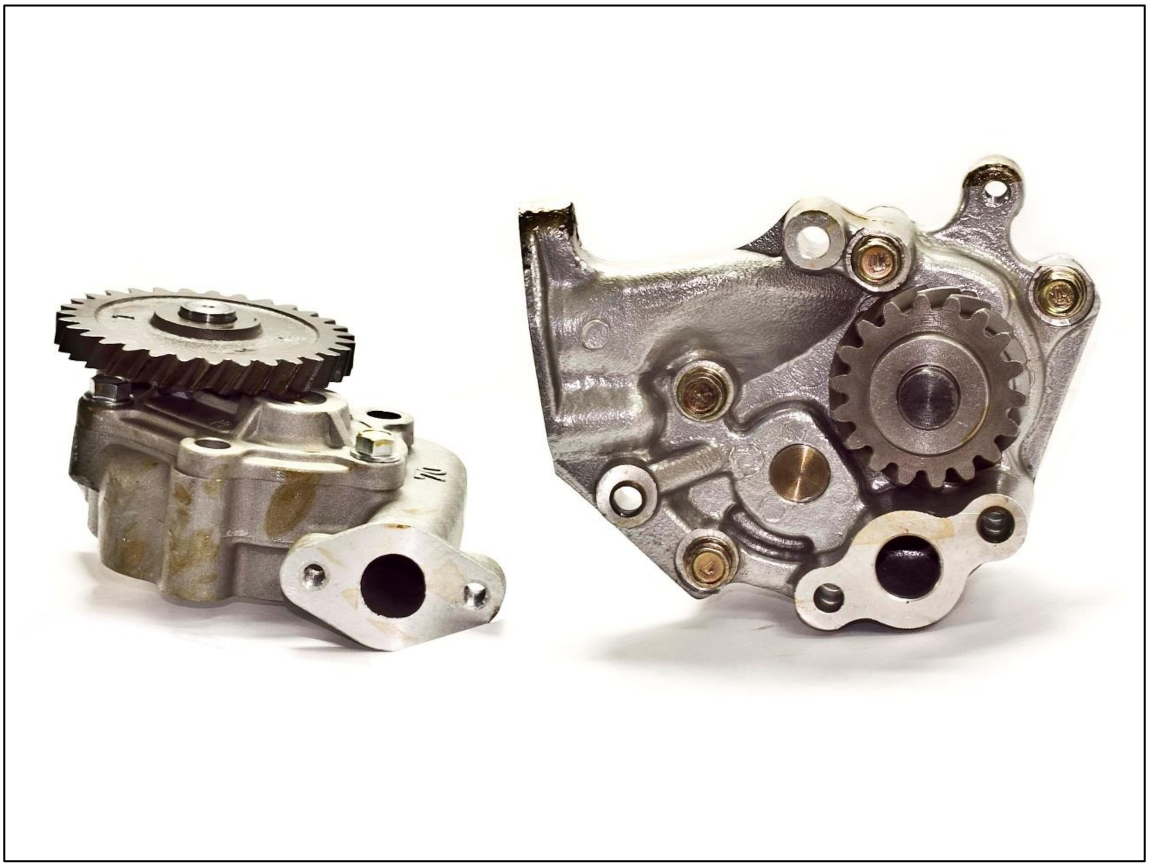


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Tuljaram Chaturchand College of Arts, Commerce and Science, Baramati - 413102

A project report on

"A STUDY OF OIL PUMP BASED ON CONTROL CHARTS"

SUBMITTED TO

DEPARTMENT OF STATISTICS

Tuljaram Chaturchand College, Baramati

MSc (Statistics)

By

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2023-2024

CERTIFICATE

This is to Certify That **Mr. Dupargude Makarand Sanjay**, **Mr. Ashtekar Shankar Kailas** and **Ms. Kadam Sujata Sanjay** are the regular students of Department of Statistics. A project on **"A STUDY OF OIL PUMP BASED ON CONTROL CHARTS"** is submitted in the partial fulfilment of the program in M.Sc. to the Department Of Statistics, Tuljaram Chaturchand College of Arts, Science and Commerce, Baramati.

This project has been conducted under my Supervision and Guidance.

Place: Baramati

Date:

Mrs. Kawade T.D.

Project Guide Examiner Head of Department

ACKNOWLEDGEMENT

Project is an attempt by every student to put his efforts into achieving some objectives under a study and concluding with some valid results. This work is an outcome of many minds. On the successful completion of our project work, we take this opportunity to thank every person associated with it.

We are grateful to our Head of Department, **Dr. V. C. Kakade** for his timely encouragement and support. Special thanks to our guide, **Mrs. T. D. Kawade** for her guidance and giving us this opportunity to work on this topic. We also thank all the teaching and non-teaching staff of our Department of Statistics, Tuljaram Chaturchand College of Arts, Science and Commerce for their kind cooperation.

Our thanks and appreciation also go to our family and friends, without whom the project would not have been completed successfully.

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ABSTRACT

This project introduces the application of the study of oil pumps in automobiles. It underscores the pivotal role of statistical methods in scrutinizing pump performance, formulating optimal maintenance strategies, and enhancing overall efficiency in automotive oil extraction operations. The paper elucidates how statistical analysis can provide valuable insights into the functioning of oil pumps, thereby facilitating data-driven decision-making in automotive engineering. By leveraging statistical tools, the paper demonstrates how we can not only predict and prevent potential failures but also extend the lifespan of oil pumps and improve the efficiency of automobiles. The findings of this project have significant implications for oil pump management and the broader field of automotive engineering.

Keywords:

Statistical Analysis, Oil Pumps, Automobiles, Performance Optimization, Maintenance Strategies, Efficiency Improvement, Automotive Engineering, Oil Pump Management.

INTRODUCTION

Statistical process control (SPC) refers to the collection of statistical procedures and problem-solving tools used to control and monitor the quality of the output of some production process, including the output of services. The aim of SPC is to detect and eliminate or, at least reduce, unwanted variation in the output of a process. The benefits include saving time, increasing profits and an overall increase in the quality of products and services. SPC has long been applied in high-volume manufacturing processes. There are primarily service industries where the "volume" or the "speed" of production is less in comparison to the usual manufacturing process and the quality characteristics are less tangible and not easily measured on a numerical scale. The key idea, however, is that the principles and concepts of SPC can be applied to any repetitive process, i.e. a process wherein the same action is performed over and over with the intention to obtain the same "outcome" or "result" on each trial. A wide range of statistical procedures are used in the various stages of SPC. Many of the statistical procedures like process capability analysis and capability indices, reliability analysis and six sigma that are used in SPC.

As we decided to work on SPC we go towards the industrial area in M.I.D.C. Chakan Pune & we visited some workshops.

In the Advik Industry the supervisor decided whether the process is in proper way or not by only casual observation & their experience. They do not have any proper tools or methodology to get information about process. Manager of workshop interested in checking a quality of their products & analyse the process statistically. So finally we decided to conduct our project in **Advik Company (Oil Pump).**

In this workshop, we observe all the parts which are produced in this industry. We observe how the products are produced? What kind of machines are used? Which part has daily requirement? Which part give a maximum profit to a workshop? And what kind of defects produced in the parts? Etc.

After discussing with Mr. Anil, production manager, we Concentrate on the part “Oil Pump” which produced daily & it is more profitable for workshop. We Consider subparts Inner Rotor & Outer Rotor of these parts which has significance effect on quality Oil Pump.

Then we consider, specification limits (control limits) of Inner Rotor & Outer Rotor which has significance effect on Inner Rotor & Outer Rotor respectively.

They provide us standard values of mean and standard deviation for the three variables "Free Flow, At1 Bar Pressure & PRV Pressure" and the values are as follows:

For Free Flow Output : Mean = 3.50 & Standard Deviation = 0.20

For Flow At1 Bar Pressure : Mean = 3.49 & Standard Deviation = 0.19

For PRV Pressure : Mean = 3.65 & Standard Deviation = 0.12

For statistical analysis we used different control charts such as CUSUM chart, EWMA chart & run chart but due to given mean and standard deviation value we need not use $\bar{X}$-R chart & $\bar{X}$-S chart.

To check normality we use probability plot & Shapiro test and data does not follows normal distribution, therefore we use non-parametric test such as Kruskal-Wallis test.

Objectives

- To check whether the Manufacturing Process is working consistently or not.
- To determine no. of defective variables among three variables.
- To study the performance of the process based on various control charts.

MOTIVATION

Being students of M.Sc. (Statistics) with a specialization in statistics and having studied a course on “Statistical Process Control,” which is applied in the industrial sector, we have experience handling datasets in practical situations during our M.Sc.

We were very interested in knowing how the data is generated, collected, and analysed in the manufacturing industry. Also, we were really interested in analysing such types of data sets.

So, we decided to carry out a project related to statistical process control (SPC).

There are various reasons for starting a study on "Statistical Analysis of Oil Pump Performance in Vehicles" that highlight its importance and applicability to the automotive sector. An important consideration is the vital function of oil pumps in guaranteeing the seamless functioning of automobile engines. In order to minimize friction, dissipate heat, and stop engine component wear and tear, oil pumps are in charge of moving lubricating oil throughout the engine. To improve vehicle performance, dependability, and safety, it is crucial to comprehend and optimize oil pump performance.

This study is further motivated by issues and challenges related to the functioning and efficiency of oil pumps. These difficulties could include changes in the viscosity of the oil, variations in temperature, and mechanical wear over time. Inadequate lubrication, higher friction, and even engine damage might result from any inefficiencies or malfunctions in the oil pump's operation. Additionally, by resulting in unanticipated breakdowns or accidents, oil pump malfunctions might jeopardize vehicle safety.

By offering insights into oil pump performance and pinpointing areas for improvement, statistical analysis is essential to tackling these problems. Statistical approaches can identify patterns, trends, and anomalies in oil pump functioning by examining data obtained from oil pump monitoring systems or diagnostic testing. Engineers can anticipate maintenance requirements, identify any problems before they arise, and improve the performance and design of oil pumps thanks to this knowledge.

METHODOLOGY

- **Control chart**

A control chart is a statistical procedure that can be depicted graphically for on- line process monitoring of a measurable characteristic (such as the mean measurement value or the percentage nonconforming items) with the objective to show whether the process is operating within the limits of expected variation. The simplest and most widely used control chart is the Shewart's-type of chart; this chart is named after the father of quality control i.e. Dr. Walter A. Shewart (1891-1967) of Bell Telephone Laboratories, who developed the chart in the 1930's and laid the foundation of modem statistical process control in his book Economic Control of Quality of Manufactured Product that was originally published in 1931. The the wider use and popularity of control charts outside manufacturing, which lead to Quality Management and Six Sigma, can be attributed to Deming (1986).

