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AI-Enabled Statistical Quality Control Techniques for Achieving Uniformity in Automobile Gap Control

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Abstract- To remain competitive, vendors in the production sector must meet the ever-evolving demands of their customers. Manufacturers can't accomplish this without a way to measure the items' quality. Analyzing the space between the back bumper and the exterior panel using quantitative methods for quality assurance is the focus of this investigation. For the purpose of trying to determine whether the production system is functioning properly, the study will employ Minitab for data evaluation and cause-and-effect analysis. Data will be collected and analyzed using quality assurance methods such as control graphs, hypothesis tests, analysis of variance, and Gage R&R. Results will be measured, and the underlying reasons will be identified. To optimize this procedure and fulfill consumer demand, such devices will be utilized.

Keywords- Manufacturing inspections, Rear Bumper, Gauge R&R test, Artificial Intelligence, machine learning, smart manufacturing

1. Introduction

Initially, the main use of vehicles was to move people and goods. Cars used to only transport people from point A to point B, but now they serve many more purposes and are essential to many households. People are prepared to shell out extra cash for a top-notch ride because of this. Vehicle producers are constantly innovating and adjusting their goods to cater to customer wants, acknowledging this transition. Their goal is to dominate the market, so they've raised the bar for vehicles. A car's aesthetics and safety features are two of its most important aspects to buyers. Crucial to these safety elements are bumpers, which, in a crash, protect the front and back ends of the car from harm. In addition to improving aerodynamics, and an efficient bumper improves the vehicle's aesthetics. Each company uses a unique bumper design to highlight their uniqueness.

Analyzing the space between the body panel and the rear bumper One effort that aims to improve the uniform appeal of automobiles is the Statistical Quality Control Techniques (SQC) project, which checks variances in the distance between the body and the rear bumper. A more uniform result will be achieved by using SQC procedures to pinpoint and eradicate causes of variance in flushness and gap size. The lightweight and durable Acrylonitrile Butadiene Styrene (ABS) is a common material for automobile bumpers. Bumpers may, however, contract or distort while being made. The goal of this study is to determine the optimal manufacturing process for the bumpers to eliminate these issues. Statistical quality control methods allow the researchers to identify and address the root causes of the gap variation issues. With this, you can adjust the gap and improve the appearance of the back bumper.

One significant aspect of a vehicle is the distance within the back bumper and the exterior of the car. A gap that is too big can render the car appear unattractive, while a gap that is too tiny can prevent the back bumper from functioning properly. It is possible to track and examine the space between car bodies and rear bumpers using statistical quality control, also known as SQC, methods. This study details the use of SQC methodologies to investigate and tackle the production disconnect among car bodies and rear bumpers. Goals of conducting a numerical quality assurance evaluation of gaps within the frame and the back bumper.

- Reviewing the statistics on gaps and flushes.
- Determine the factors that cause the total variation in the gap.
- Verify that the present distance measurements are within the allowed tolerance limits by doing a Gage R&R Crossed Study on both the left and right sides of the item.

To acquire reliable data, eleven identical automobiles were measured precisely at five locations on each side using a tapper scale and dial gauge. This allowed for consistent and exact gap readings. There were five distinct points, labeled 1, 2, 3, 4, and 5, in Figure 1 that displayed the distance between the left side rear bumper and body panel.

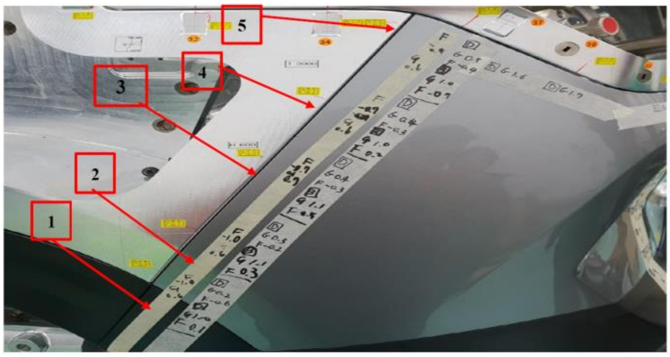

Fig 1: Gap present between the bumper and body on the left-hand side.

The vehicle's rear bumper is shown on the right side of Figure 2. The five elements are 1, 2, 3, 4, and 5. We can determine the distance and flushness between the back bumper and the exterior panels at these five designated spots using a dial measuring instrument and taper scale.

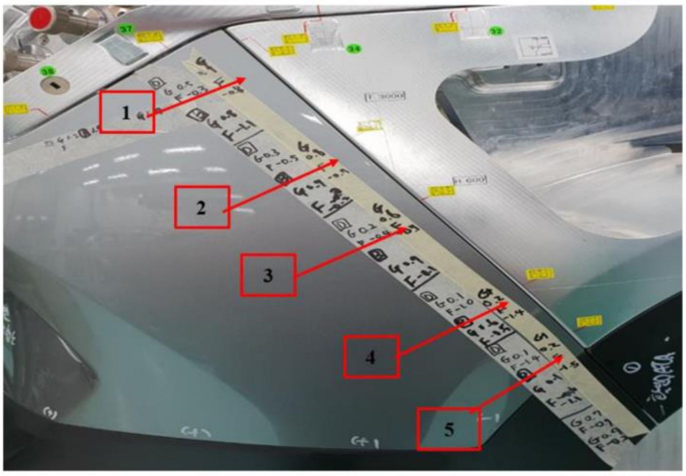

Fig 2: Gap present between the bumper and body on the right-hand side.

