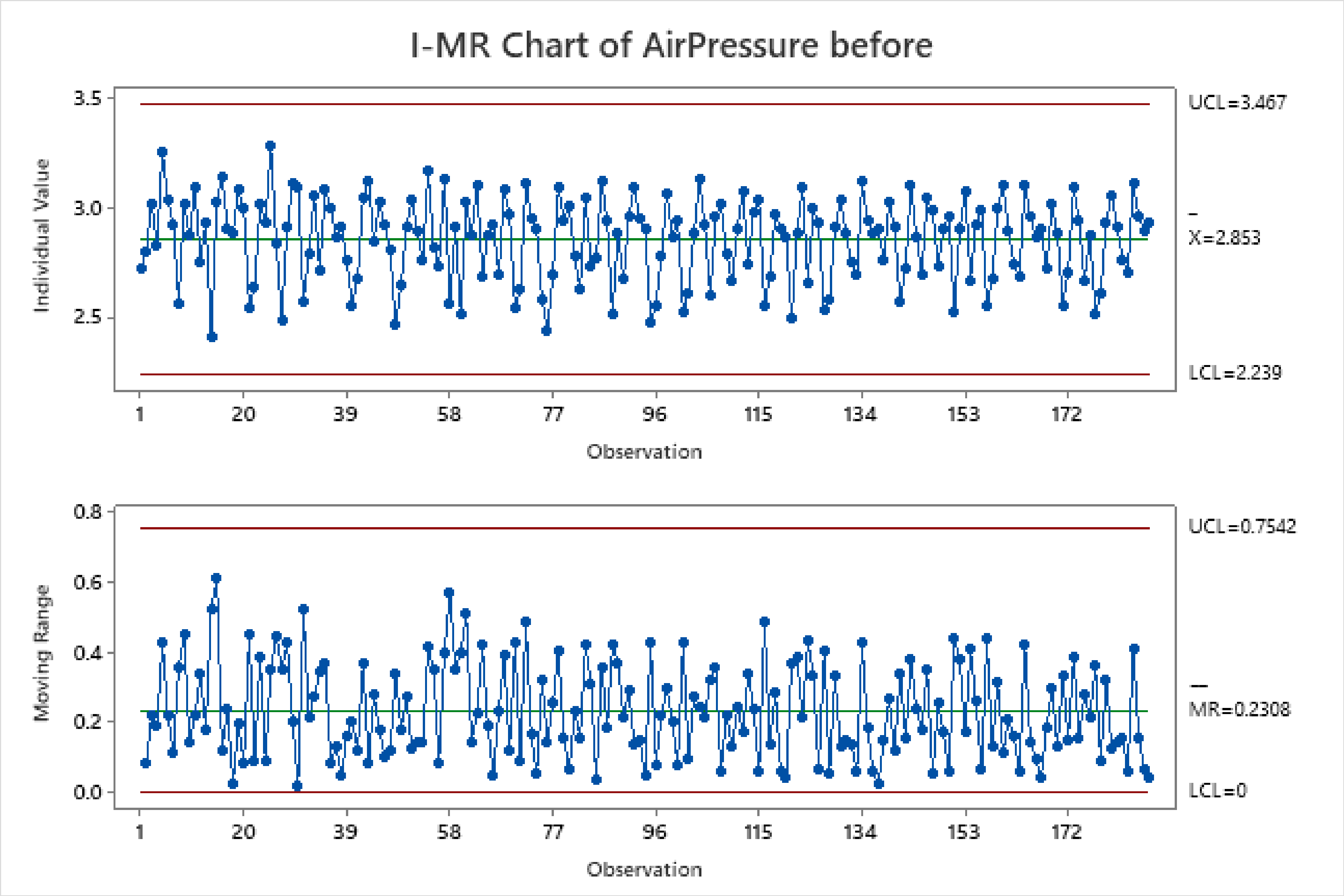
•Since P value is less than 0.05, there is enough evidence to reject the null hypothesis and we can conclude that the difference between the population means is statistically significant.

