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Mechanical and Manufacturing Engineering

Six Sigma

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1 Introduction

1.1 Belron Background

Belron is a multinational company that specialises in motor vehicle glass repair and replacement services. It operates in over 30 countries under many names such as Autoglass in the United Kingdom and Carglass in mainland Europe. The company serves both commercial and individual customers, insurance providers, fleet operators, and automotive manufactures to insure high-quality vehicle glass solutions.

Belron is committed to innovation and safety, as they are continuously developing advanced testing methods to improve the durability and impact resistance of automotive glass. One of Belron's key focuses is ensuring that their repair and replacement services meet real-world conditions. To achieve this, the company employs specialist equipment for testing, such as stone chip simulators to replicate damages caused from road debris. From these testing methods inconsistencies are often seen, especially in simulated impact forces, which can affect the test results. Addressing these issues is critical for improving the reliability of the test results to ensure that customers receive the highest standard service.



Figure 1: Belron Company logo.

1.2 Project overview

1.2.1 Why the project is being conducted

Belron uses windscreen stone chip simulators to replicate the damage that is caused by road debris. To impact the glass at controlled speeds, the simulators use compressed air to launch

the stone chips via a sabot in a barrel. Although this method is working well at higher speeds, the system is currently experiencing inconsistent firing speeds at low velocities.



Figure 2: Image showing stone chip simulator .

The inconsistent firing speeds at low velocities causes variability in the impact forces that are reflected on the glass, rendering the test results as unreliable. This can impact the effectiveness of Belron's quality control and product development processes as the damage reflected on the glass will not match real-world conditions.

The main objectives of this project are to:

- 1. Identify the root causes of the speed variability.**
- 2. Develop and implement solutions to help improve the firing consistency.**
- 3. Improve the consistency and repeatability of impact testing results.**

Improving the simulator's performance will increase confidence in the test data, helping Belron to have better product development, improved safety standards, and accurate quality control processes. This project directly aligns with Belron's commitment to innovation and continuous improvement in the automotive glass testing industry.

1.2.2 Project benefits

This project aims to improve the consistency and reliability of the windscreen stone chip simulator for Belron's testing, by addressing the issue of variable firing speeds. Successfully mitigating the speed variability will provide many key benefits such as:

- 1. Improvement in the accuracy and reliability of result:**

- Ensuring consistent firing speeds at low velocities will mean that the impact forces on the glass will be more predictable and will better portray real world conditions.

2. Increased efficiency:

- The improvement of speed variability will reduce the amount of unreliable and inconclusive tests, saving time and resources. The saving of time will allow for faster product development and validation.

3. Enhanced product development and quality control:

- Result reliability will allow for the enhancement of glass repair and replacement solutions.

4. Cost savings:

- A reduction in test re-runs caused by the inconsistent firing speeds will reduce the waste of windscreens used for testing, resulting in a reduction in operational costs. Overall costs will be saved as there will be less risk of defects and recalls.

5. Compliance with safety standards:

- More accurate results ensure that Belron's windscreen repairs will meet the industry regulations and safety regulations, insuring customer trust.

Overall, this project will ensure that Belron's windscreen testing process is more reliable and repeatable, allowing for the results to be accurate. This will ensure that their repairs and replacements will be of top quality benefiting both the company and the customers.

2 Define phase

2.1 Problem statement

Belron's windscreen stone chip simulator, which uses compressed air and a sabot to fire stone chips at windscreens, is experiencing inconsistent firing speeds at 35mph. This variability in speed results in unreliable impact forces, leading to unreliable test results that do not portray the real world conditions faced by their customers.

Without this issue being addressed, the results will continue to be unreliable, potentially impacting product development, quality control, regulations, and safety standards.

The project aims to analyse and mitigate the causes of the speed inconsistencies at 35mph. This ensures that the simulator delivers consistent and repeatable impact forces. Improving

the accuracy of Belron's testing conditions helps them enhance their repair products, reduce rework costs, and helps them keep their commitment to innovation and safety in the automotive glass repair industry.

2.2 Process Mapping

A process map is a diagram that gives a visual representation of the key steps that are involved in setting up and firing Belron's windscreen stone chip simulator. This will help in identifying variations in the firing speed and highlights areas that can be improved.

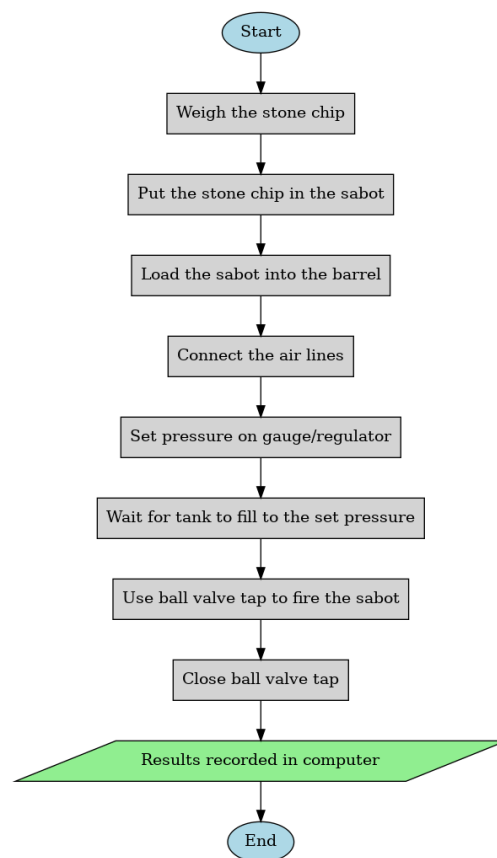


Figure 3: Flow chart of sabot firing process.