- **Variables and Attributes control charts**

A quality characteristic that can be measured on a numerical scale is called a variable. Examples include width, length, temperature, volume, speed etc. When monitoring a variable we need to monitor both its location (i.e. mean or average) and its spread (i.e. variance or standard deviation or range). Sample statistics most commonly used to monitor the location of a process are the sample mean and the sample median or some other percentile (order statistic), whereas the sample range, the sample standard deviation and the sample variance are regularly used to monitor the process variation. In situations where it is not practical or the quality characteristics cannot conveniently be represented numerically, we typically classify each item as either conforming or nonconforming to the specifications on the particular quality characteristic(s) of interest; such types of quality characteristics are called attributes. Some examples of quality characteristics that are attributes, are the number of nonconforming parts manufactured during a given time period or the number of tears in a sheet of material. The p-chart and the np-chart are attribute charts that are based on the binomial distribution and are used to monitor the proportion (fraction) of nonconforming items in a sample and then number of nonconforming items in a sample, respectively. Another type of attribute chart is the-chart, which is based on the Poisson distribution, and is useful for monitoring the number of occurrences of nonconformities (defects) over some interval of time or area of opportunity, rather than the proportion of nonconforming items in a sample.

- **Parametric and Nonparametric control charts :**

In the process control environment of variables data (i.e. data that can be measured on a continuous numerical scale) parametric control charts are typically used; these charts are based on the assumption that the process output follows a specific distribution, for example, a normal distribution. Often this assumption cannot be verified or is not met. It is well-known that if the underlying process distribution is not normal, the control limits are no longer valid so that the performance of the parametric charts can be degraded. Such considerations provide reasons for the development and application of easy to use and more flexible and robust control charts that are not specifically designed under the assumption of normality or any other parametric distribution. Distribution- free or nonparametric control charts can serve this broader purpose.

<u>Multivariate Control Chart</u>

In many industrial processes, quality of the product may depend on two or more quality characteristics (may be dependent), which need to be controlled and monitored simultaneously. In the last decade or two, various multivariate procedures have been developed for simultaneous monitoring of such characteristics. Most of these procedures are to detect shifts in the process mean vector. In such a case, data in terms of vectors follow p-variate normal distribution with mean vector $\boldsymbol{\mu}$ and covariance matrix $\boldsymbol{\Sigma}$. Hotelling (1947) introduced the Hotelling's T2 control chart to monitor the multivariate process and its operation is based only on the most recent observation, therefore it is insensitive to detect small and moderate shifts in the mean vector. Since last decade many researchers developed efficient multivariate control charts by using Hotelling's T2 statistic.

Multivariate Control Chart to monitor the mean vector:

Multivariate control chart to monitor the mean vector of a multivariate normally distributed process namely, Hotelling's T 2 chart. Let $\mathbf{X_1, X_2, \dots, X_n}$ be a random sample from Np ($\boldsymbol{\mu_0}$, $\boldsymbol{\Sigma_0}$) distribution. Here, $\boldsymbol{\mu}$ is the process mean vector and $\boldsymbol{\Sigma}$ is the process covariance matrix. These vectors represent measurements of p quality characteristics. Let $\bar{X}$ be a sample mean vector of the above sample and ($\boldsymbol{\mu 0}$, $\boldsymbol{\Sigma 0}$) be the in-control mean vector and the covariance matrix respectively. The problem of interest is to detect shift in the mean vector **μ.** The hypothesis testing problem is to test **Ho: μ = μ0** against **H1: μ ≠ μ0**

The test statistic for testing **Ho** against **H1** is given by

$$\boxed{T^2 = \mathbf{n}\,(\overline{\mathbf{X}} - \boldsymbol{\mu}_0)'\,\boldsymbol{\Sigma}_0^{-1}(\overline{\mathbf{X}} - \boldsymbol{\mu}_0)}$$

The Hotelling's T^2 chart :

This control chart is used to detect shifts in the mean vector for the multivariate normal data. The upper control limit of this chart is k = $\chi^2_{p,\alpha}$ where, $\chi^2_{p,\alpha}$ is the upper 100α percentage point of chi square distribution. If the process is in-control, a test statistic T2 is distributed as a chi-square variate with p degrees of freedom, otherwise it follows a non-central chi-square distribution with a non-centrality parameter λ^2. Where

$$\lambda^2 = \quad n(\boldsymbol{\mu} - \boldsymbol{\mu}_0)'\boldsymbol{\Sigma}_0^{-1}(\boldsymbol{\mu} - \boldsymbol{\mu}_0) \;\; n(\boldsymbol{\mu} - \boldsymbol{\mu}_0)'\boldsymbol{\Sigma}_0^{-1}(\boldsymbol{\mu} - \boldsymbol{\mu}_0)$$

STATISTICAL ANALYSIS

Descriptive Statistics: OP50 Free Flow Output, OP50 Flow at1 bar Pressure, OP50 PRV Open Pressure

Statistics

Variable	Mean	SE Mean	StDev	Variance	Sum of Squares	Q1	Median
OP50 Free Flow Output	3.5038	0.00312	0.2933	0.0860	109184.5526	3.4200	3.5000
OP50 Flow at1 bar Pressure	3.4953	0.00288	0.2708	0.0733	108549.7088	3.4000	3.4900
OP50 PRV Open Pressure	3.6537	0.00222	0.2083	0.0434	118284.9262	3.5800	3.6900

Variable	Q3	Skewness	Kurtosis
OP50 Free Flow Output	3.6300	-0.85	32.41
OP50 Flow at1 bar Pressure	3.6200	-3.44	28.75
OP50 PRV Open Pressure	3.7800	-3.73	35.60

Interpretation for all three variables:

1. **OP50 Free Flow Output:**

• Mean: 3.5038

• Standard Deviation: 0.2933

• Median: 3.5000

• Variance: 0.0860

The OP50 Free Flow Output has an average value of 3.5038, with a moderate level of variability indicated by a standard deviation of 0.2933.

2. OP50 Flow at 1 bar Pressure:

• Mean: 3.4953

• Standard Deviation: 0.2708

• Median: 3.4900

• Variance: 0.0733

The OP50 Flow at 1 bar Pressure has a mean value of 3.4953, with a slightly lower variability compared to Free Flow Output, as indicated by a standard deviation of 0.2708.

3. OP50 PRV Open Pressure:

• Mean: 3.6537

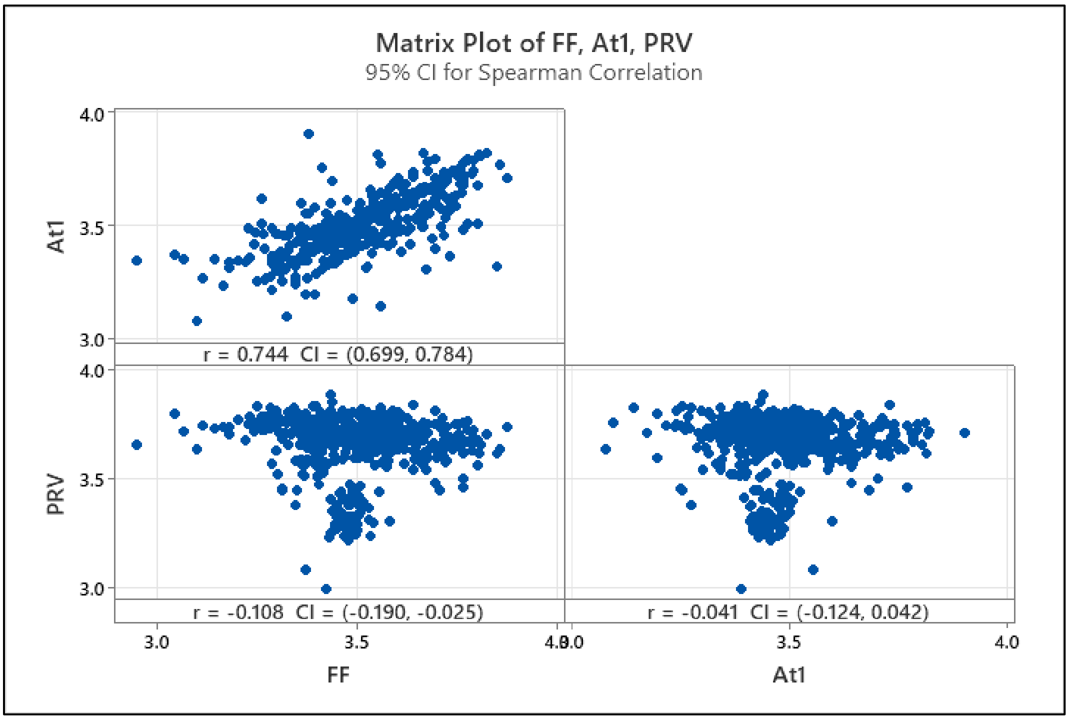
• Standard Deviation: 0.2083

• Median: 3.6900

• Variance: 0.0434

The OP50 PRV Open Pressure has a higher mean value of 3.6537 compared to the other variables, with the lowest variability indicated by a standard deviation of 0.2083.

Correlation: FF, At1, PRV



Correlations

	FF	At1
At1	0.744	
PRV	-0.108	-0.041

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
At1	FF	552	0.744	(0.699, 0.784)	0.000
PRV	FF	552	-0.108	(-0.190, -0.025)	0.011
PRV	At1	552	-0.041	(-0.124, 0.042)	0.332

Interpretation:

From the Above Plot, The variables FF & At1 are positively Correlated and there is negative correlation between PRV-FF and PRV-At1 variables.

To Check the Normality :

H_0 : The given data follows Normality. **V/s**

H_1 : The given data does not follows Normality.

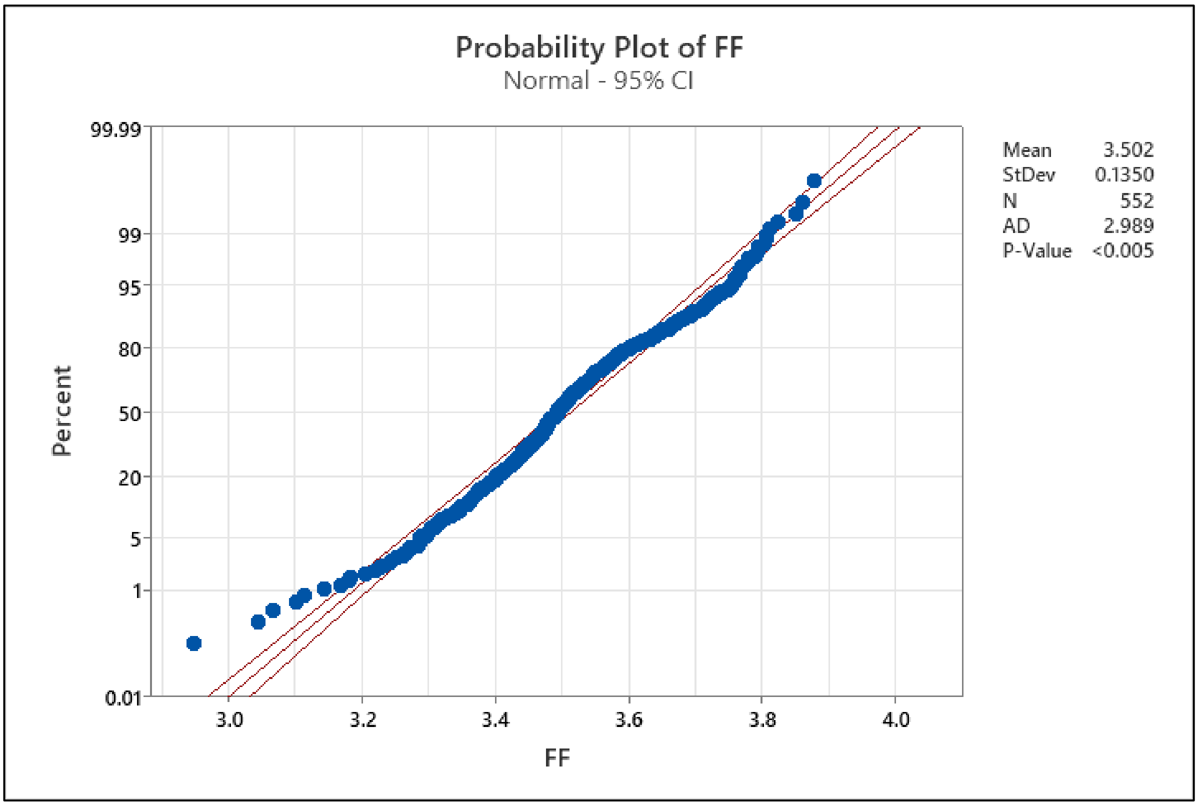
From Shapiro.test -

```
> library(readxl)

> data = read_excel("552.xlsx")

> test <- shapiro.test(c(data$FF,data$At1,data$PRV))

> print(test)

Shapiro-Wilk normality test

data:  c(data$FF, data$At1, data$PRV)

W = 0.97957, p-value = 1.291e-14
```