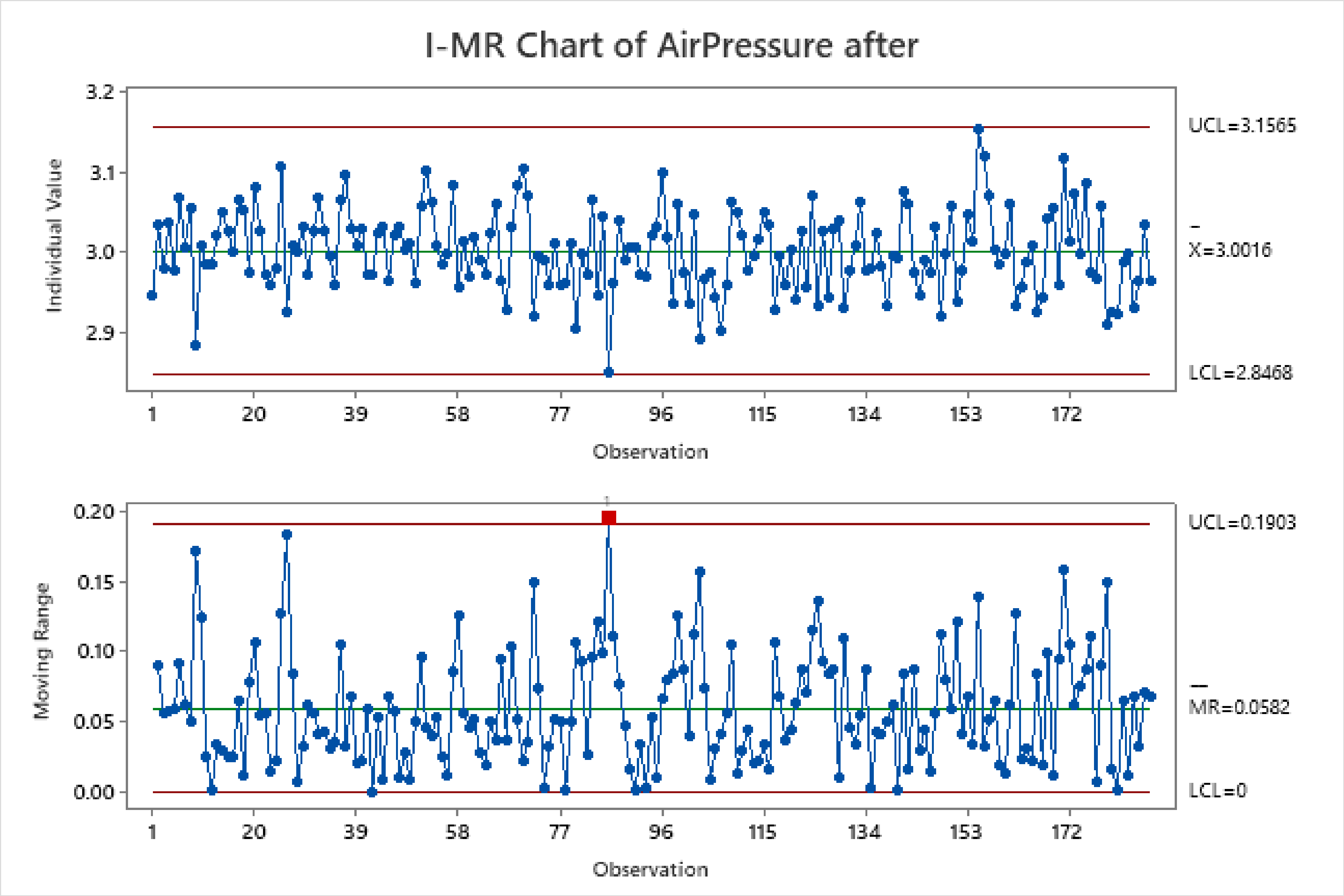
- **H0**: There is no significant difference between the mean blow air pressure before and after improvement
- **H1**: There is a significant difference between the mean blow air pressure before and after improvement.

$p < 0.05$ → reject H0

- Air pressure is statistically validated as critical root cause.
- The 2-Sample t-Test confirmed that the improvement actions caused a statistically meaningful change in the air pressure

IMPROVE (STATISTICAL VALIDATION FOR IMPROVEMENT – I-MR CHART)





Inference:

- As seen in control chart, before improvement mean was high and there was high variability in the Air Pressure and after improvement, it has achieved to target Air pressure and less variability.
- There is a significant reduction in variation in Air pressure.

PROPOSED ACTIONS & CONTROL PLAN

Proposed Actions

- Replaced faulty air pressure regulator
- Installed digital pressure sensors with alarms
- Fixed leakage at joints & valves
- Added moisture trap to airline
- Standardized air pressure setting sheet
- Introduced hourly compressor output monitoring
- Applied preventive maintenance checklist

CONTROL PLAN

- Digital pressure monitoring
- Alarm at ±0.1 bar deviation
- Daily moisture trap draining
- Weekly valve leakage audit
- Monthly regulator calibration
- Standard operating procedure updated
- Operator training & certification

FMEA FAILURE MODE AND EFFECTS ANALYSIS

Item: Blow Molding Machine
Model: Current
Core Team: ABC (Engineering), DEF (Production), GHI (Quality)

