

ASSESSING LIVER FUNCTION RISK ACROSS POLYETHENE, POLYPROPYLENE,  
POLYSTYRENE, AND PVC WORKERS

Name of Student

Course

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Date

Assessing Liver Function Risk across Polyethene, Polypropylene, Polystyrene, and PVC  
Workers

Introduction

Manufacturing plastic products involves exposure to various organic solvents, many of which are harmful to liver health. The Health and Safety Executive (HSE) is investigating whether solvent inhalation has led to early signs of liver stress in employees across the plastic industry, particularly focusing on the LDH-5 to LDH-1 ratio as an indicator of liver cell disaggregation. The study encompasses employees from four plastic sectors: polyethene (PE), polypropylene (PP), polystyrene (PS), and polyvinyl chloride (PVC), chosen to minimise confounding variables. The primary goal is to compare LDH ratios to assess occupational risk. At the same time, the secondary aim evaluates the relationship between years of service and LDH ratios, indicating potential cumulative exposure effects. Statistical analysis will be applied to interpret the findings related to workplace health and safety.

Descriptive Statistics and Graphical Summaries

Before formal statistical tests, the dataset underwent primary screening for inconsistencies, values, and defects. Necessary checks included plausibility and internal consistency checks. Notable findings included an unusual case of a 17-year-old participant, potential gender coding errors, LDH ratios within biological range, correctly entered industry codes, and significant precision errors in length of service data, suggesting possible conversion issues. These inaccuracies may bias summary statistics and hypothesis testing assumptions.

The descriptive statistics indicate significant insights for inferential statistics, particularly in LDH ratios across four industries: PS has the highest mean LDH ratio, 1.031, and PE the lowest, 0.877, with PVC and PP in between. PVC workers have the longest average service

length (11 years), and age averages are consistent, ranging from 36 to 41 years. Outlier analysis reveals mild to moderate outliers in LDH ratios for PP and PVC, potentially due to biological variation or data issues. LDH distributions in PS and PVC show slight positive skewness, indicating physiological stress, while the age distribution is symmetric. A balanced gender distribution (65 male and 51 female) enhances the generalisability of the findings (Table 1, Figures 1-8).

**Table 1: Summary Statistics**

*LDH5:LDH1*

<b>Industry</b>	<b>Mean</b>	<b>Median</b>	<b>Standard Deviation</b>
PE	0.877451	0.870501	0.175452
PP	0.921710	0.900315	0.246435
PVC	0.969881	0.948643	0.199921
PS	1.03114	1.01827	0.164317

*Length of Service*

<b>Industry</b>	<b>Mean</b>	<b>Median</b>	<b>Standard Deviation</b>
PE	7.71035	6	6.82148
PP	9.67887	8.55395	7.46093
PVC	10.9919	9.74982	6.97709
PS	7.73546	7.14971	3.87350

*Age*

<b>Industry</b>	<b>Mean</b>	<b>Median</b>	<b>Standard Deviation</b>
PE	36.36	31	13.5428
PP	40.7333	41	13.6734
PVC	40.5459	39.9322	10.7632
PS	37.8623	36.3902	8.51414