Interpretation :

Here, p-value is extremely small (1.291e-14), we can say that the combined data from the 'FF', 'At1', and 'PRV' columns **do not follow a normal distribution**.

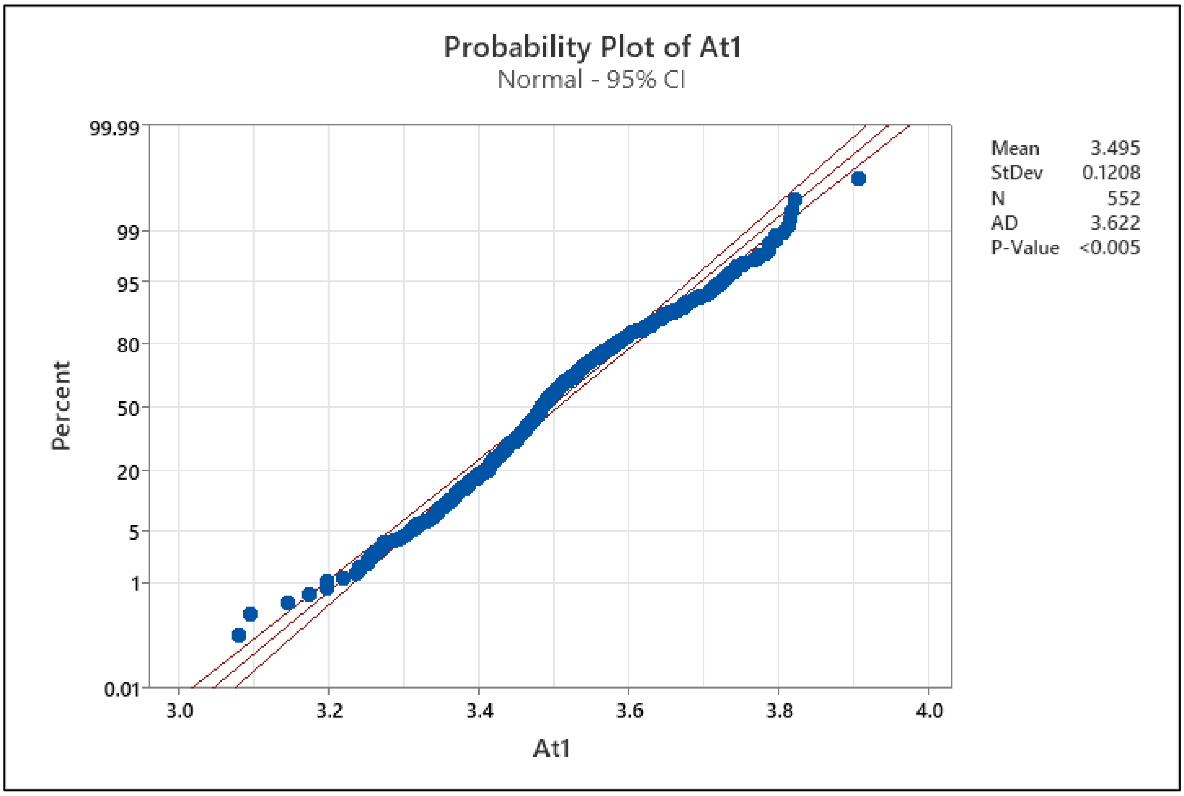
Probability Plot of FF, At1, PRV



Interpretation :

In the above Probability plot, several data points, especially at the lower end, deviate from the red line. This deviation indicates that the data does not follows normality.

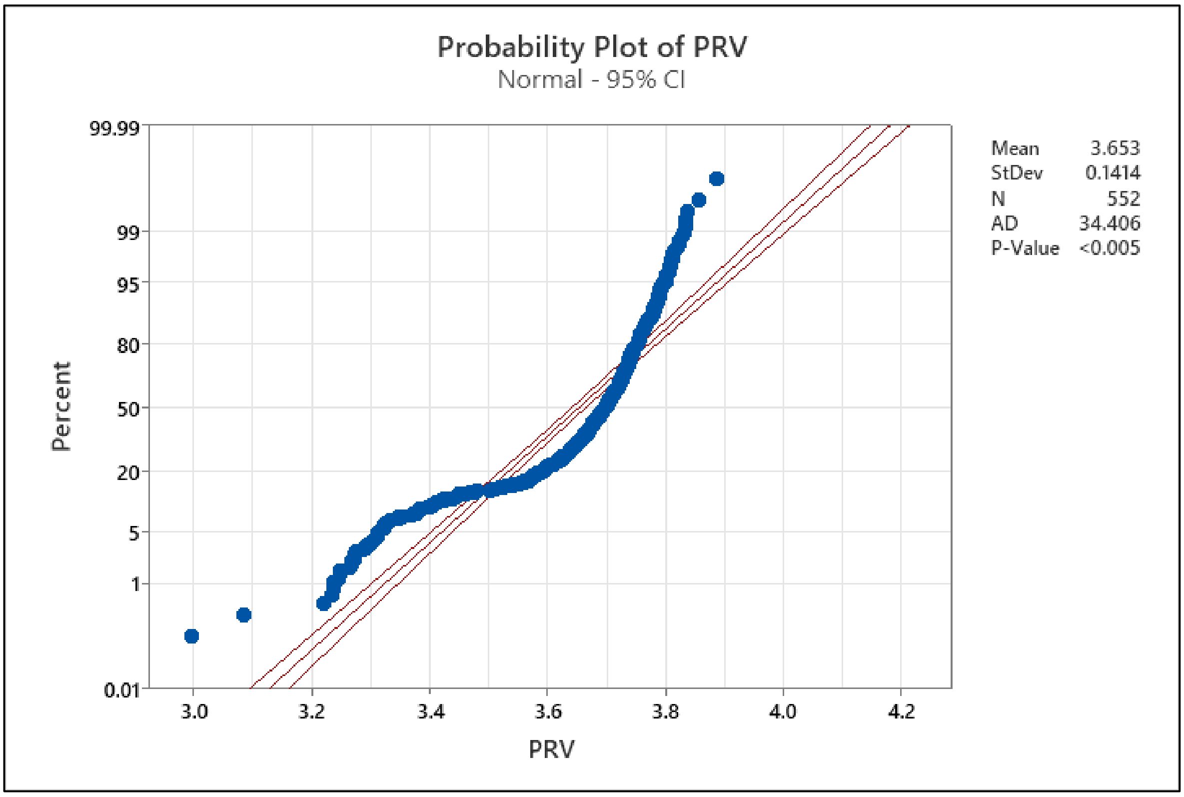
Therefore, we can say that the data for 'Free Flow' does not follow normal distribution.



Interpretation :

In the above Probability plot, several data points, especially at the lower end, deviate from the red line. This deviation indicates that the data does not follows normality.

Therefore, we can say that the data for 'At1' does not follow normal distribution.



Interpretation :

In the above Probability plot, several data points, especially at the lower end, deviate from the red line. This deviation indicates that the data does not follows normality.

Therefore, we can say that the data for 'PRV' does not follow normal distribution.

Conclusion:

The P-values for all three variables are less than α = 0.05 (level of significance), so we conclude that the given data is not normally distributed.

Therefore, we have to use Non-Parametric tests.

Non-Parametric Tests :

Kruskal-Wallis Test: FF versus Shift

Descriptive Statistics

Shift	N	Median	Mean Rank	Z-Value
I	184	3.48969	274.8	-0.17
II	184	3.52594	318.8	4.41
III	184	3.47750	235.8	-4.24
Overall	552		276.5	

Test

Null hypothesis	H_0: All medians are equal		
Alternative hypothesis	H_1: At least one median is different		
Method	**DF**	**H-Value**	**P-Value**
Not adjusted for ties	2	24.95	0.000
Adjusted for ties	2	24.95	0.000

Interpretation:

Here, the p-value is less than the significance level ($\alpha = 0.05$), we reject the null hypothesis. We have strong evidence to conclude that there are significant differences in the medians of the OP50 Free Flow Output among the shifts.

Kruskal-Wallis Test: At1 versus Shift

Descriptive Statistics

Shift	N	Median	Mean Rank	Z-Value
I	184	3.47656	281.9	0.57
II	184	3.50438	299.3	2.37
III	184	3.48094	248.3	-2.94
Overall	552		276.5	

Test

Null hypothesis	H_0: All medians are equal		
Alternative hypothesis	H_1: At least one median is different		
Method	**DF**	**H-Value**	**P-Value**
Not adjusted for ties	2	9.72	0.008
Adjusted for ties	2	9.72	0.008

Interpretation:

The P-value is **0.008**. This is less than the common significance level (α=0.05).So, in this case, we reject the null hypothesis because the P-value is less than 0.05. This suggests that there is a statistically significant difference between the medians of the groups.