2. Literature Review

The importance of quality assurance in the automobile sector has been highlighted by research into applying Statistical Quality Control (SQC) approaches to improve the uniformity of the space between the rear bumper and the body of vehicles. Researchers have shown that controlling the distance between the rear bumper and the body is crucial to performance. We will go over some SQC methods that work well for tracking and bettering production processes, including control charts and gage R&R analysis. To demonstrate the economic benefits and cost-effectiveness of defect prevention, case studies showcase SQC solutions that successfully achieve consistent gap control. Customer satisfaction and gap control: a relationship study.

When it comes to making sure a product or process lives up to or beyond consumer expectations, statistical quality control (SQC) is the way to go. Data regarding a product or process is gathered and analyzed using statistical methods to find and remove sources of variance. Although SQC methods have been around for a long time, they really took off in the early 1900s when Walter Stewart came up with quality control charts at Bell Laboratories. The scientific technique of management was created by Frederick.et.al in the late 19th century, and Stewart's work was based on their work. During WWII, SQC methods were widely employed to guarantee the quality of military equipment and weapons. Many sectors, including manufacturing, healthcare, and finance, make use of SQC methods, which were further refined and developed after the war. Design of experiments (DOE), process improvement methodology, control charts, and capacity analyses are among the most significant SQC techniques. Reduce variance, identify and eliminate sources of errors, improve process capabilities, and reduce costs—these are just a few ways in which SQC methodologies can enhance product and process quality. If a company is serious about raising the bar on product and process quality, it must employ SQC methodologies.

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It was in the context of manufacturing that statistical quality control (SQC) methods were first devised. In subsequent years, these methods have been refined to assess less conventional topics, such as automobile AWS (Torie.g 2018). This article discusses the difficulties of quality control, the methods currently used, and suggests a new way to improve control effectiveness, especially for highly competent processes with low variability (Yuyun, H., Neneng, S., Lusyana, L., & Purwandari, T., 2020). Quickly identifying the assignable cause allows the organization to investigate and implement corrective action prior to increasing the number of non-conforming production units, which is the primary goal of SPC (Leonard. E., 1984). A novel strategy for a pressing problem in automotive quality control, providing an all-encompassing answer to the problem of finding minute flaws on the surfaces of automobiles, even in non-flat regions. In 2017, Jaime, Ernesto Solanes, Laura A., and Jaime Tornero published their findings. Using SPC to improve process quality in the car sector. With the help of SPC, businesses will be able to detect and eliminate process variability, which will result in consistently high-quality goods. The company's success will be enhanced by this proactive approach, which will decrease manufacturing costs, waste, and rework while simultaneously improving customer satisfaction (Radu G, Matias J, and Susana G, 2016). Contributing to the success in the long run through improving product quality, operational efficiency, and customer satisfaction (Srikaeo, Frust, and Ashton, 2005).

Manufacturing high-quality automobiles is an absolute must, and statistical quality control (SQC) methods are key to getting there. Consistent gap management between the body and rear bumper of automobiles is achieved by the use of SQC techniques like gage R&R analysis and control charts, which allow manufacturers to successfully monitor and improve manufacturing processes.

3. Methods and Tools

In this study, we utilized various ways to determine the variance in the space between the vehicle's rear bumper and body panel on both sides. In this investigation, a dial gauge was used for flush checking, a taper scale was used, and an ANOVA was applied to the crossing gauge R&R study. Tolerances can be achieved with the use of these approaches and instruments.

- **Gauge R & R Crossed With ANOVA**

That's Analysis of Variance, or ANOVA for short. It is a method of statistical analysis that compares the averages of multiple groups. If you want to know if the changes you saw between groups were significant or if they were just random, ANOVA is the way to go. One way to evaluate the measuring system's variability when multiple operators take readings of the same components is with a crossed gauge repeatability and reproducibility (R&R) study. As seen in Figure 3, this sort of research involves several measurements of each component by each operator. The study can then evaluate the parts-to-part variance as well as the repeatability and reproducibility of the measuring system.

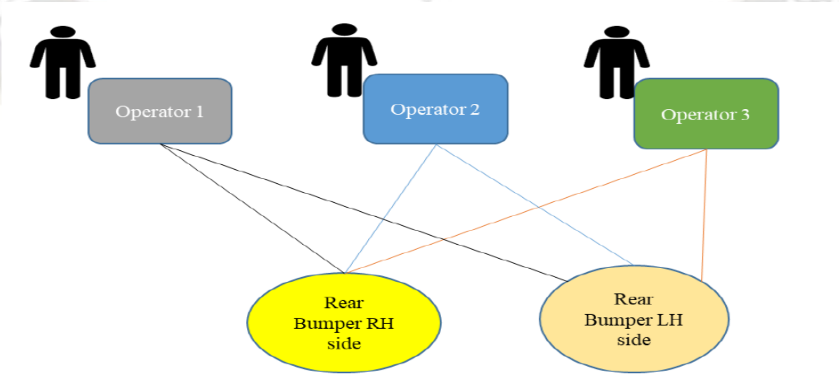

Fig 3: Gauge R&R Flow Chart

Hypothesis Test: In quality control, hypothesis testing is an essential statistical tool for determining if a process is behaving as intended. Decisions regarding process quality and improvement opportunities can be derived from comparing sample data to a pre-defined hypothesis.,

Control Charts: To analyze the gap, this project makes use of X-bar and R-bar control charts to track the measurements of the space between the rear bumpers. If there is variance in the process, these graphs might help you spot patterns and

trends. They can analyze and take remedial measures before quality problems emerge by visually analyzing the data and immediately analyzing points that depart from the intended

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range.

