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Application of the averages and ranges method for the evaluation of the measurement system of an automotive component manufacturing company

Aplicación del método de medias y rangos para la evaluación del sistema de medición de una empresa fabricante de componentes automotrices

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Abstract

Objective: To evaluate the degree of reliability of the measurement system of a company that manufactures automotive components, guaranteeing the quality of the products supplied to its customers.

Methodology: The development of the research is based on four phases: diagnostic evaluation, definition of methods and resources, development of the R&R and analysis of results. These studies were developed based on the MSA applying the method of means and ranges.

Contribution: The results of the research determine that the current measurement system is adequate with respect to the processes analyzed, however, improvements are required to achieve the quality standards demanded by the automotive industry. Within the measurement system, 21.48% corresponds to the repeatability component, which is attributable to the measuring instrument; the reproducibility component has 5.818% and the GR&R interaction component represents 22.258%, which is within the standard recommended by the AIAG; however, this will serve as a basis for the company to orient its processes towards an improvement that allows a percentage of less than 10%.

Repeatability and reproducibility, Components of variation, Measurement system

Resumen

Objetivo: Evaluar el grado de confiabilidad del sistema de medición, de una empresa fabricante de componentes automotrices, garantizando la calidad de los productos suministrados a sus clientes.

Metodología: El desarrollo de la investigación se basa en cuatro fases: evaluación diagnóstica, definición de métodos y recursos, desarrollo del R&R y análisis de resultados. Dichos estudios fueron desarrollados basados en el MSA aplicando el método de medias y rangos.

Contribución: Los resultados de la investigación determinan que el sistema de medición actual es adecuado respecto a los procesos analizados, sin embargo, se requieren mejoras para lograr los estándares de calidad que demanda la industria automotriz. Dentro del Sistema de Medición tenemos que un 21.48% corresponde al componente de repetibilidad, la cual es atribuible al instrumento de medición, por parte del componente de reproducibilidad se tiene un 5.818% y el componente de la interacción GR&R representa un 22.258% el cual se encuentra dentro del estándar recomendado por la AIAG, sin embargo, esto servirá de base para que la empresa oriente sus procesos hacia una mejora que permita un porcentaje menor al 10%.

Repetibilidad y reproducibilidad, Componentes de variación, Sistema de medición

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Introduction

This research presents the evaluation of the measurement system implemented in a company that manufactures automotive components, through Repeatability and Reproducibility studies, with the objective of evaluating the development of metrological competences in the personnel in such a way that the company is able to demonstrate internally and externally sufficient reliability and competence in its measurement processes. The methodology developed consists of four phases: diagnostic evaluation, definition of methods and resources, development of the R&R and analysis of results.

It is important to clarify that an exhaustive quantitative study of the measurement system (personnel, instruments and methods) has not been carried out in response to the objectives of personnel development. However, an analysis is made at a level that corresponds to the objectives of this work.

The implementation of repeatability and reproducibility studies at the beginning and end of the work shows a decrease in the contribution of variation by the operators. Post-training evaluations demonstrate knowledge and ability to detect the main problems with measuring instruments (lubrication, bias, linearity, among others). These studies were developed following a methodology based on the MSA (Measurement System Analysis) with which it was possible to identify the level of reliability of the measurement system.

Problem statement

The company under study started operations in 1999 in the adhesives business, the key activity of the company is to provide high quality materials that meet the strict standards of this industry, including OEM approvals or development of new projects with alternative materials.

The production process of adhesives in its different presentations consists of a series of unitary operations, such as: master cutting of jumbo rolls, liner release, liner change, die-cutting, PULL-TAB, and die-cutting, among others. In each of these stages, from raw material to finished product, tests are carried out by the quality control department, in order to evaluate if the values obtained are within the specifications of the product in question.

In spite of the execution of these controls, there is variability of finished product in both the assembly and conversion areas, in the production of adhesives, due to the lack of specific regulations governing the production processes to ensure the quality of the final product, the quality control for these products and specifically for Manual Die-cuts, FOAMS, Planetary Rolls, BUTILOS, and Die-cuts coming from the rotary and die-cutting machine is based on the results obtained in the control of the finished product. In this sense, although there are several quality characteristics evaluated to control production, the mass of finished product is the quality reference at different points of the process.