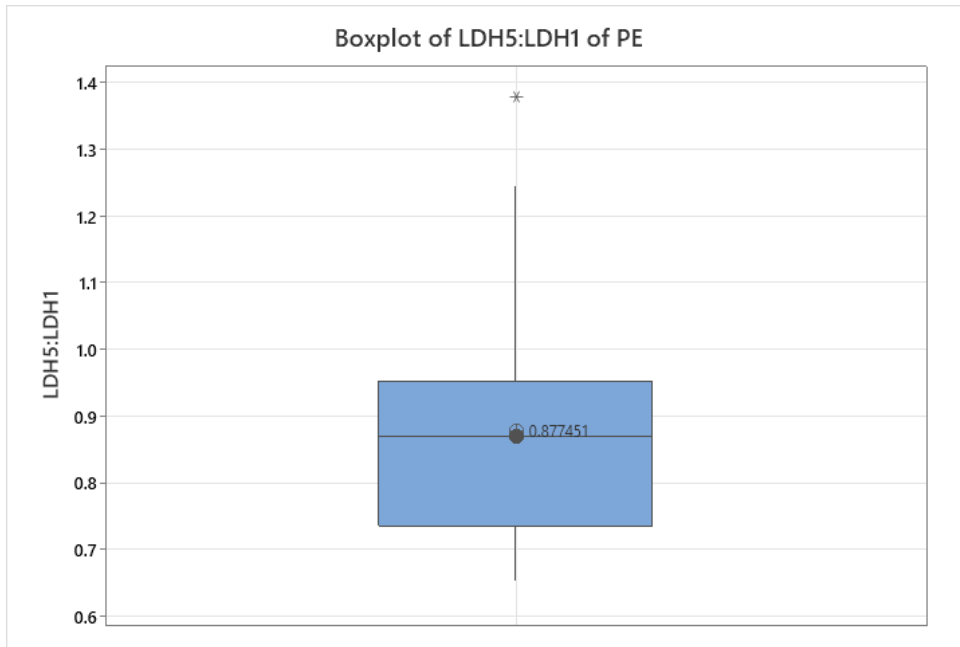


Figure 1: Boxplot of LDH5:LDH1 of PE

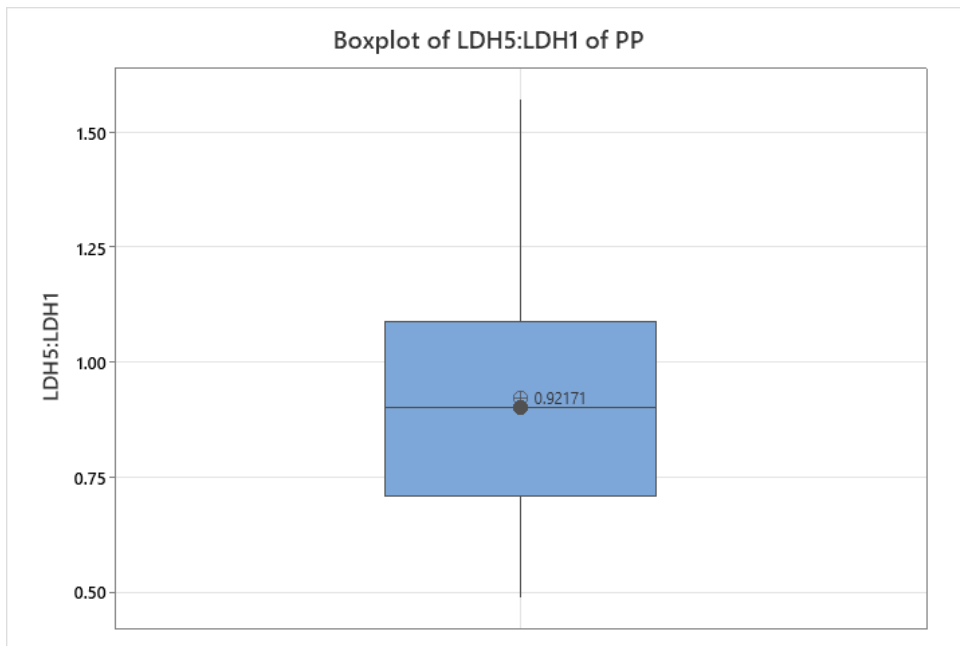


Figure 2: Boxplot of LDH5:LDH1 of PP

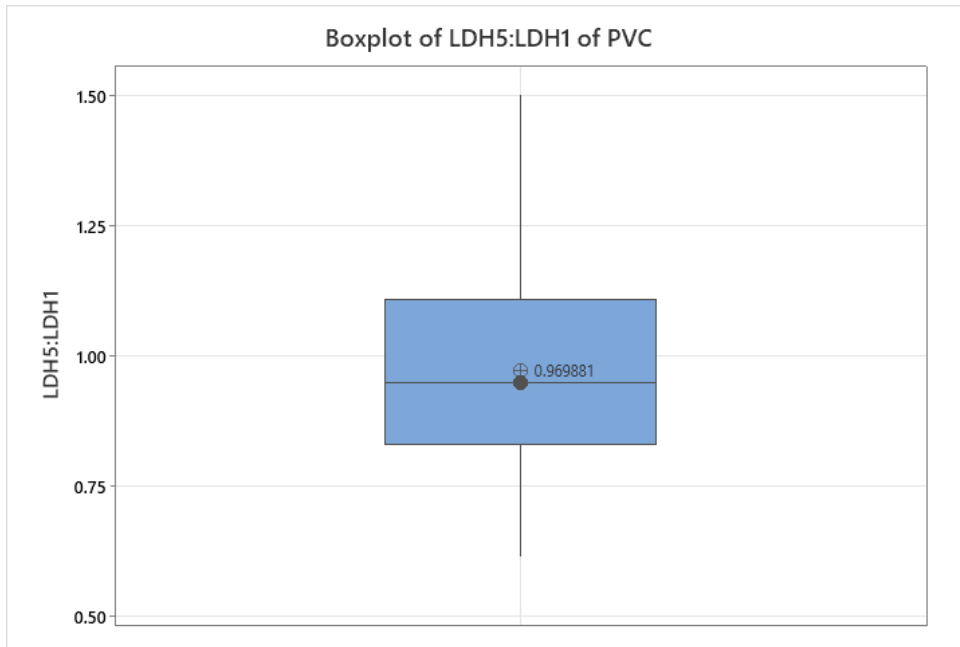


Figure 3: Boxplot of LDH5:LDH1 of PVC

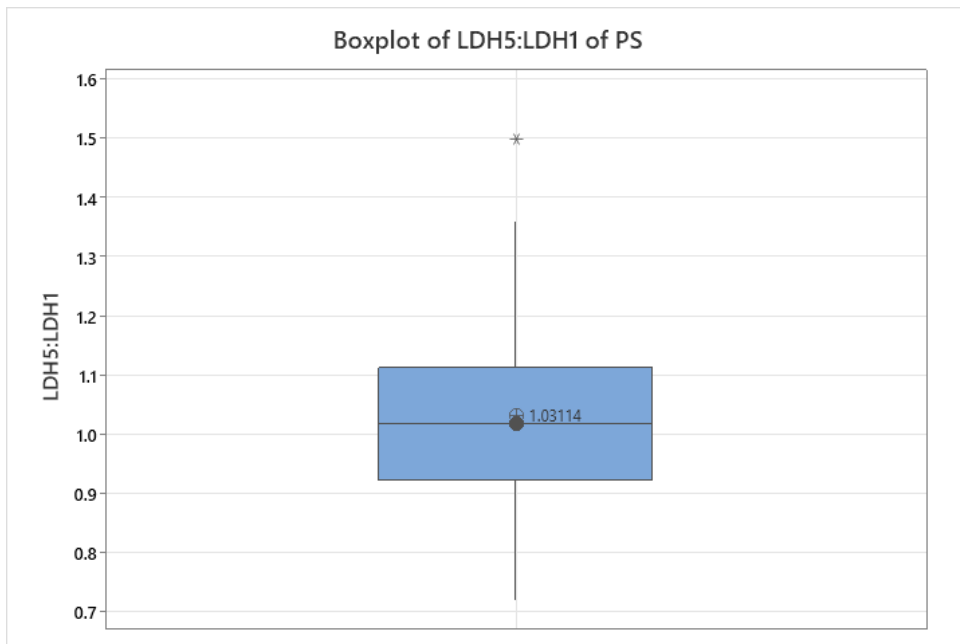


Figure 4: Boxplot of LDH5:LDH1 of PS

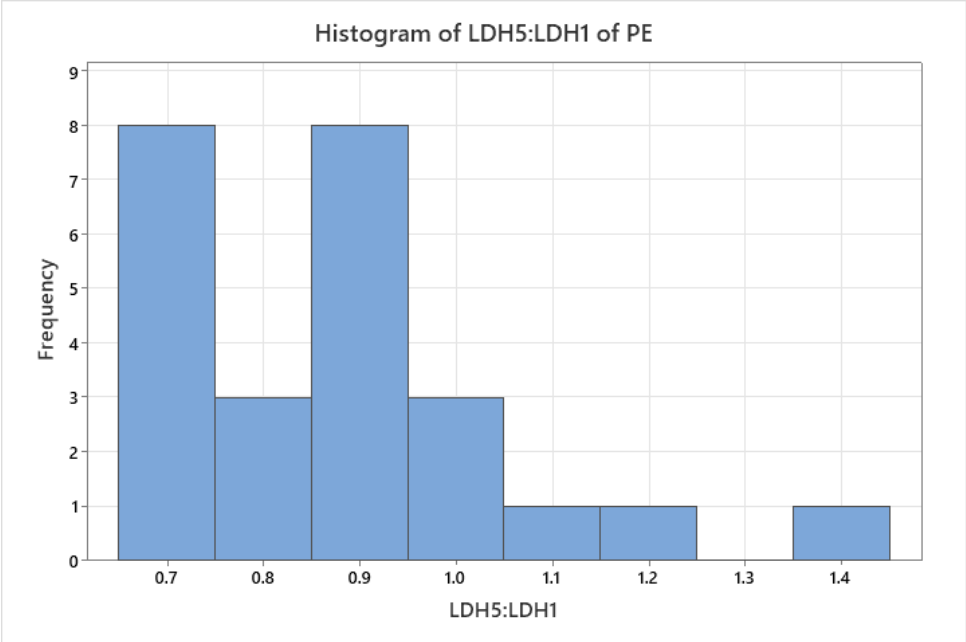


Figure 5: Histogram of LDH5:LDH1 of PE

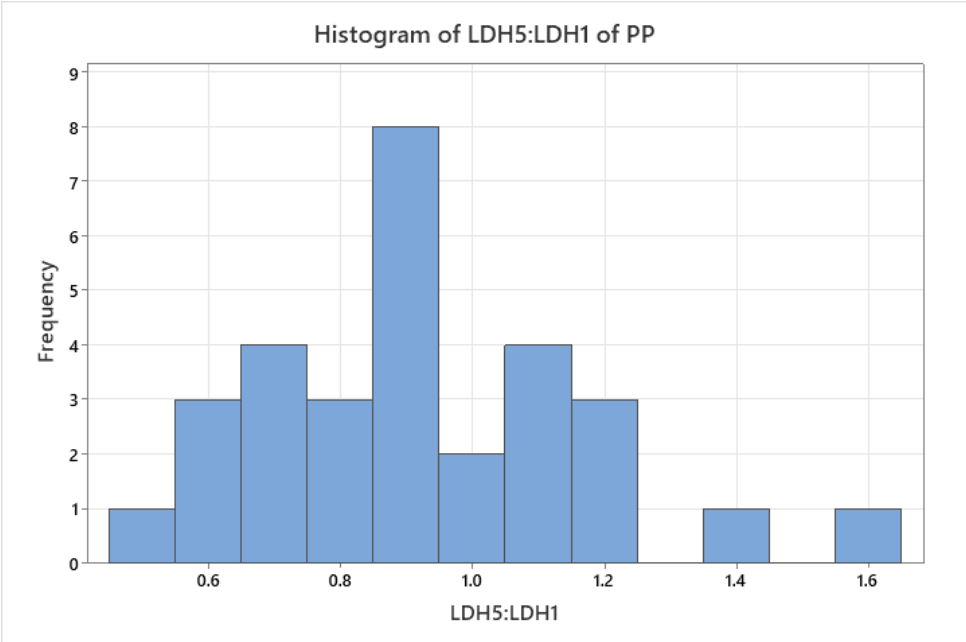


Figure 6: Histogram of LDH5:LDH1 of PP

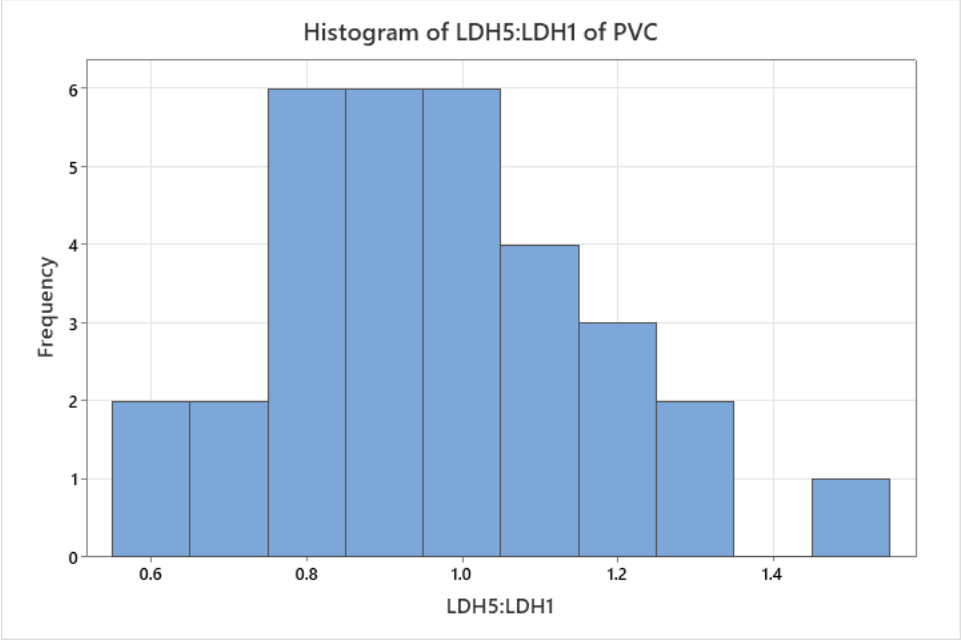


Figure 7: Histogram of LDH5:LDH1 of PVC

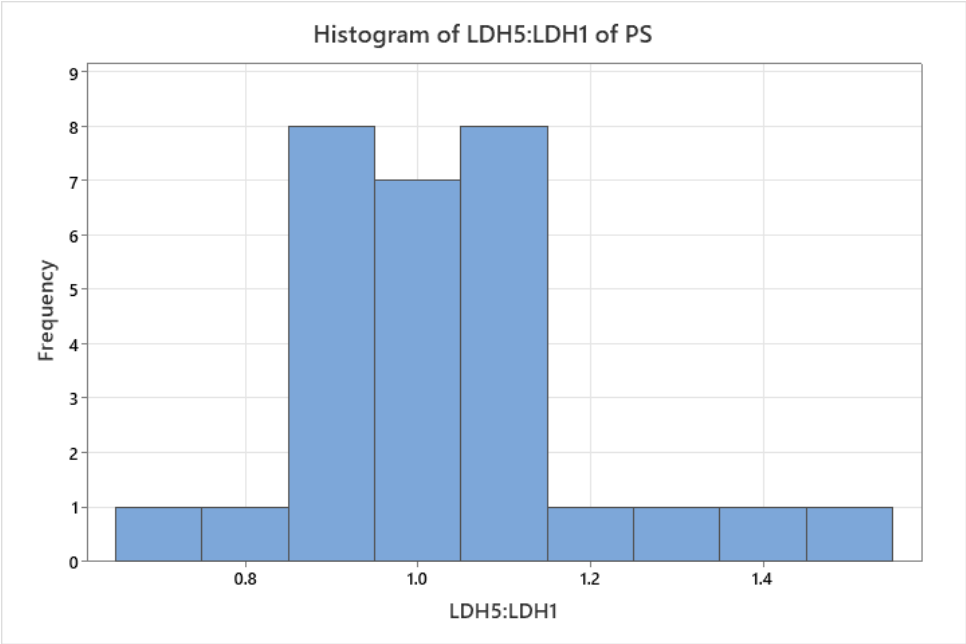


Figure 8: Histogram of LDH5:LDH1 of PS

Test Choice

Normality (Anderson-Darling test) Assessment

The distribution of the LDH ratio across industries was tested before choosing the hypothesis tests using the Anderson-Darling test of normality. When the  $p$ -value is higher than 0.05, the data follows a normal distribution, whereas when the size of the  $p$ -value is less than 0.05, the data is deviated significantly, which requires non-parametric tests (Yang and Berdine, 2021). Visual evaluation (histograms) was also employed to determine skewness, heavy tails and outliers which might influence the suitability of parametric procedures.

#### *Two-Variance Test*

To identify differences of variances among groups, Levene (non-normally distributed data) takes two variance tests. The null hypothesis is tested with the use of equal variances, which would be tested using the test, as a  $p$ -value greater than 0.05 would indicate that the variances are equal, and a  $p$ -value less than 0.05 would indicate that the null assumption is not met. What makes this testing significant is that one needs to be able to use the pooled two-sample  $t$ -test or the Welch form.