From the above flow chart areas of potential variation can be identified. Below are the areas that variation can arise from:

1. **Sabot alignment:** If the sabot is misaligned in the barrel, there will be an increase in friction which will affect the speed at which the sabot is moving down the barrel.
2. **Sensor accuracy:** If the sensors responsible for capturing speed are not calibrated properly, they can create inaccurate readings resulting in speed variation.

3. **Pressure regulation:** Variable firing speeds can be caused by inconsistent pressure build up.
4. **Conditions in barrel:** Resistance can be caused by wear and tear, as well as debris in the barrel.

2.3 Voice of customer and Critical to quality

2.3.1 Voice of the Customer

Understanding the voice of the customer (VoC) is particularly important for ensuring that the windscreen stone chip simulator meets their expectations. The VoC can be categorized into two categories which are: internal and external customers.

Internal customers: Are internal to the organization e.g. management, employees, and any other department that is in the organization.

External customers: Are not part of the organization. They are usually the ones that use our products or services e.g. clients, end-users, and shareholders.

The VoC is collected from test engineers, quality assurance teams, and end-users who rely on the test results being accurate and repeatable. This can be gathered in many ways such as surveys, interviews, focus groups, and observations.

In Belron's case the voice of the customer (VoC) comprises of the following:

1. **Test engineers:** They require a consistent firing speed to help ensure that the impact forces are replicated accurately onto the windscreen.
2. **Product development/repair team:** Require reliable test results in order to develop better formulae and repair techniques.
3. **Regulatory & compliance team:** Expect test conditions to align with industry safety standards.
4. **Customers:** Rely on Belron's testing accuracy to guarantee the safety and durability of the windscreen repairs.

2.3.2 Critical to Quality (CTQ)

To translate the Voice of the Customer (VoC) into measurable quality standards, Critical to Quality (CTQ) factors have to be identified. The CTQ factors will guide the project's

improvement efforts, by ensuring that the stone chip simulator delivers consistent, repeatable, and accurate results that align with the customers' expectations.

CTQ	Requirement	Target Value
Firing Speed Consistency	Variation must remain within the acceptable limits.	+/- 2 mph
Air Pressure Control	Pressure at firing must be stable and consistent.	Stable at set velocity pressure
Sabot Alignment	Sabot must be properly aligned for there to be a uniform propulsion.	Centred in the barrel
Impact Force Accuracy	Force applied to the windscreen should match real world conditions.	N/A
Data Reliability	Speed measurements should be repeatable across multiple tests.	N/A

Table 2: Table showing the requirements and target values for CTQ.

2.4 Project Scope

Due to unreliable impact forces and inaccurate test results at low velocities with Belron's windscreen stone chip simulator, this project will focus on identifying and mitigating the causes of the variability in the low speed velocities to improve test repeatability and accuracy.

2.4.1 In Scope

Analysing speed variability:

- Analysing firing speed inconsistencies using the data collected.
- Analyse the impact of the sabot alignment, barrel friction, air pressure fluctuations, and sensor accuracy.

Measure phase and data collection:

- Perform machine capability studies to quantify the variation.

- Perform measurement system analysis to make sure speed sensors are reliable.

Root cause analysis:

- Use tools such as 5 whys, and Pareto analysis to identify the main sources of variation.

Improvement and validation:

- Execute changes to the Sabot alignment, barrel conditions, and air pressure regulation to reduce the variability seen.
- Perform a validation through pilot testing.

Control measures:

- Create a strict maintenance schedule for sensor calibration and for cleaning the barrel.

2.4.2 Out of scope

- **Complete redesign of the simulator:** The project will not create a new testing system and will only focus on improving existing processes.
- **Material testing of windscreen glass:** The study is focused on the simulator and not on any glass properties.
- **Testing different projectile types:** Only the current setup of the stone chip and sabot will be analysed.
- **Long-term research:** Short-term research and process improvement using six sigma is the main focus of the project.

Defining the scope of the project will help make the improvements achievable, measurable, and aligned with Belron's goals.

2.5 Project Charter

Project Title: Improving Speed Consistency In The Windscreen Stone Chip Simulator

Project Sponsor: Belron Engineering

Project Leader: Sheunesu John Ziki

Team Members: Test Engineers

Problem Statement:

The windscreen stone chip simulator experiences inconsistent firing speeds, particularly at low speeds of 35mph. This leads to unreliable impact forces and inaccurate test results. The potential causes include air pressure fluctuations, sabot misalignment, barrel friction variations, and sensor inaccuracies. This inconsistency affects test reliability, product development, and compliance with industry standards.