- **Taper Scale**

Figure 4 shows how a taper scale, sometimes called a taper gauge or taper feeler gauge, is essential in businesses that value accuracy for the sake of proper fit and operation. The machining, metalworking, and assembly industries frequently use components with tapered characteristics, and this specialist equipment is created to measure the gaps or clearances in these parts. The gauge can manage a wide range of taper angles and sizes because to its succession of thin, flat metal blades of varied thickness, each of which is calibrated with accurate measurements. An operator can evaluate a gap by inserting a blade, chosen according to the anticipated taper, between two surfaces. One easy way to find out how much room there is between a car's bumper and body is to use the taper scale. Checking if the car is inside the allowed range for this crucial quality feature is made much easier with this helpful tool. In addition to measuring tapers and gaps, it is a multipurpose instrument.

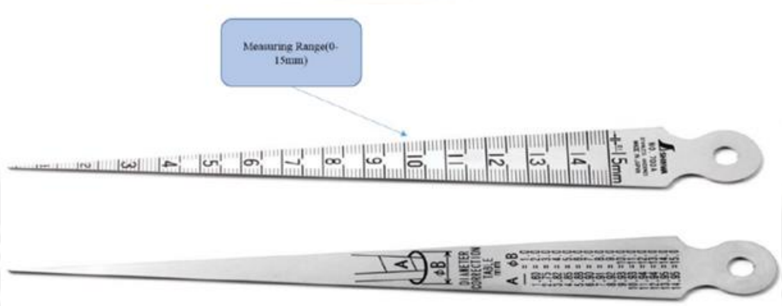

Fig 4: Taper Scale

- **Dial Gauge**

Below Figure 5 shows a dial gauge for flush checking, a type of precision measuring tool often used in quality control and production to determine if two adjacent surfaces are flush with one other. In most cases, a dial gauge will have a plunger or needle attached to the dial face; alternative names for this type of indicator include dial test indicator and dial indicator. Graduations are marked on the dial face to enable exact measurements. A movable arm or stand holds the gauge, allowing for convenient positioning. Placing the gauge in touch with both surfaces allows one to check their flushness; any variation is indicated by the movement of the needle on the dial face.

Fig 5: Digital Gauge

4. Data Collection and Analysis

After the vehicle was assembled, it was subjected to a comprehensive inspection of the rear bumper and body gap at vehicle's production plant. Accurate assessment of the gaps between the vehicle body and the rear bumper was achieved by selecting a representative sample of automobiles and taking exact measurements using a tapper scale. To evaluate the consistency and precision of the assembly in meeting the required specifications for the gap dimensions, this data collecting method is essential for quality control and assurance. Assembling automobiles requires a high

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degree of accuracy, which is why a tapper scale is essential. By zeroing down on the vehicle's back bumper and body gap. To guarantee that every vehicle in Table 2 satisfies both the company's and the customer's expectations for visual appeal and general build quality, the collected data is a great tool for monitoring and optimizing the production process.

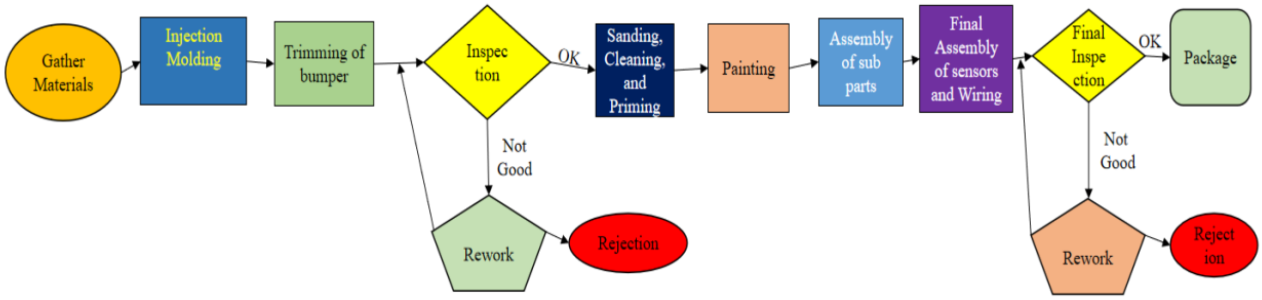

Fig 6: Rear Bumper Process Flow Chart

Place	Defect Type	Acceptable Limit (mm)
Body Panel to Rear Bumper	Gap	0-1
Body Panel to Rear Bumper	Flush	-0.7 to -1.2