#### *Decision on Parametric and Non-Parametric Tests*

A two-sample  $t$ -test is employed to make a pair-wise comparison that assumes that the two groups are similar and approximately normal with equal variances, used to compare the mean ratio of LDH in relation to various groups. In the event of non-parametric normality or equal variances, the Mann-Whitney test, a non-parametric test of rank, which is defined using ranked data, is applied and in skewed distributions and where outliers and varying variances are present. The approach will offer a statistical validity of all the comparisons in question based on the nature of the information.

#### *ANOVA One-Way*

The levels of lactate dehydrogenase (LDH) of four industries were compared using PE, PP, PVC and PS. A one-way Analysis of Variance (ANOVA) model was used. Emerson (2022) says that the statistical model of ANOVA makes several assumptions, namely, the residual values are normally distributed, the elements of the sample are equal and independent. In fact, ANOVA is best adapted to make a comparison of three or more groups.

### Results and Interpretation

#### Normality Test Results

The variability of probability plots is presented in Figures 9-12.

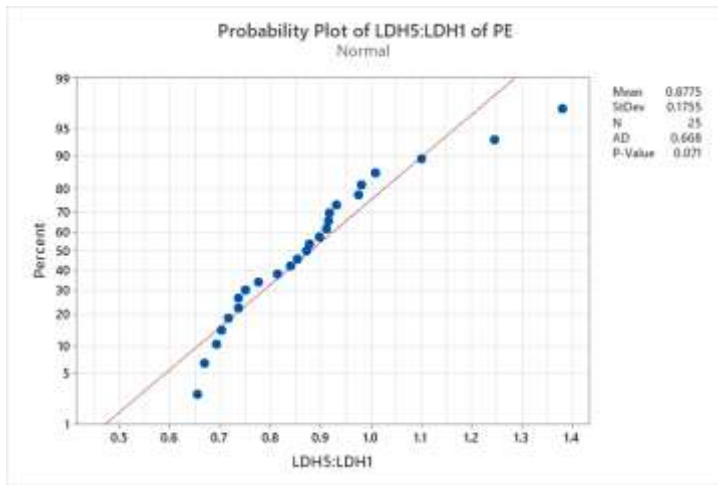


Figure 9: Probability Plot of LDH5:LDH1 of PE

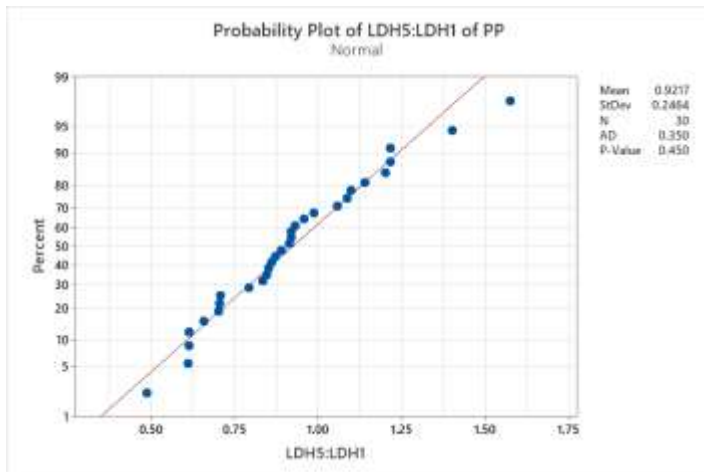


Figure 10: Probability Plot of LDH5:LDH1 of PP

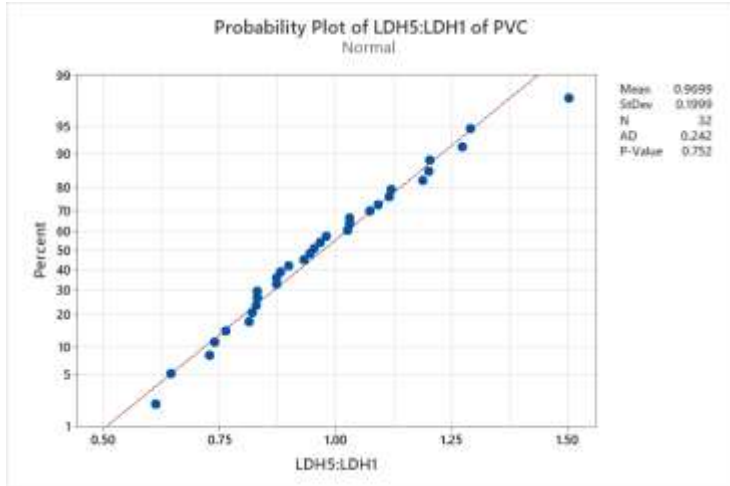


Figure 11: Probability Plot of LDH5:LDH1 of PVC

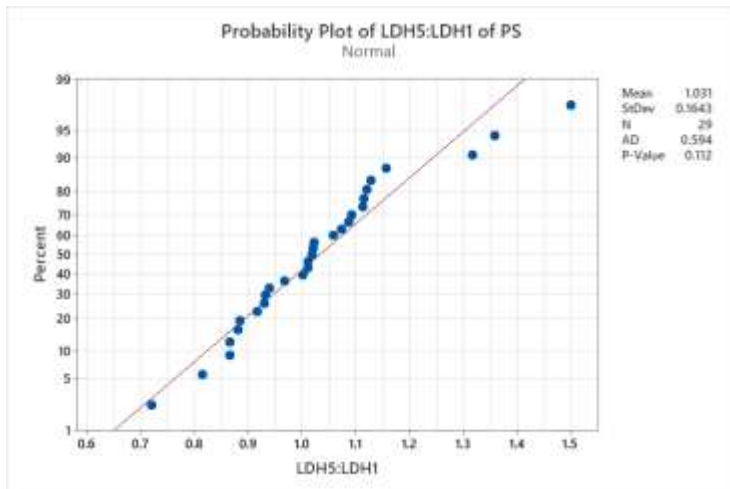


Figure 12: Probability Plot of LDH5:LDH1 of PS

*Interpretation*

The Anderson-Darling test showed that the null hypothesis of normality could not be rejected, because the *p*-values for all of these groups were over 0.05 when analysing the LDH-5:LDH-1 ratio in various industry groups. The AD values are in the graphs. Coming hotfooting from this, the ratio distributions in these groups approximate the normal distribution, making it safe to use parametric tests like two-sample t-tests and ANOVA in the next stage of analysis.

