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Conducting a Gage R & R Study: An Application Example in Automotive Industry

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Abstract

In today's intense competitive environment; In order to sustain their existence, businesses want to reduce the variability in their processes and thus increase their productivity. For this; they aim to improve their processes quickly by using various statistical and non-statistical methods. Often, they focus directly on the process itself to achieve this. This may cause improvement works to fail. One of the main reasons for this is that variability due to the measuring system is ignored. Because; the total variability in processes occurs in two ways, from the measurement system and from the process itself. In order to obtain a permanent solution, the adequacy of the measurement system must first be statistically tested. Measurement system analysis (Gage R&R), a statistical method, is used to test the measurement system. With this work; Literature research has been carried out regarding the usage areas of measurement system analysis. Following the literature search; an industry application project was discussed. Statistical evaluation of the project results was made.

Keywords: Measurement System Analyze (Gage R&R), Measurement System, Automotive Industry, Gage R&R Case Study, Statistics, Manufacturing Process.

Ölçüm Sistemi Analizi Çalışması Yapmak: Otomotiv Endüstrisinde Bir Uygulama Örneği

Özet

Günümüz yoğun rekabet ortamında; işletmeler varlıklarını sürdürebilmek için süreçlerindeki değişkenlikleri azaltmak ve böylece verimliliklerini arttırmak isterler. Bunun için; çeşitli istatistiksel ve istatistiksel olmayan yöntemleri kullanarak süreçlerinin hızlı bir şekilde iyileşmesini amaçlarlar. Genellikle bunu sağlamak için doğrudan sürecin kendisine odaklanırlar. Bu da iyileştirme çalışmalarının başarısızlıkla sonuçlanmasına neden olabilmektedir. Bunun temel nedenlerinden biri ölçüm sisteminden kaynaklanan değişkenliğin göz ardı edilmesidir. Çünkü süreçlerde yer alan toplam değişkenlik ölçüm sisteminden ve sürecin kendisinden olmak üzere iki şekilde gerçekleşir. Kalıcı bir çözümün elde edilebilmesi için öncelikli olarak ölçüm sisteminin yeterliliğinin istatistiksel olarak test edilmesi gerekir. Ölçüm sisteminin test edilmesi için bir istatistiksel yöntem olan ölçüm sistemi analizi (Gage R&R) kullanılır. Bu çalışma ile; ölçüm sistemi analizinin kullanım alanlarıyla ilgili olarak literatür araştırması gerçekleştirilmiştir. Literatür araştırmasını takiben; bir endüstri uygulama projesi ele alınmıştır. Proje sonuçlarının istatistiksel değerlendirmesi yapılmıştır.

Anahtar Kelimeler: Ölçüm Sistemi Analizi (Gage R&R), Ölçüm Sistemi, Otomotiv Endüstrisi, Tekrarüretilebilirlik ve Tekrarlanabilirlik, Gage R&R Vaka Çalışması, İstatistik, Üretim Süreci

1. INTRODUCTION

Quality is an indispensable phenomenon for manufacturers. It is a way of life for consumers. With this feature; customer satisfaction is the number one priority for organizations. The success of an organization; It is associated with providing the highest quality in the shortest time with the lowest cost. When this is achieved, customer satisfaction can be achieved. Customer satisfaction also means profitability for companies (Taghizadegan, 2006). Therefore; companies aim to maintain customer satisfaction. If this is achieved, companies can survive in today's fierce competitive environment. To achieve this, they are constantly trying to control and improve their processes. They use a variety of statistical and non-statistical methods to identify and eliminate sources of variability in their processes. In order to determine the improvement areas correctly and to meet customer requirements; accurate measurement of process variation is one of the biggest problems in a manufacturing process (Tavera Sainz, 2013). The total variability in a system is due to the variability of the process itself and the measurement system variability (See equation 1).

$$\sigma^2_{Total} = \sigma^2_{Process} + \sigma^2_{Measurement\ system} \quad 1$$

In order to determine the real variability of the process in any study, the measurement system must first be verified (Rasis, Gitlow, & Popovich, 2002) (Gerger & Firuzan, 2020) (Hahn, Doganaksoy, & Hoerl, 2 (Aized, 2012) (Breyfogle, 1999) (Eckes, 2001) (Hahn, Doganaksoy, & Hoerl, 2000) (Pande, Neuman, & Cavanagh, 2000).

Gage R&R is verified in any problem-solving techniques (Prashar, 2016). The aim of the Gage R&R studies is applied to ensure that the measurement system is statistically reliable. Gage R&R study evaluate how much of the total variance is due to the measurement system related (Kaushik & Khanduja, 2009) (Gerger & Firuzan, 2020). As point out (Kumar, Antony, Singh, & Tiwari, 2006), "*a gauge repeatability and reproducibility (R&R) study was conducted to identify the sources of variation in the measurement system and to determine whether it was accurate or not*".

Measurement values constitute the most important components of any quality systems. Measurements are an indispensable element in process improvement and problem-solving processes. Because it causes the possibility of making the wrong decision; An appropriate and incorrect measurement system can adversely affect business performance. Goals of the measurement system competence research are as follows (Montgomery, 2009):

- Understand how much of the total variance observed are due to the measurement system.
- Separate variance elements in the measurement system.
- Evaluate the competence of the measurement system.