Table 1: Acceptable Limits

Station No	Station Name	Process Details
OP10	Injection Molding	This station melts and injects a plastic material into a mold to form the basic shape of the rear bumper.
OP20	Trimming of Bumper	Excess material from the injection molding process is removed to achieve the final shape of the bumper.
OP30	Inspection of Injection Bumpers	In this process the quality inspectors check the injection part of rear bumper and good parts will be sent to OP40
OP40	Sanding, Cleaning, and Priming	The surface of the bumper is sanded smooth, cleaned thoroughly, and coated with a primer for better paint adhesion.
OP50	Painting the rear bumper	This station involves the application of paint to the rear bumper, likely contributing to both its aesthetic appeal and protective properties.
OP60	Sub assembly of parts	Additional components like brackets, sensors, and lights are attached to the painted bumper.
OP70	Final assembly of sensors and wiring	Sensors and their wiring are installed and connected to the bumper's electrical system.
OP80	Final Inspection	A final quality control inspection is conducted to ensure all components are properly assembled and functional.
OP85	Rework area	Any identified defects from the final inspection are repaired or corrected in this area.
OP90	Package section	The completed rear bumper is carefully packaged for storage or transportation.

Table 2: Process of Rear Bumper

4.1 Experimental Data Samples Left Side

In Table 3, you can see the values of the gaps between the rear bumper and the body panel on the left-hand side. Three different operators measured eleven different vehicles, and the data presented here is a selection of those measurements. This technique validates the gap by measuring the values between the car's rear bumper and body panel using a tapered scale. After that, the digital dial gauge is used to measure the flush values. Three separate operators take note of the flush values as the dial gauge is mounted on the surface of the rear bumper on the left side of the vehicle. A comprehensive assessment of the vehicles' rear bumper flushness and gap size is made possible by integrating these two measuring techniques into the data collection procedure. Quality control and the detection of any production discrepancies can both benefit from this data.

Sl no	Car Sample No	Operator	Gap No	Gap Value(mm)	Flush Value (mm)	Sl no	Car Sample No	Operator	Gap No	Gap Value (mm)	Flush Value (mm)
1	8	1	1	0.98	-1.02	28	5	1	3	1.13	-0.97
2	4	1	2	0.94	-1.3	29	1	1	4	0.88	-1.24
3	5	1	3	1.08	-0.97	30	4	1	5	0.91	-1.24
4	7	1	4	0.81	-1.23	31	3	1	1	0.9	-1.02
5	6	1	5	1.12	-1.1	32	8	1	2	1.07	-1.22
6	9	1	1	0.87	-1.08	33	2	1	3	0.99	-1.2
7	3	1	2	1.09	-1.24	34	7	1	4	0.97	-1.1
8	2	1	3	1.12	-0.98	35	9	1	5	0.91	-0.9
9	1	1	4	0.96	-1.25	36	6	1	1	0.95	-0.95
10	3	2	5	0.89	-1.1	37	4	2	2	1.02	-1.31
11	8	2	1	1.2	-1.26	38	8	2	3	0.93	-1.2
12	6	2	2	0.98	-1.2	39	9	2	4	0.97	-1
13	1	2	3	0.96	-0.97	40	6	2	5	0.95	-1.05
14	2	2	4	1.08	-1	41	1	2	1	0.99	-1.04

Table 3: Data samples of gaps on LHS

- **Gauge R&R Test – ANOVA Method Using Minitab for Gap Values**

Both the Car No factor and the eleven vehicles used in the research were chosen at random from a bigger pool of potential participants. According to table 4, the Car No factor values are 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, and 11. Similarly, the Operator factor has three levels and is completely random. What this means is that out of a bigger population, the three operators who took part in the study were chosen at random. The Operator factor can take on the values 1, 2, and 3.

Factor	Type	Levels	Values
Car No	Random	11	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11
Operator	Random	3	1,2,3

Table 4: Factor Information

- **Gauge Two-Way ANOVA Table with Interaction**

Given that the part factor affects the gap values (F=2.97483, p=0.030), the two-way ANOVA with interaction from Table 5 yields a P-value lower than 0.05. The p-values for the effects of operators (F=0.00826, p=0.992) and the interaction between operators' sources and parts (F=0.67057, p=0.797) are greater than 0.05, rendering them statistically inconsequential. What this means is that the measurement is unaffected by operators or their interactions with parts, but that parts do contribute to outcome variances.

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Source	DF	SS	MS	F	P
Parts	8	0.101337	0.0126671	2.97483	0.030
Operators	2	0.000070	0.0000352	0.00826	0.992
Parts * Operators	16	0.068130	0.0042581	0.67057	0.797
Repeatability	27	0.171450	0.0063500		
Total	53	0.340987			

Table 5: ANOVA Table

- **ANOVA Table without Interaction**

The results from Table 6 shows that the part factor affects the response variable (F=2.27351, p=0.040) since the p-value is less than 0.05, while the impact of operator's source (F=0.00632, p=0.994) is statistically insignificant because the p-value is more than 0.05. This indicates that parts factor contributes to variations in the result, while operators do not significantly affect the measurement.