Kruskal-Wallis Test: PRV versus Shift

Descriptive Statistics

Shift	N	Median	Mean Rank	Z-Value
I	184	3.67356	237.9	-4.02
II	184	3.69719	277.6	0.12
III	184	3.71216	314.0	3.90
Overall	552		276.5	

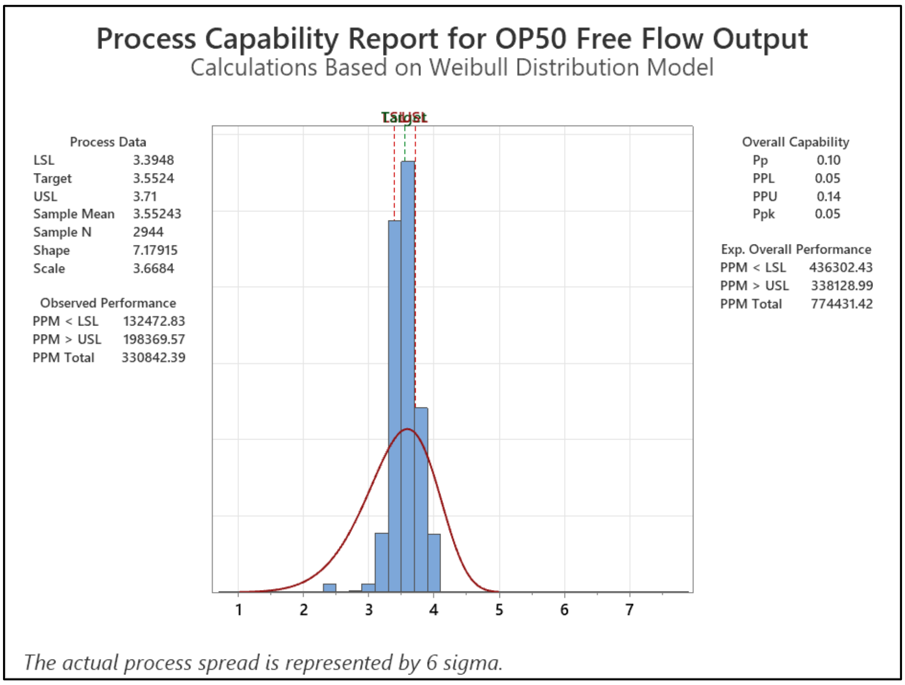
Test

Null hypothesis	H_0: All medians are equal		
Alternative hypothesis	H_1: At least one median is different		
Method	**DF**	**H-Value**	**P-Value**
Not adjusted for ties	2	20.94	0.000
Adjusted for ties	2	20.94	0.000

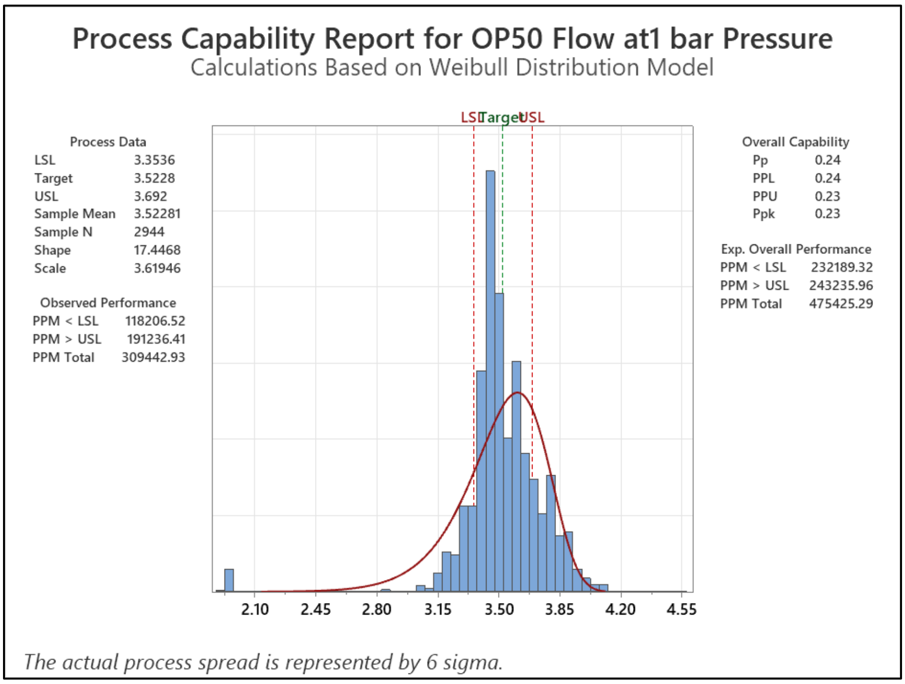
Interpretation: Here, the p-value is less than the significance level (α = 0.05), we reject the null hypothesis. We have strong evidence to conclude that there are significant differences in the medians of the OP50 PRV Pressure among the shifts.

For Shift 1:

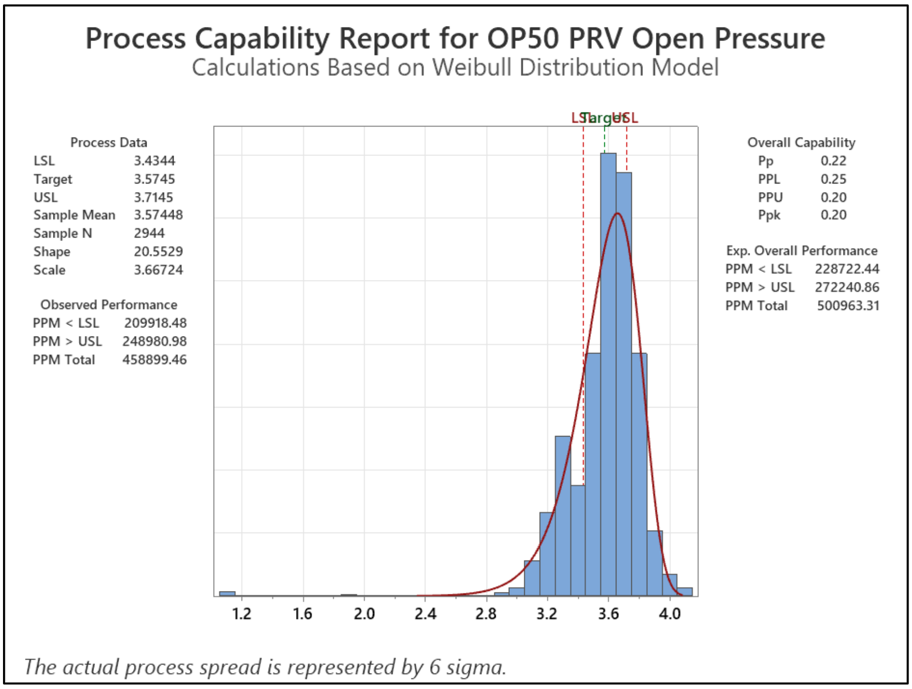
Process Capability Report for OP50 Free Flow Output



Process Capability Report for OP50 Flow at1 bar Pressure



Process Capability Report for OP50 PRV Open Pressure



Interpretation:

OP50 Free Flow Output: PPM Total = **774431.42**

OP50 Flow at1 bar Pressure: PPM Total = **475425.29**

OP50 PRV Open Pressure: PPM Total = **500963.31**

Comparing these three values:

774431.42 > 500963.31 > 475425.29

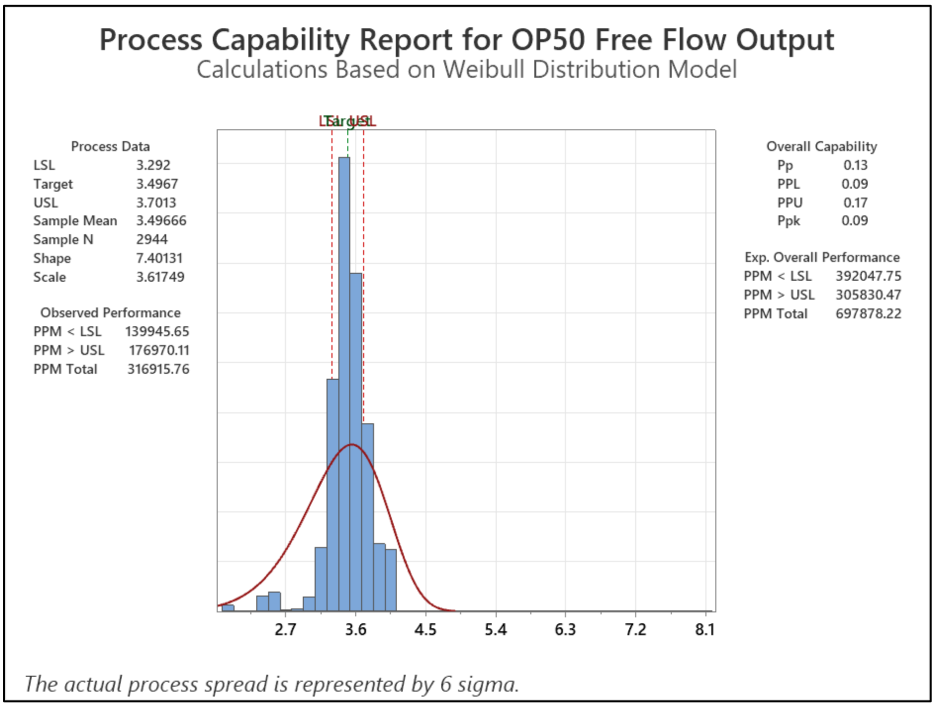
This means the OP50 Free Flow Output process has the highest total expected defects of **774431.42 ppm**, indicating the **lowest process capability** among the three.

The OP50 Flow at 1 bar Pressure process has the lowest total expected defects of **475425.29 ppm,** indicating it has the **highest process capability** of these three processes.

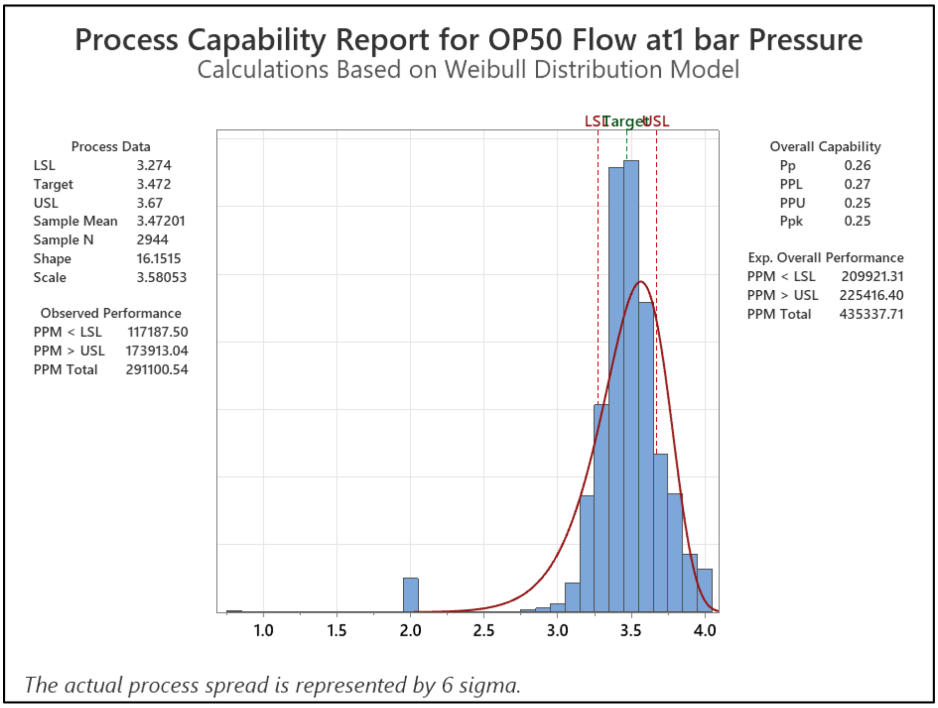
The OP50 PRV Open Pressure process has **500963.31 ppm** total expected defects, which falls in between the other two processes in terms of capability.