The finished product mass evaluation process also represents an area of opportunity within the production process, since the measuring system used lacks specifications regarding the conditions in which the measuring instrument must be maintained and operated; there is also a lack of an operating and calibration procedure, as well as a verification and preventive maintenance plan.

Justification

The development of this work is supported through the application of a statistical tool known as: Repeatability and Reproducibility Studies where the criteria of the people who make decisions to accept or reject a product according to its measurement can be validated. The analysis of the measurement system (MSA), operating procedures, as well as a standardized method and operator training will be implemented. This project is intended to serve as a methodological guide for subsequent studies.

R&R study is one of the only tools that can provide the reliability to determine the degree of valid criteria that a group of people can have to make decisions, even this study can determine if the competences of the people who make decisions are depending on external factors such as: control of their hand strength, an inadequate distribution of their work center, lack of training with the measuring instrument, etc.

Literature review

Barragan (2017) in his research presents how technological progress constantly improves the techniques in devices used in new generation medicine, which requires studies to evaluate these techniques and compare them objectively with respect to previous generations. Therefore, we propose a study to evaluate the repeatability and reproducibility of retinal and choroidal thickness measurements using OCT-SS technology in a cohort of eyes with DME and to compare the variability of macular measurements obtained using spectral domain OCT versus swept source OCT in patients with DME. If we can confirm that retinal and choroidal thickness in eyes with DME can be quantified with good reliability, repeatability and reproducibility using the new OCT devices incorporating swept source technology (OCT-SS), we will be able to incorporate this novel technology into daily clinical practice.

Concluding that retinal and choroidal thickness in eyes with DME can be quantified with good reliability, repeatability and reproducibility using the new OCT devices incorporating swept source technology.

As we can see, repeatability and reproducibility studies are beginning to be used in medicine, so Perez (2019) suggests that, repeatability is applied by measurements made under conditions as stable as possible, taken with small differences in time, by the same operator and with the same equipment, reproducibility is used in measurements that are made under different conditions.

Algarín (2019) shows how in any chemical activity, involving analysis, research, manufacturing and inspection, much of the decision making and conclusions are made based on the reliable measurements that are made. The pillars of measurement are equipment, methods and personnel. Demonstrating that, within the category of equipment, mass measurements are widely used to know the error and uncertainties with which they are obtained. In addition, it adds that in many occasions organizations do not consider the impact of having quality measurement systems, the fact that measurements are not accurate can lead to errors in the calculation, analysis and conclusions of the process capability studies.

With the realization of the study, it allowed to demonstrate the conflicts referring to the people and equipment of the CAFESCA laboratory, this by means of the method of Repeatability and Reproducibility, the conflicts are referred in the case of the systematized tests to slight failures of the equipment that probably, are the location of where they are or also the attention that maintained each operator when making each one of the tests, added to that, the systematized tests with reference to the guidelines of AIAG (2002) are acceptable.

For Saravia (2020) within their analysis they conclude that organizations do not consider the impact of not having quality measurement systems, the fact that measurements are not accurate can lead to errors in the calculation, and in the analysis and conclusions of the process capability studies.

Emphasizing that when operators do not measure a part consistently, there is a risk of rejecting items that are in good condition or accepting items that are in poor condition. Adding that it is not only a matter of the operator but also if the measuring instruments are not calibrated correctly, errors can also be made and if both cases occur, we have a deficient measurement system that can make a capacity study seem unsatisfactory when in fact it is satisfactory. This can result in unnecessary costs.
In its repeatability and reproducibility study, it identifies the "part" factor as the one with the highest contribution to the total variability and that the measurement system is adequate, which is supported by recognized indices.

Garzón (2015) within the study called "Evaluation of the measurement system in the manufacture of aluminum hydroxide gel" highlights the importance of evaluating the measurement system, so that at least three components are taken into account: operator, measurement equipment and the parts or samples to the object of measurement.

Theoretical foundation

Measurement System Analysis (MSA)

The MSA Manual developed by AIAG (2002) defines measurement systems as the set of instruments or gages, standards, operations, methods, devices, software, personnel, environment and assumptions used to quantify a unit of measurement or prepare for the evaluation of a characteristic or property to be measured. It is the complete process used to obtain measurements. ISOES Consulting, (2021)

Measurement quality

"The basic concept of MSA is measurement quality, which is the statistical properties of multiple measurements obtained from a measurement system operating under stable conditions."

