HE Pennypacker Water Pumps Lean Six Sigma Report

Submitted to:

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1.0 Improvement Opportunity: Define Phase

1.1 Problem Statement

Over the past year, HE Pennypacker (HEP), a company producing water pumps, has been facing a problem with high reject rates in dimensions of the main components of its product, vanes. Currently, the total defect rate is 7.6% from two parallel assembly lines (A and B). The defective vanes, while causing deficiency in pump operation, will also cause an additional $112,248 projected annual quality cost based on detective parts and preventative maintenance for HEP.

1.2 Description of the Process

Currently, HEP inspects every produced vane at each process, and there are two possible defect opportunities: off-limit length or squareness. The vane manufacturing process is as shown in Figure 1. After grinding, all the vanes will go through the deburring process and at where vanes are 100% inspected.

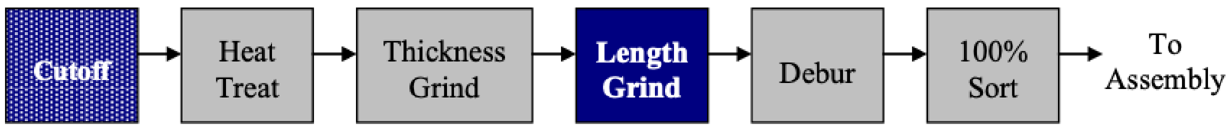


Figure. 1 The Process of Production

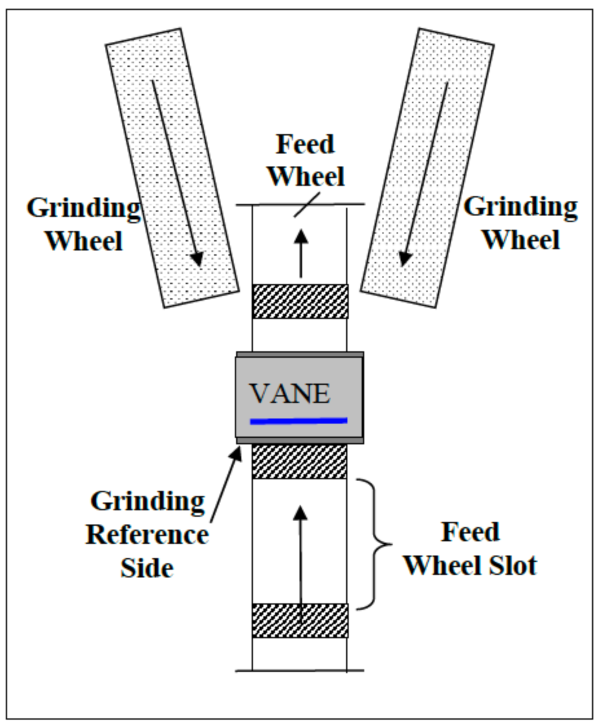


Figure. 2 Length/Squareness Measures After Grinding Process

To lower the defect rate, the operator will adjust the grinder every 40,000 parts. This is called the Preventative Maintenance (PM) process. However, in observing the process, the team discovered that operators do not always follow this guideline and seem to only adjust when scrap rates jump dramatically. In addition to the above PM adjustments, operators may adjust feed rates (e.g., between 13000 to 15000 cm/sec) and coolant flow rates (e.g., between 130 to 150 liters/minute) to try and extend the life between preventative maintenance (PM) cycles.

1.3 Identification of key measures (metrics)

Since there are two defect opportunities for each part, we should use DPMO to count for defects. Based on the attached data file, we can get DPMO = 43,578.5, meaning that in 1 million opportunities, there will be 43,578.5 defects.

If there's a statistically significant difference between the current DPMO and the new method, we could say that our improvement is successful.

1.4 Discussion of project scope

Though vanes may encounter additional inspection for other measures, in this project, we only focus on length and squareness rejects.

2.0 Current State of the Process: Measure Phase

2.1 Current Performance Level

The dataset we used to measure the current state collects the historical data of 2-month production. It has 160 observations and provides the insights of quality and production details of two parallel assembly lines (A and B) including the amount of total production units, the defect parts and the number of defects categorized by day, shift, preventive maintenance adjustment cycle.

Current State Key Y Outputs

The current state of production could be measured by yield, PPM defective and DPMO.

Table. 1 Measurement of Current Process

	Defective Parts	% defective	PPM Defective	DPMO
Assembly Line A	43,164	6.8%	68136.40	39,441.6
Assembly Line B	53,136	8.3%	83269.60	47,685.4
Total	96,300	7.6%	75730.53	43,578.5

Distribution

First, based on the sample set, the team ran Anderson-Darling testf to determine the distribution for both assembly line A and B. For assembly line A, shown by Figure.3, the plot depicts that the distribution is skewed to the right. Most shifts have defect rate from 2% - 10%, whereas there are shifts that have a high defect rate (15% - 25%.) The distribution of defect rate in assembly line B is shown below. A bimodal distribution represents that the manufacturing process of vanes may encounter some special causes that lead to a high defect rate in line B.

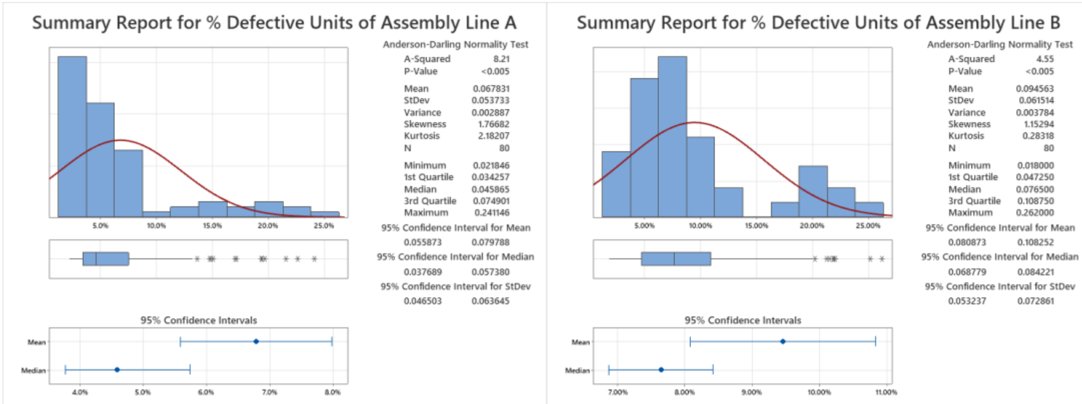


Figure. 3 Histogram of defective rate in Line A and B

Statistical Process Control (SPC)

Next, since we have 2 defect opportunities and the subgroup size varies by shifts, examine the process stability by using U-Chart. Plotting U-chart for each assembly line, we can clearly tell that both assembly line A and B are statistically out of control since most subgroups fall outside $\pm 3\sigma$control limits. Since the variation of the defect rate is inherent and predictable, there's a potential common cause leading to the high defect rate. Also, the high defect rate seems like a chronic problem since it goes above 0.10 in almost every 4-5 shifts. Besides, by comparing the U-Chart from line A and line B, no clear difference was found between the two assembly lines, meaning that the problem might be common.