*2- Variance Test*

Two Variances - LDH Ratio vs gender for PE

Descriptive Statistics

gender	N	StDev	Variance	95% CI for $\sigma$
f	11	0.140	0.020	(0.088, 0.272)
m	14	0.196	0.039	(0.114, 0.392)

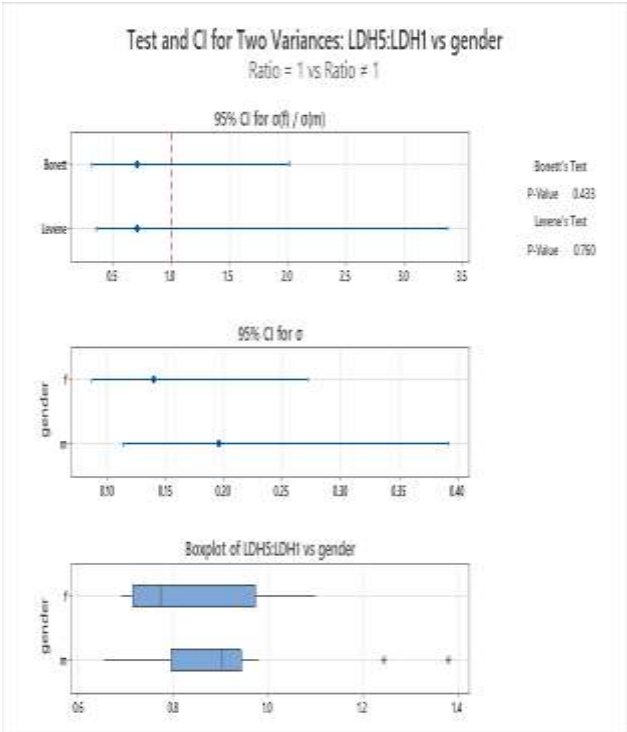
Ratio of Standard Deviations

Estimated Ratio	95% CI for Ratio using Bonett	95% CI for Ratio using Levene
0.713344	(0.327, 2.020)	(0.365, 3.373)

Test

Null hypothesis  $H_0: \sigma_1 / \sigma_2 = 1$   
 Alternative hypothesis  $H_1: \sigma_1 / \sigma_2 \neq 1$   
 Significance level  $\alpha = 0.05$

Method	Test			
	Statistic	DF1	DF2	P-Value
Bonett	*			0.433
Levene	0.10	1	23	0.760



LDH5:LDH1 test against gender for PP

**Method**

$\sigma_1$ : standard deviation of LDH5:LDH1 when gender = f  
 $\sigma_2$ : standard deviation of LDH5:LDH1 when gender = m  
 Ratio:  $\sigma_1/\sigma_2$   
 The Bonett and Levene's methods are valid for any continuous distribution.

**Descriptive Statistics**

gender	N	StDev	Variance	95% CI for $\sigma$
f	9	0.262	0.069	(0.148, 0.593)
m	21	0.225	0.050	(0.163, 0.342)

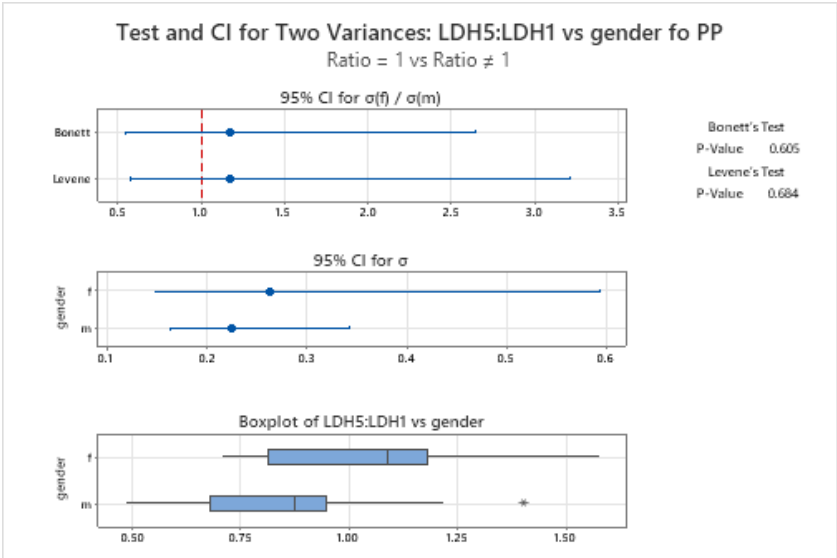
**Ratio of Standard Deviations**

Estimated Ratio	95% CI for Ratio using Bonett	95% CI for Ratio using Levene
1.16660	(0.539, 2.642)	(0.574, 3.213)

**Test**

Null hypothesis  $H_0: \sigma_1 / \sigma_2 = 1$   
 Alternative hypothesis  $H_1: \sigma_1 / \sigma_2 \neq 1$   
 Significance level  $\alpha = 0.05$

Method	Test			
	Statistic	DF1	DF2	P-Value
Bonett	*			0.605
Levene	0.17	1	28	0.684



Test and CI for the Ratio of LDH5:LDH1 vs gender for PVC

Method

$\sigma_1$ : standard deviation of LDH5:LDH1 when gender = f  
 $\sigma_2$ : standard deviation of LDH5:LDH1 when gender = m  
 Ratio:  $\sigma_1/\sigma_2$   
 The Bonett and Levene's methods are valid for any continuous distribution.

Descriptive Statistics

gender	N	StDev	Variance	95% CI for $\sigma$
f	15	0.185	0.034	(0.139, 0.283)
m	17	0.207	0.043	(0.143, 0.340)

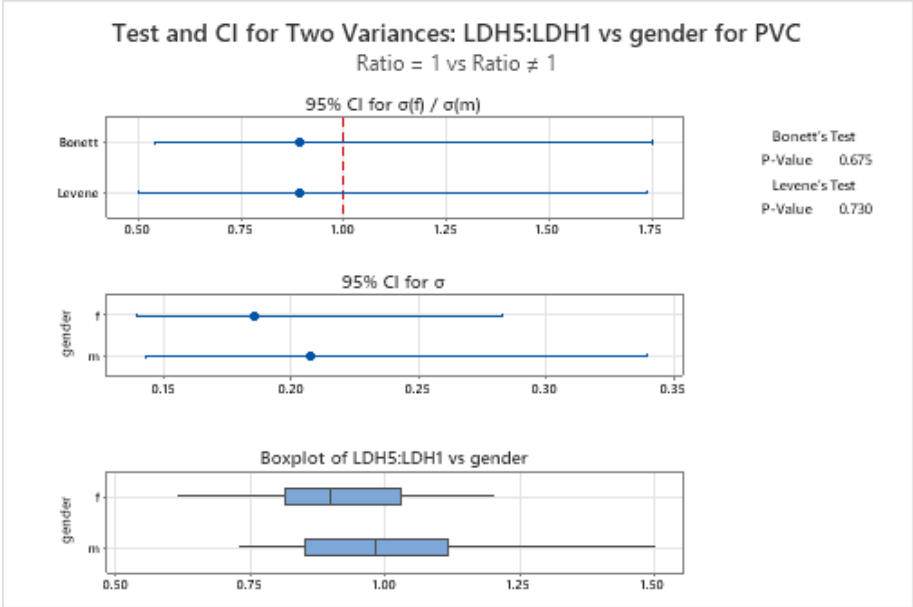
Ratio of Standard Deviations

Estimated Ratio	95% CI for Ratio using Bonett	95% CI for Ratio using Levene
0.893273	(0.540, 1.750)	(0.498, 1.733)

Test

Null hypothesis  $H_0: \sigma_1 / \sigma_2 = 1$   
 Alternative hypothesis  $H_1: \sigma_1 / \sigma_2 \neq 1$   
 Significance level  $\alpha = 0.05$

Method	Test			
	Statistic	DF1	DF2	P-Value
Bonett	*			0.675
Levene	0.12	1	30	0.730



LDH5:LDH1 vs gender for PS

Method

$\sigma_1$ : standard deviation of LDH5:LDH1 when gender = f  
 $\sigma_2$ : standard deviation of LDH5:LDH1 when gender = m  
 Ratio:  $\sigma_1/\sigma_2$   
 The Bonett and Levene's methods are valid for any continuous distribution.