Measurement system variance consists of two components; reproducibility and repeatability (See equation 2).

$$\sigma^2_{Measurement\ system} = \sigma^2_{Repeatability} + \sigma^2_{Reproducibility} \quad 2$$

Repeatability is the variance of a part between the measurements performed by an operator with the same measurement device and under the same working conditions. Reproducibility is the variance of the average of measurements performed by different operators on the same part with the same measurement device (Joglekar, 2003) (Hwang & Horng, 2018) (Weaver, Hamada, Vardeman, & Wilson, 2012).

1.1. Preparation of a Gage R&R Study

The planning and analysis of a measurement system is defined by AIAG in six steps. These are (AIAG, 2010):

- Determining the approach to be used
- Determination of sample parts, number of repetitions, and number of appraisers
- Selection of meters (among those who use the measuring device)
- Selection of sample parts to be measured (depending on the design of the Gage R&R study)
- Determination of the sensitivity and expected variability of the measuring device
- Checking the measurement method's compliance with the defined procedure

1.2. Gage R&R Çalışmasında Karşılaşılan Problemler

There are 8 common issues in the planning, preparation and execution of a Gage R&R study. These are (Tavera Sainz, 2013):

- Failure to select samples that include the distribution of tolerance.
- Not randomly selecting samples during measurements.
- Measuring inexperienced and untrained personnel in the process.
- Mixing or changing samples during the run.
- During the Gage R&R study; the employee organizing the experiment is not in the field.
- Publish the results with the names of the measures.
- Gage R&R study is done once, the results are considered unlimitedly valid.
- Gage R&R work performed on only one equipment is deemed valid for all similar equipment.

1.3. Parameters of Gage R&R

Gage R&R çalışmaların 5 tane parametresi bulunmaktadır. These are (AIAG, 2010):

- Equipment Variation (EV)
- Appraiser Variation (AV)
- Gage R&R
- Part Variation (PV)
- Total Variation (TV)

1.3.1. Equipment variation

It is the measurement of the variability of the appraiser. It is obtained by measuring the same feature of the same piece more than once with the same instrument. It is calculated as specified in the equation below (AIAG, 2010).

$$EV = K_1 \bar{\bar{R}} \quad (3)$$

K_1 is a constant that depends on the number of attempts.

- For 1 trial → $K_1: 0.8862$
- For 1 trial → $K_2: 0.5908$

1.3.2. Appraiser variation – AV

Appraiser variability is the difference between different measurements when measuring the same feature on the same part more than once with the same instrument (AIAG, 2010). It is calculated as follows.

$$AV = \sqrt{(\bar{X}_{diff.} * K_2)^2 - \frac{AV^2}{nr}} \quad (4)$$

$n = parts$
$r = trials$
K_2 is a constant that depends on the number of appraisers.

- For 1 trial → $K_2: 0.7071$
- For 1 trial → $K_2: 0.5231$

1.3.3. Gage R&R

Gage R&R is the combination of measurement variability and equipment variability (AIAG, 2010). It is calculated as follows.

$$GRR^2 = EV^2 + AV^2 \quad (5)$$

1.3.4. Part variation – PV

PV is calculated by multiplying the range of part averages by a fixed value of K_3. (AIAG, 2010). K_3 values are shown in Table 1. It is calculated as follows.

$$PV = R_p * K_3 \quad (6)$$

Table 1. K_3 depends on the number of parts.

Parts	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
K_3	0.7071	0.5231	0.4467	0.4030	0.3742	0.3534	0.3375	0.3249	0.3146

1.3.5. Total variation - TV

It shows the total variation in the process. It is the sum of the measuring system variation and the part variation (AIAG, 2010).

$$TV^2 = GRR^2 + PV^2 \quad (7)$$

Calculation of percentage effects is as follows.

$$\%EV = 100 * \frac{EV}{TV} \quad (8)$$

$$\%AV = 100 * \frac{AV}{TV} \quad (9)$$

$$\%GRR = 100 * \frac{GRR}{TV} \quad (10)$$

$$\%PV = 100 * \frac{PV}{TV} \quad (11)$$

Evaluation of gage R&R analysis is done according to the following rules (Airbus, 2011) (AIAG, 2010):

- *If* $Gage\ R\&R < 10\%$: The measuring system is acceptable.
- *If* $10\% < Gage\ R\&R < 30\%$: It can be accepted depending on the importance of the application, the cost of the meter, the cost of repair, etc.
- *If* $Gage\ R\&R \geq 30\%$: The measuring system needs to be improved. Try to identify and fix problems.

1.4. Number of Distinct Category (ndc)

Another important issue in evaluating the validity of the measurement system is '*ndc*'. It is a measure of the number of different categories that can be distinguished by the measuring system. It should be $ndc \geq 5$ (Airbus, 2011) (AIAG, 2010). It is calculated as follows.

$$ndc = 1.41 * \frac{PV}{GRR} \quad (12)$$

As the obtained 'ndc' value increases, the reliability of the measurement system increases.

1.5. Correction Criteria of Measurement System Analysis

If the measurement system variability is calculated as unacceptable ($GRR\% > 30$), the measurement system needs improvement. Where to start improvement should be done by looking at % EV and % AV values.

Evaluation of measurement system analysis results should be made according to the following two conditions (AIAG, 2010) (Airbus, 2011).

- If the repeatability rate is greater than the reproducibility ($repeatability > reproducibility$), the reasons may be as follows.
  - ✓ The measurement device may need maintenance.
  - ✓ The measuring device may be redesigned to be more robust.
  - ✓ For measurement; measurement and part may need to be clamped or positioned to improve.
  - ✓ It might be excessive part variability.