For Shift 2:

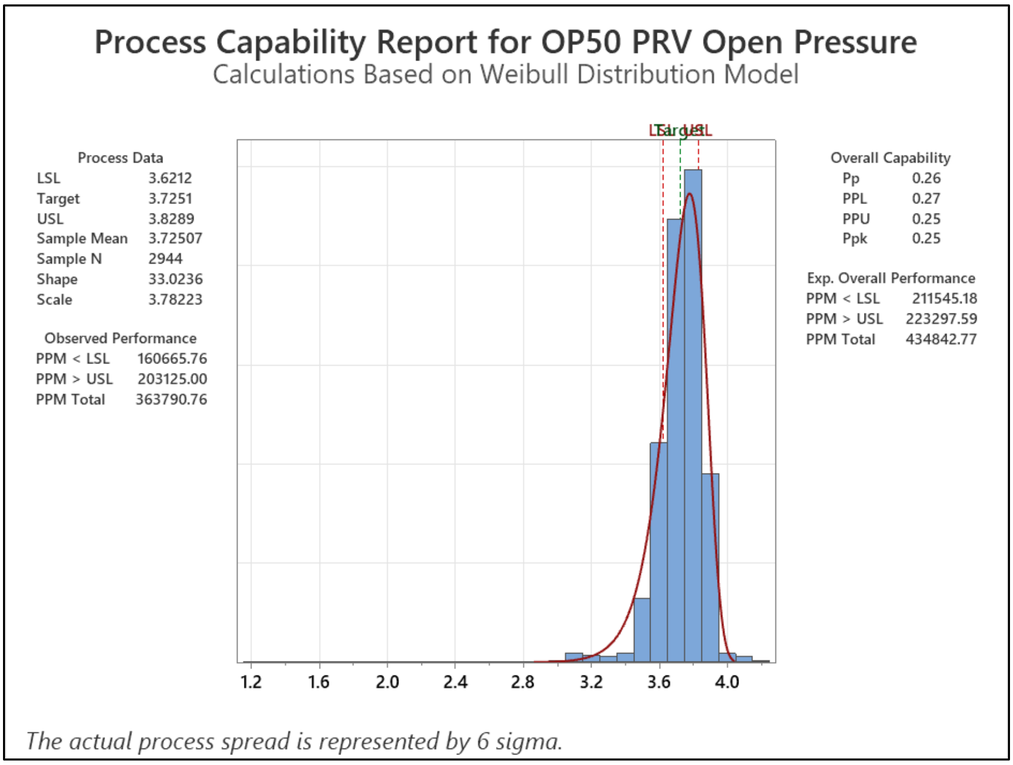
Process Capability Report for OP50 Free Flow Output



Process Capability Report for OP50 Flow at1 bar Pressure



Process Capability Report for OP50 PRV Open Pressure



Interpretation:

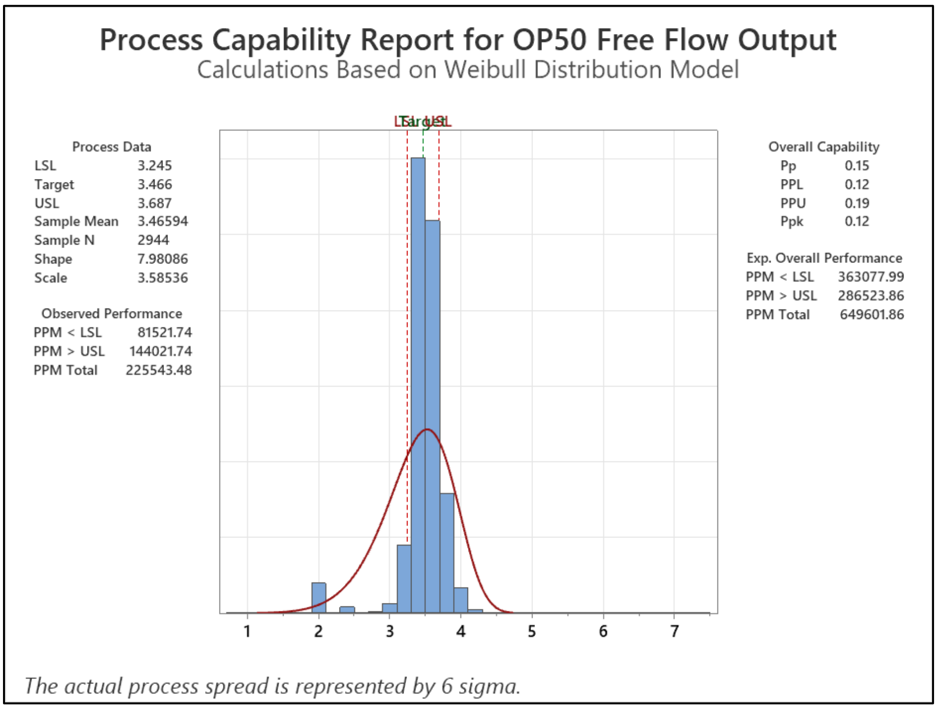
OP50 Free Flow Output: The "PPM Total" is **316915.76**. This indicates that there are approximately 774,431 defects per million opportunities in this process. This is the highest total expected defects among the three processes, indicating the lowest process capability.

OP50 Flow at 1 bar Pressure: The "PPM Total" is **291100.54**. This means there are approximately 475,425 defects per million opportunities in this process. This is the lowest total expected defects among the three processes, indicating it has the highest process capability.

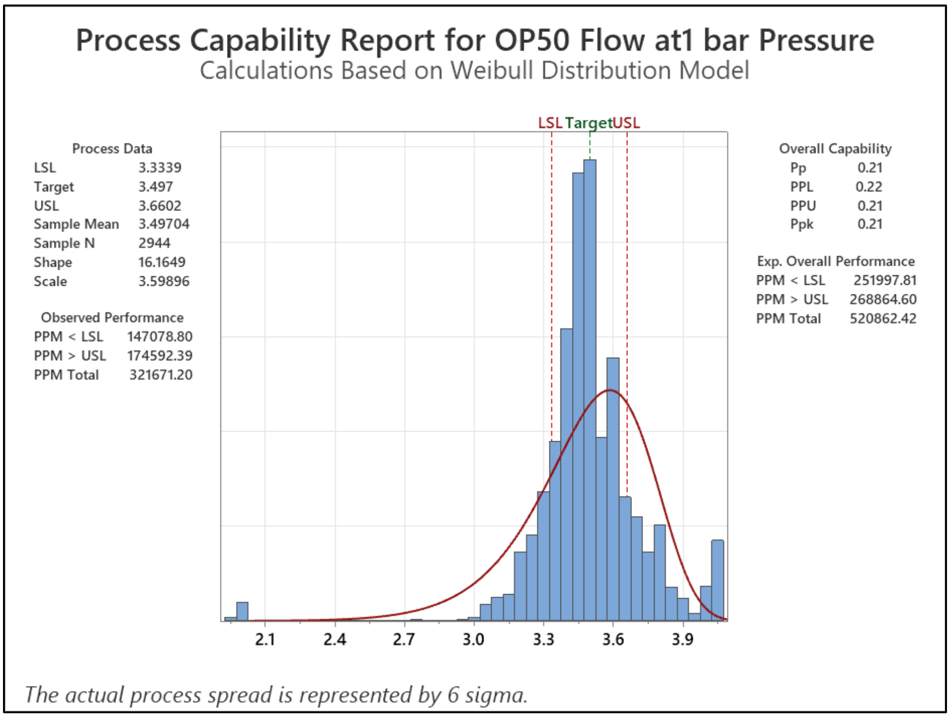
OP50 PRV Open Pressure: The "PPM Total" is **363790.76**. This indicates that there are approximately 500,963 defects per million opportunities for this process. This value falls in between the other two processes in terms of capability.

For SHIFT 3:

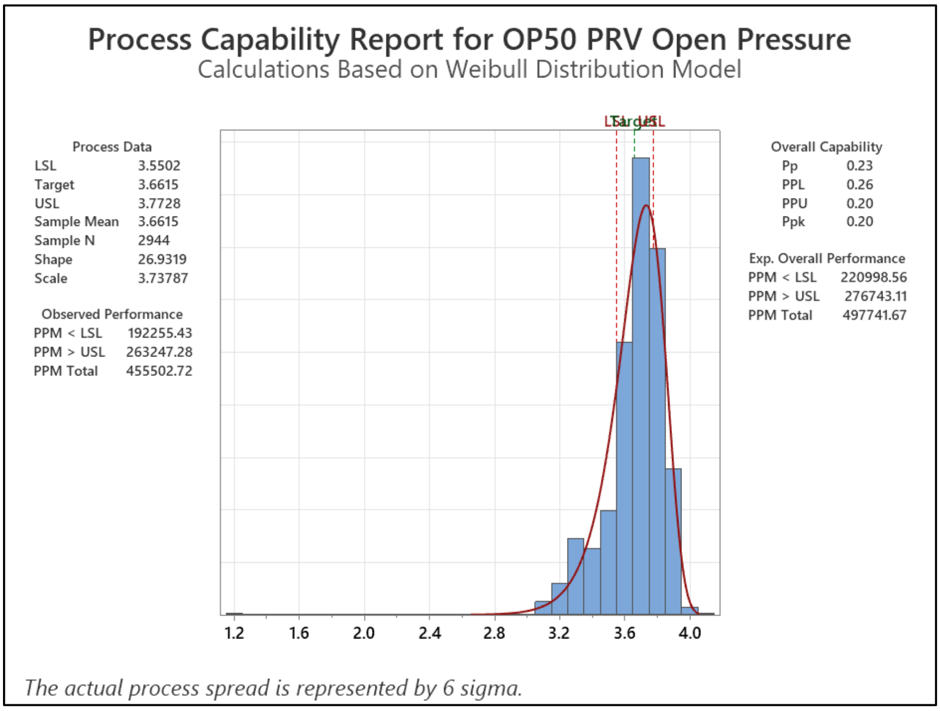
Process Capability Report for OP50 Free Flow Output



Process Capability Report for OP50 Flow at1 bar Pressure



Process Capability Report for OP50 PRV Open Pressure



<u>Interpretation</u>:

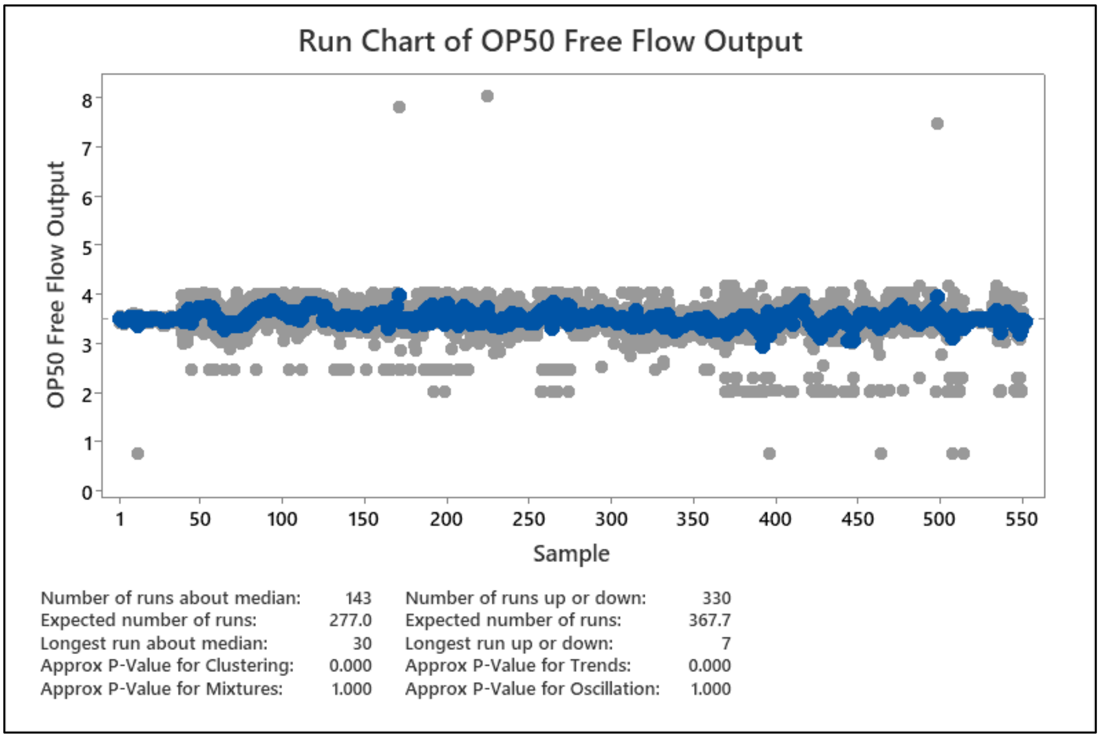
OP50 Free Flow Output: The "PPM Total" is **225543.48**. This indicates that there are approximately 225543 defects per million opportunities in this process. This is lowest total expected defects among the three processes, indicating it has the highest process capability.

OP50 Flow at1 bar Pressure: The "PPM Total" is **321671.20**. This means there are approximately 321671 defects per million opportunities in this process. This value falls in between the other two processes in terms of capability.

OP50 PRV Open Pressure: The "PPM Total" is **455502.72**. This indicates that there are approximately 455502 defects per million opportunities for this process. This is the highest total expected defects among the three processes, indicating the lowest process capability.

Conclusion: From the above Ppm total values, we can conclude that "OP50 PRV Open Pressure" has most defects among the three variables & "OP50 Flow at1 bar Pressure" has least defects among the three variables.

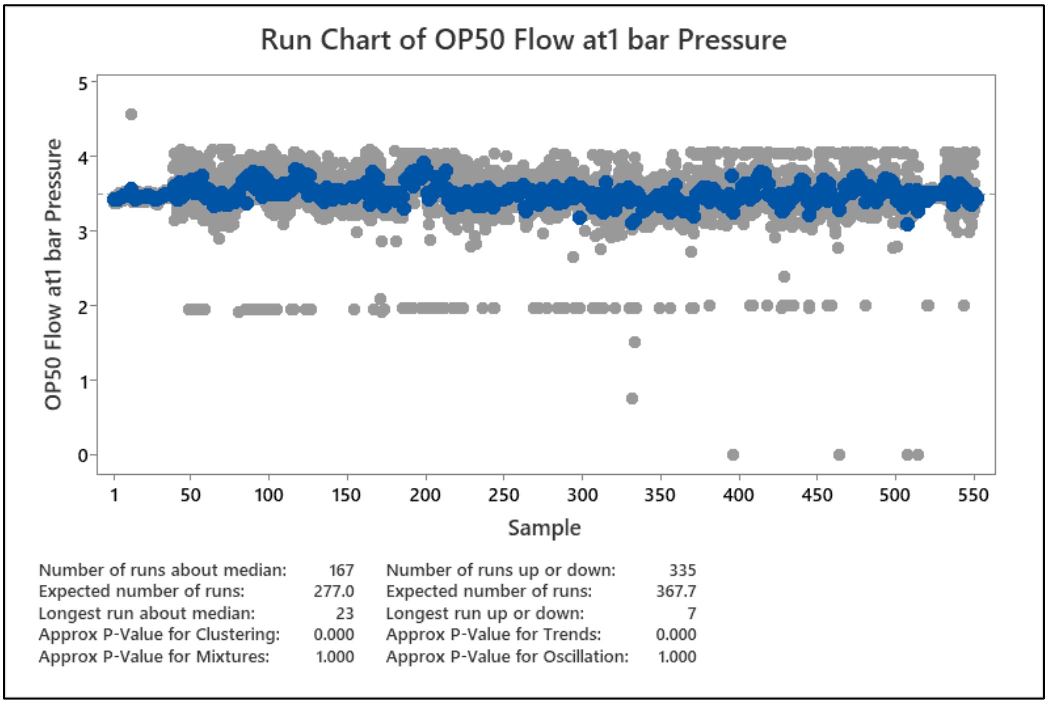
RUN CHART for free Flow :



Interpretation:

The P-values for Mixtures & Oscillation are looks fine, but the test for Clustering & Trend are Significant at the 0.05 level of significance. Because the P-values for the Cluster test (p=0.000) and for Trend test (p=0.000) are less than $\alpha = 0.05$. Hence, we can conclude that special causes are affecting the process of OP50 Free Flow Output and we should investigate possible sources. Clusters and Trend can be evidence of sampling or measurement problems, but we need to collect more data for sure.

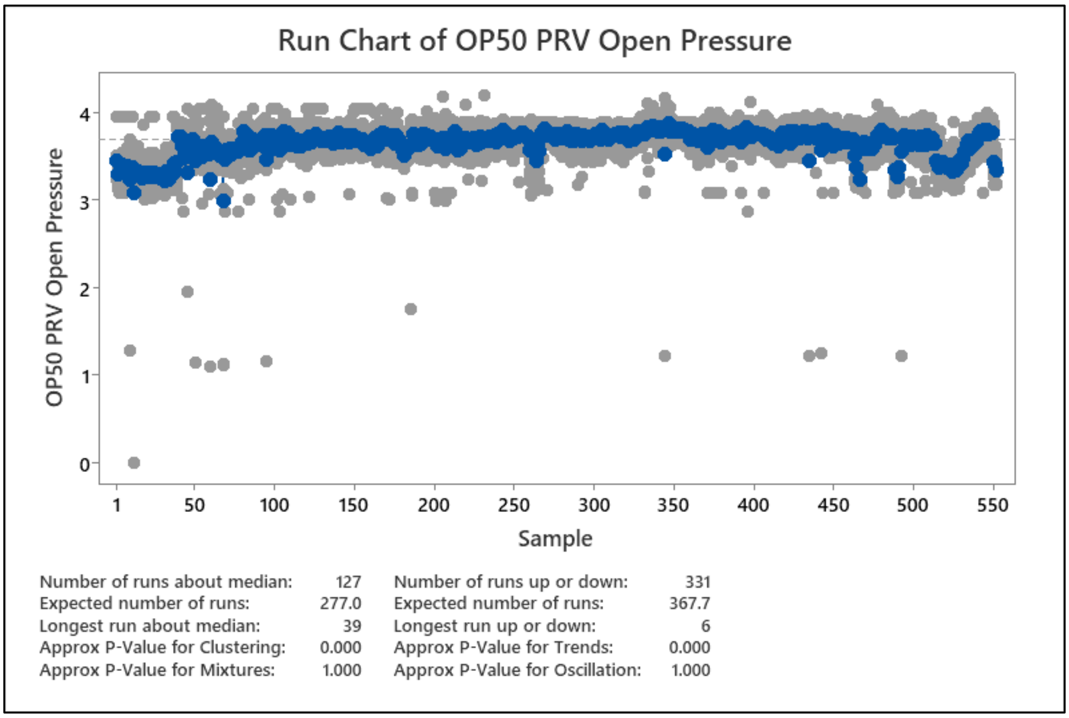
RUN CHART for at1 Pressure :



Interpretation:

The P-values for Mixtures & Oscillation are looks fine, but the test for Clustering & Trend are Significant at the 0.05 level of significance. Because the P-values for the Cluster test (p=0.000) and for Trend test (p=0.000) are less than $\alpha = 0.05$. Hence, we can conclude that special causes are affecting the process of OP50 Flow at1 bar Pressure and we should investigate possible sources. Clusters and Trend can be evidence of sampling or measurement problems, but we need to collect more data for sure.

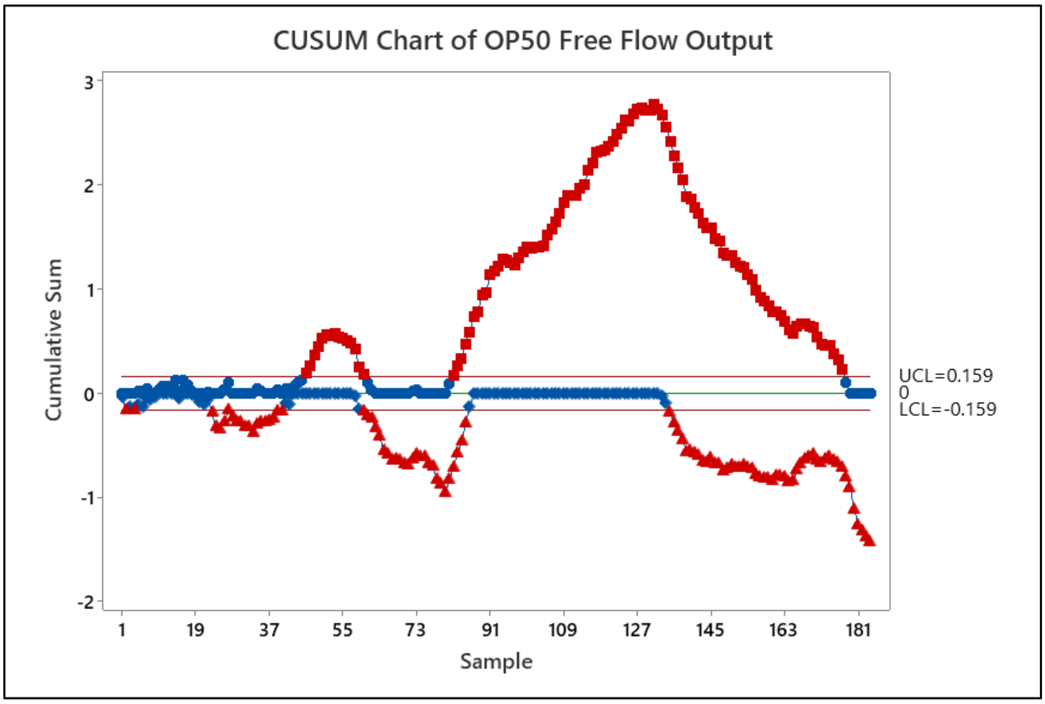
RUN CHART for PRV Pressure :