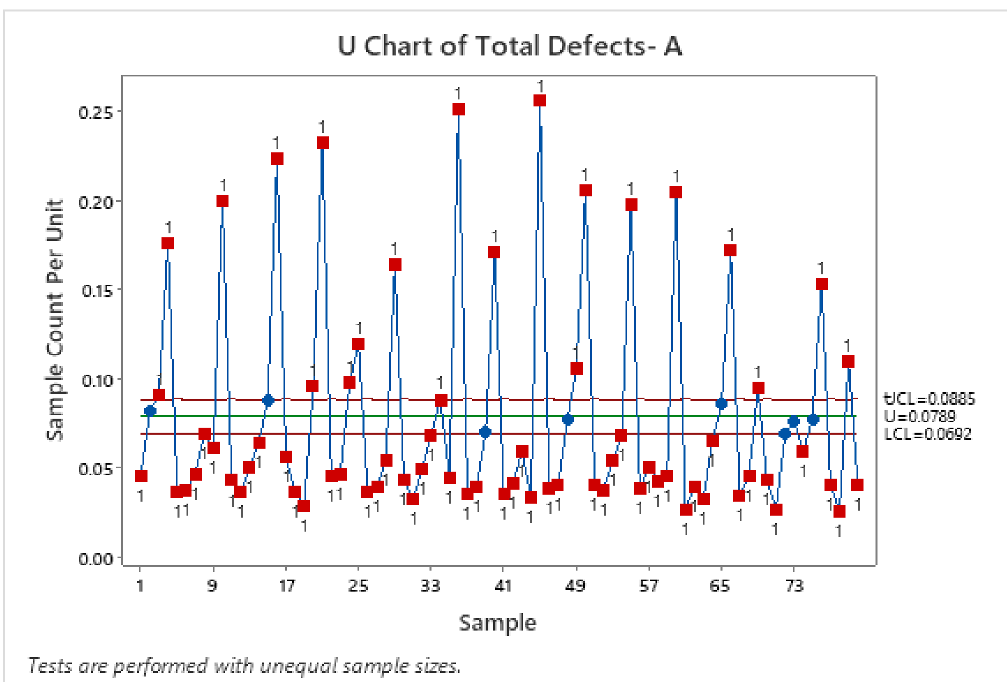


Figure. 4 U Chart of Total Defects of Assembly Line A

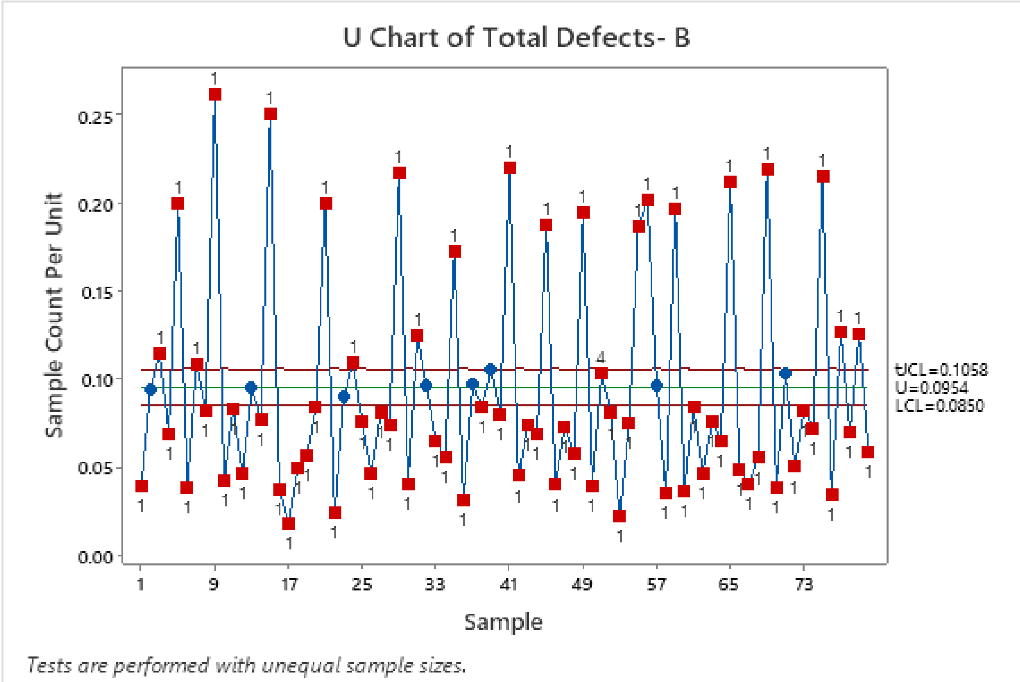


Figure. 5 U Chart of Total Defects of Assembly Line B

Pareto Analysis

- Defects by Defect Types

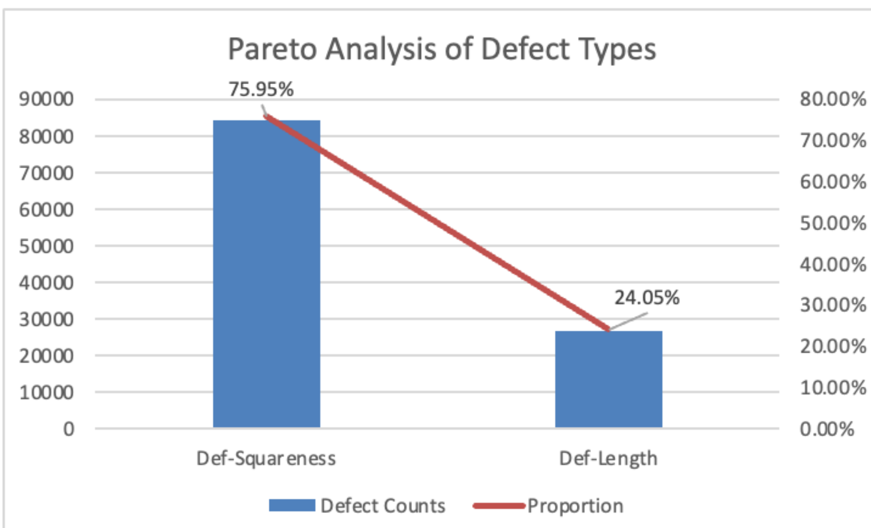


Figure. 6 Pareto Analysis of Defect Types

The defects in squareness account for 75.95% of the total number of defects in the previous two months. Then, when lowering the defect rate of vanes, defects in squareness could be handled first.