Bias and variance

These are the statistical properties most commonly used to characterize data quality. Bias refers to the location of the data relative to the reference (master) value. Variance refers to the dispersion of the data.

One of the most common reasons for poor data quality is excessive variation in the measurement system.

A significant proportion of this variation may be due to the interaction of the measurement system and its environment. For example, a system used to measure the volume of liquid in a tank may be sensitive to changes in ambient temperature. Then, the changes in volume detected may be due to changes in ambient temperature and changes in volume itself.

If the variation due to environmental factors is very large, it can mask the variation in the process, and in that case the data from the measurement system is not useful. One of the most important parts of the study of measurement systems is aimed at monitoring and controlling their variation.

This means, among other things, that one must learn how the measurement system interacts with its environment so that only data of acceptable quality are generated. This is very similar to the approach that is applied to understand and control the variation of a manufacturing process.

Thus, a measurement process can be viewed as a manufacturing process that produces numbers (data) as outputs. Viewing a measurement system in this way is useful because it allows us to bring in all of the concepts, philosophy and tools that have already been proven to be useful in the area of statistical process control.

During the measurement process, the variation of the process is detected, in order to have knowledge of:

- What the process should be doing.
- What may be wrong.
- What the process is doing.

Guidelines for Determining Repeatability and Reproducibility

The study of gages for variables can be performed using a number of different techniques. These are:

- Range method
- Method of averages and ranges (including the control chart method).
- ANOVA method. ISOES Consulting, (2021)

Except for the rank method, the design of the study data is very similar for each of these methods. As presented, the methods ignore variation within parts (such as rounding, flatness, etc.).

However, the total measurement system includes not only the gage itself and its respective bias, repeatability, etc., but may also include the variation of the parts to be evaluated. The determination of how to handle the variation within the parts needs to be based on a rational understanding of the expected use of the part and the purpose of the measurements.

Finally, all techniques in this section are subject to the prerequisite of statistical stability.

Ranking and Averaging Methods

The method of averages and ranges (X & R) provides an estimate of repeatability and reproducibility for a measurement system. Unlike the method of ranges, this approach allows the variation of the measurement system to be sectioned into two separate components: repeatability and reproducibility, but not their interaction AIAG (2002).

The steps involved in performing this method according to Llamosa, Meza and Botero (2007) are:

1. Determine the equipment to be tested, the number of operators and the number of tests to be carried out by each operator.

2. Each operator carries out the corresponding tests on each piece of equipment and records the corresponding results in the respective format for subsequent study.

3. The operators repeat the measurements, but this time in a different order and without observing the measurements previously made by their colleagues.

4. With the data from the form, the range of each part of the equipment is calculated by means of the following equation:

$$R = X_{max} - X_{min} \tag{1}$$

5. The average rank of each operator is calculated using the equation:

$$\underline{R} = \frac{1}{n}\sum_{i=1}^{n} R_i \tag{2}$$

Where n: is the number of measurements made by each operator.

6. The average rank of all ranks is calculated by means of the equation:

$$\underline{R} = \frac{1}{m} \sum_{i=1}^{m} \underline{R}i \tag{3}$$

Where m: is the number of operators and Ri is the average rank of each operator.

7. The percentage repeatability of the measurements is calculated using the equation:

$$\%Repetibilidad \ \frac{K_1 * \underline{R}}{T} * 100\% \tag{4}$$

Where K1: is a constant that depends on the number of measurements made by each operator and gives a 99% confidence interval for these characteristics, R: is the average range of all ranges, T: is the tolerance of the measured characteristic, in this case of the tested equipment.

8. The average measurement for each operator is calculated using the equation:

$$\underline{xi} = \frac{1}{nr}\sum_{i=1}^{n}. Xi \tag{5}$$

Where n: is the number of tests per operator, r is the number of parts and xi is each of the operator's measurements.

9. Calculate the difference between the highest and the lowest average of the operators by means of the equation:

$$\underline{x_D} = Xmax - Xmin \text{ ....} (6)$$

10. The reproducibility percentage is calculated by means of the equation:

$$\% \ Reprod. = \sqrt{\frac{\left(K_2 * \underline{x_D}\right)^2 - \frac{(k_1 \ \underline{R})^2}{nr}}{T}} * 100\% \text{ ....} (8)$$

Where:

K2: is a constant that depends on the number of operators and provides a 99% confidence interval for these characteristics.

xD: is the difference between the largest and smallest average of the operators.

n: is the number of tests per operator. r: is the number of parts measured.