Source	DF	SS	MS	F	P
Parts	8	0.101337	0.0126671	2.27351	0.040
Operators	2	0.000070	0.0000352	0.00632	0.994
Repeatability	43	0.239580	0.0055716		
Total	53	0.340987			

Table 6: Two-Way ANOVA Table without Interaction

- **Gage R&R Variance Components**

In Table 7, we can see how the Gage R&R study's variance components were calculated. The results show that the total gage R&R and repeatability component accounts for 82.49% of the total variation. This is above the permissible range according to the recommendations set by the Automotive Industry Action Group (AIAG). Therefore, it is necessary to ensure that the measurement system is consistent. There is an unacceptable amount of variation between components, as the part-to-part component accounts for 17.51% of the total. In addition, the repeatability component and the operator's component also contribute zero, suggesting that these factors have little to no impact.

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.0055716	82.49
Repeatability	0.0055716	82.49
Reproducibility	0.0000000	0.00
Operators	0.0000000	0.00
Part-To-Part	0.0011826	17.51
Total Variation	0.0067542	100.00

Table 7: Gage R&R Variance Components

- **Gage Evaluation**

Measurements do not agree with one another, according to the gage evaluation, which Ninety percent of the variation and forty-four percent of the tolerance are outside of the permissible range, as shown in Table 8. This indicates that when the same part is measured by other operators, they will get different findings. Some variance between the sections is shown by Part-to-Part. Within the allowed range, it explains 42% of the volatility and 20% of the tolerance. The results can still show some variation in the measurements among components, even if the operators are constant. The measurements are largely unaffected by reproducibility and operator factors. Neither of them contributes more than one percent to the overall data variation. This ensures that the measurements are consistent regardless of who takes them or when they are taken, and that various operators produce identical findings.

Source	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)	%Tolerance (SV/Toler)
Total Gage R&R	0.0746433	0.447860	90.82	44.79
Repeatability	0.0746433	0.447860	90.82	44.79
Reproducibility	0.0000000	0.000000	0.00	0.00
Operators	0.0000000	0.000000	0.00	0.00
Part-To-Part	0.0343887	0.206332	41.84	20.63
Total Variation	0.0821840	0.493104	100.00	49.31

Table 8: Gage Evaluation

- **Gage R&R Chart**

Using the Gage R&R method to determine gap values Figure 7 shows the results of a Minitab analysis of several charts. The data values depicting the distance between the back bumper and the body panel are shown in the graph. Looking at this data will help us determine what's really causing the differences in gap readings. For a more accurate assessment of the disparities in the gap values, the Minitab program is useful for determining and comprehending the variables that contribute to the variability.

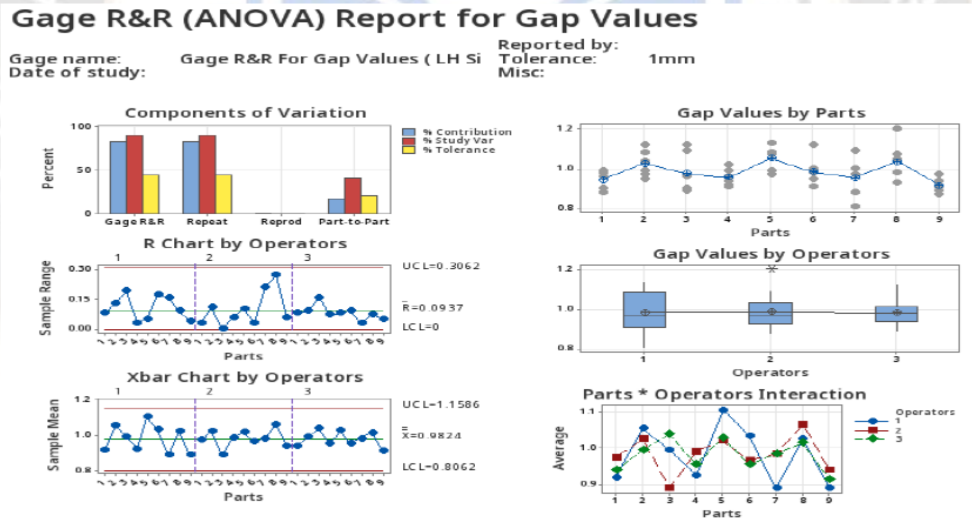

Figure 7. Gage R&R study chart for LH side Gap.

4.2 Experimental Data Samples Right Side

The data for the distances between the right-hand side body pane and the rear bumper can be found in table 3. Three different operators measured eleven different vehicles, and the data presented here is a selection of those measurements. To validate the gap, the values are measured using a taper scale between the car's rear bumper and body panel. After that, the digital dial gauge is used to measure the flush values. The dial gauge is mounted on the rear bumper surface of the vehicle on the right-hand side, and the three operators record the flush values. A comprehensive assessment of the vehicles' rear bumper flushness and gap size is made possible by integrating these two measuring techniques into the data collection procedure. Quality control and the detection of any production discrepancies can both benefit from this data.