- Defects by PM Cycle Period

Since the operator tunes the machine every time after 40,000 parts go through the process (or if an outrageous defect rate occurs), we perform Pareto analyses to isolate the key point. The first Pareto chart is on the Performance Maintenance Day. Stratified days into 3 groups: first run after PM, Normal days, and Last run before next PM. As shown by figure 7, more than 80% of the high defect effects come from “Last Run” and “Normal” days, meaning these two types of days are most influential on the problem.

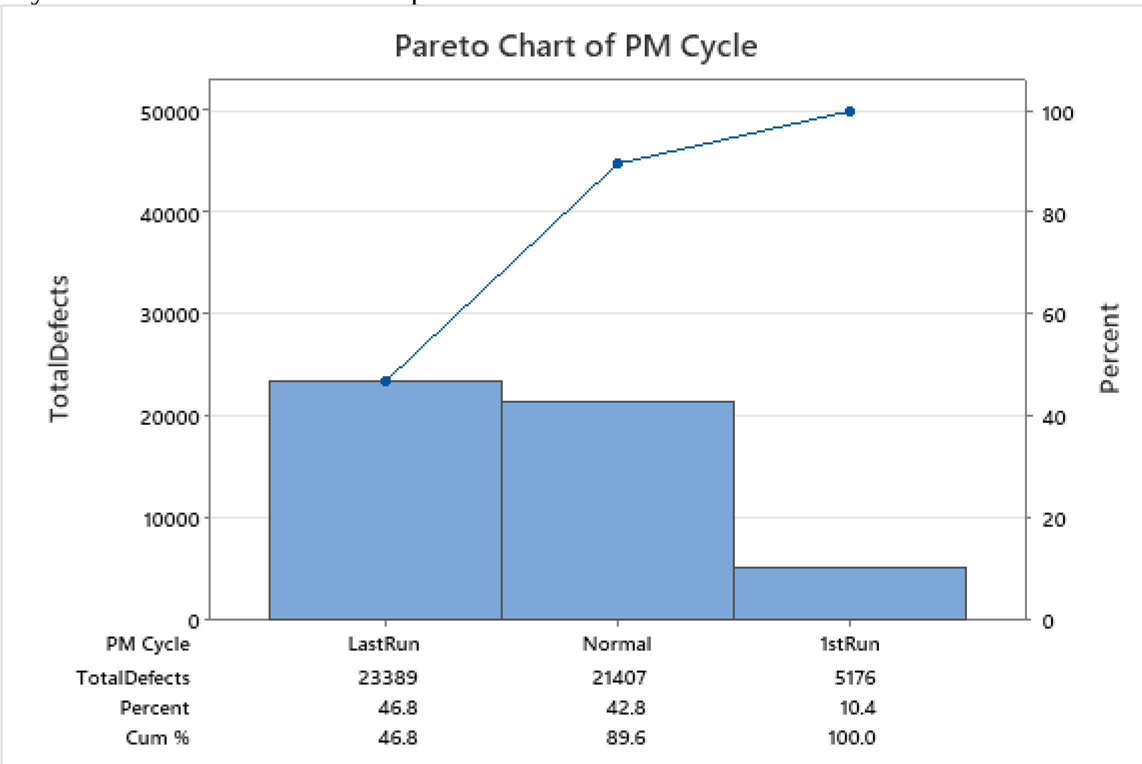


Figure. 7 Pareto Chart of PM Cycle

2.2 Identification of Target Performance Levels or Project Goals

- Our current process has a 7.8% defect rate in general, and the DPMO is 43578 units. we wish to reduce this level to 4%.
- Our current total annual quality cost is $112,248, we wish to reduce this cost to less than $80,000.
- We need to make sure while reducing the cost and defect rate, our production still meets monthly demand.