Descriptive Statistics

gender	N	StDev	Variance	95% CI for $\sigma$
f	13	0.142	0.020	(0.080, 0.295)
m	16	0.183	0.033	(0.115, 0.330)

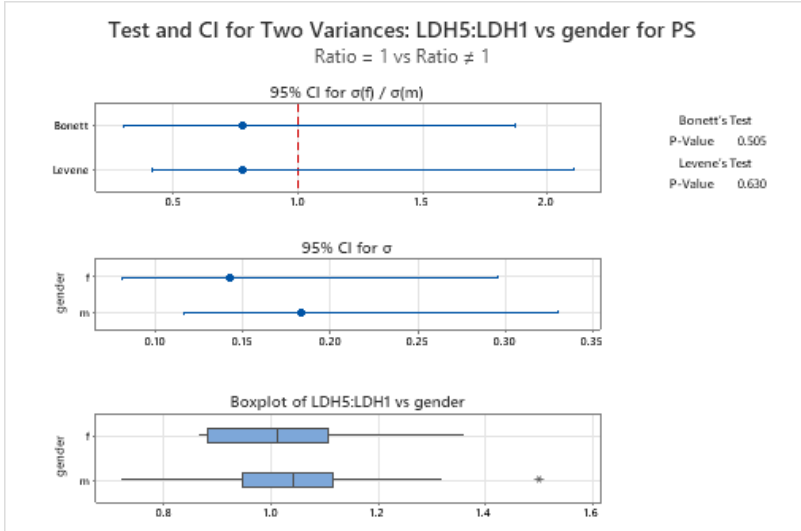
Ratio of Standard Deviations

Estimated Ratio	95% CI for Ratio using Bonett	95% CI for Ratio using Levene
0.775992	(0.295, 1.866)	(0.410, 2.106)

Test

Null hypothesis:  $H_0: \sigma_1 / \sigma_2 = 1$   
 Alternative hypothesis:  $H_1: \sigma_1 / \sigma_2 \neq 1$   
 Significance level:  $\alpha = 0.05$

Method	Test			P-Value
	Statistic	DF1	DF2	
Bonett	*			0.505
Levene	0.24	1	27	0.630



### Interpretation

Two-variance tests were done to determine the difference in the LDH-5:LDH-1 ratio of the male and female workers in various industries. There was no significant difference in variance in the PE, PP, PVC, and PS industry ( $p > 0.05$ ). The visual evidence indicated that there were confidence intervals and boxplots with wider variability of females in PP, and the other sectors reflected the same distribution.

### 2-Sample t-tests

PE (LDH5:LDH1) vs. PP (LDH5:LDH1\_PP)

#### Method

$\mu_1$ : population mean of LDH5:LDH1

$\mu_2$ : population mean of LDH5:LDH1\_PP

Difference:  $\mu_1 - \mu_2$

*Equal variances are not assumed for this analysis.*

#### Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
LDH5:LDH1	25	0.877	0.175	0.035
LDH5:LDH1_PP	30	0.922	0.246	0.045

#### Estimation for Difference

Difference	95% CI for Difference
-0.0443	(-0.1588, 0.0703)

#### 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
-0.78	51	0.442

*PVC (LDH5:LDH1) vs. PS (LDH5:LDH1\_PS)*

### Method

$\mu_1$ : population mean of LDH5:LDH1  
 $\mu_2$ : population mean of LDH5:LDH1\_PS  
 Difference:  $\mu_1 - \mu_2$

*Equal variances are not assumed for this analysis.*

### Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
LDH5:LDH1	32	0.970	0.200	0.035
LDH5:LDH1_PS	29	1.031	0.164	0.031

### Estimation for Difference

Difference	95% CI for Difference
-0.0613	(-0.1547, 0.0322)

### 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
-1.31	58	0.195

### Interpretation

The study compared mean LDH ratios between PE and PP workers using a 2-sample *t*-test due to unequal variances. With a *p*-value of 0.442 for PE and PP, and 0.195 for PVC and PS comparisons, both *p*-values exceed 0.05, indicating no significant difference in liver function biomarker levels between the two industries. The confidence interval further addresses the potential difference in means observed.

Mann-Whitney Test (Non-parametric)

*PE (LDH5:LDH1) vs. PP (LDH5:LDH1\_PP)*

**Method**

$\eta_1$ : median of LDH5:LDH1  
 $\eta_2$ : median of LDH5:LDH1\_PP  
 Difference:  $\eta_1 - \eta_2$

**Descriptive Statistics**

Sample	N	Median
LDH5:LDH1	25	0.870501
LDH5:LDH1_PP	30	0.900315

**Estimation for Difference**

Difference	CI for Difference	Achieved Confidence
-0.0330532	(-0.156623, 0.0647851)	95.11%

**Test**

Null hypothesis  $H_0: \eta_1 - \eta_2 = 0$   
 Alternative hypothesis  $H_1: \eta_1 - \eta_2 \neq 0$

Method	W-Value	P-Value
Not adjusted for ties	665.00	0.560
Adjusted for ties	665.00	0.560

*PVC (LDH5:LDH1) and PS (LDH5:LDH1\_PS)*

**Method**

$\eta_1$ : median of LDH5:LDH1  
 $\eta_2$ : median of LDH5:LDH1\_PS  
 Difference:  $\eta_1 - \eta_2$

**Descriptive Statistics**

Sample	N	Median
LDH5:LDH1	32	0.94864
LDH5:LDH1_PS	29	1.01827

**Estimation for Difference**

Difference	CI for Difference	Achieved Confidence
-0.0610245	(-0.154155, 0.0227112)	95.13%

**Test**

Null hypothesis  $H_0: \eta_1 - \eta_2 = 0$   
 Alternative hypothesis  $H_1: \eta_1 - \eta_2 \neq 0$

Method	W-Value	P-Value
Not adjusted for ties	901.00	0.191
Adjusted for ties	901.00	0.191

**Interpretation**

The outcomes of the Mann-Whitney tests showed no significant differences ( $p > 0.05$ ) between the groups, with the p values of 0.560 between PE and PP and 0.191 between PVC and PS. This similarity of the parametric and non-parametric results makes it more plausible to believe that there are no statistically significant differences between genders and industry at the pairwise level.

**ANOVA Results**

### Method

Null hypothesis All means are equal  
 Alternative hypothesis Not all means are equal  
 Significance level  $\alpha = 0.05$

*Equal variances were assumed for the analysis.*

### Factor Information

Factor	Levels	Values
Factor	4	LDH5:LDH1_PE, LDH5:LDH1_PP, LDH5:LDH1_PVC, LDH5:LDH1_PS

### Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	3	0.3582	0.11942	2.98	0.035
Error	112	4.4950	0.04013		
Total	115	4.8533			