- If the reproducibility rate is greater than the repeatability ($\text{repeatability} > \text{reproducibility}$), the reasons may be as follows.
  - ✓ The appraiser may need to be better trained in how to use and read the instrument.
  - ✓ Calibration in the instrument may not be clear.
  - ✓ A fixture can be used to properly use the instrument.

2. LITARATURE REVIEW

One of the most important steps in process improvement is verification of the measurement system. Therefore; the measuring system is actively used in many industries. There are some studies about the measurement system in the literature. Some of these studies are related to theory, while others include various application examples.

In this study; Gage R&R studies applied in various industries are examined. Taking industry examples into consideration; Bayesian approach is considered for the analysis of Gage R&R data. It is explained how easy it is to perform Bayesian analysis for Gage R&R data (Weaver, Hamada, Vardeman, & Wilson, 2012).

In this work of Guitar; He discussed the Gage R&R approach. A misapplied Gage R&R study; It discussed how firms reduce their resources and the efficiency of their operations. He stated that the purpose of the Gage R&R study was 'to understand the sources of variability generated by the system' (Guitar, 2015).

In this study; the steel alloy pipe production process has been studied. The measurement system of steel alloy pipes produced by cold working is discussed (Liu & Batson, 2003).

The authors in this article; proposed a new method for multivariate analysis of measurement systems (Peruchi, Balestrassi, Paulo de Paiva, & Ferreira, 2013).

In this study; Gage R&R has been applied for three different selected lathes. Findings have shown that the Gage R&R method can be used actively in the performance evaluation of machines (Saikaew, 2018).

With this work; explained how the Gage R&R study can be performed in cases where measurements cannot be repeated due to various reasons (Hamada & Borror, 2012).

In this research article; it showed that the GRR statistical model is a useful tool for investigating uncertainties in a PLQY measurement system (Green & Buckley, 2012).

This study carried out by FMT employees; the use of the Gage R&R study in measuring the leak test is described (Staff, 2010).

In this study; it was emphasized that the importance of Gage R&R studies increased with QS 9000 systems. The results of the analysis that companies wishing to obtain the QS 9000 certificate have started to carry out their Gage R&R studies regularly have been shared (Dasgupta & Murthy, 2001).

In this study; the practicality of the Gage R&R system has been tried to be proven for continuous quality improvement, especially for small and medium-sized automobile enterprises. The importance of Gage R&R studies in the automotive industry has been explained. The study was carried out in 4 companies located in Gujarat, India. Companies supply original equipment to the automotive industry (Doshi & Desai, 2019).

In the study; the adequacy of the measurement system of programmable power devices has been tested with the Gage R&R study. A Gage R&R case study was conducted on the tea machine (Erdmann, Does, & Bisgaard, 2010).

3. APPLICATION

In today's complicated manufacturing atmosphere, it is essential that companies continually develop their business processes, to sustain their competitive market. The industrial statistical field has entered many statistical techniques for managing and improving processes in numerous industries (Joglekar 2010; Montgomery 2012; Montgomery & Runger 2013; Prashar, 2016).

The aim of the Gage R&R studies is applied to ensure that the measurement system is statistically reliable. Gage R&R study evaluate how much of the total variance is due to the measurement system related. (Kaushik & Khanduja, 2009). As point out Kumar et al. (2006), "a gauge repeatability and reproducibility (R&R) study was conducted to identify the sources of variation in the measurement system and to determine whether it was accurate or not".

Gage R&R study had been carried out by a team established under the control of the continuous improvement manager. Team is formed among competent employees, working at relevant departments or cooperating actively in addition to that on a voluntary basis. Team aims to collect data on the flexibility of the seals and evaluate the results. At first, the team examines the door glass seal in detail. Glass seals in automobile ensure that the moving glasses of the car operate silently and with the minimum friction possible in the housing. Also, these seals help to isolate dust, heat, water, and noise, thus contributing to the cleanliness of the windows (Gerger & Firuzan, 2020).

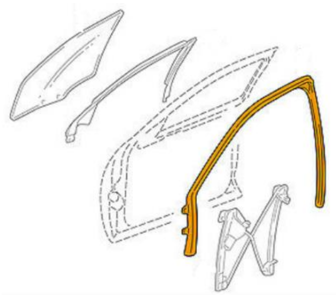

Figure 1. Location of the front door glass seal on a vehicle

The location of the glass seal on the vehicle is shown in Figure 1. Glasses move inside the housing indicated with red color lines. The glass should move with a certain degree of flexibility in the seal. Therefore, team examined the technical characteristics of the door glass seal and product standards thereof.

The flexibility of the front door glass seal was determined as the quality characteristic that caused the customer complaint. XYZ[1] provides the technical specification to the rubber producer company states the limits as 9±2 Newton. The rubber manufacturing company inspects the product "online" for mastic and outer surface damage following production and the measurements for the flexibility of the glass seal are conducted according to the equivalent of globally accepted quality standards with the device shown in Figure 2. The measurement device is compliant with EN ISO 178 and ASTM D970 quality standards.

[1] The automobile manufacturer company was named XYZ due to the competitive conditions.