3.0 Analysis and Findings: The Analyze Phase

3.1 Potential Cause Identification

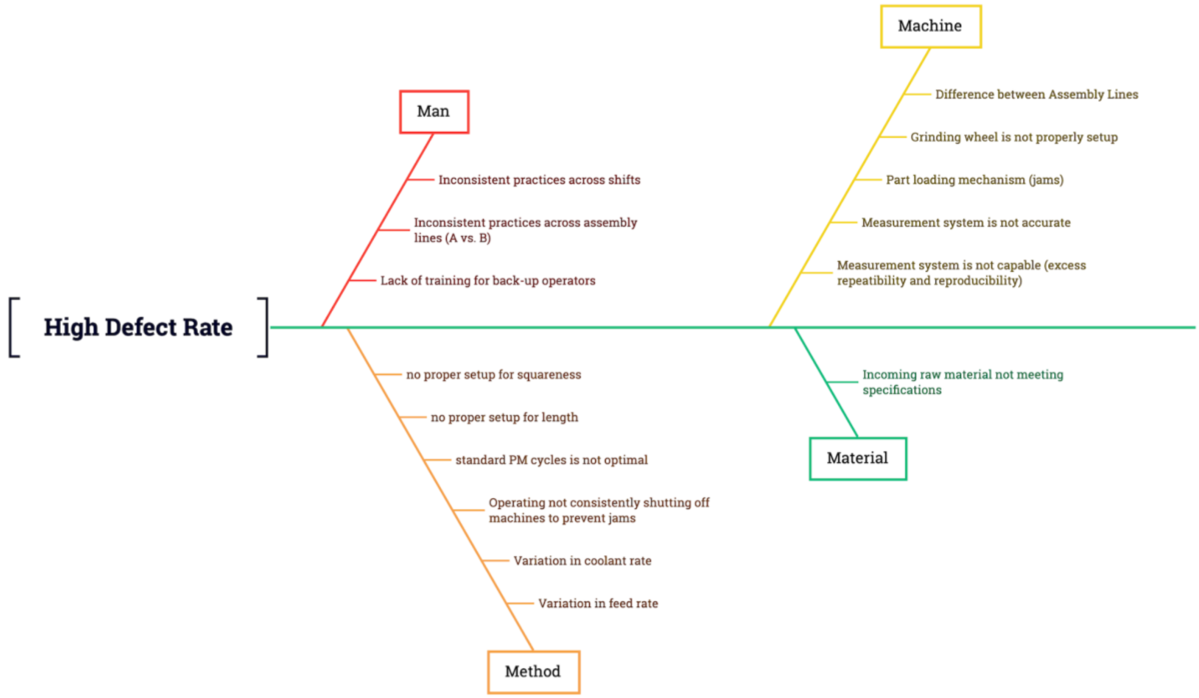


Figure. 8 Cause – Effect Analysis

The team identified 15 root causes of high reject rate in vanes dimensions from 4 main aspects, which are man, method, machine, and material respectively. The later analysis will follow the instruction of qualitative analysis and figure out if these reasons have an impact on the defects in vanes.

3.2 Quantitative Analysis of Regular Production Defects

Variation in Assembly Lines

There exist differences in defects across two assembly lines. From figure. 9, assembly line B generally has more total number of defects compared to assembly line A. While performing 2-sample t-tests, only defects in length observed a significant difference between 2 assembly lines. The inconsistent practices across assembly lines exist influencing the defects in the length of vanes.

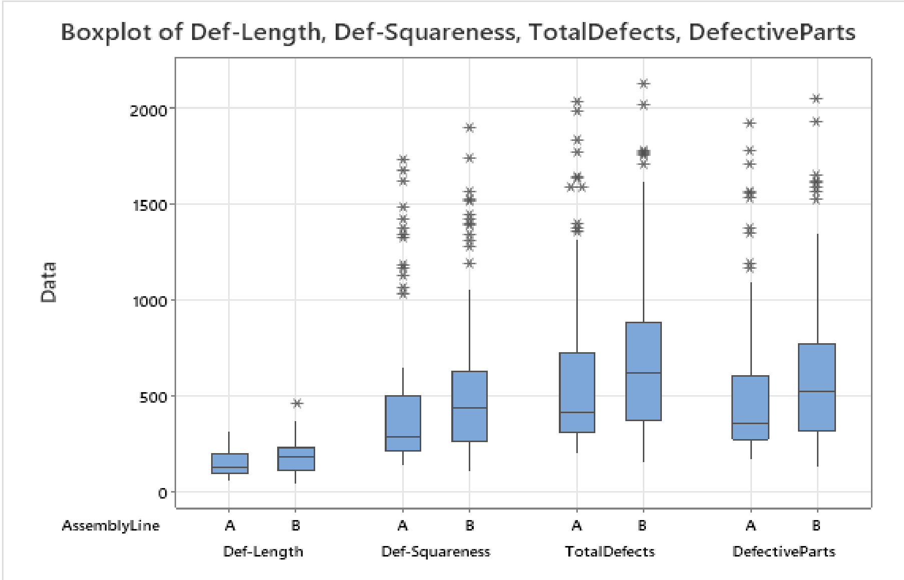


Figure. 9 The Stratification Boxplot by Assembly Line

Variation in Shift

Through figure. 10, it could be observed that shift 1 has more defects than shift 2. Based on the 2-sample t-test, there exists a significant difference of mean between 2 shifts in terms of squareness defects, length defects and total defects while the mean of shift 1 is significantly greater than that of shift 2. Then, it could be concluded that there exists variation or inconsistency across shifts.

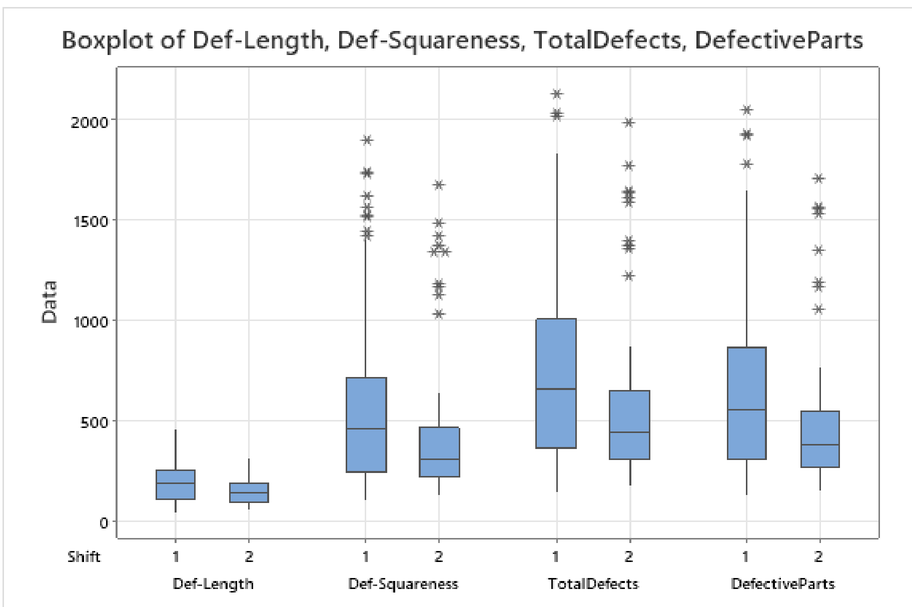


Figure. 10 The Stratification Boxplot by Shift

PM Process Effectiveness

According to the regression model, the percentage of defects will increase with time going on after the PM adjustment. PM adjustment will decrease the defect rate.

For assembly line A, our regression model shows a substantial positive relationship between the cumulative number of parts produced and the defect rate. When the cumulative parts increase as the PM cycle goes on, the percentage of defects increases. The regression of these two factors is

$$\%\text{Defective Units} = -0.00135 + 0.000003\ \text{CumParts\_PM}_A$$

which is statistically significant with a P-value of 0.000 in the ANOVA test.