Project Objectives:

The main objective is to analyse and mitigate the causes of the firing speed variability at 35mph, by applying Six Sigma methodology. The other objective is to ensure that the simulator provides consistent, repeatable, and accurate test results.

Business Improvement:

- **Improved accuracy** – Reliable impact simulations allow for enhanced product testing.
- **Increased efficiency** – Reduction in test repeats and also improved repeatability.
- **Cost savings** – Removes unnecessary testing, helping to reduce the operational costs.
- **Compliance and safety** – Ensure their products and replacements align with industry standards.
- **Innovation** – Supports continuous improvement in testing methodologies.

Scope:**In Scope:**

- Root cause analysis of speed variability.
- Data collection and measurement system analysis.
- Implementation of process improvements.
- Validation and control measures for long term stability.

Out Of Scope:

- Complete redesign of the simulator.
- Testing of alternative projectile types.
- Research on new firing mechanisms.

Key Deliverables:

- Process analysis report to identify speed variability causes.
- Improvement plan with proposed solutions.
- Pilot testing results demonstrating the improved consistency.
- Control plan for improved results maintenance.

Timeline And Milestones:

Phase	Key Activities	Timeline
Define	Problem statement, project charter, VoC	Week 1-2
Measure	Data collection, process mapping	Week 3-5
Analyse	Root cause analysis, statistical analysis	Week 6-8
Improve	Implementation and test solutions	Week 9-11
Control	Development of monitoring and control measures	Week 12-14

Table 2: Table showing timeline and milestones.

Success Criteria:

- Reduction of firing speed variation to within $\pm 3mph$ of the target velocity.
- Improved test repeatability.
- Measurable improvement in process capability (Cp/Cpk) values.

Required Resources:

- Sensors for data collection.
- Air pressure regulators for controlled firing conditions.
- Data analysis software for evaluation e.g. Minitab and Excel.
- Engineering support for modifications and testing.

3 Measure Phase

The measure phase is important to help understand the stone chip simulators current performance and to help identify the extent of the variability in firing speeds at the 35mph setup. The specified limits at the 35mph set up should be ± 2 mph of this making the limits 33mph and 37mph. This phase involves producing reliable data collection methods, verifying the measurement system, and determining the processes capability.

3.1 Measurement variation

The initial observations of the simulator showed inconsistencies in firing speeds at the low velocity of 35mph. The inconsistent speeds affect the impact forces applied to the glass, which affects the results reliability. To investigate this issue, data on the firing speeds was collected across many tests, under controlled conditions. This helps to capture the extent of the variation seen.

The main variable of interest is the actual speed, which is a continuous data type measured in miles per hour (mph). This allows for statistical analysis such as mean, standard deviation, and process capability indices. Other supporting variables include:

- Set velocity – mph
- Air pressure – PSI
- Temperature – degrees Celsius
- Mass – grams

This data will allow for there to be quantitative and graphical analysis

3.2 Data Collection Plan

A systematic data collection plan was developed to ensure consistency, accuracy, and traceability of the results as shown in table 3 below:

Variable	Measurement Method	Unit	Notes
Set Velocity	Manual input from control interface	mph	Target firing speed

Actual Velocity	Measured by speed sensors	mph	Main variable
Mass	Measured beforehand on a digital scale	grams	Mass of each stone
Temperature	Lab conditions	Degrees Celsius	Recorded as cold, room, and hot
Number Of Tests	Test samples	1000+	Enough for statistical analysis

Table 3: Table showing data collection plan.

3.3 Measurement System Analysis (MSA)

Before any process improvement based on the firing speed data can be conducted, it is important to confirm that the measurement system on its own is reliable. If the system used for data collection is not consistent it means that the data could be inaccurate. A Gauge Repeatability and Reproducibility (Gauge R&R) study evaluates the amount of variability introduced by the measurement system compared to the total process variability. (Moreno *et al.*, 2025)

3.3.1 Components Of The Measurement System

Component	Description
Speed Measuring Instrument	High-speed sensor
Measurement Variable	Actual Firing Velocity (mph)
Operators	2 trained engineers performing the measurements.
Trials	10 identical tests repeated 3 times each by both operators.

Table 4: Table showing the components of the measurement system.

Table 4 above shows the components they will be used in the Gauge R&R study. The test was conducted under controlled conditions to help reduce any external variation and to isolate variation caused by the measurement system alone. Below is the design of the study used:

- 10 tests with the same setup, mass, and conditions.
- 2 operators measured the same 10 tests 3 times each.
- $10 \text{ tests} \times 2 \text{ operators} \times 3 \text{ trials} = 60 \text{ measurements}$

3.3.2 Results

Table 5 below shows the results of the study conducted. The Gauge R&R study used controlled data designed to evaluate the measurement system variation. This means the absence of extreme outliers in the chart is acceptable.