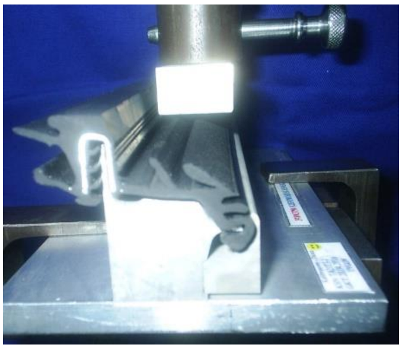

Figure 2. Flexibility test (Personal archive, 2015)

Glass seal with part number ID37 produced for XYZ automobiles is being produced only on a machine with code number F22. The production department works six workdays and three shifts. In every shift, one operator man the machine, code number F22. Only ID37 glass seals for the XYZ cars are manufactured with this machine.

3.1. Conducting Gage R&R

In order to determine the measurement system variance, the team performs measurements in accordance with the request of XYZ car manufacturer. Measurements are conducted on unformed five single parts with three repetitions, manufactured at different times in three shifts. Each one of these five parts are cut into nine equal pieces with a length of 40 cm. To achieve the randomly in the part selection, operators do not know which box contains the parts of which profile and the order of parts. Measurements are performed destructively. Measurement results of front door seals are given in Table 2.

Table 2. Gage R&R measurement result

Operator	Part 1	Part 2	Part 3	Part 4	Part 5
A	6.91	7.15	6.99	6.88	6.90
A	6.92	7.19	7.00	6.89	6.91
A	6.92	7.19	7.00	6.89	6.91
B	7.14	7.36	7.18	7.25	7.09
B	7.01	7.31	7.11	7.21	7.01
B	7.09	7.31	7.11	7.21	7.01
C	6.97	7.32	6.83	7.29	6.98
C	6.98	7.39	6.89	7.29	6.99
C	6.98	7.39	6.89	7.29	6.99

Primarily, a normality test was conducted to be able to perform a measurement system analysis on the collected data. The results of the trial are shown in Figure 3.

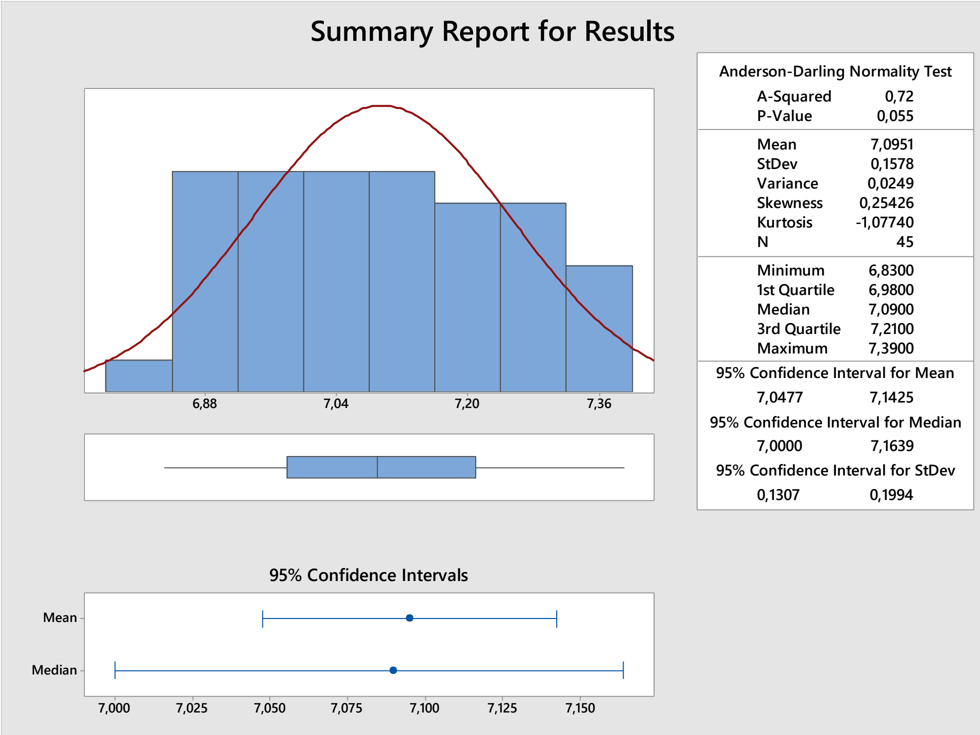

Figure 3. Gage R & R data normality test

According to the Anderson-Darling Normality Test; A-Squared value was determined as 0.72 and P-Value as 0.055. These values show that the data is distributed normally. Measurement system analysis is performed in consequence of the normal distribution of the data. The measurement system analysis is shown in Figure 4.