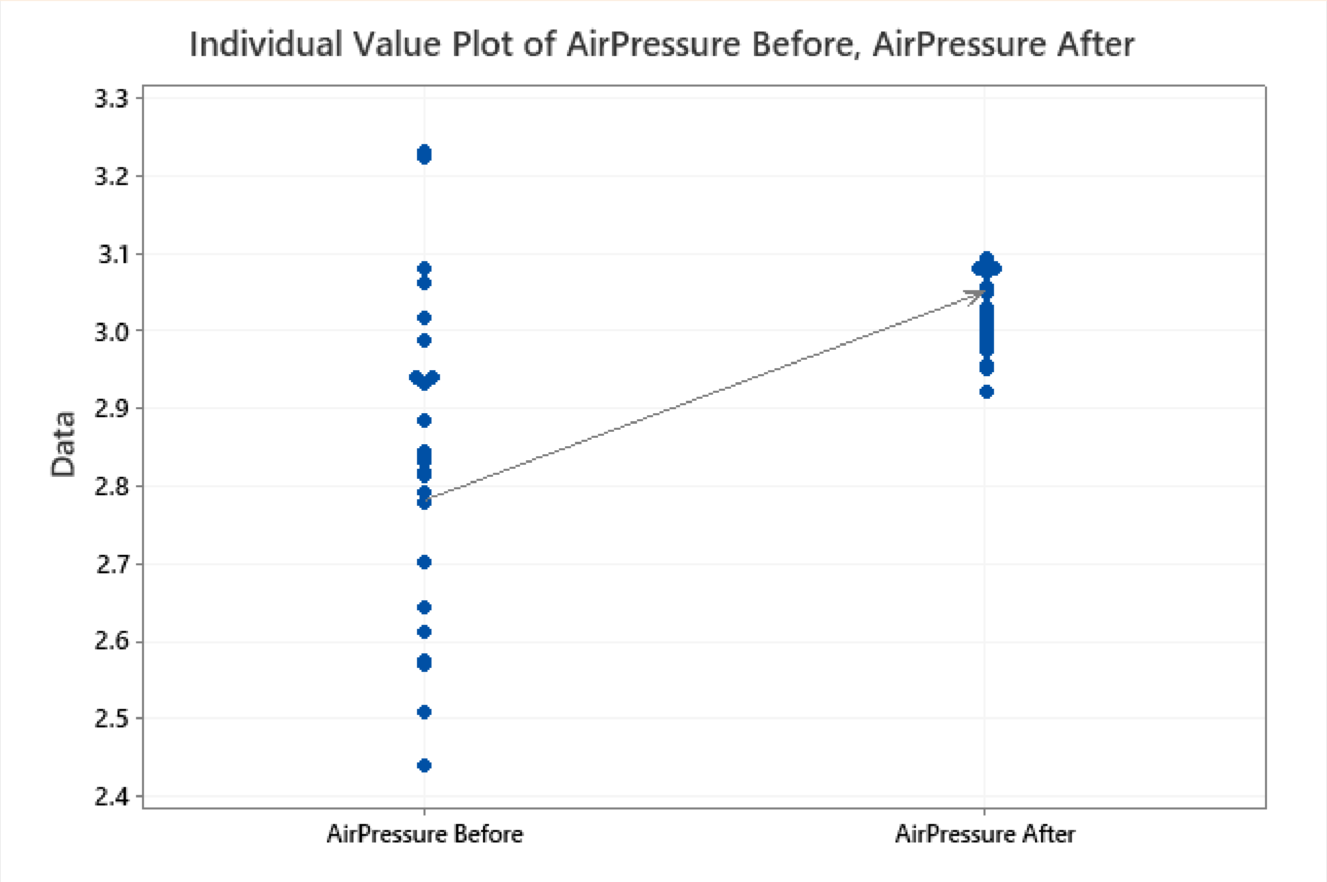
Responsibility: Mr. XYZ
Prepared by: Mr. XYZ

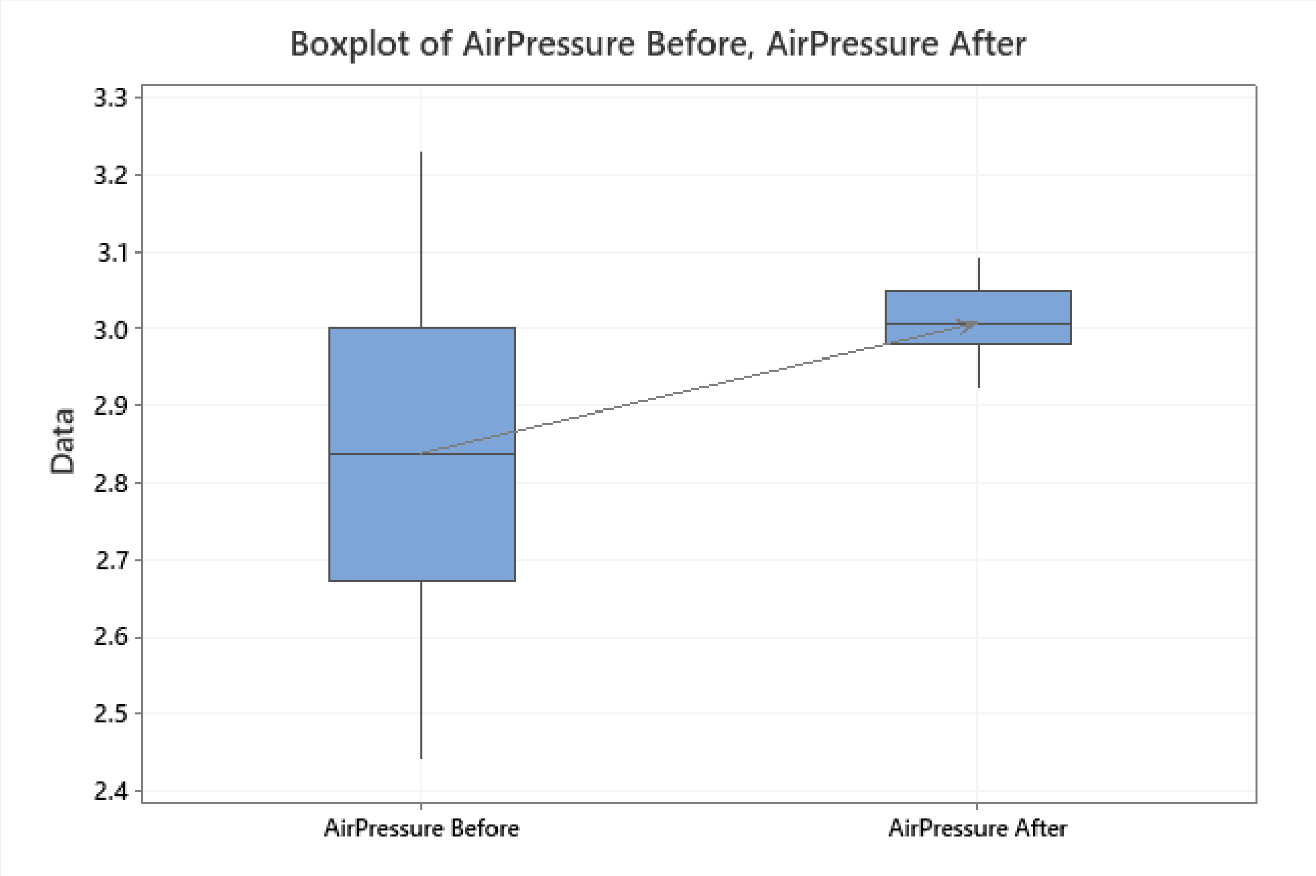
FMEA Number: BM-001
Page: 1 of 1
FMEA Date (Orig): 10/02/2025
Rev.: 1