Key:

- **Repeatability** – Variation when the same operator measures the same part multiple times.
- **Reproducibility** – Variation between different operators measuring the same part.
- **Part to part variation** – Differences in measured values between different firings.
- **Total Gage R&R** – Combined effect of repeatability and reproducibility.

Source of Variation	% Contribution to Total Variance
Repeatability	5.4%
Reproducibility	3.2%
Gage R&R (Total)	8.6%
Part-to-Part Variation	91.4%

Table 5: Table showing results from the Gauge R&R study.

Table 5 shows that the total Gage R&R is 8.6%, which is below the acceptable threshold of 10%. This indicates that the measurement system is suitable for this application. Part to part variation has the highest percentage, meaning that most of the variation is caused by the process, not the measuring instrument or human error. Both the repeatability within operators and the reproducibility between operators are minimal.

Figure 4 below shows a box and whisker plot which shows the velocity variation across tests and between the two operators. This helps to visualise the differences in repeatability and reproducibility within and between operators.

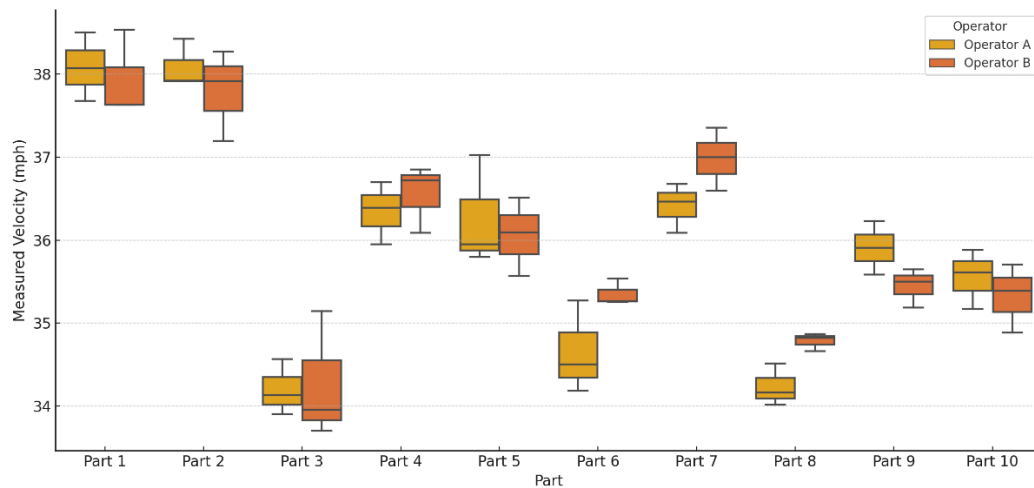


Figure 4: Image showing box and whisker plot.

Each box on the plot represents the spread of the measured velocities for a particular part. The vertical spread shows how much variation occurred across the three tests. The narrow boxes represent high repeatability which means less variation by the same operator. If both operators' boxes are similarly aligned for each part it suggests good reproducibility.

From Figure 4 the box plot shows tight grouping with little overlap between the operators, which means that the variation within each part is small and variation between operators is minor.

3.3.3 Conclusion

In conclusion it's seen that the measurement system used to record the actual firing speeds is accurate, consistent, and contributes minimal errors to the data. Any variability seen in firing speeds can be attributed to the process rather than the instrumentation. This validates the dataset for further analysis and six sigma improvements.

3.4 Statistical Analysis And Process Capability (Minitab Non-Normal Analysis)

This section of the report evaluates the actual firing speed of the stone chip simulator using a non-normal capability analysis in Minitab. The actual velocity data at 35mph did not follow a normal distribution, this prompted Minitab to automatically apply a nonparametric method that uses Cnpk, Cnpl, and Cnpu indices to ensure a more accurate assessment of the process performance.

3.4.1 Normality Test

A normality test was performed using the Anderson-Darling (AD) test in Minitab. The p-value was found to be less than 0.05. This shows that the velocity data significantly deviates from a normal distribution. This prompted the following nonparametric capability indices:

- **Cnpl** – Relative to the lower specification limit (LSL)
- **Cnpu** – Relative to the upper specification limit (USL)
- **Cnpk** – Relative to the minimum Cnpl and Cnpu representation of the overall process capability.

3.4.2 Data Summary

Table 6 below shows computed results are from over 60 recorded firing cycles:

Metric	Value
Set Velocity (Target)	30 mph
Mean Actual Velocity	32.99 mph
Standard Deviation (σ)	6.61 mph
Minimum Actual Velocity	13.82 mph
Maximum Actual Velocity	39.61mph
Lower Spec Limit (LSL)	33 mph
Upper Spec Limit (USL)	37 mph

Table 6: Table showing summary of data.

3.4.3 Capability Results (Minitab)

Table 7 below shows the computerised capability results produced in Minitab:

Index	Meaning	Value (example)
Cnpl	Capability Lower Limit	0.10

Cnpu	Capability Upper Limit	0.13
Cnpk	Overall Nonparametric Capability	0.10

Table 7: Table showing capability results.