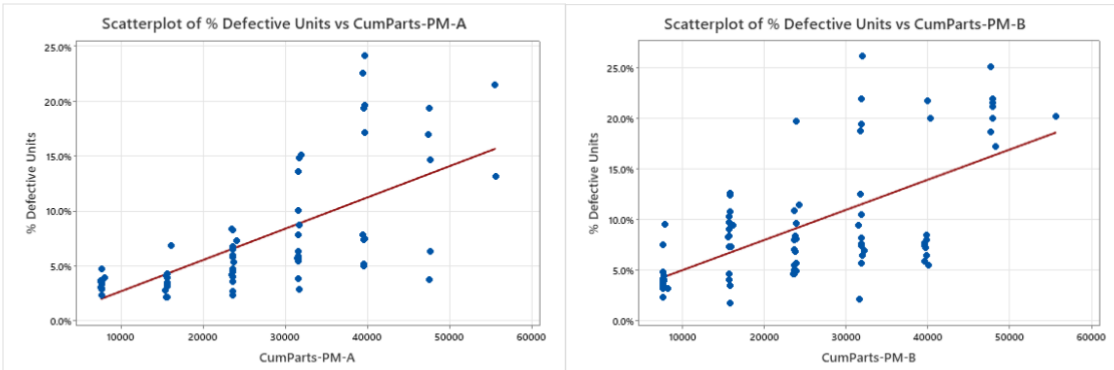


Figure. 11 Scatter Plot of % Defective Units v.s. Cumulative Parts Before PM by Assembly Line

Assembly line B, similarly, shows a substantial positive correlation between the cumulative number of defects and defect rate. The regression of these two factors is

$$\%\ Defective\ Units = 0.0207 + 0.000003\ CumParts\_PM_B$$

which is statistically significant with a P-value of 0.000 in the ANOVA test.

3.3 Special Case - Dimension

In the previous analysis, the defects in squareness contribute to the majority of defects. Also, based on the data of special cases, defects in squareness happen more frequently than that in length. Thus, the defects reduction in squareness should be handled first.

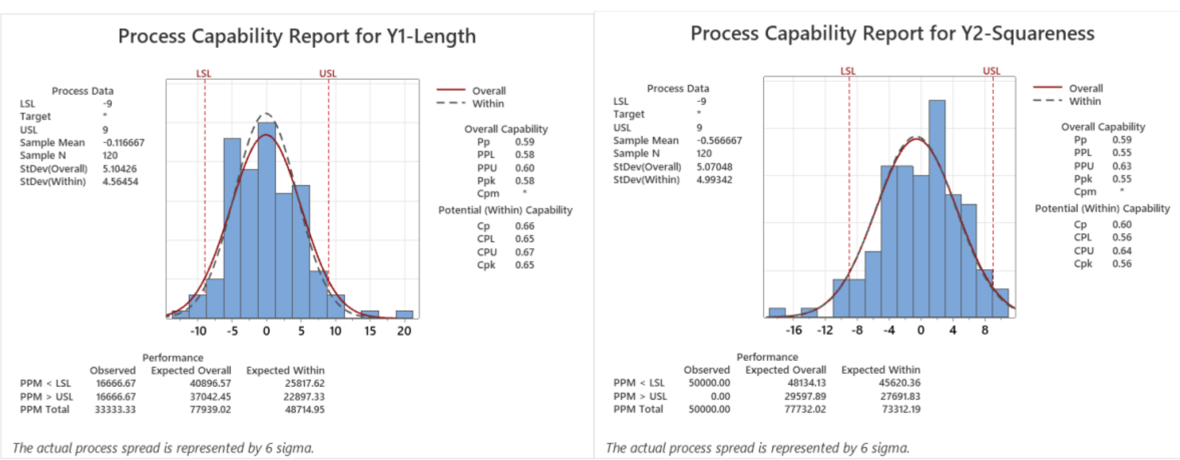


Figure. 12 Process Capability Analysis by Types of Defects

The team first look into the distribution of the squareness defect data and length defect data. Based on the Anderson-Darling normality test, the distributions of both length and squareness follow normal distribution. Then, we applied process capability analysis based on the normal distribution. The process capability indices all below 1.33, we conclude that the process is not capable of consistently producing products and may exist shifts in mean.

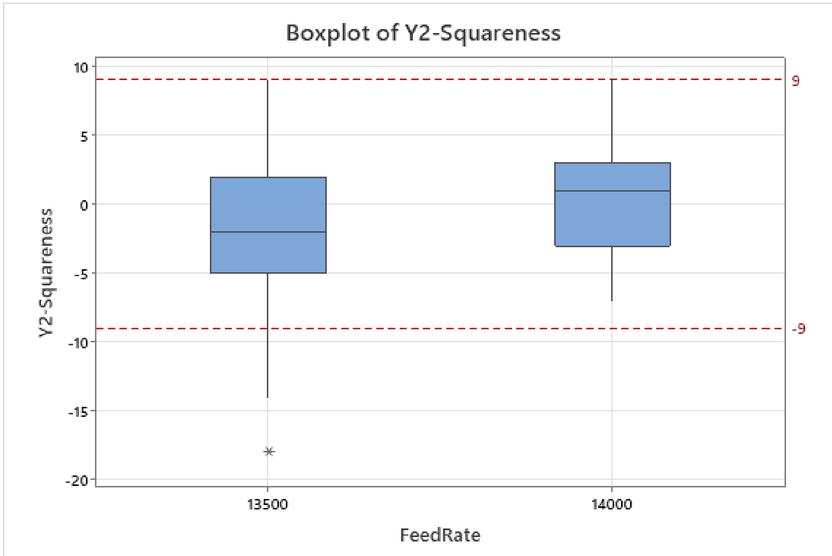


Figure. 13 Boxplot of Squareness by Feed Rate

The team then probe into the potential influence factor of high squareness defect rate. Conducting a 2-sample t-test on whether the feed rate will leads to different defect rate, it shows that the when the feed rate is 13500 cm/sec, the mean of squareness is significantly less than the one when feed rate is 14000 cm/sec (See Appendix). When the feed rate is 14000 cm/sec, the grinding process shows better squareness. Further, there is no significant difference in squareness defect rates by different assembly lines, PM cycle sample sets or coolant flow rate. (See Appendix 1). Therefore, we could conclude that when feed rate is 14000 cm/sec, the defect rate reduces.