Interpretation :

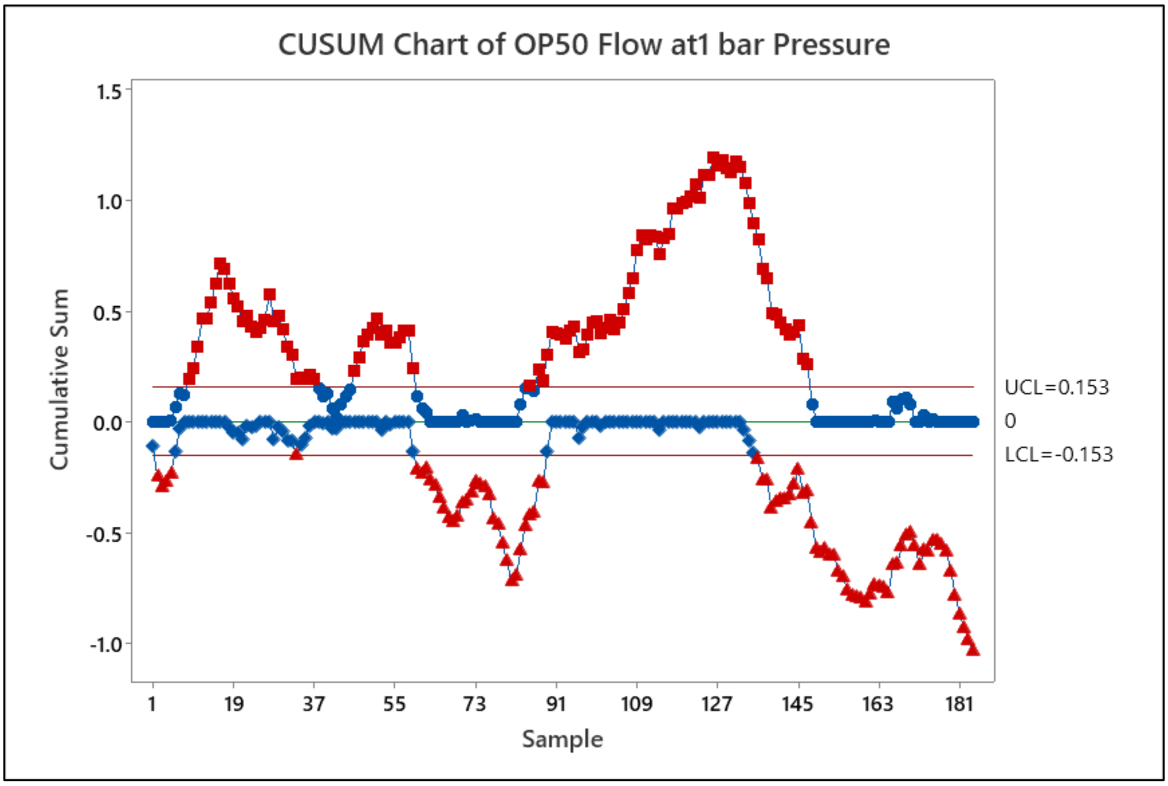
The P-values for Mixtures & Oscillation are looks fine, but the test for Clustering & Trend are Significant at the 0.05 level of significance. Because the P-values for the Cluster test (p=0.000) and for Trend test (p=0.000) are less than $\alpha = 0.05$. Hence, we can conclude that special causes are affecting the process of PRV Open Pressure and we should investigate possible sources. Clusters and Trend can be evidence of sampling or measurement problems, but we need to collect more data for sure.

CUSUM Charts : For n=48



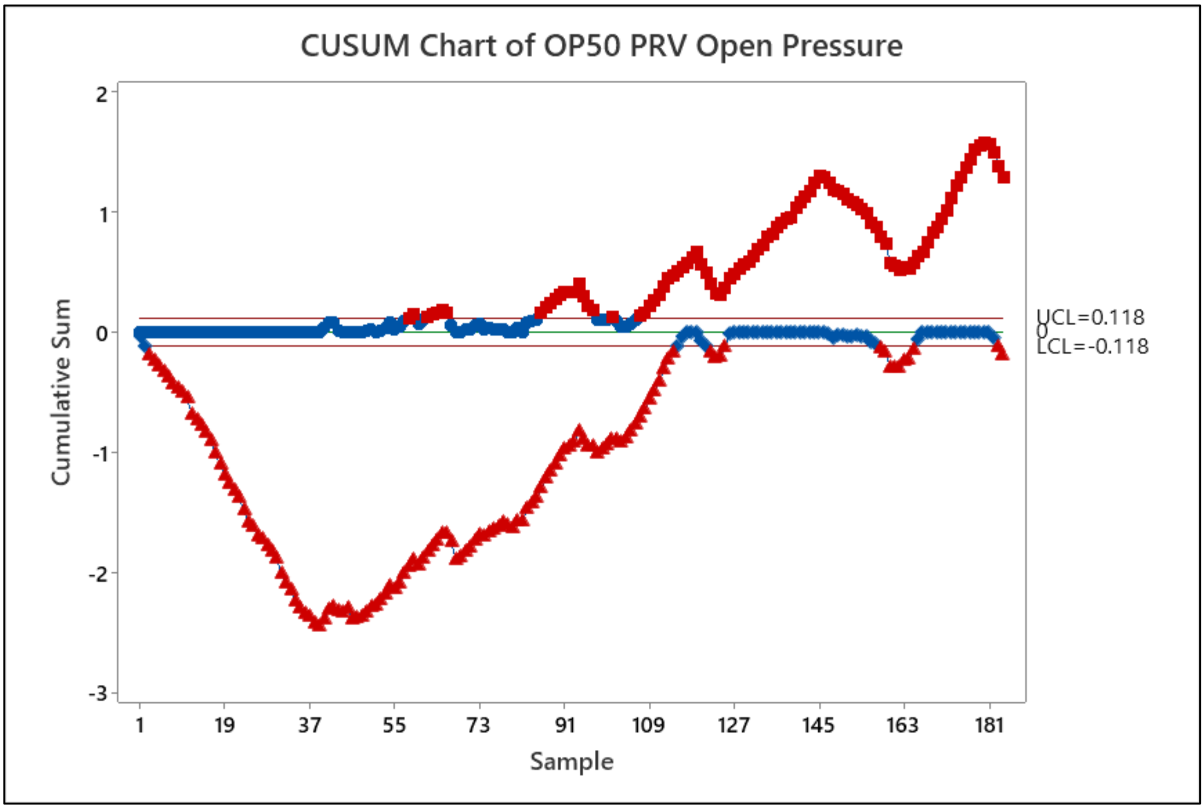
Interpretation :

The above CUSUM chart for OP50 Free flow Output signals earlier at sample 23 indicating the Downward shift in the process median & signals at sample 42 indicating the upward shift in the process median, sample at 130 indicating the Downward shift in the process median & sample 81 indicating the most likely upward shift in the process median.



Interpretation :

The above CUSUM chart for OP50 Free At1 bar Pressure signals earlier at samples 8 & 43 indicating the Upward shift in the process median & samples at 87 indicating the most likely Upward shift in the process median, samples 4 and 59 indicating the Downward shift in the process median and sample 136 indicating the most likely Downward shift in the process median.



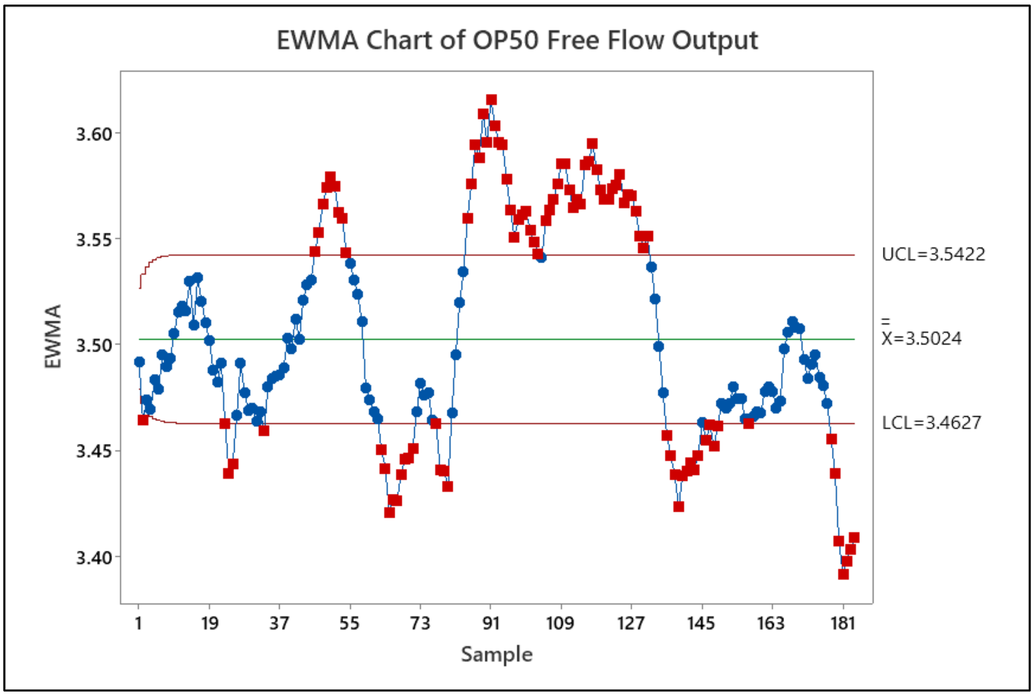
Interpretation :

The above CUSUM chart for OP50 Free At1 bar Pressure signals earlier at samples 57 & 88 indicating the Upward shift in the process median & samples at 107 indicating the most likely Upward shift in the process median, samples 124 and 159 indicating the Downward shift in the process median and sample 5 indicating the most likely Downward shift in the process median.