As seen in figure 5 below is a histogram that shows the distribution is skewed slightly low which confirms the Cnpk = 0.10 seen in the capability analysis. This is below the industry standard of 1.33. This shows that the process of firing the stone chip is not capable of meeting the specified limits of 33-37mph consistently.

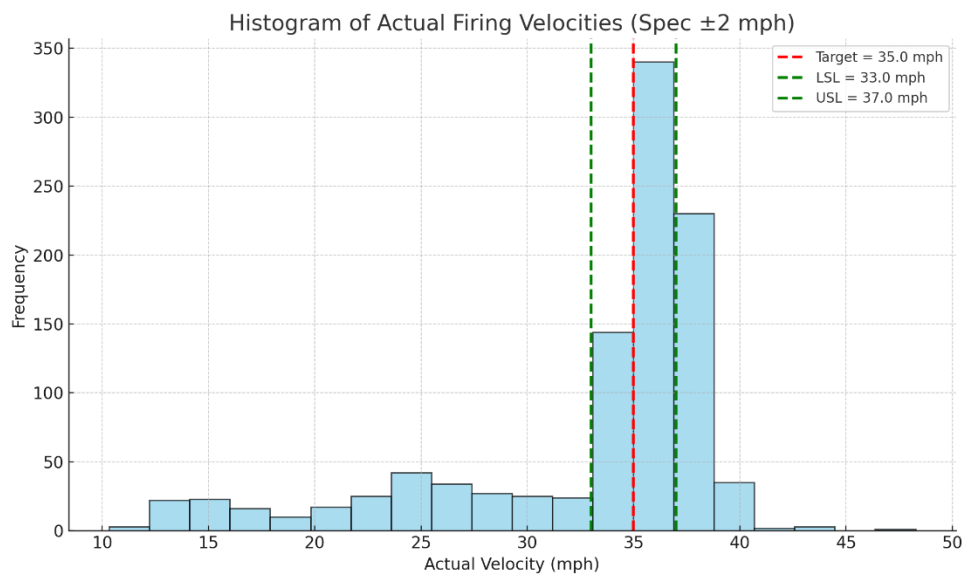


Figure 5: Image showing Minitab process capability report for actual velocity.

The main critical point of concern is the low Cnpl value, which shows a pattern of underpowered velocities. This makes the impact results seen on the windscreen unreliable.

3.4.4 Conclusion

Due to the data being non normal the use of Cnpk provides a more reliable interpretation of the process capability. The capability report showed that the simulator is currently has 50% of its shots failing to meet the limits.

4 Analyse Phase

This section looks to identify the root causes of the inconsistency in firing speeds at 35mph. It will show how frequently the process fails to meet the performance targets.

4.1 Fishbone Diagram (Brainstorming)

Figure 6 below shows a fishbone diagram that was used to organise the potential causes of the velocity inconsistencies:

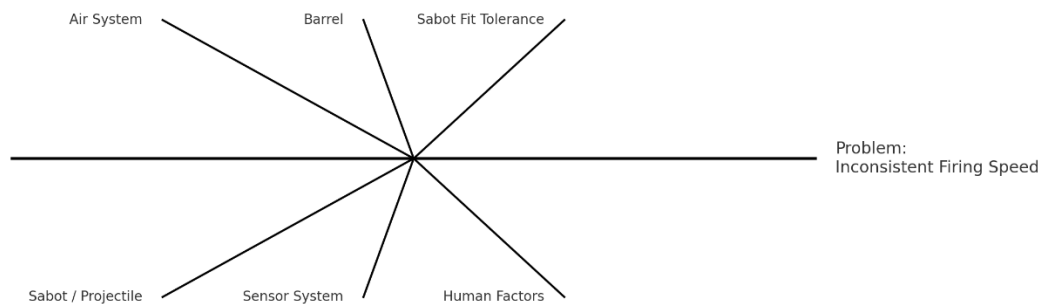


Figure 6: Image showing a fishbone diagram with possible root causes.

Categories of potential causes:

- **Air System:** Inconsistent regulator output, pressure lag, leakage
- **Sabot/Projectile:** Weight, aerodynamic issues
- **Barrel:** Wear, buildup of residue, friction
- **Sensor System:** Calibration issues, delay, or alignment issues
- **Sabot Fit Tolerance:** too tight, too loose, sabot play
- **Human Factors:** Loading inconsistencies

4.2 Pareto Analysis

Figure 6 below is a Pareto chart showing the speed deviations shown in the data at 35mph considering the specified limits of ± 2 mph:

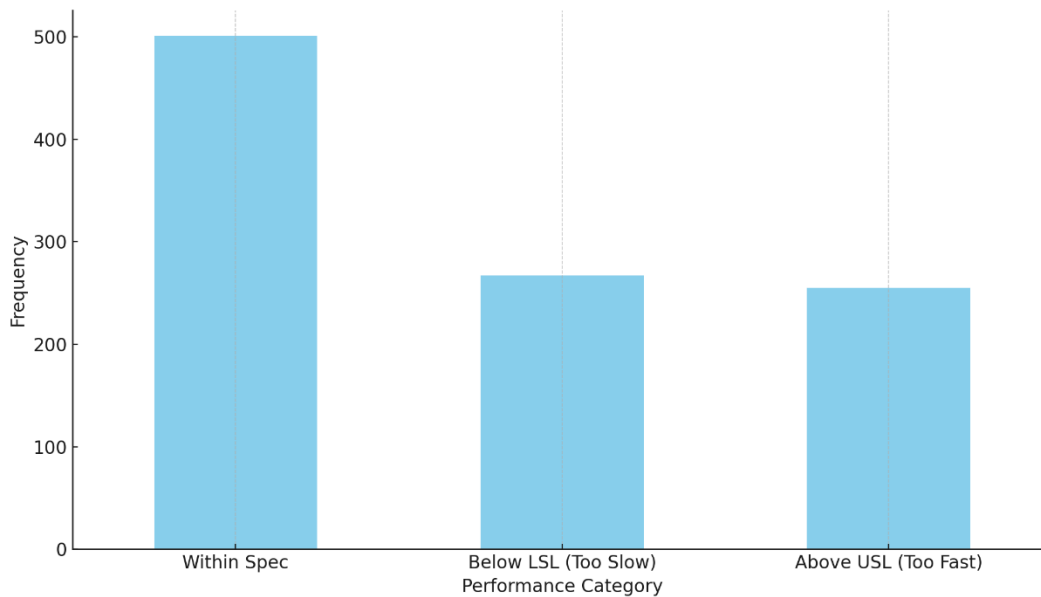


Figure 7: Image showing a Pareto chart of the speed deviations at 35mph.

Category	Count
Within Spec	501
Below LSL (Too Slow)	267
Above USL (Too Fast)	255
Total	1023

Table 8: Table showing results from pareto analysis.

From Figure 7 and Table 8 above we see that 49% (501 of 1023) of the shots are in the range of 33-37mph which is the set target velocity. 267 (26%) of the shots fall below the limit of 33mph showing how having low velocities is a major part of the simulators problem. Shots that exceeded the upper limit of 37mph made up 25% (255) of the data, which shows that the simulator has the same problem in this regard as the shots below the minimum limit. This proves that at the 35mph the simulator has a possibility of over or under shooting showing the unstable firing at this speed. These results align with the results seen in the capability results seen in Table 7.

4.3 Root Causes and Hypotheses

Root Cause Hypothesis	Expected Impact	Planned Investigation
Pressure delivery instability	Affects both slow and fast shots	Regulator review, real-time pressure monitoring
Barrel friction & contamination	Slows sabot inconsistently	Clean barrel, test firing post cleaning
Sabot material or design variation	Causes erratic acceleration	Try different material and finish
Sabot tolerance fit	Off-centre launch unpredictable drag	Modify sabot tolerance fit to be tighter in barrel
Operator handling errors	Inconsistent load position or delays	Solved by sabot tolerance fit

Table 9: Table showing possible root causes and hypothesis.

4.4 Analyse Phase Conclusion

With the limits of $\pm 35mph$, it shows that the simulator is failing to produce consistent and reliable shots at this speed, as only 49% of the trials are in spec. The Cnpk being 0.10 is backed by seeing that the shots are near equally split between under and over speed shots. This chapter has showed the important need to focus on the possible root causes outlined in Table 9 in the improve phase.

5 Improve Phase

The improve phase involved physical testing to validate practical solutions to the root cause of the inconsistency in firing speeds produced by the simulator. The root cause was the aluminium sabots tolerance fit in the barrel. By machining and post machining testing, it was seen that a substantial improvement came by using close fit nylon sabots.

5.1 Sabot Background

- The simulator originally came with nylon sabots.
- A more recent decision was made, which introduced aluminium sabots with diameters between 31.70mm and 31.80mm, in a nominal 32mm barrel.

- After 15 years of wear. It is assumed that the barrels diameter had slightly increased, which worsened the sabot fit.
- Poor sabot fit caused inconsistent acceleration due to leaked air pressure.

5.2 Sabot Redesign Testing

To address the issue of sabot tolerance fit in the barrel, it was decided to use the original nylon sabots that came with the simulator. Two nylon sabots were machined with tight tolerances of $\pm 0.005mm$ as seen in Table 10 below:

Sabot Type	Nominal Diameter	Fit Description
Loose running sabot	31.750 mm	Slightly better than aluminium sabots
Close running sabot	31.950 mm	Much tighter fit to focus on improvement testing

Table 10: Table showing new sabots specifications.

Test Setup:

- Tests were done using the close fit nylon sabot with the diameter of 31.950mm.
- A total of 50 shots were done at 35mph.
- The velocity measurements were done using the high speed sensors, as they were deemed fit for purpose as seen earlier in this report.
- The specification limits of $\pm 2mph$ (33-37mph) of the target velocity of 35mph stayed the same.