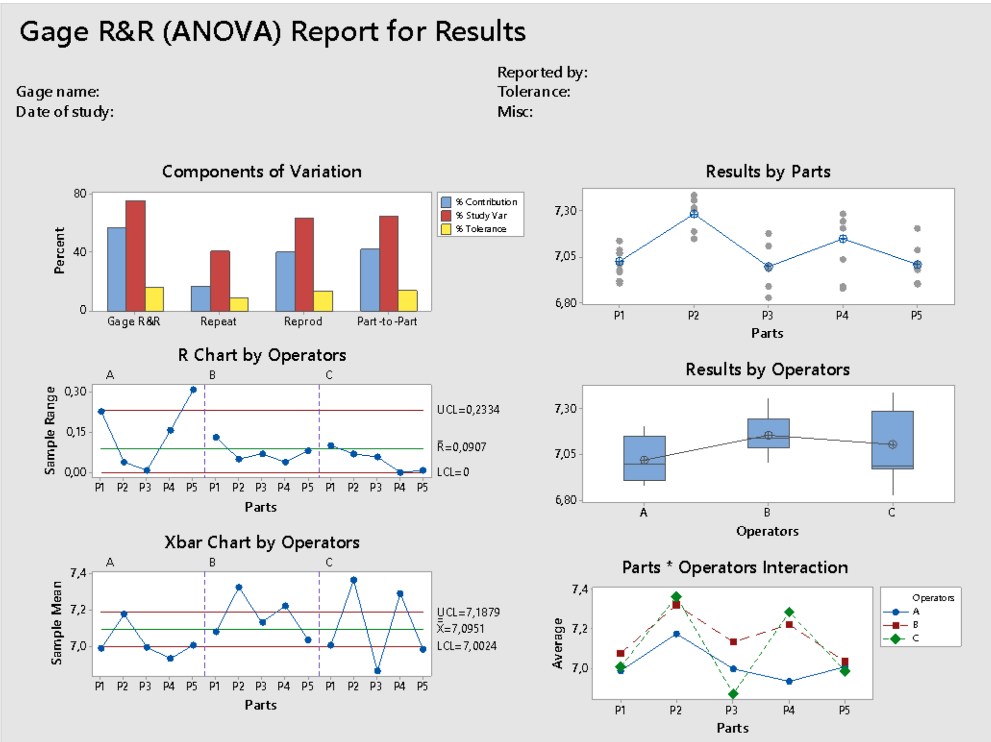

Figure 4. Gage R & R analysis result

The evaluation of Gage R&R results is given in Figure 4 and Table 2 ANOVA report (below).

- **%Study Variance bars** show that the 75.77% of the variance results from the measurement system. For a good measurement system, it is expected that the variance caused by the measurement system is smaller in comparison with the part-to-part variance. If Gage R&R, reproducibility and repeatability bars column are high, that means the measurement system is unstable (George et al., 2005). In Figure 4, the variance caused by the measurement system being bigger shows that the measurement system is inadequate.
- **Results by parts** show the measurement values and averages taken for each part. In this chart, it is desirable that the data collected for each part overlap each other. However, it can be seen in Figure 4 that the measurement variance of the parts is excessive.
- **In the R Chart by Operators**, it is expected that the range of the values measured by the operator for each part is smaller. Measurement ranges being under control show the consistency between the measurements of the operators. In Figure 4, it can be seen that especially the measurements of operator "A" is bigger than the variance of the measurement results of operators' B and C.
- **In chart Results by Operators**, horizontal line tilting shows the effect of the operators. If the line connecting the means is flat or almost flat, there are no significant differences between operators (George et al., 2005). In Figure 4, it is seen that the variance between the operators is big. The line is expected to be straight so that the variance among by the operators is at a minimum.
- **$\bar{X}$ Chart by Operators** shows whether the variance is a result of the measurement system or the process itself. In this chart, it is an expected condition that the cause of the variance is not the measurement system but rather the process itself. Measurements being within control limits shows that an incorrect or faulty measurement system was employed. In this case, the variance caused by the parts are bigger than the variance caused by the measurement system. In Figure 4, the result of the $\bar{X}$ Chart shows that the measurement system is inadequate.
- **Parts*Operators Interaction** shows the interaction of operators and parts. In case there is no interaction, parallel or overlapping laps are seen. Therefore, it is a favored condition that the lines are parallel to or overlapping each other. When Figure 4 is examined again, it can be seen that a strong interaction exists.

Table 3. Gage R&R Study – Anova

Gage R&R Study - ANOVA Method

Two-Way ANOVA Table with Interaction

Source	DF	SS	MS	F	P
Parts	4	0.55910	0.139776	4.52169	0.033
Operators	2	0.14599	0.072996	2.36138	0.156
Parts * Operators	8	0.24730	0.030912	6.45199	0.000
Repeatability	30	0.14373	0.004791		
Total	44	1.09612			

α to remove interaction term = 0.05

Gage R&R

%Contribution

Source	VarComp	(of VarComp)
Total Gage R&R	0.0163037	57.41
Repeatability	0.0047911	16.87
Reproducibility	0.0115126	40.54
Operators	0.0028056	9.88
Operators*Parts	0.0087070	30.66
Part-To-Part	0.0120959	42.59
Total Variation	0.0283996	100.00

Process tolerance = 4

		Study Var	%Study Var	%Tolerance
Source	StdDev (SD)	(5.15 × SD)	(%SV)	(SV/Toler)
Total Gage R&R	0.127686	0.657583	75.77	16.44
Repeatability	0.069218	0.356472	41.07	8.91
Reproducibility	0.107297	0.552578	63.67	13.81
Operators	0.052967	0.272783	31.43	6.82
Operators*Parts	0.093312	0.480554	55.37	12.01
Part-To-Part	0.109981	0.566405	65.26	14.16
Total Variation	0.168522	0.867888	100.00	21.70

Number of Distinct Categories = 1

ANOVA results are explained below:

- **Study Variance** has been determined as R&R %= 75.77 %. R&R % being > 30% shows that an inadequate measurement system is employed to see the actual process variance (Automotive Industry Action Group [AIAG], 2010; Airbus, 2011).
- **Number of Distinct Categories:** If a number of distinct categories is equal five or greater than this value, the measurement system can discern over five groups within the data range and is often considered to have acceptable discrimination (AIAG, 2010; Airbus, 2011). However, this value is equal to 1 in Table 3 shows that the measurement system is utterly inadequate.
- **A high reproducibility value** with 63.67 % has been determined. Possible reasons for this condition are the difference between operators. The team decides to research the causes of this difference. Reproducibility value being under 10 % shows that the measurement system is highly sufficient.
- **A high repeatability value** with 41.07 % has been detected. As maintenance, repair, calibration, etc. requirements of the measurement devices might be the reason for this condition, the team requested an examination from the maintenance department of the factory. It is accepted in AIAG (2010) that the repeatability value being between 10-30 % is marginal. The calibration of the

measurement device has been verified, and it was detected that the calibration values are conforming.