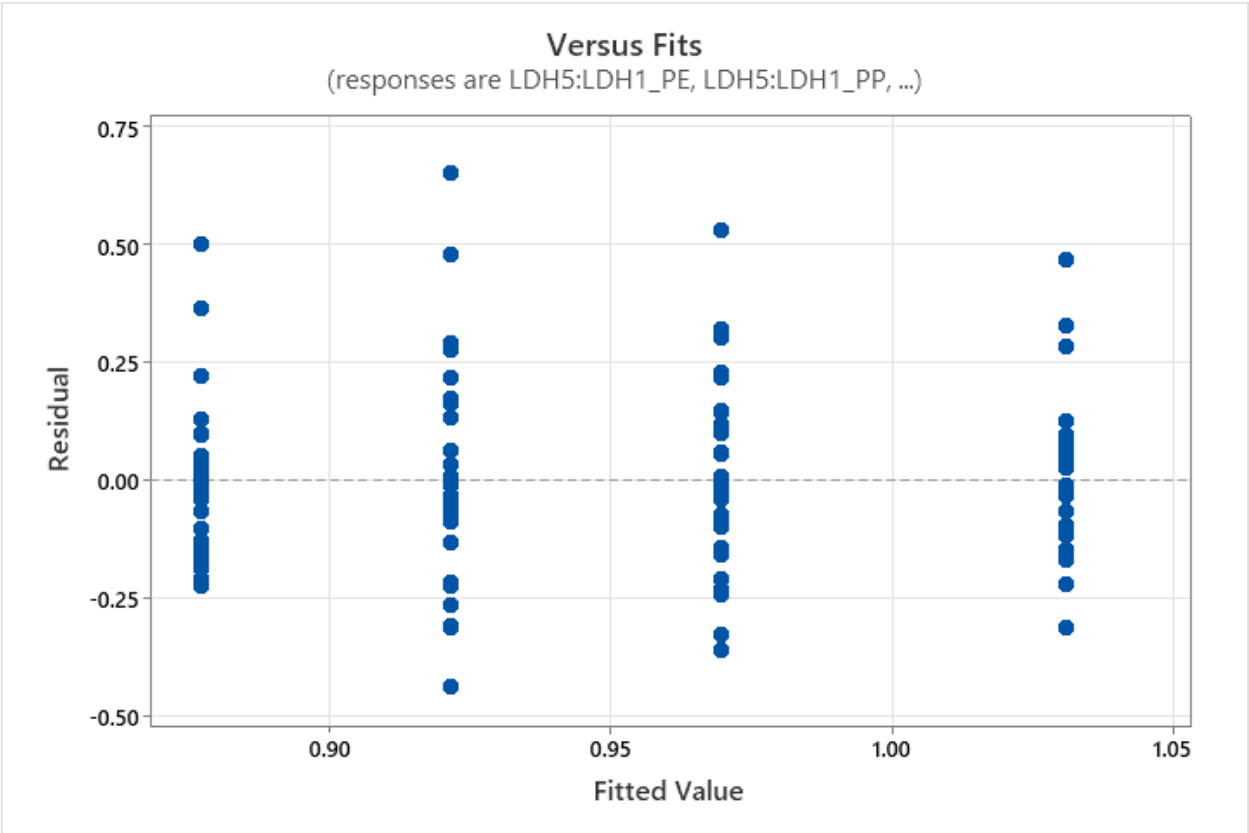
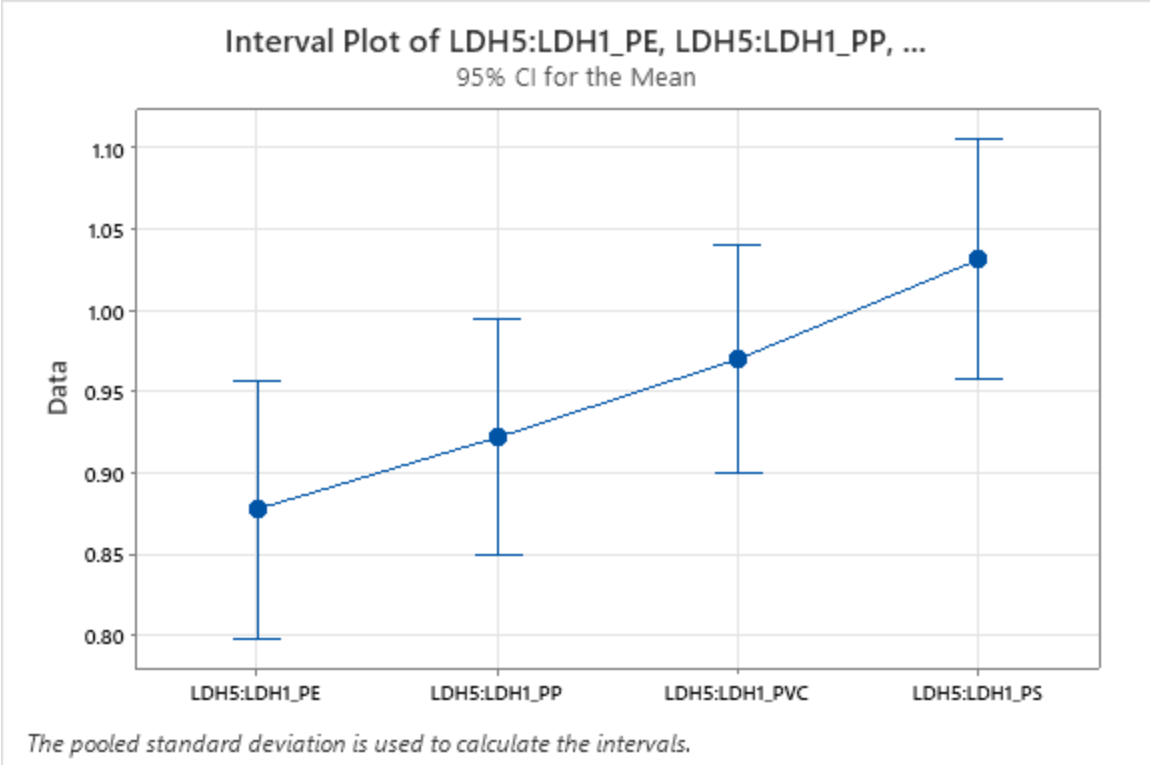
### Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.200335	7.38%	4.90%	0.73%

### Means

Factor	N	Mean	StDev	95% CI
LDH5:LDH1_PE	25	0.8775	0.1755	(0.7981, 0.9568)
LDH5:LDH1_PP	30	0.9217	0.2464	(0.8492, 0.9942)
LDH5:LDH1_PVC	32	0.9699	0.1999	(0.8997, 1.0401)
LDH5:LDH1_PS	29	1.0311	0.1643	(0.9574, 1.1048)

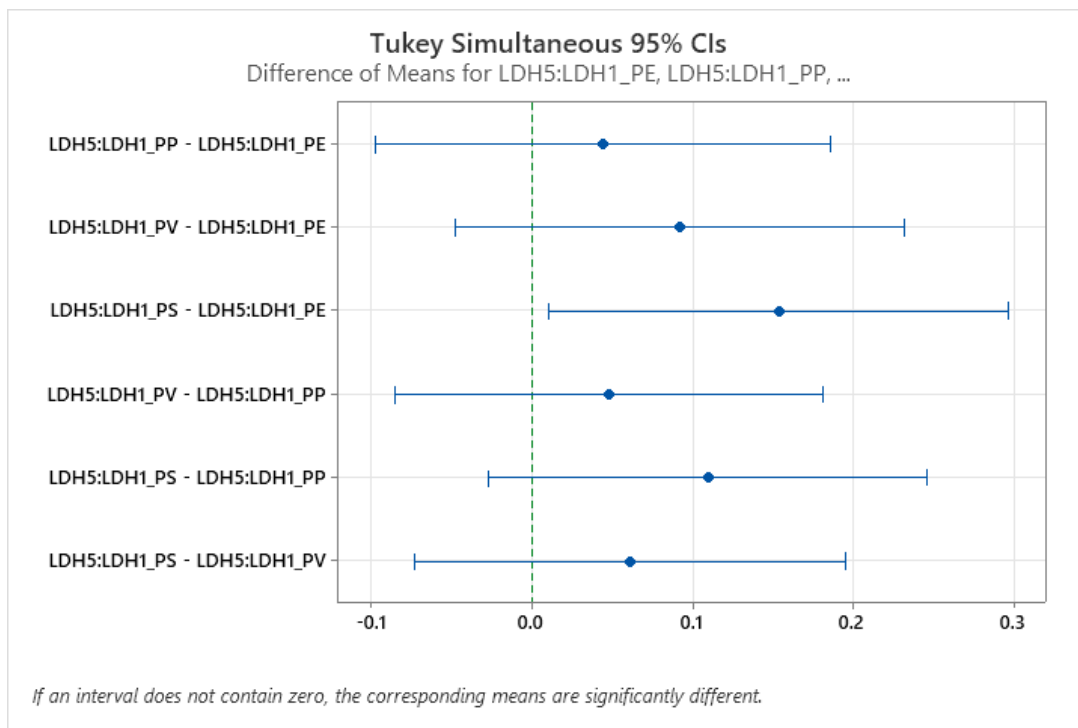
*Pooled StDev = 0.200335*



### Interpretation

The one-way ANOVA examining LDH ratios across four industries (PE, PP, PVC, PS) found no significant differences ( $p = 0.035$ ), with industry type explaining only 7.4% of the variance. Although PS workers had the highest mean LDH ratio and PE workers the lowest, these differences were not statistically significant. The residual analysis supported the assumption of homoscedasticity, indicating consistent variance across groups.

### Tukey Results



### Interpretation

Due to the significance of the obtained results from ANOVA analysis ( $F(3,112) = 2.98$ ,  $p = 0.035$ ), Tukey HSD was utilised to explore the differences of the LDH-5:LDH-1 ratios across various industries. The majority of the confidence intervals included 0, indicating the absence of significant differences for many of the pairs. The comparison between PS (polystyrene) and PE (polyethene), however, was the only one to indicate a significant difference, suggesting that

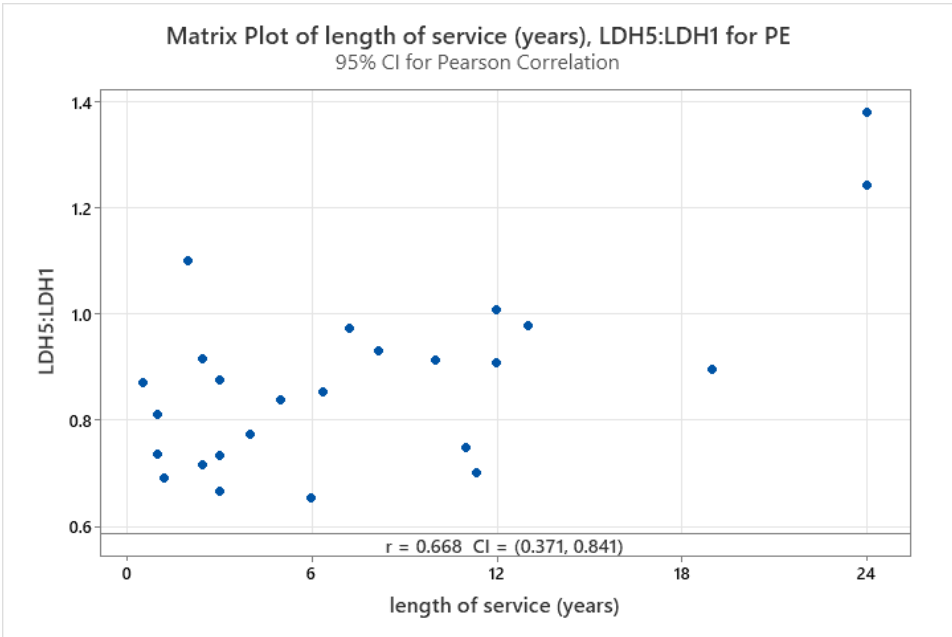
polystyrene employees may be at a greater risk of liver overload. Moreover, these results signify the importance of monitoring exposure within the PS industry.