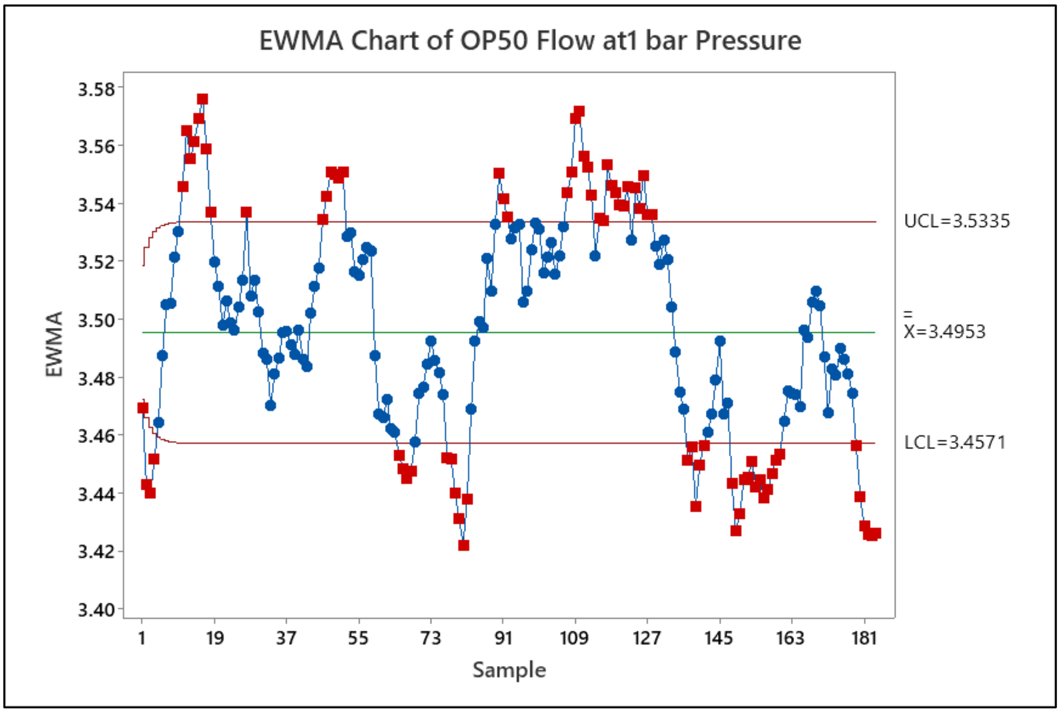
Conclusion :

From above Three CUSUM charts, we can conclude that the Process is out-of-statistical control and does not meet the desired stability (Not Stable).

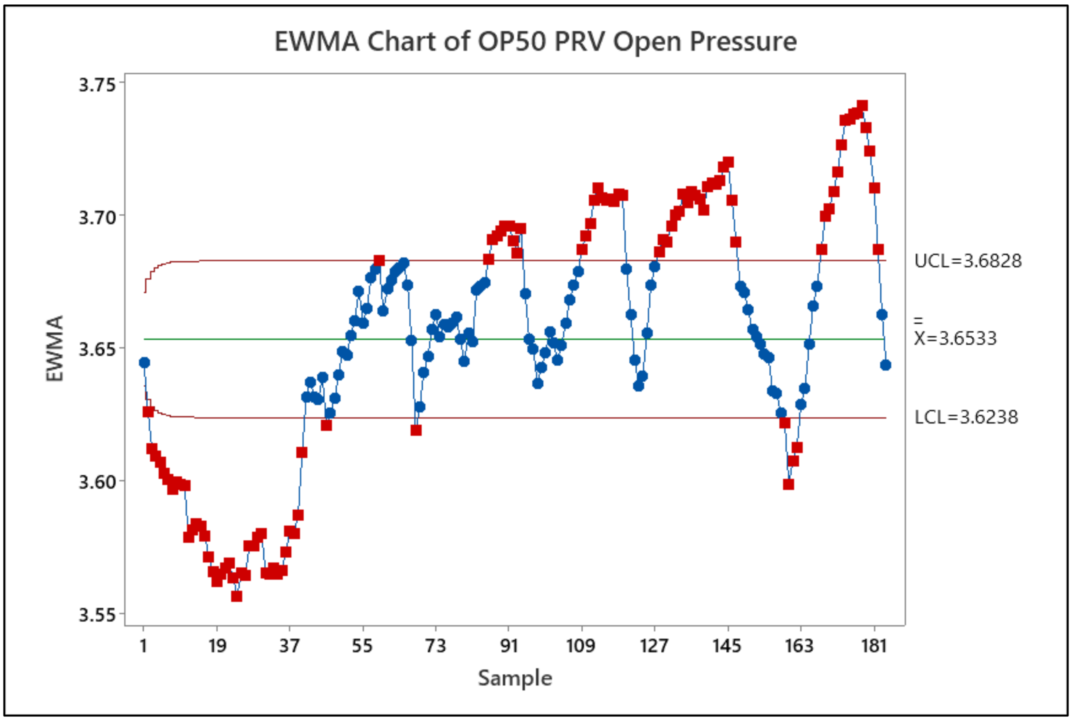
<u>EWMA Chart</u> : for n=48



Interpretation : The above EWMA chart shows that, the process is Out-of-control.



Interpretation : The above EWMA chart shows that, the process is Out-of-control.



Interpretation:

The above EWMA chart shows that, the process is Out-of-control.

Conclusion:

From the Above EWMA charts, We can Conclude that the Process is inconsistent.

Hotelling T^2:

Hypothesis to be tested:

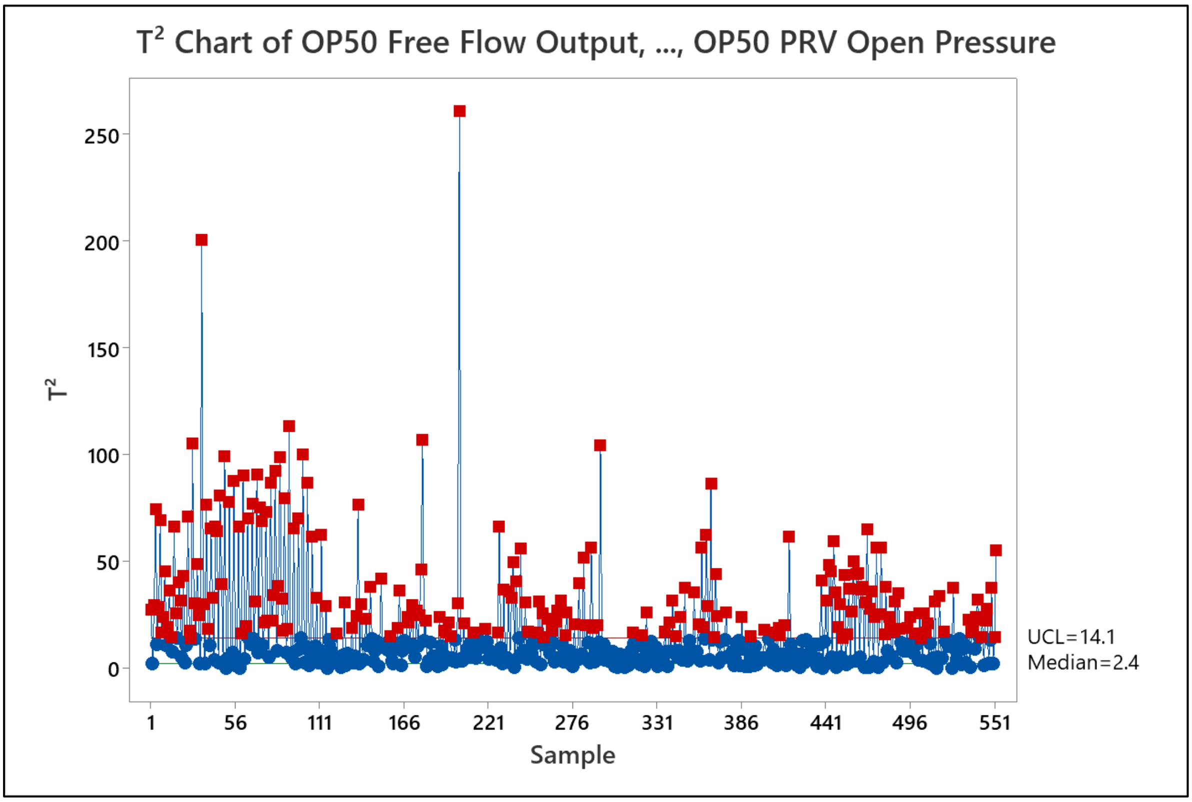
Ho: $\mu = \mu_0$ against **H1: $\mu \neq \mu_0$**

Here, Hotelling T^2 value 16.41949 & $\chi^2_{p,\alpha}$ = 7.815.

Hotelling T^2 value 16.41949 is greater than $\chi^2_{p,\alpha}$ = 7.815.

Therefore we reject the Null Hypothesis H_0. i.e means are not equal.

T² Chart of OP50 Free Flow Output, ..., OP50 PRV Open Pressure



Interpretation :

From above Hotelling T^2 chart, we can say that the process is out of control.

CONCLUSION

- The Process of variables is not working consistently.

- The variable PRV Pressure contributes most defectives in the process.

- The Process of variables “Free Flow Output, Flow At1 bar Pressure & PRV Pressure” are statistically out-of-control & not stable.

SCOPE & LIMITATION

- **Scope:**

  We can do similar analysis for other parts and also for other quality variables.

- **Limitations:**

  Our analysis is restricted to quality characteristics.

  During this project we consider only 3 subparts Free Flow Output, Flow At1 bar pressure & PRV pressure of the product oil pump with its quality variables due to time constraints.

- **Suggestion:**

1. **Address Variable Process Consistency**: Since the process of variables is not working consistently, it's crucial to identify the root causes of this inconsistency. This might involve reassessing equipment calibration, maintenance schedules, or operator training to ensure that variables are controlled effectively throughout the production process.
2. **Focus on PRV Pressure**: Given that PRV Pressure contributes most to defectives, it's imperative to investigate and address any issues related to PRV Pressure control. This could involve recalibration of pressure regulation equipment, conducting regular checks to ensure pressure levels are within acceptable ranges, or implementing additional quality control measures specifically targeting PRV Pressure.
3. **Stabilize Variable Processes**: The identification of statistically out-of-control and unstable processes, such as Free Flow Output, Flow At1 bar Pressure, and PRV Pressure, underscores the need for process stabilization efforts. This could involve implementing tighter process controls, utilizing statistical process control techniques, or conducting root cause analysis to identify and eliminate sources of variability.
4. **Optimize Third Shift Performance**: Since the third shift is identified as the most defective shift, it's essential to investigate the factors contributing to this trend and implement measures to improve performance during this shift. This might involve reviewing staffing levels, training programs, or workflow processes specific to the third shift to identify opportunities for improvement.

REFERENCES

- Introduction to Statistical Quality Control-Douglas C. Montgomery
- Classification Of Distribution Free Quality Control Chart- Bakir, S.T.(2001)
- A Multivariate Synthetic Control Charts for Monitoring Process Mean Vector

  (V.B. Ghute & D.T. Shirke)

APPENDIX

Hotelling T^2:

```
>library(readxl)

>data = read_excel("C:/Users/Makarand/Desktop/SHIFTS.xlsx")

>X = t(data)

>n = 16

>f = n - 1

>p = 3

>Mu = colMeans(data);Mu

>Mu1 = t(Mu);Mu1

>mu = matrix(c(3.761875,3.64375,3.667125), byrow = TRUE, nrow = 1)

>Mu0 = t(mu);Mu0

>a = Mu1 - t(Mu0);a

>b = sqrt(n);b

>a1 = b * a;a1

>Si = cov(data);Si

>T = (a1)%*%solve(Si)%*%t(a1);T
```

Shapiro Test :

```
> library(readxl)

> data = read_excel("552.xlsx")

> test <- shapiro.test(c(data$FF,data$At1,data$PRV))

> print(test)
```