Moreover, it shows that the variance of squareness can be influenced by PM cycle periods, feed rate and coolant flow rate. The standard deviation of squareness in the last run before the next PM cycle is much greater than other periods. The higher feed rate and lower coolant flow rate may also lead to smaller standard deviation. (Appendix 2 and 3)

Performing similar tests on length outputs, it shows different PM cycle periods will influence the mean of vanes length and higher feed rate will also decrease the difference towards 0. Similarly, there is no significant difference by different assembly lines and coolant flow rates. In terms of standard deviation, it possesses a influencing pattern in PM cycle and feed rate, however, there is no significant influence in different coolant flow rates.

3.4 Special Case – Shutoff

The team discovers that the feed wheel used to carry the vanes through the grinder is a potential source of problems. If the track jams, the plunger that feed vanes into the conveyor will continue try pushing parts on feed wheel slot, which may cause vane seating improperly for square grinding. Currently, operator are asked to turn off the machine manually when track jams. However, some operators are less disciplined and do not shut down the machine in time.

To evaluate this effect, the team tests the usage of an automatic shut off mechanism for Line A to prevent feed jam occurrences. After installing a new automatic shut off, they run 30,000 parts and record the number of length and squareness defects (across both shifts).

1.Defect Rate Analysis with/without shut-off:

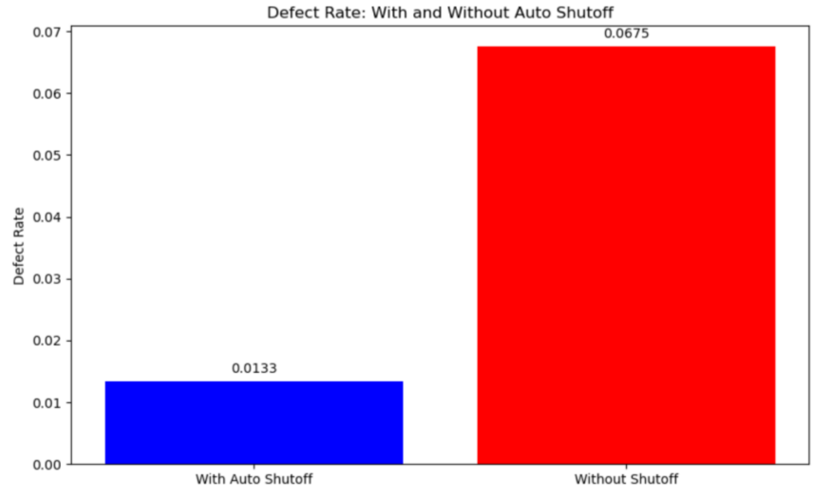


Figure. 14 Defect rate with\without shut-off

Using the Auto Shutoff feature, the defect rate was found to be substantially lower compared to when the feature was not in use. From this special study, they produce 400 defective vane parts. For comparison, for 30,000 parts runs, they typically produce 2025 total defective (with ~505 length and ~1652 squareness defects). Specifically, the defect rate with the Auto Shutoff was approximately 1.33%, whereas without the feature it was roughly 6.75%. This indicates a significant enhancement in quality when the Auto Shutoff feature is employed.

2. Defect Type Analysis:

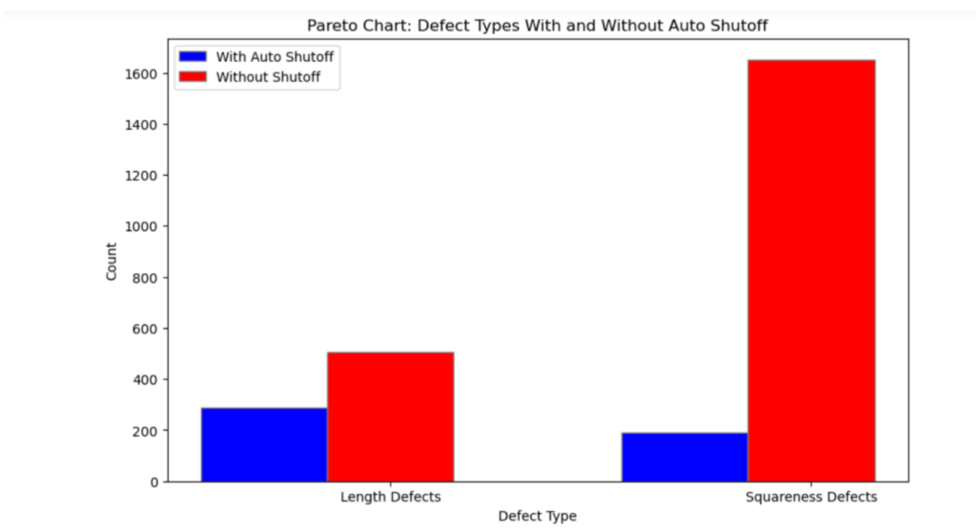


Figure. 15 Defect Types with\without shut-off

A bar chart was used to visually compare the distribution of different defect types under the two conditions. It was observed that "Length Defects" were less prominent with the Auto Shutoff, whereas "Squareness Defects" showed a drastic reduction when using the feature. Among 480 defects, there are 288 squareness defects and 192 lengths defects. This visualization provides a clear indication of the areas of improvement and where the Auto Shutoff feature has its most significant impact.

In conclusion, the Auto Shutoff feature appears to be highly beneficial in reducing the overall defect rate and especially effective in minimizing squareness defects. Implementing this feature can lead to significant improvements in the production quality of Machine A.

4.0 Recommendations: The Improve Phase

To reduce the defects units in vanes of HEP, the following actions are recommended:

- Standardize and better monitoring procedure.
- Perform preventive maintenance every 15,000 parts.
- Add Auto Shut-Off mechanism to both assembly line A and B

Standardize & Monitoring Procedure

Operators should strictly follow the requirements of production. From observing data, operations did not strictly perform preventive maintenance for every 40,000 parts. Based on the previous analysis, the defect rate will increase greatly with the increase of cumulative parts produced after every time preventive maintenance.

Clear and specified coolant rates and feed rates could also reduce the defect rate. Based on the previous study, the **higher feed rate and lower coolant rate** will reduce the difference from expected dimensions and narrow the standard deviation of squareness and length.

Specifically, the performance of assembly line B is significantly lower than that of assembly line A. As shown in Figure 9, assembly line B typically has a higher total number of defects, particularly with respect to squareness defects. Its overall defect count is about 40% higher than that of assembly line A. Additionally, based on Figure 10, shift 1 consistently has a higher count in every defect category compared to shift 2. Therefore, we believe that retraining the operators in shift 1 and specifically tuning assembly line B can effectively improve the production. The team should prepare an additional training for operators in line B to align the defect rate.