Process Function	Potential Failure Mode	Potential Effect(s) of Failure	S (Sev)	C (Class)	Potential Cause(s) / Mechanism(s) of Failure	O (Occur)	Current Process Controls	D (Detect)	RPN	Recommended Action(s)	Responsibility & Target Completion Date	Action Results – Actions Taken	S	O	D	RPN
Bottle Blow Molding	**Incorrect Air Pressure (High)**	Thin walls → Bottle deformation → Leakage complaint	7	N/A	Regulator drift / valve wear / sensor miscalibration	6	Pressure gauge reading, shift check	6	**252**	1. Calibrate pressure regulator 2. Install pressure alarm for USL exceedance	XYZ / 15/02/2025	Regulator recalibrated & alarm enabled	5	3	4	**60**
Bottle Blow Molding	**Incorrect Air Pressure (Low)**	Thick walls → Overweight bottle → Scrap increase	6	N/A	Compressor fluctuation / clogged filter	5	Manual pressure monitoring	6	**180**	Replace air filter, stabilize compressor output	XYZ / 15/02/2025	Filter replaced & compressor serviced	4	3	4	**48**
Bottle Forming	**Uneven Wall Thickness**	High rejection rate; dimensional variability	8	N/A	Incorrect mold temp / improper cooling time / inconsistent air pressure	7	Hourly QC check, mold temp monitor	5	**280**	1. Optimize mold temp 2. Automate cooling time control	ABC / 18/02/2025	Mold temp standardized, cooling auto-set	6	3	4	**72**
Blow Heating Zone	**Incorrect Mold Temperature**	Bubbles, deformities, weak structure	7	N/A	Chiller variation, heater malfunction	5	Temp gauge; operator checks	5	**175**	Install auto-shutdown for temp deviation	GHI / 20/02/2025	Auto-shutdown active	5	3	3	**45**
Cooling System	**Cooling Time Too Short**	Warped bottles; soft structure	6	N/A	Timer malfunction; operator override	5	Manual timer logging	6	**180**	Replace timer + restrict manual override	DEF / 22/02/2025	Timer replaced & override locked	4	3	4	**48**
Cooling System	**Cooling Time Too Long**	Slow cycle → Low productivity	4	N/A	Cooling valve sticking; delay in cycle reset	4	Cycle time checks	5	**80**	Service cooling valve	DEF / 22/02/2025	Valve serviced	3	2	4	**24**

CONTROL

IMPROVE –AFTER IMPROVEMENT (STATISTICAL VALIDATION FOR IMPROVEMENT – HYPOTHESIS TESTING)