*Correlation Analysis*

*Pearson Correlation*

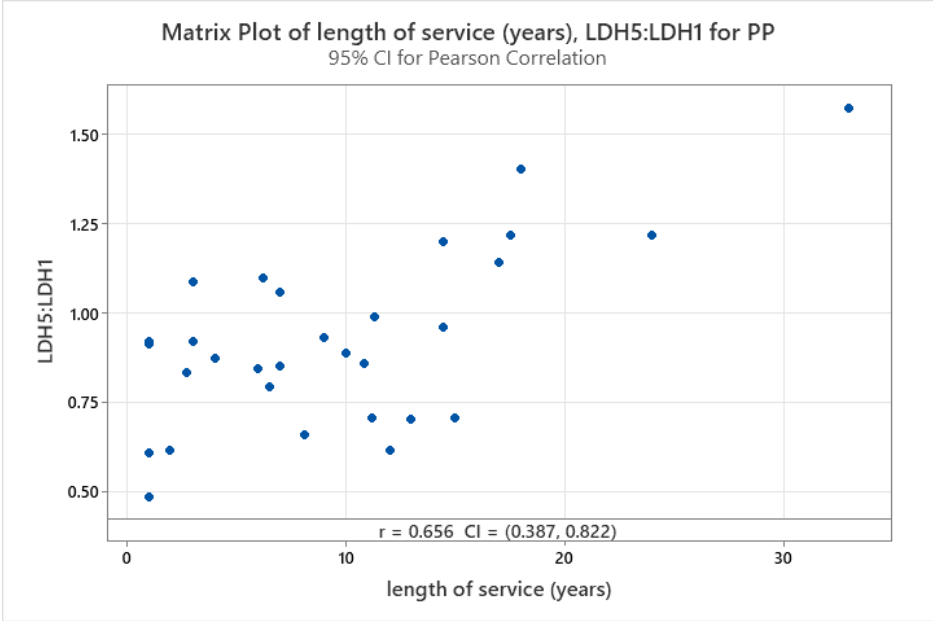
**Pairwise Pearson Correlations**

Sample 1	Sample 2	N	Correlation	95% CI for $\rho$	P-Value
LDH5:LDH1	length of service (years)	25	0.668	(0.371, 0.841)	0.000



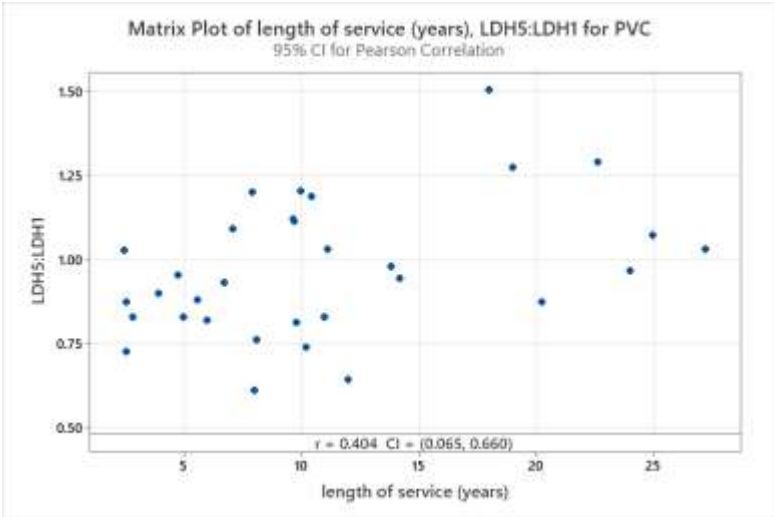
**Pairwise Pearson Correlations**

Sample 1	Sample 2	N	Correlation	95% CI for $\rho$	P-Value
LDH5:LDH1	length of service (years)	30	0.656	(0.387, 0.822)	0.000



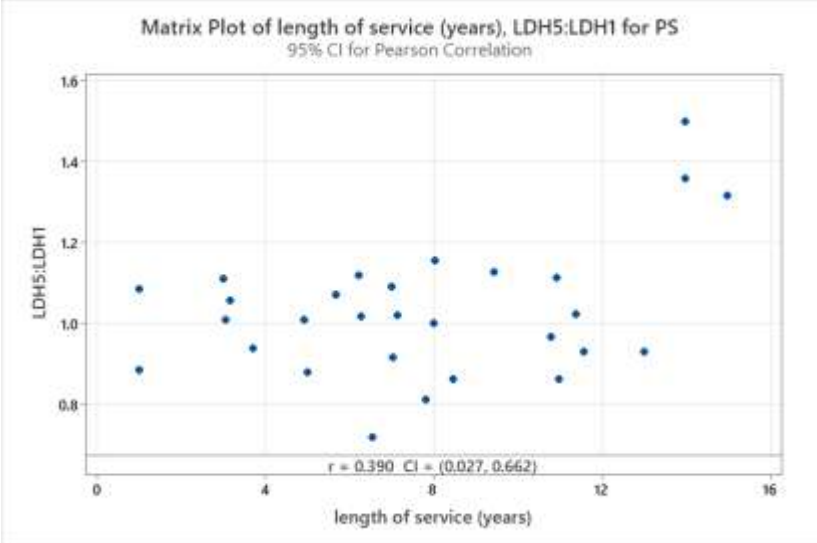
Pairwise Pearson Correlations

Sample 1	Sample 2	N	Correlation	95% CI for $\rho$	P-Value
LDH5:LDH1	length of service (years)	32	0.404	(0.065, 0.660)	0.022