3.2. Analyzing and Improvement of Not-acceptable Gage R&R Results

By all these analysis results showing the inadequacy of the measurement system, the reasons are examined in detail. Brainstorming and Ishikawa's cause-and-effect diagram (Figure 5) was used to this end.

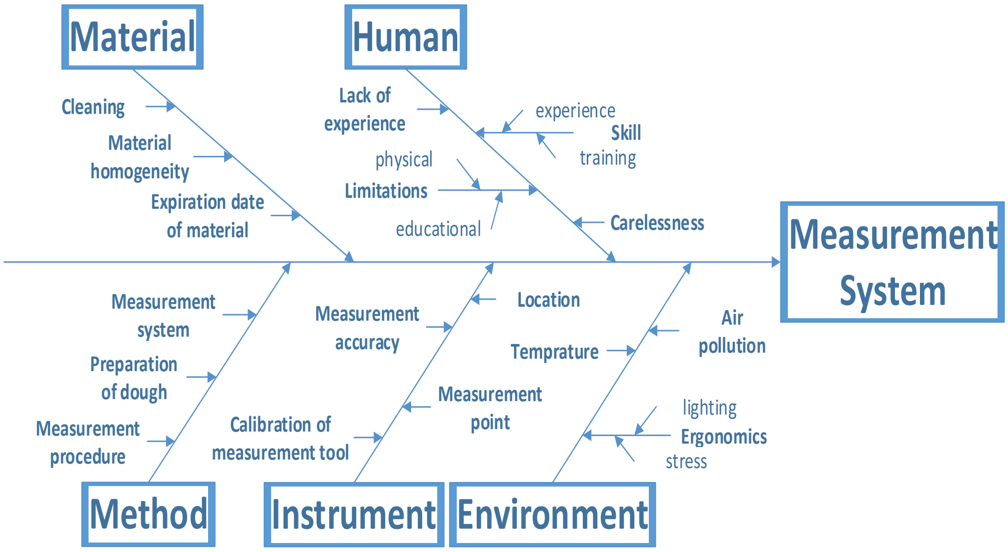

Figure 5. Cause and effect analysis of the measurement system errors

The team researched the factors causing the inadequacy of the measurement system by focusing on the factors defined in the cause-and-effect diagram.

It shall be ensured that before front door glass seal is inserted into the measurement device no foreign object such as burrs etc. is present. Such debris may prevent the glass seal from seating properly in the measurement device and cause incorrect measurement results. In the review conducted by the team, it was detected that the cleanliness of the measurement device and environmental conditions were neglected. On this matter, training sessions for the personnel working in all three shifts and the responsible managers were held. It was requested to make sure that the areas in contact with the rubber shall be clean before inserting the glass seal into the measurement device. To this end, "rubber burr, etc. waste inspection on the seal and/or measurement device" clause was included in the inspection plan.

Door glass seal no. MTA2034 consists of four different main doughs. Doughs are formed in computer-controlled, automatic mixing machines. Inspections showed that the dough is highly homogenous.

Goods in/out tracking process of the dough are conducted digitally, and the dough is consumed before the one-month expiry date. Doughs prepared in mixers with 145 liters' capacity are stored in cold storage facilities to prevent them being affected by the environmental and weather conditions. Doughs remain in the storage ten days in average, due to the application of First-in, First-out principle. Specifications state the storage period of dough in cold storage facilities as one month.

Flexibility measurement value is shown on the screen of the machine with a big font size. Therefore, no hindrance regarding the physical conditions was determined.

Since all three personnel working in the section have a technical high school background, they do possess the capability to work in the process. No nonconformities regarding the educational background of the personnel were detected.

Experience is a determining factor in the measurement device usage. Rubber manufacturer considers the working hours of the personnel a sufficient period to gain experience. Hence, no irregularities regarding the lack of experience were detected at the first stage.

Technical training records of the personnel were examined. Measurements are conducted through destructive tests. Therefore, seals produced as a single piece are separated by 40 cm long, equal pieces for the measurement process. Each personnel were observed during the measurement process. As a result of this observation, it was detected that the seal pieces to be measured are inserted into the device differently. Measurement shall be conducted after the seal is seated flat into the grooves of the measurement device. However, measuring the seal without being correctly seated delivers varying measurement results. The team arranged training for the personnel regarding the correct usage of the measurement system and recording the results. The team also requested regular, yearly recurring training on the issue.

The stress level of the personnel affects the accuracy of the measurements and the quality of the work. Keeping the stress level under control helps the operators to show required sensitivity. The personnel assigned to this process were briefed on this matter with a training session. Department managers were also asked to pay the utmost attention to this issue.

Measurements are conducted by placing glass door seals into the measurement device as requested by the customer. As a preventive action, recurrence training was conducted on how to correctly insert the glass seal into the measurement device and conducting the measurement.

Doughs are prepared in automated machines, fully controlled by computers. Each stage of the dough production is directed by the computer system.

A training session was arranged for the measurement procedure, and three operators working in the process were informed on the procedure.