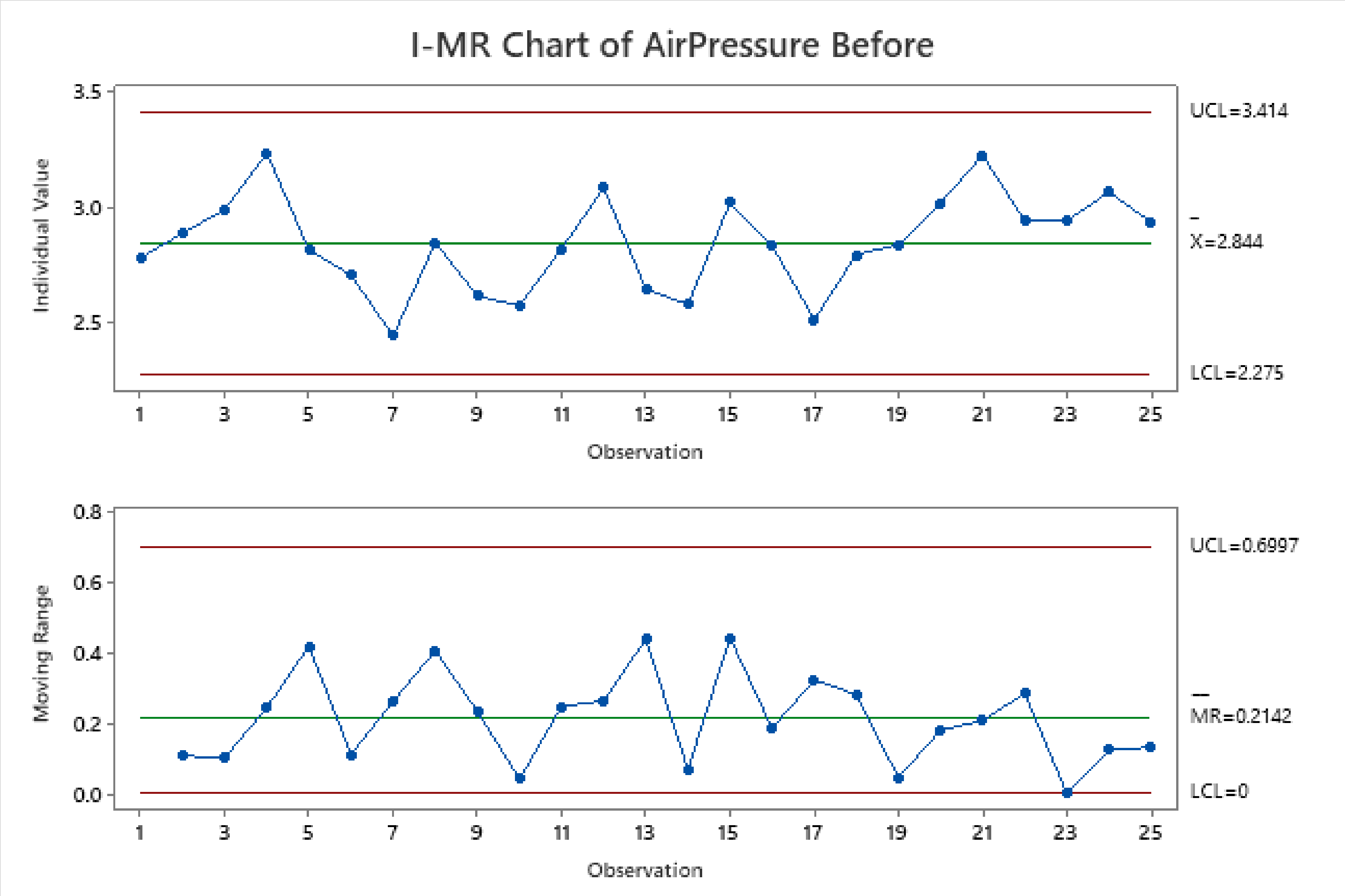


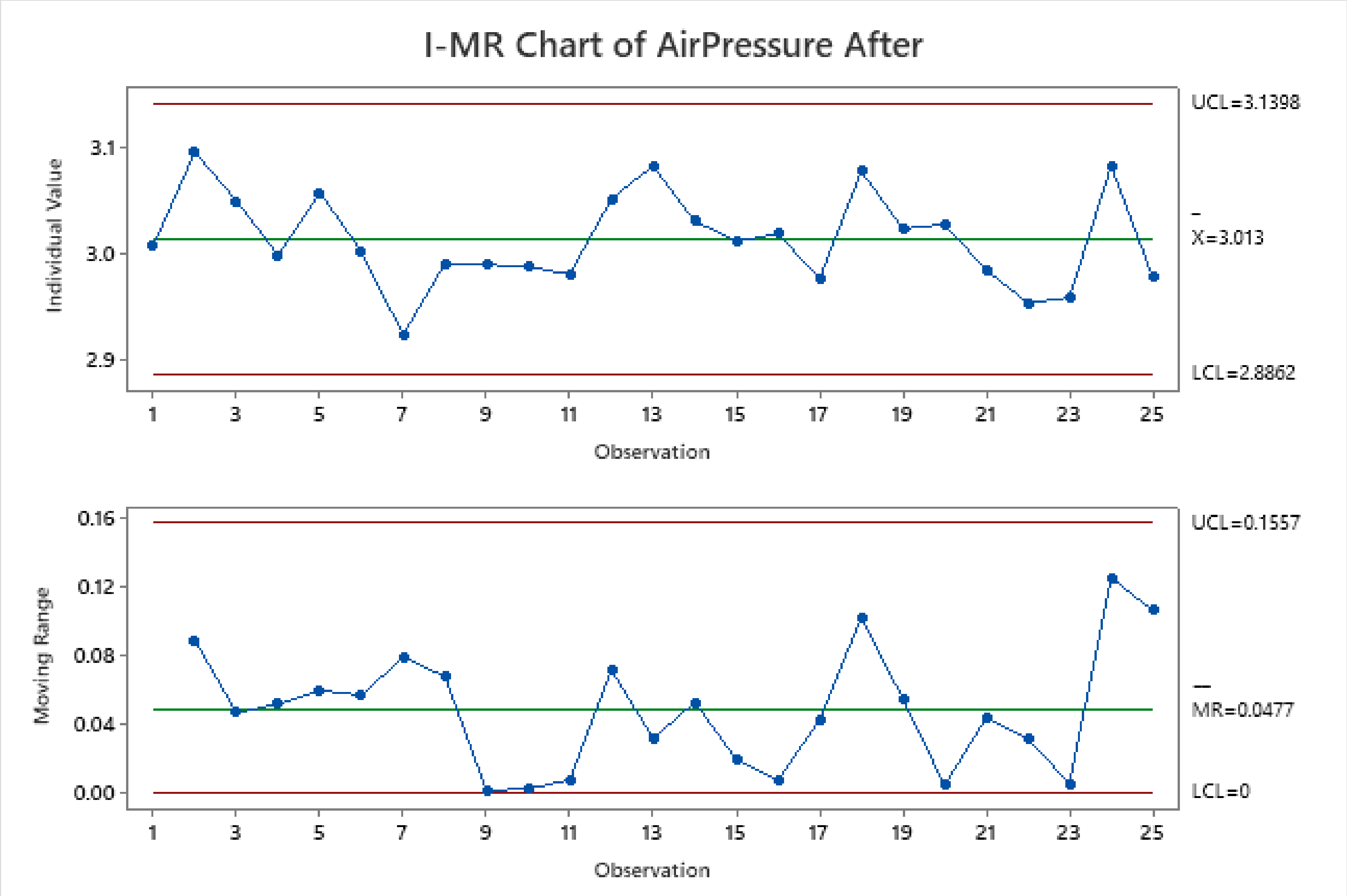


Inference:

- Since P value is less than 0.05, there is enough evidence to reject the null hypothesis and we can conclude that the difference between the population means is statistically significant.
- It is also visible from the individual value plot & box plot, there is clear difference in mean after improvement which is closer to required Air Pressure (3 Bars)

IMR CHARTS





- **The reduction in the difference between the Upper Control Limit (UCL) and Lower Control Limit (LCL), coupled with the shift in the Center Line, confirms the significant success of the process improvement project, driven by optimizing Compressor Temperature and Valve Opening.**

MEASURES

1. Improving Compressor Temperature Control (Coping with Heat)

The goal is to maintain the optimal temperature setpoint by stabilizing the cooling system.

- Upgrade Cooling System: Ensure the compressor's cooling circuit is robust, clean, and properly sized.
- PID Control: Implement a high-precision PID controller to constantly monitor the temperature and immediately adjust the cooling rate (e.g., chiller or fan speed) to correct any drift.
- Insulation & Environment: Insulate critical components and ensure the compressor area has stable, adequate ventilation to minimize external thermal influence.

2. Improving Valve Opening Control (Position Repeatability)

The goal is to ensure the valve position is always exact, minimizing flow variability.

- High-Precision Hardware: Replace older valves with high-performance actuated valves equipped with advanced digital positioners.
- Position Feedback Loop: The positioner must use a sensor (feedback) to monitor the actual valve stem position and constantly correct it against the desired control signal.
- Calibration & Maintenance: Regularly characterize and calibrate the valve to ensure the electronic signal translates accurately to the physical opening ($\%$). This minimizes errors like hysteresis (stickiness).