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Sl no	Car Sample No	Operator No	Gap No	Gap Value (mm)	Flush Value (mm)	Sl no	Car Sample No	Operator No	Gap No	Gap Value (mm)	Flush Value (mm)
1	8	1	1	0.89	-1.02	28	5	1	3	0.89	-0.99
2	4	1	2	1.05	-1.25	29	1	1	4	1	-1.23
3	5	1	3	1.09	-0.99	30	4	1	5	1.12	-1.25
4	7	1	4	1.07	-1.24	31	3	1	1	0.97	-1.04
5	6	1	5	0.98	-1.15	32	8	1	2	0.91	-1.22
6	9	1	1	0.85	-1.08	33	2	1	3	0.94	-1.19
7	3	1	2	0.9	-1.24	34	7	1	4	0.89	-1.1
8	2	1	3	0.99	-1	35	9	1	5	1	-0.98
9	1	1	4	1.03	-1.25	36	6	1	1	0.82	-1.05
10	3	2	5	0.89	-1.13	37	4	2	2	0.95	-1.31
11	8	2	1	0.92	-1.25	38	8	2	3	0.83	-1.2
12	6	2	2	0.97	-1.2	39	9	2	4	1.07	-1.11
13	1	2	3	1.01	-1.05	40	6	2	5	0.9	-1.08
14	2	2	4	1.05	-1.06	41	1	2	1	1.17	-1.04

Table 9: Data samples of gaps on RHS

- **Gauge R&R Test – ANOVA Method Using Minitab for Gap Values**

There are eleven levels to the random factor "Car no," which stands for various automobile models. The numbers 1 through 10 represent these tiers. A third level random factor, the factor operator denotes the several people or operators that contributed to the measurements. Levels 1, 2, and 3 have been assigned to these.

Factor	Type	Levels	Values
Car No	Random	11	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11
Operator	Random	3	1,2,3

Table 10: Factor Information

- **Two-Way ANOVA Table with Interaction**

A particular response variable's Parts and Operators are revealed by the two-way ANOVA with interaction. The Parts factor in Table 11 does not approach statistical significance, despite the fact that it shows a small fluctuation (F-statistic 2.20231, p-value 0.085). There is no significance in the Operators interaction term (p = 0.664) or the Parts * Operators interaction term (p = 0.528). This means that the total variation in the response variable is not significantly affected by either factor or their interaction.

Source	DF	SS	MS	F	P
Parts	8	0.078500	0.0098125	2.20231	0.085
Operators	2	0.003744	0.0018722	0.42020	0.664
Parts * Operators	16	0.071289	0.0044556	0.95174	0.528
Repeatability	27	0.126400	0.0046815		
Total	53	0.279933			

Table 11: Two-Way ANOVA Table with Interaction

- **Two-Way ANOVA Table without Interaction**

With an F-statistic of 2.13435, which is greater than the critical F-value, and a p-value of 0.053, which is less than the significance level of 0.05, the Parts factor from Table 12, which has 8 degrees of freedom and a sum of squares of 0.078500, shows a significant impact on the variability. This provides more evidence that various components reliably affect the response variable's variability. No statistically significant effect of the Operators component with two degrees of freedom and a smaller sum of squares (0.003744) on variability is seen. With an F-statistic of 0.40723, it is not statistically significant, but the p-value of 0.668 puts it beyond the cutoff. This suggests that the variability of the response variable is not consistently altered by various operators.

Source	DF	SS	MS	F	P
Parts	8	0.078500	0.0098125	2.13435	0.053
Operators	2	0.003744	0.0018722	0.40723	0.668
Repeatability	43	0.197689	0.0045974		
Total	53	0.279933			

Table 12: Two-Way ANOVA Table without Interaction

- **Gage Evaluation**

The consistency of the measurement system is seen in table 13. When the same operator measures the same part, the findings could vary, which is not acceptable according to AIAG. The repeatability component accounts for 91.71% of the study variance and 40.68% of the tolerance. There is zero effect of Reproducibility and Operators on the study's tolerance and variance. The research variance and tolerance are also affected by part-to-part fluctuations, which account for 39.87% of the total and 17.69% of the allowed variation when taking measurements accurately. There is room for improvement in part-to-part variability, but overall, the Gage Evaluation shows that the system is reliable with operator and repeatability impacts.

Source	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)	%Tolerance (SV/Toler)
Total Gage R&R	0.0678042	0.406825	91.71	40.68
Repeatability	0.0678042	0.406825	91.71	40.68
Reproducibility	0.0000000	0.000000	0.00	0.00
Operators	0.0000000	0.000000	0.00	0.00
Part-To-Part	0.0294819	0.176891	39.87	17.69
Total Variation	0.0739364	0.443619	100.00	44.36

Table 13: Gage Evaluation

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- **Gage R&R Chart**

Visual inspection of the measuring system's repeatability and reproducibility is presented in this Gage R&R graph from Figure 8, which measures the gap between the right-hand side rear bumper and the body panel. This graph provides useful insight into the measurement's overall accuracy and dependability by analyzing the contributions of several types of variation, such as repeatability, reproducibility, and part-to-part variation.