Measurement sensitivity of the machine is complying with the customer specifications and international standards, therefore suitable for this particular process.

The measurement device is visually inspected each day by the operator, maintained, and controlled with monthly periods by the maintenance department. As shown in Table 3.3, a high repeatability value such as 41.07% shows that a nonconformity may be present, caused by the measurement device. Therefore, maintenance team repeated the maintenance and fixture settings of the measurement device.

The measurement device is calibrated with six-month periods. Following the customer complaint, the calibration of the measurement device is verified.

It was detected that the temperature of the working environment was 22 ± 2 ^{o}C and the lighting was at 3000 lux. Environmental temperature is fairly suitable for the production. However, the lighting was improved, and the emittance was raised up to 4000 lux.

3.3. Renewal of the GRR Study

In order to bring the measurement system to the adequate level, the company implemented required improvements regarding the factors given in Figure 5. Following the corrective and preventive actions, glass seal flexibility measurements were completed. Measurement results are shown in Table 4.

Table 4. New Gage R&R results

Operator	Part 1	Part 2	Part 3	Part 4	Part 5
A	8.52	8.57	8.55	8.58	8.62
A	8.52	8.58	8.55	8.56	8.62
A	8.53	8.58	8.55	8.57	8.62
B	8.52	8.57	8.56	8.58	8.62
B	8.52	8.57	8.55	8.58	8.62
B	8.53	8.58	8.57	8.57	8.61
C	8.53	8.56	8.57	8.59	8.61
C	8.51	8.57	8.56	8.59	8.61
C	8.51	8.57	8.55	8.59	8.61

New measurement data have been tested for normality. As shown in Figure 6, the data are normally distributed.

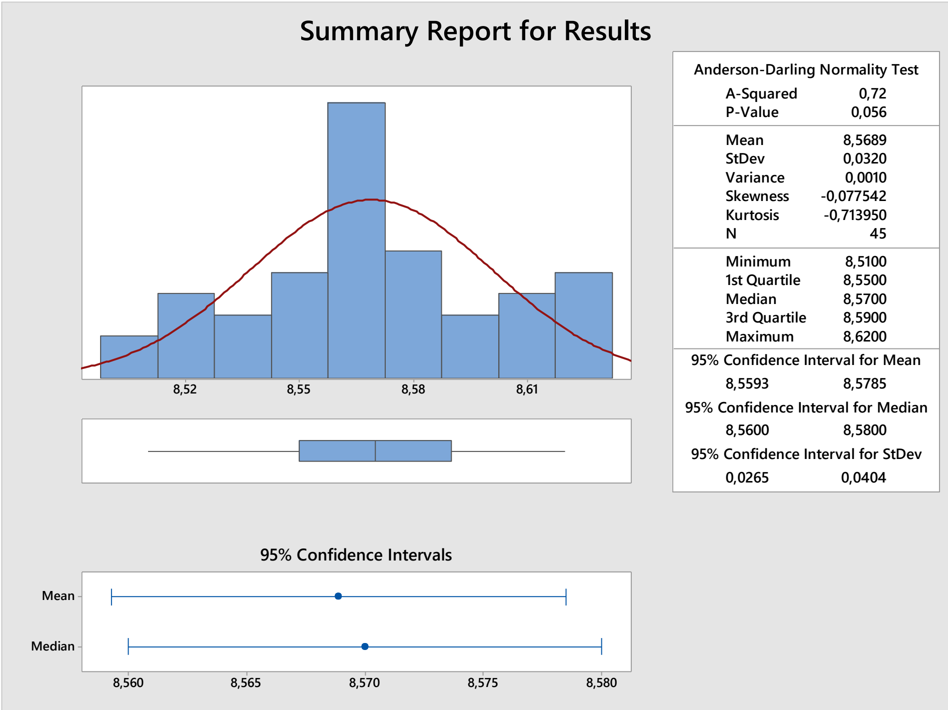

Figure 6. Normality test for new measurement result

In consequence of the normal distribution of the data, measurement system analysis was performed. Analysis results are given in Figure 7 as a diagram and in Table 5 in analysis format.