Perform Preventive Maintenance Every 15,000 Parts

The team should increase the frequency of PM. According to the analysis, 80% of defects occur prior to calibration, and the defect rate increases the longer the time since the last calibration. Therefore, we should increase the calibration frequency and ensure that the calibrations are done rigorously and quantitatively.

There exists a tradeoff between cumulative parts to perform preventive maintenance and defects rate. The less parts cumulative before preventive maintenance resulted in more PM cycles, the lower the defect rate will be. Based on previous regression analysis of cumulative parts and defects rate, we assume the performance of line B could be improved as good as line A, then the quality cost could be expressed as

$$C_{quality} = \#\ of\ Production * \%\ Defective\ Units * 0.16 + \#\ of\ Production * \frac{100}{CumParts}$$

$$\%\text{Defective Units} = -0.00135 + 0.000003\ \text{CumParts}$$

Through programming, we get the most cost-effective PM cumulative parts of 14435, with an expected defect rate of 4%. For the ease and feasibility of operations, we suggest performing preventive maintenance every 15,000 parts.

Incorporate Auto Shut-Off Mechanism to Both Assembly Lines

Firstly, based on the previous analysis of defect types, defects in squareness account for 75.95% of the total defects. This indicates that our primary focus should be on improving squareness defects.

Secondly, there's potential for Machines to incorporate the auto shut-off feature. From our analysis comparing the defect rates of Machine A with and without the auto shut-off, we found that machines equipped with the auto shut-off feature have a defect rate of only 1.33%, significantly lower than the 6.75% of those without it. Additionally, the Pareto chart analysis reveals that the auto shut off feature is highly effective in reducing both squareness defects and length defects. Notably, for squareness defects, it reduces the number from 1652 defects per 30,000 productions to just 192.

5.0 Monitoring and Control: The Control Phase

There are 5 ways to continuously monitor and control the production after the improvement.

1.Monitoring: Regularly monitor the production process to ensure the sustainability of the improvement measures.

2.Training: Continuously train employees to ensure they understand and follow the new processes and standards, including regular calibration and regular maintenance.

3.Feedback: Establish a feedback mechanism that allows employees to report any issues or suggestions.

4.Re-Evaluation: Periodically reassess the production process to ensure targets are met.

5.Continuous Improvement: Based on new data and feedback, continuously seek opportunities for improvement.

6.0 Post-DMAIC/Summary/Conclusion

HEP's vane manufacturing process has been facing a high reject rate of 7.6% in its two assembly lines. According to recent two-month data, the current process has a DPMO of 43,578.5. HEP projects a loss of $112,248 in total for the quality cost.

The team measures the current performance level based on a dataset of 160 observations from 2 months of production, followed by a comprehensive root cause analysis. After identifying 15 root causes, various solutions were recommended. These include the standardization and better monitoring of procedures, as well as performing preventive maintenance.

The team proposed several methods to improve the defect rate. First, reformulate the standard PM frequency from once per 40,000 parts to 15,000 parts. From our study, the less parts cumulative before preventive maintenance resulted in more PM cycles, the lower the defect rate will be. Based on previous regression analysis of cumulative parts and defects rate, we conclude that 15000 is the optimal point to balance between the PM cost and defect cost.

Besides, the team incorporate auto shut-off feature to both line A and B, which could reduce the defect rate dramatically. In the special analysis case, the team implemented the auto shut-off to machine A, which reduce the defect rate from 6.75% to 1.33%. The effectiveness also applies to machine B.

Based on the improvement, the team collects a one-month Post DMAIC data and calculate the post-DMAIC annual data based on that, shown in Table 2. The defect rate drops from 7.6% to 4%, which achieved our improving goal. What's more, the quality cost reduced from $112,248 to $100,757.

Table. 2 KPI Summary

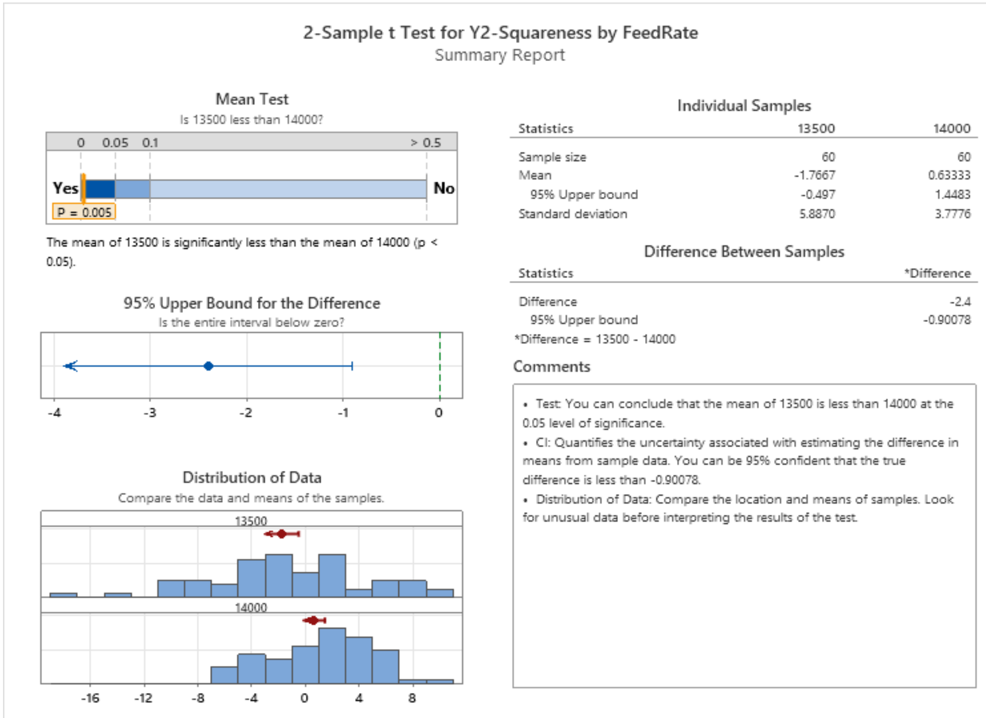
	Pre-DMAIC	**Post DMAIC**
Total Parts	7,629,684	7,560,000
Total Defective Parts	577,800	302,400
% Defective	7.6%	4.0%
Total Good Parts	7,051,884	7,257,600
# of PM Cycles	198	524
Total Quality Cost	$112,248	$100,757
	Difference	$11,491 (-11.4%)

Even though in Post DMAIC, the annual production is less than pre-DMAIC's total production, the new process could still reduce the quality cost of $10,563 with the same production amount, which is about 11.4% of improvement.
Implementing these recommendations significantly reduce the defect rate, improve product quality, and thereby increase customer satisfaction. It also has the potential to reduce costs related to rejects and reworks.