CONTROL PLAN

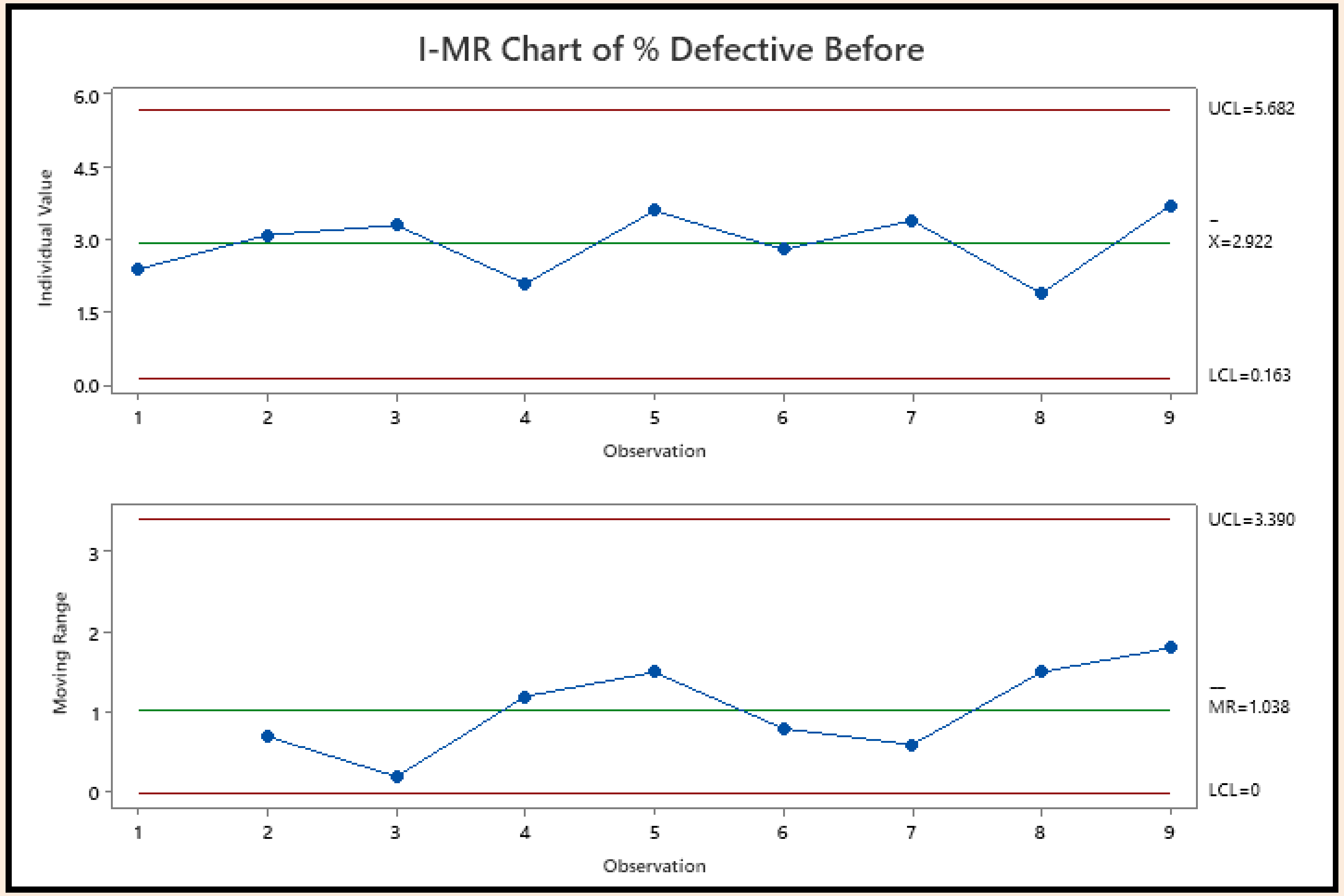
Control Plan Number: PBM-001-2025
Part Number/Latest Change Level: PET Bottle – Blow Molding
Part Name/Description: Preform, Blow Molding Heater, Mold & Cooling Unit
Organization/Plant: ABC Plastics, UAE
Organization Code: ABC-PET-001

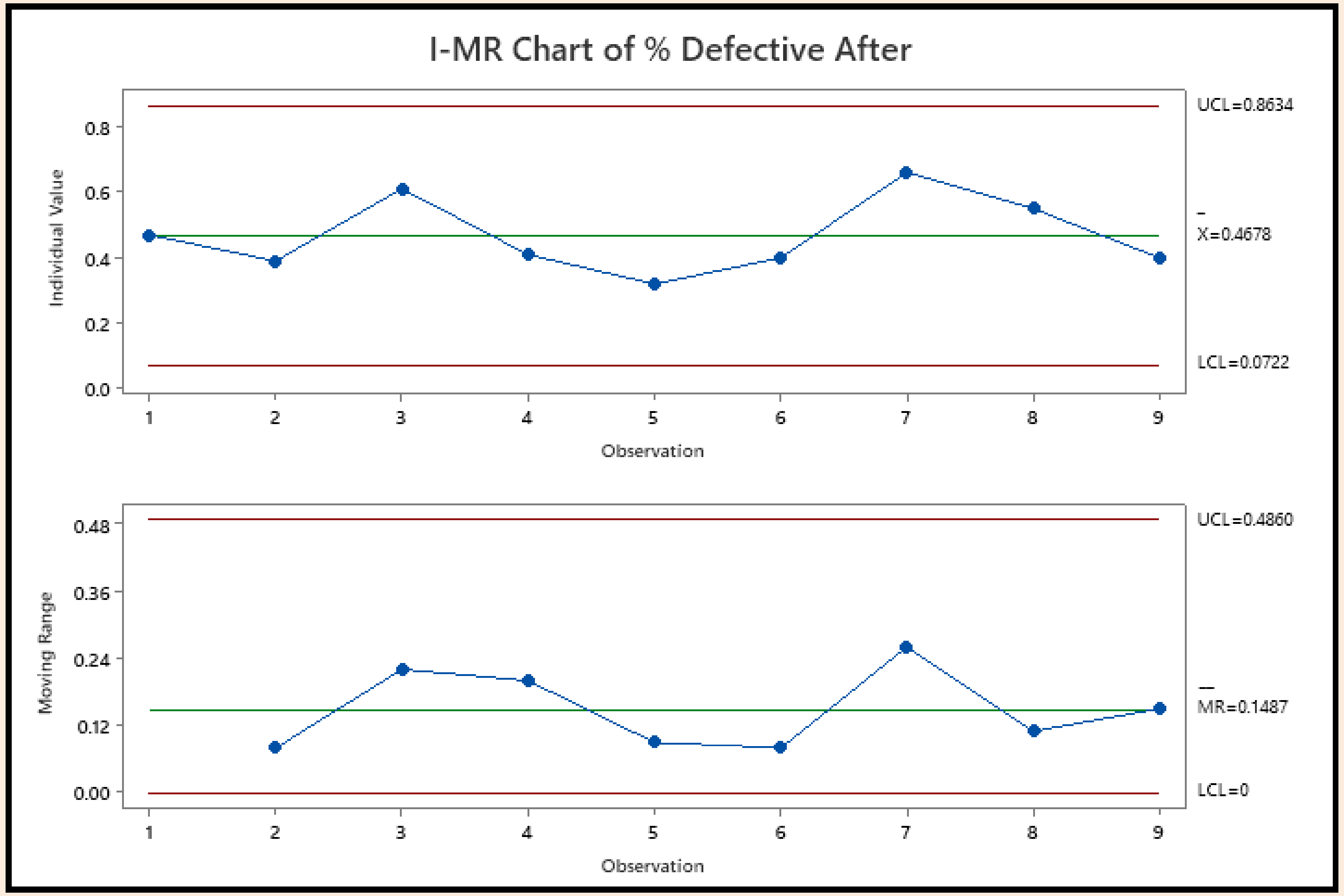
Key Contact/Phone: Mr. XYZ / Production Manager / +971 XXXX XXXX
Core Team: Mr. XYZ & Team
Organization/Plant Approval/Date: 10/02/2025
Other Approval/Date (If Req'd): N/A