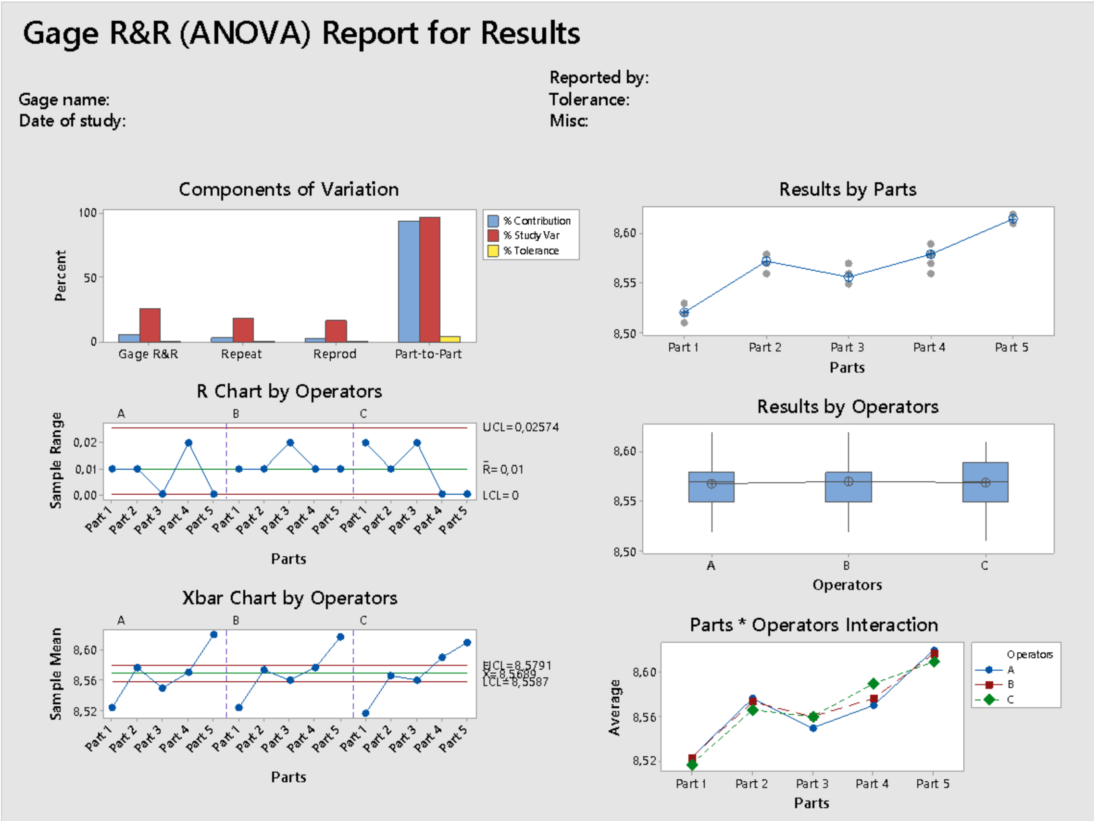

Figure 7. Gage R&R analysis results of the new measurement results

Following the implementation of improvements, the variation value caused by the measurement system (components of variation) was taken down from 75.77% to 25.25%.

- **Results by Parts** shows the measurements were taken for each part and the average values. As shown in Figure 7, the measurement variance of the parts was reduced. It can be seen that especially the measurement results of the 5th part are quite close.
- **R Chart by Operators** shows the consistency between the measurements of the operators, measurement results being under control. It can be seen that the measurements of all five parts conducted by each operator are within the control limits of the range.
- **Results by Operators** shows the effect of the operators on the measurements. The measurements of operator B vary only insignificantly from those of the operator A and C. It is expected that the horizontal line is straight to prove the measurement difference between the operators are at a minimum level. Here too, there is a very small difference in the B operator.
- $\overline{X}$ **Chart by Operators** shows that the measurement system is adequate. Measurements being outside the control limits shows that the variation is caused by the variability of parts.
- **Parts * Operators Interaction** graph shows that the lines are parallel to one another and that there is no interaction between the two. This situation, measurement is a desirable condition in the analysis of the site.

Table 5. Gage R&R Study – ANOVA for new data

Gage R&R Study - ANOVA Method

Two-Way ANOVA Table with Interaction

Source	DF	SS	MS	F	P
Parts	4	0.0424889	0.0106222	71.3433	0.000
Operators	2	0.0000311	0.0000156	0.1045	0.902
Parts * Operators	8	0.0011911	0.0001489	3.3500	0.007
Repeatability	30	0.0013333	0.0000444		
Total	44	0.0450444			

α to remove interaction term = 0.05

Gage R&R

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.0000793	6.38
Repeatability	0.0000444	3.58
Reproducibility	0.0000348	2.80
Operators	0.0000000	0.00
Operators*Parts	0.0000348	2.80
Part-To-Part	0.0011637	93.62
Total Variation	0.0012430	100.00

Process tolerance = 4

Source	StdDev (SD)	Study Var (5.15 × SD)	%Study Var (%SV)	%Tolerance (SV/Toler)
Total Gage R&R	0.0089028	0.045849	25.25	1.15
Repeatability	0.0066667	0.034333	18.91	0.86
Reproducibility	0.0059004	0.030387	16.74	0.76
Operators	0.0000000	0.000000	0.00	0.00
Operators*Parts	0.0059004	0.030387	16.74	0.76
Part-To-Part	0.0341131	0.175682	96.76	4.39
Total Variation	0.0352557	0.181567	100.00	4.54

Number of Distinct Categories = 5

In accordance with the new measurement results, ANOVA results of the acquired data are evaluated. Study variance was reduced to Study Variance (R&R %) = 25.25%. R&R% being <30% shows that the measurement system was marginally suitable. This value is accepted by the customer. Another comparing value, % contribution value is calculated as 6.38. Since this value is 2% < % Contribution < 9%, it is another evidence for the conditional acceptability with customer approval.

Number of Distinct Categories: In Table 5, the discriminant value was five. If the number of distinct categories is greater than five, the measurement system can discern over five groups within the data range and is often considered to have acceptable discrimination (McCarty et al., 2004).

4. CONCLUSION

As a result of the improvements performed on the measurement system the variance caused by the measurement system was reduced from 75.77% to 25.25%. This improvement rate achieved was defined as marginally acceptable by AIAG (2010).

This application study is meaningful in terms of showing the importance of measurement system analysis. Because; if the process was directly improved without performing the measurement system analysis, the process improvement work would have failed. In this case; the firm's resources would have been wasted. Not only would resources be wasted, but also the level of trust in improvement work in the company would be reduced. This will disrupt the company's improvement culture.

Whether in processes with quantitative or qualitative variability; before starting improvement work, the measurement system analysis should be tested to be statistically significant. With regard to the verification of the measurement system, the variations resulting from the process itself should be improved.

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