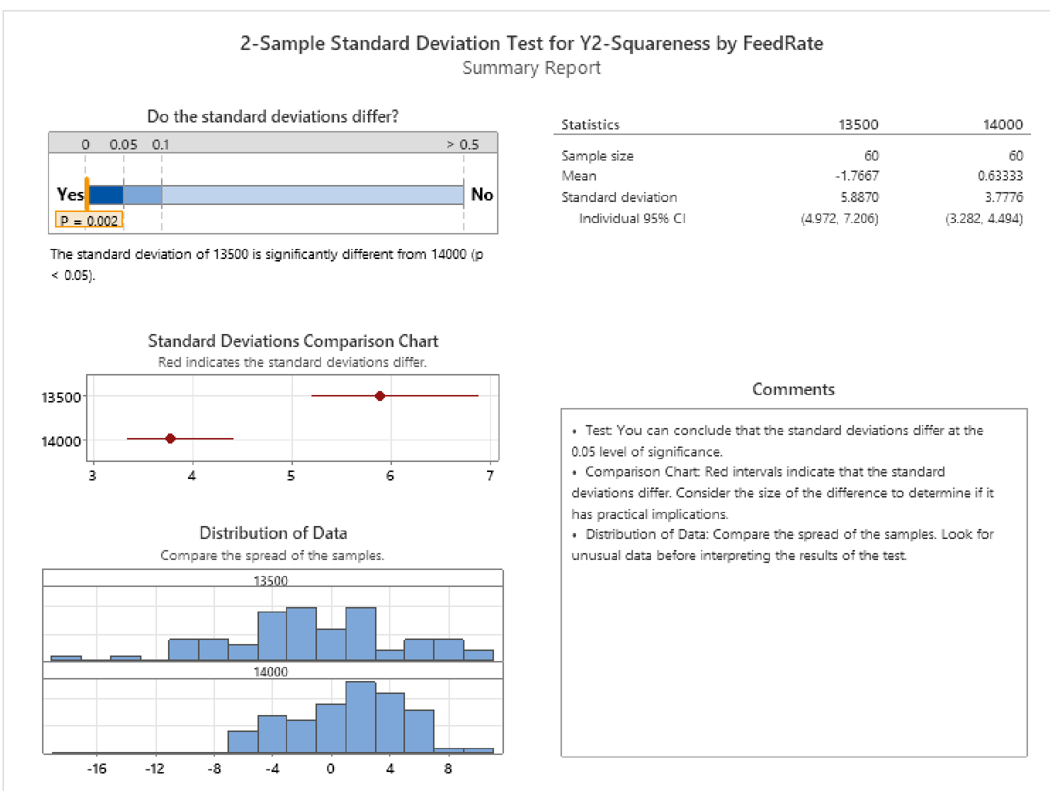
Furthermore, the methodologies and solutions applied in this project are not limited to vanes but can also be applied to other components of the water pump or even to different product lines. Future projects could explore automation as a means to further reduce defects.

Appendices

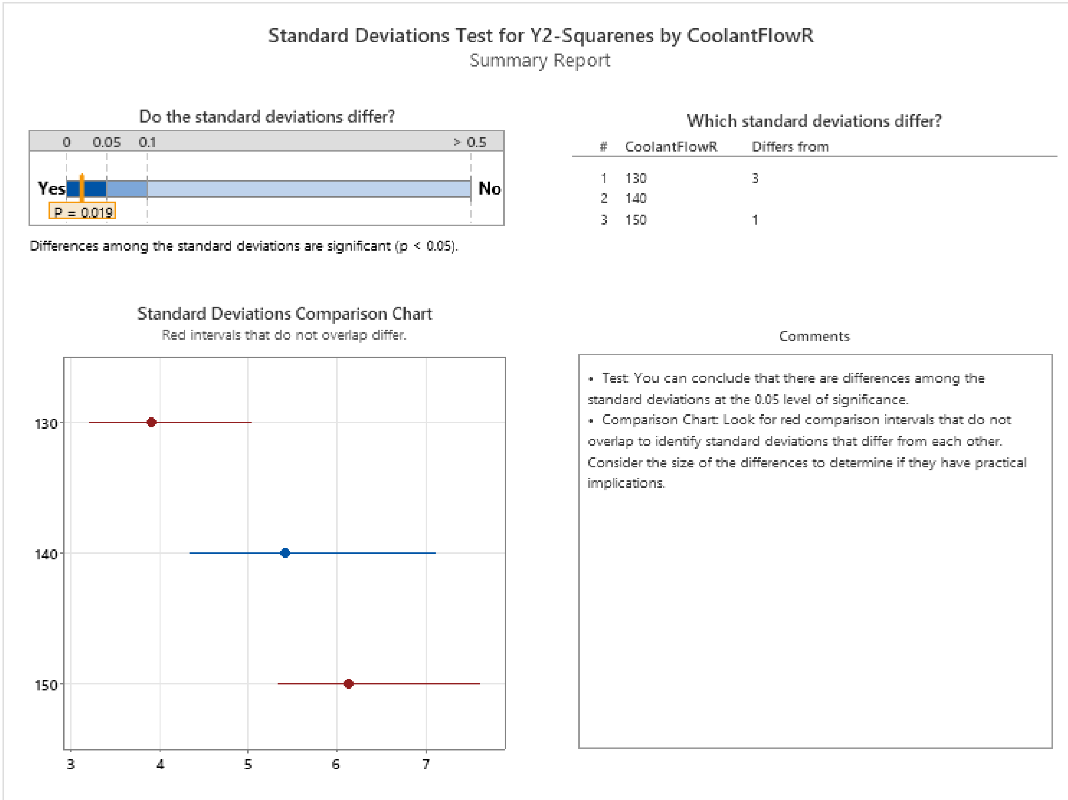
- Appendix 1: 2 sample t-test for Squareness by Feed Rate



- Appendix 2: 2 sample standard deviation test for squareness by feed rate



- Standard Deviation Test for Squareness by Coolant Flow Rate



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