5.3 Additional Tests

Alongside the development of the nylon sabots, tests on the possible root causes that mentioned in Table 9 in the analyse phase were also conducted as seen below:

Test Area	Observation
Air pressure system	Minor fluctuations observed with no major effect on velocity spread
Sensor calibration	Results were consistent; measurement system deemed reliable
Operator procedure	No significant impact; repeatable loading achieved

Table 11: Table showing other tests conducted and their observed result.

The results from these tests were consistent with earlier results. This suggests that they were not the root cause of the speed fluctuation at 35mph. This prompted attention to be directed towards the sabot fit as it had more measurable results.

5.4 Results Close Fit Nylon Sabot

Table 12 below shows the results seen from the close fit nylon sabot:

Metric	Value
Mean Velocity	34.96 mph
Standard Deviation	1.02 mph
Min Velocity	33.08 mph
Max Velocity	37.46 mph

Table 12: Table showing close fit sabot results

5.5 Capability Results

The capability results for the close fit nylon sabot are shown in Table 13 and the histogram in Figure 8 below. The data managed to pass a normality test as the p value was found to be 0.55. this means that Cpk can be used however, Cnpk was used as the primary measure due to the following reasoning:

- Its more robust to outliers due to it being percentile based.
- It reflects real world process characteristics under tests conditions.
- It gives a clearer picture of the practical improvement.

Index Type	Value	Interpretation
Cnpk	0.82	Improved, real-world capable
Cpk	0.64	Still below standard
Cp	0.66	Spread is still wider than ideal
Cnpl	1.05	Excellent control on low end
Cnpu	0.82	Few overspeed shots remain

Table 13: Table showing capability results.

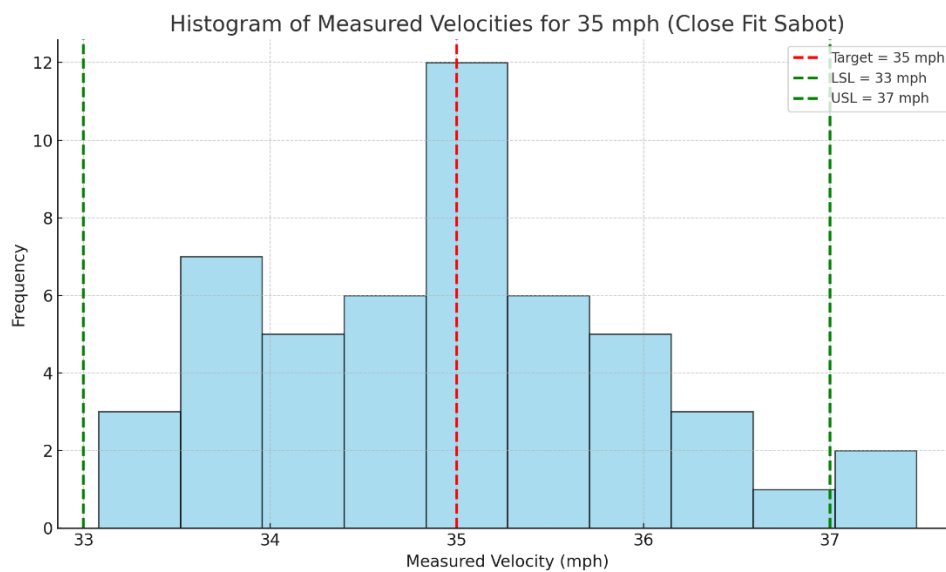


Figure 8: Image showing process capability report for close fit nylon sabot.

We can see from the histogram in Figure 8 that the velocities at 35mph are tightly clustered around the 35mph target. More than 95% of all the shots fell within the specified limits. There has been a big decrease in the variance which made the velocity readings more predictable. The improvement strongly supports that the poor tolerance fit of the sabot in the barrel was allowing air leakage and velocity inconsistencies.

5.6 Comparison (Before And After)

Metric	Before (Aluminium)	After (Nylon Close Fit)
Shots Within Spec (35 mph)	49%	98%
Std. Deviation	6.61mph	1.02 mph
Velocity Range	13.82 – 39.61 mph	33.08 – 37.46 mph
Cnpk	0.10	0.82
Cpk	0.10	0.64

Table 14: Table showing comparison of results before and after.

From Table 14 above we see that the tolerance changes have transformed the simulator from not capable to near capable, with minimal cost and design complexity.

5.7 Improve Phase Conclusion

In the improve phase a number of changes were made such as retiring the aluminium sabots in preference of the close fit nylon sabots. This shows that the sabots tolerance was the dominate factor affecting velocity variability. This pushed the process toward capability as seen statistically and visually.

6 Control Phase

This part of the report will look into ensuring that the improvements achieved in the improve phase are maintained over time. It will focus on standardising the process, preventing regression, and establishing a framework for monitoring performance going forward.