Date (Orig): 10/02/2025
Date (Rev): 1
Customer Engg. Approval/Date: N/A
Customer Quality Approval/Date: N/A
Other Approval/Date (If Req'd): N/A

Part / Process Number	Process Name / Operation Description	Machine / Device / Tools for Mfg.	Characteristics – No.	Characteristics – Product	Characteristics – Process	CTQ?	Product / Process Specification / Tolerance	Evaluation / Measurement Technique	Sample Size	Sample Freq.	Control Method	Reaction Plan
1	Air Pressure Setting	Pressure Regulator, Air Line	1a	–	Maintain blow pressure	Y	3.00 bar ± 0.24 (LSL 2.76 / USL 3.24)	Digital pressure gauge	NA	Hourly	SPC Monitoring	Adjust regulator; calibrate if out of spec
2	Mold Temperature Control	Heater, Chiller Unit	1b	–	Maintain mold temperature	Y	105°C ± 5°C	Temperature controller display	NA	Twice per shift	Alarm + Auto-shutdown	Call maintenance; replace heater/chiller if deviation continues
3	Wall Thickness Measurement	Ultrasonic Thickness Gauge	2a	Good material flow	Maintain uniform wall thickness	Y	0.45 mm ± 0.05 mm	Ultrasonic thickness tester	NA	Every hour	QC Inspection (Control Chart)	Adjust parameters; isolate defective batch
4	Cooling Time Control	Cycle Timer	3	–	Cooling cycle stabilization	Y	5.0 s ± 1.0 s	Timer display, PLC cycle log	NA	Per batch	Cycle Time Monitoring	Replace timer; restrict HMI override
5	Preform Heating	IR Heater	4	–	Heating preform correctly	N	100–110°C	Visual + temperature display	NA	Twice per shift	Heater cycle check	Replace heating lamp if ineffective

CONTROL CHART FOR DEFECT RATE BEFORE AND AFTER COMPARISON





CONCLUSION

Sample No.	Air Pressure (Before) [Bar]	Status (Before)	Air Pressure (After) [Bar]	Status (After)
1	2.779	OK	3.007	OK
2	2.886	OK	3.095	OK
3	2.988	OK	3.049	OK
4	3.232	OK	2.998	OK
5	2.814	OK	3.057	OK
6	2.703	**Defect**	3.001	OK
7	2.441	**Defect**	2.923	OK
8	2.846	OK	2.99	OK
9	2.613	**Defect**	2.989	OK
10	2.572	**Defect**	2.987	OK
11	2.819	OK	2.98	OK
12	3.082	OK	3.051	OK
13	2.644	**Defect**	3.082	OK
14	2.576	**Defect**	3.03	OK
15	3.018	OK	3.011	OK
16	2.833	OK	3.018	OK
17	2.511	**Defect**	2.976	OK
18	2.792	OK	3.077	OK
19	2.837	OK	3.023	OK
20	3.017	OK	3.027	OK
21	3.224	OK	2.984	OK
22	2.94	OK	2.953	OK
23	2.94	OK	2.958	OK
24	3.064	OK	3.082	OK
25	2.933	OK	2.977	OK

Inference:

- **Earlier number of defects: 7/25 = 28%**
- **After improvement number of defects = 0/25**
- **There is a significant reduction in defect percentage after improvement.**

- **The project has achieved its intended results after improving the Air Pressure by identifying the variation cause and reducing defects percentage.**