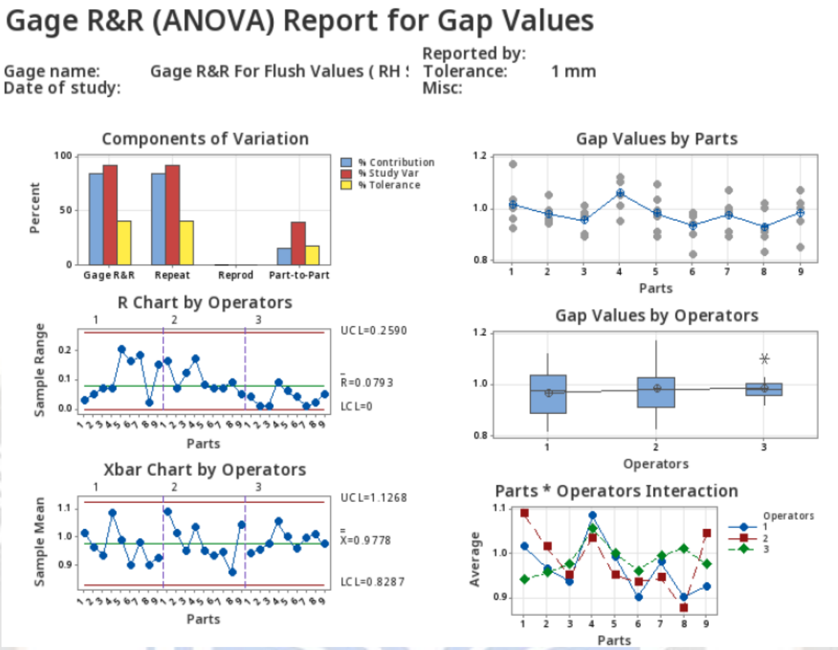

Figure 8. Gage R&R study chart for RH side Gap.

5. Results and Discussions

Eleven vehicles manufactured by the same company had their data physically collected. Gage R&R and Anova were used to construct graphs and hypothesis tests in Minitab. We started by measuring the distance between the rear bumper and the body panel on the right and left sides, and then we used a taper scale tool to get the gap values. Three people were responsible for measuring the gaps, and a dial gauge was used to measure the flush values.

5.1 Rear Bumper LH side Gap Measurements Analysis

Operators and their interactions had a statistically substantial impact on the gap values, according to the Gage R&R ANOVA study, although individual parts had less of an impact. Section 4's Gage R&R analysis showed a significant degree of repeatability; in fact, repetition accounted for 82.49% of the overall variation. But for 17.51% of the overall variation, part-to-part variation was found to be a significant contributor. The Gage Evaluation provided additional evidence of the high repeatability; the study's variation fell under the rejection range for 90.82 percent. According to the operator's R-chart, operator 2 may have a different measurement methodology for some components than the others. There was some variation from part to part, as shown by the tiny fluctuations in the X-chart from Figure 7. From what we can tell from the box and whisker plot, operator 1 is the one most likely to have measurements that are within the allowed range. Operator 2 and operator 3 follow closely behind. In general, the gap measurement system was adequate, but it might be even better if the variation from part to part were addressed.

5.2 Rear Bumper RH side Gap Measurements Analysis

Out of the entire variation, 91.71% is attributable to Gage R&R and repeatability, which is higher than the 10% permissible limit set by AIAG. This shows that the measuring system is very inconsistent. There is inherent variability between parts, as evidenced by the part-to-part variation accounting for 39.87% of the total variation. While part-to-part variation is within acceptable limits, the overall variation is greatly impacted by both Gage R&R and repeatability, as seen in the Gage R&R study graph. Possible discrepancy in operator 2's readings is shown by the R-bar graph. From what we can tell from the box and whisker plot, operator 1 is the one most likely to have measurements that are within the allowed range. Operator 2 and operator 3 follow closely behind. When broken down by operator, the X-bar chart shows that 2 and 3 have gap values that are significantly higher than the tolerance limit.

5.3 Improvements Scenarios

After the analysis of the gap and flush between the rear bumper and body panel using the Minitab software tool like Gage R&R and hypothesis test with the help of these tools, we noticed some variation's part to part and operator measuring the multiple parts. Finally, to maintain the consistency between part-to-part variations some of the improvement scenarios mentioned. Upon analyzing the left and right sides of the rear bumper, we discovered that there was some variation from one component to another. This was since certain spots exceeded the acceptable limits specified by the customer. Still, raising the hold-on pressure from 65 bar to 68 bar adds 5 grammes to the weight of the rear bumper. Table 14 shows the sample readings of X1, X2, and X3 of the distance between the rear bumper and body panel. The real weight is now 715 grams, and 10 components were fabricated. We next used an X-bar chart and an R-bar chart to display these samples. All the samples fall within the permitted range, as we have noted.

	X1	X2	X3	X-Bar	R-Bar
RHS	0.97	0.95	0.89	0.94	0.08
RHS	0.88	0.9	0.91	0.90	0.03
RHS	0.91	0.93	0.92	0.92	0.01
RHS	0.97	0.99	0.95	0.97	0.04
RHS	0.85	0.89	0.91	0.88	0.06
LHS	0.93	0.92	0.93	0.93	0.01
LHS	0.98	0.97	0.96	0.97	0.01
LHS	0.9	0.92	0.91	0.91	0.02
LHS	0.89	0.9	0.92	0.90	0.03
LHS	0.92	0.95	0.97	0.95	0.05

Table 14: Sample Data Weight Changed

The distance among the back bumper of the vehicle and the body decreases as the weight of the component increases, adhering to the acceptable limit of 1mm. The obtained values from five distinct locations on the left and right sides are all within the acceptable range, as indicated in Table 9. The X-Bar value, which represents the sample mean of the values, is also calculated and concluded to be within the acceptable range. Figure 9 presents the plotted X-Bar values, from which the UCL value of 1.0064 and LCL value of 0.8 are also determined to be within acceptable limits.