6.1 Control Plan

To manage all the important process elements that impact firing speed consistency a control plan was developed as seen in Table 15 below:

Element	Control Method	Frequency	Responsible
Sabot dimensions	Inspect all of the new sabots with vernier callipers (± 0.005 mm)	Every batch	Technician
Barrel condition	Visual inspection and cleaning for dirt to reduce friction	Before each test run	Technician
Air pressure	Check regulator output (PSI) against setpoint for speed	Before each run	Test operator
Sensor calibration	Cross check with known speed object	Monthly	Technician
Velocity recording	Use high-speed sensor logging with timestamp	Every shot	Test operator

Table 15: Table showing the control plan.

6.2 Standardisation

Standard Operating Procedure (SOP):

- Sabot production: Nominal diameter = 31.950mm, tolerance = ± 0.005 mm.
- Handling and loading steps.
- Barrel maintenance and inspection routines.

The standard operating procedure includes:

- Visual references for the correct sabot fit.
- Instructions on how to load the sabot to reduce misalignment issues.
- Calibration instructions for sensors.

6.3 Visual Control And Error Reduction

- A gauge will be developed for quick and easy sabot diameter check.
- Sabot trays with labelled size slots will be used to prevent the wrong sabot from being loaded.
- A colour code system will be used to distinguish standard sabots from experimental ones.

6.4 Training & Handover

The technicians and operators will be trained on:

- SOPs
- Sabot measurement tools
- Maintenance checklists

A handover document summarising all the control steps, charts, and instructions has been shared with the technicians and operators.

6.5 Risk Mitigation & contingency Plan

Potential Risk	Mitigation
Incorrect sabot fit in future	Strict QC inspections, using fit gauge
Barrel wear affecting fit	Scheduled barrel re-inspection every 3 months
Air regulator drift	Weekly pressure calibration
Operator deviation from SOP	Refresher training every 6 months

Table 16: Table showing the risk mitigation and contingency plan.

6.6 Future Capability Monitoring Plan

Metric	Target	Monitoring Tool	Review Frequency
% Shots Within Spec	≥ 95%	Test log & histogram	Monthly
Cpk / Cnpk	≥ 1.00	Minitab or Excel analysis	Quarterly
Mean velocity deviation	±0.2 mph	Statistical review	Monthly

Table 17: Table showing the future capability monitoring plan.

6.7 Conclusion Of Control Phase

This chapter puts the necessary structures to make sure the gains achieved in the improve phase are not lost. Through the SOPs, monitoring plans, risk controls, and training, Belron can now confidently maintain and build upon the results achieved.

7 Report Conclusion

The improved simulator setup using the close fit nylon sabots significantly enhanced firing consistency, as shown by both C_{npk} (0.82) and C_{pk} (0.64) values. Over 95% of shots now fall within the 33-37mph range at 35 mph.

Remaining variation is minimal but influenced by inconsistencies in stone chip mass. Since launch velocity depends on mass under constant force, standardising or sorting chips by weight could further improve consistency.

The process is now stable, repeatable, and near-capable which is a step forward in achieving accurate and reliable windscreen impact simulations.

8 References

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9 Appendix

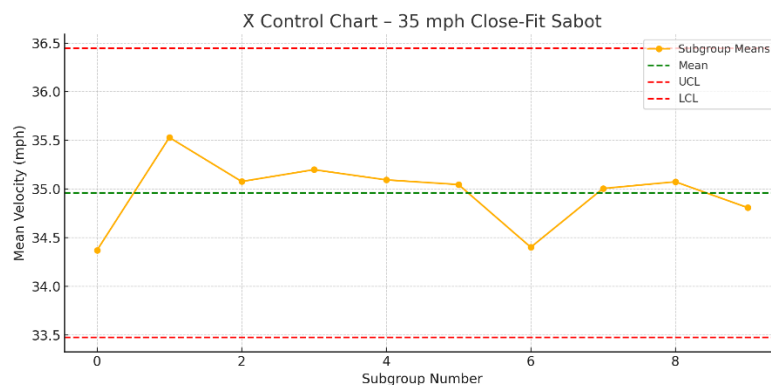
Failure Modes table

Failure Mode	Effect of Failure	Severity (1-10)	Occurrence (1-10)	Detection (1-10)	RPN
Incorrect sabot fit (future batch)	Inconsistent velocity, out-of-spec shots	8	4	3	96
Barrel wear affecting sabot fit	Increased friction, speed variability	7	5	4	140
Air pressure instability	Unstable launch force, velocity drift	6	3	3	54
Sensor misalignment or drift	Incorrect speed readings, poor data	6	3	4	72
Operator loading inconsistency	Shot-to-shot variability	5	4	3	60

Aluminium sabot data: [TOF Analysis.xlsx](#)

Close Fit Sabot (Nylon): [new results for close tolerance sabot.xlsx](#)

Process control chart:



The $\bar{X}$ chart shows the average firing speed for small batches of 5 shots. All the results are well within the expected range, with no unusual spikes or dips.

This means the process is running smoothly and consistently. It's a good sign that the new close-fit nylon sabot is doing its job keeping the shots close to the 35 mph target. If more testing is done in the future, this chart can be used to spot any issues early and keep things on track.