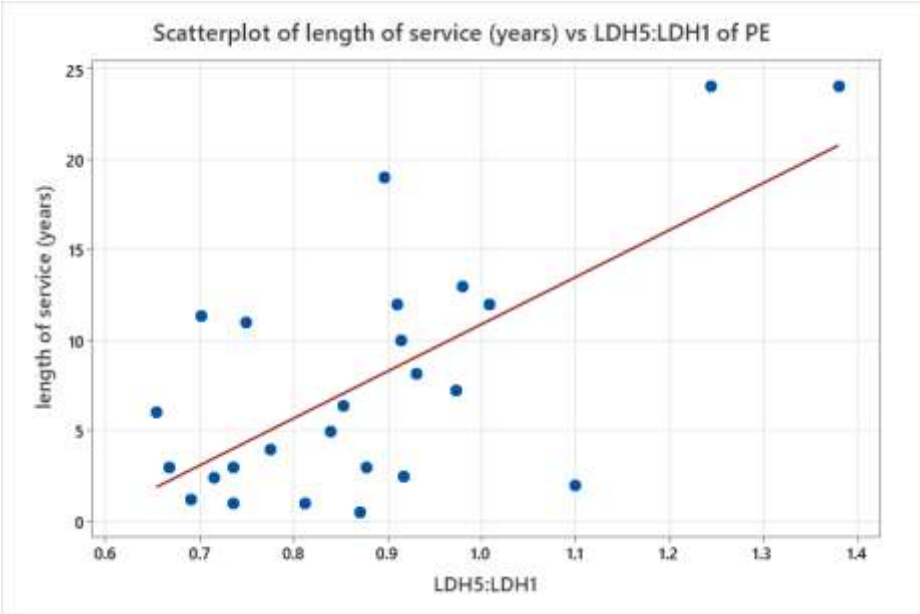


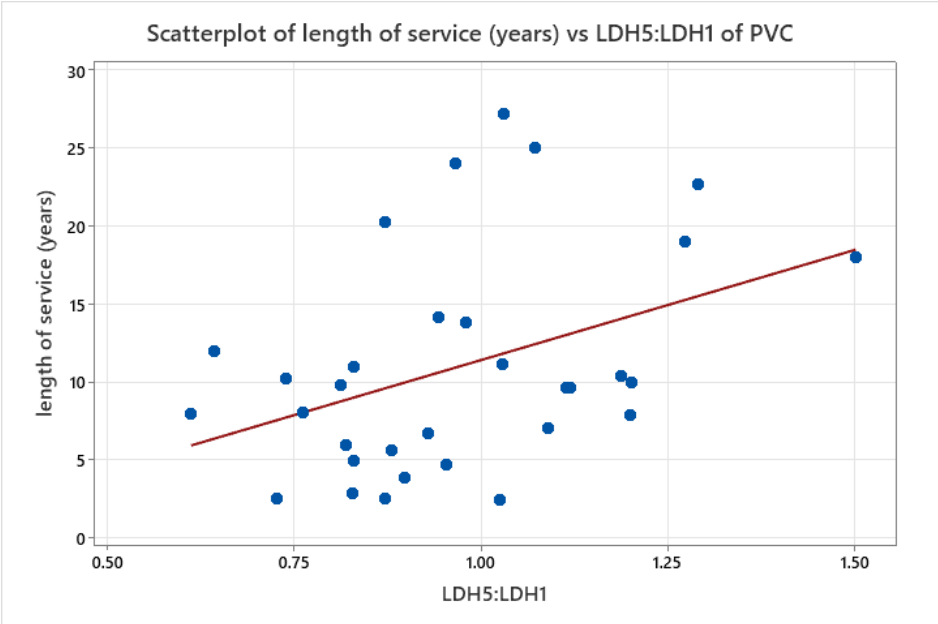
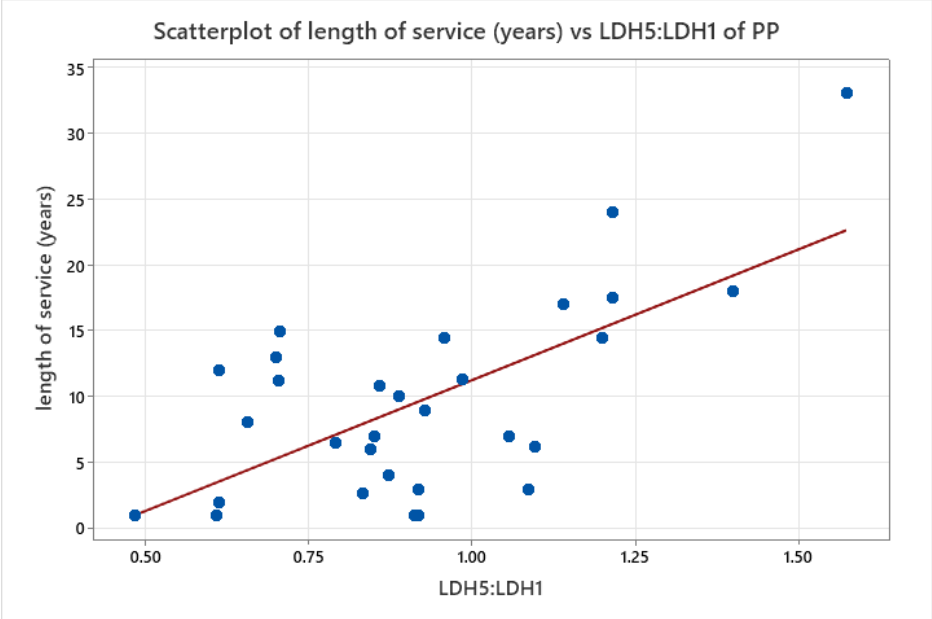
Pairwise Pearson Correlations

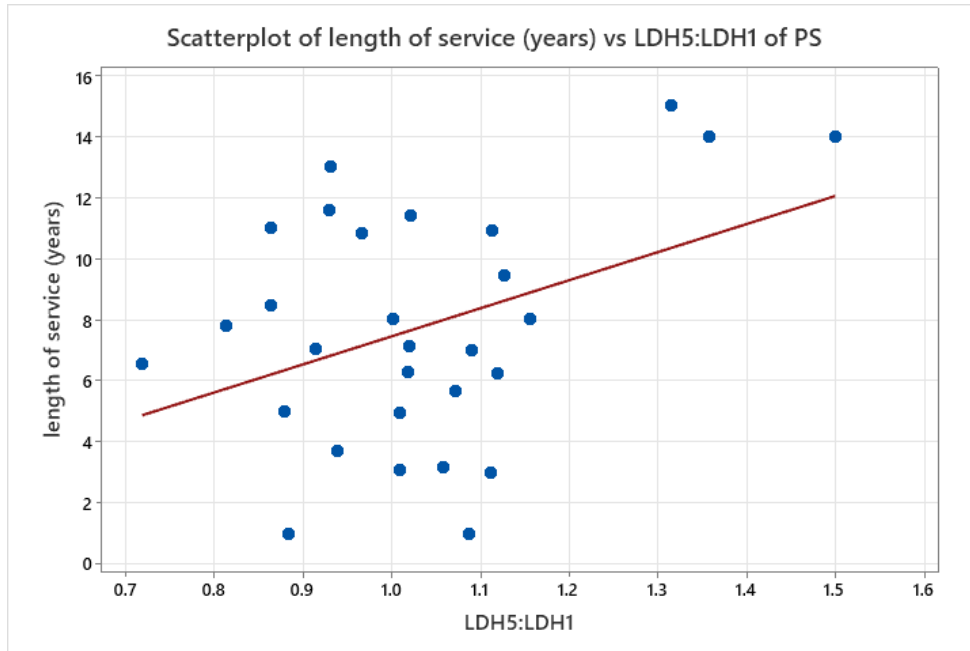
Sample 1	Sample 2	N	Correlation	95% CI for $\rho$	P-Value
LDH5:LDH1	length of service (years)	29	0.390	(0.027, 0.662)	0.037



Scatterplot







### *Interpretation*

In all the industries, the length of service had a considerable association with LDH ratios; however, the correlation varied. The most significant correlation in PE ( $r = 0.668$ ,  $p < 0.001$ ) and PP ( $r = 0.656$ ,  $p < 0.001$ ) suggests that there is a definite association with longer service and higher LDH ratios in these industries. Correlations in PVC ( $r = 0.404$ ,  $p = 0.022$ ) and PS ( $r = 0.390$ ,  $p = 0.037$ ) were also statistically significant, though weaker. The scatterplot, however, showed that no relationship existed between the length of service in the plastic industry and the LDH ratios. It showed very few points with a weak positive correlation trend, particularly in PVC, although the points were quite scattered. Therefore, more tests are needed to answer the research objective.

### Study Design Evaluation

#### *Strengths of the Study*

The main strength of the research is that the inclusion and exclusion criteria designed by the HSE were very extensive and improved the internal validity of the study because it was

limited to workers who had no confounding factors. The selection of individuals to provide the best estimation of the effect of occupational exposure on liver enzyme ratios was restricted to smokers, high alcohol drinkers, non-full-time employees, and individuals with known medical conditions. The random sampling of the study also played down the selection bias, and the sampled workers represented their industries. Furthermore, a reliable biomarker (LDH-5:LDH-1 ratio) of all subjects facilitated similarity and removed inconsistencies in data collection methodology.

#### *Major Design Faults*

Although the study has its strengths, they are minimal, and this limits the strength and generalisability of the study findings. The absence of a control group also hampers the likelihood of assigning changes in the LDH ratios to the workplace exposure, in particular, because there were no comparisons with individuals who were not exposed to work. Moreover, the cross-sectional design merely records information at a single time, perceiving causation as well as differentiating among diverse effects of exposure. It is also based on self-reported alcohol and smoking history, whereby the validity of the measurements is affected by the possibility of recall bias. The misclassification errors in the dataset also have problems related to the integrity of statistical assumptions. Finally, the application of LDH-5:LDH-1 as a single measure of liver status is insufficient, and liver disease is a multifactorial condition, most commonly measured using a combination of numerous biochemical parameters.

#### *Minor Faults*

Some minor limitations of the study were observed, such as an imbalance in sample size between industry groups, with a range of 25 to 32, which could influence the statistical power and test performance. The absence of measurements of the environmental exposure to solvents at

the workplace, e.g. concentration of the solvent at the workplace, limits the possibility to relate the changes in the LDH with the particular level of exposure instead of using the employment sector as a proxy. Controlling for age was not done, which could conceal the service length-LDH ratios relations. In addition, personal protective equipment (PPE) use was not considered in the study, which is key in interpreting the exposure-effect relationships.

### *Suggested Improvements*

A longitudinal study demonstrating changes in LDH ratios and cumulative exposure over time is necessary for improving future work in the area. The inclusion of standard liver function biomarkers like ALT, AST, bilirubin, and GGT in addition to the current panel used in the study will allow for a more complete assessment of liver health. The implementation of environmental monitoring of solvent levels in the workplace could assist in the development of a quantitative exposure response model. Data quality is likely to improve with more rigorous data entry constraints. Additionally, the analysis could be more focused on determining at-risk sub-groups based on factors like age, use of PPE, shift patterns, and specific tasks.

### Conclusion

This study evaluated LDH-5:LDH-1 ratios as markers of liver stress among workers in four plastic manufacturing industries—polyethene, polypropylene, polystyrene, and polyvinyl chloride. The analysis showed no significant differences in these ratios across industries or genders, suggesting that industry type and solvent exposure do not impact liver enzyme levels. However, limitations such as the absence of a non-exposed control group and reliance on self-reported data, including questionable information like that of a 17-year-old employee, raise concerns about data accuracy. Overall, the findings indicate no strong link between LDH ratios and liver stress in this context, highlighting the need to refine diagnostic thresholds for

occupational liver health assessments.

Reference List

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