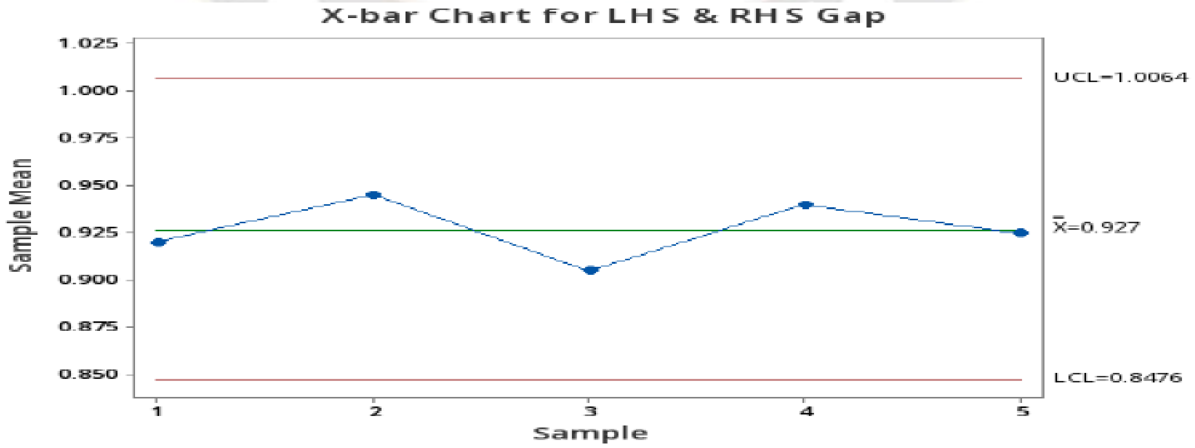

Figure 9. X-bar chart for LH & RH side after improvement

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The plot of R-Bar values, which illustrate the range value (i.e., the difference between the highest and lowest value in each sample), is depicted in Figure 10. The values UCL=0.1046 and LCL=0, as well as the r value (0.032) calculated as the average of all ranges, were obtained from Figure 10.

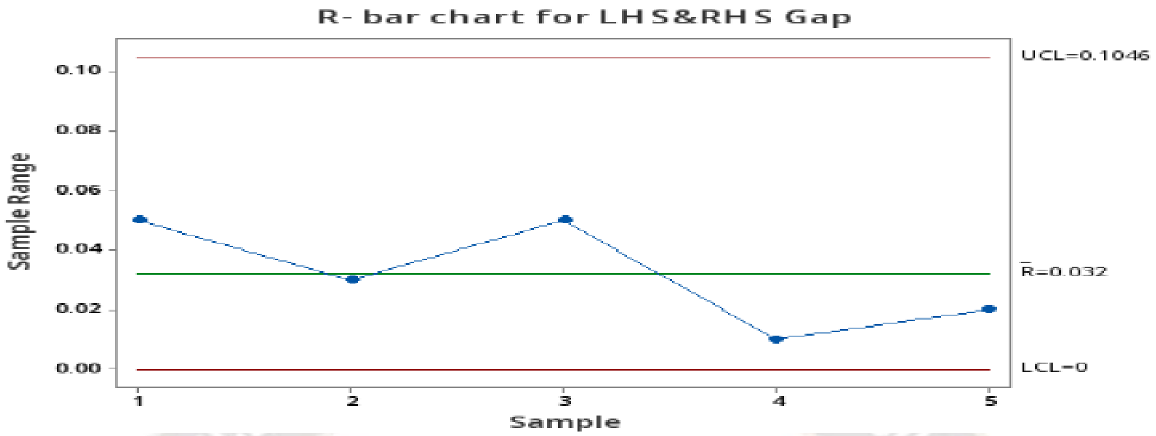

Figure 10. R-bar chart for LH & RH side after improvement

6. Calibration Schedule for Measuring Instruments

The critical procedure of comparing the readings of an instrument to a recognized standard is known as instrument calibration. By conducting this comparison, any discrepancies in the instrument's readings can be detected and, if required, rectified to ensure precision and uniformity. As we make some adjustments to the maintenance schedules for instruments. In the past, instruments such as dial gauges, Vernier calipers, and height gauges were inspected annually. However, after the analysis, we instituted inspection schedules mandating instrument checks every six months. Additionally, the training of inspection personnel to ensure accurate checks was a prerequisite for this change.

7. Conclusion

The efficacy of statistical quality control methods in evaluating the distance between the rear bumper and body panel is illustrated in this project. By utilizing data analysis and SQC tools such as the generated hypothesis test, Gauge R&R Anova, X-bar and R-bar charts, the deviation between the sample mean and sample range can be assessed, as well as the inter-part variation can be evaluated. In addition, a Gage R&R Evaluation was performed to assess the instruments' precision through the examination of reproducibility and repeatability across various operators. The analysis revealed that augmenting the weight of the component from 710gm to 715gm led to a decrease in gap values, thereby restoring them to the acceptable range. Furthermore, for future production lines, additional potential enhancements to detect the defect rate of the gap between the rear bumper and body panel were identified.

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