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T: is the tolerance of the measured characteristic, in this case of the tested equipment.

11. The percentage of the ratio of repeatability to reproducibility is calculated using the equation:

$$\%R\&R = \sqrt{(\%Repe)2 + (\%Repro)2} \ldots.. (9)$$

12. The results obtained are interpreted, using the following criteria: If %R & R < 10% the measurement system is acceptable. If 10% ≤ %R & R < 30% the measurement system may be acceptable depending on its use, application, cost of the measuring instrument, cost of repair. If %R & R > 30% the measurement system is considered as not acceptable and requires improvement in terms of operator, equipment, method, conditions, etc.

Control charts

Control charts or control charts are tools used to carry out quality control of products and were originally developed by Walter Andrew Shewhart in the 1920s; however, they were disseminated worldwide by William Edwards Deming and allow the definition of the optimum limits and parameters in a given process.

The purpose of a control chart is to observe and analyse the behaviour of a process over time, by statistically monitoring samples of the production by evaluating a quality characteristic; this is an effective procedure to ensure that a manufacturing process is under statistical control and, consequently, that the variability is due only to non-assignable causes.

Control charts for variables are used to evaluate continuous quality characteristics, i.e., those that intuitively require a measuring instrument to obtain data, such as weight, volume, voltage, length, resistance, temperature or humidity. Gutiérrez, de la Vara (2013).

Control Charts X-R-Bar

The design of control charts is a tool that determines the optimal parameters to reduce the expected cost per unit of a certain process, given a desired level of performance.

In industry, there are processes considered massive, where a large number of units, parts or components are produced during a small period of time, some of these processes perform thousands of operations per day, while others perform several tens or hundreds, in both cases we are facing a massive process; if in addition, the output variable of interest is of continuous type, which requires a measuring instrument to obtain data, we are in the ideal conditions to apply the X-R control charts. Gutiérrez, de la Vara (2013).

Average X control charts are tools belonging to statistical process control, to improve the quality and productivity of a company; they allow monitoring changes or shifts in the mean in a process by establishing three parameters: the sample size (n), the sampling interval (h) and the control limit coefficient (k).

The X-R control charts are diagrams for the study of continuous variables applied to massive processes, where subgroups are obtained periodically, measured and the mean and range are calculated and recorded in the corresponding chart; at the exit of the process, every certain time or number of pieces, a sample or subgroup is taken, to which the corresponding quality characteristic is determined and the mean and range are calculated for each period of time; the X chart allows the variation between the subgroups to be analysed to detect changes in the process mean, while the R chart analyses the amplitude or magnitude of the variation of the process.

R&R study by ANOVA method

The r&R studies make it possible to evaluate experimentally that part of the total variability (σ^2total) observed in a process through the measurements made is attributed to the measurement system; in this sense, the sources of variability that can be evaluated through the r&R study are: variability attributed to the product itself (σ^2prod), variability due to the measuring instrument (σ^2instr) and the variability introduced by the operators (σ^2oper); therefore, the total variability observed is given by the following equation, where the total variability is the sum of the above-mentioned factors.

$$\sigma^2 total = \sigma^2 prod + \sigma^2 instr + \sigma^2 oper \quad (10)$$

In this sense, as can be seen in equation 11, repeatability corresponds to the variability given by the measuring instrument or non-human factor, and equation 12 shows how reproducibility is given by the variability introduced by the operator or human factor.

$$\sigma^2 repeti = \sigma^2 instr \quad (11)$$

$$\sigma^2 reprod = \sigma^2 oper \quad (12)$$

Therefore, the total variability obtained through an r&R study (σ^2r&R) corresponds to the sum of repeatability and reproducibility as shown in the equation below:

$$\sigma^2 r\&R = \sigma^2 repeti + \sigma^2 reprod \quad (13)$$

For the determination of the repeatability and reproducibility of a measurement system, three methods can be used, which are based on the statistical evaluation of the dispersions of the results, either in the form of range or through the variance or standard deviation; these methods are range, mean and range and analysis of variance. AIAG (2002).

Methodology

The following diagram represents the methodological structure for the development of the R&R study:

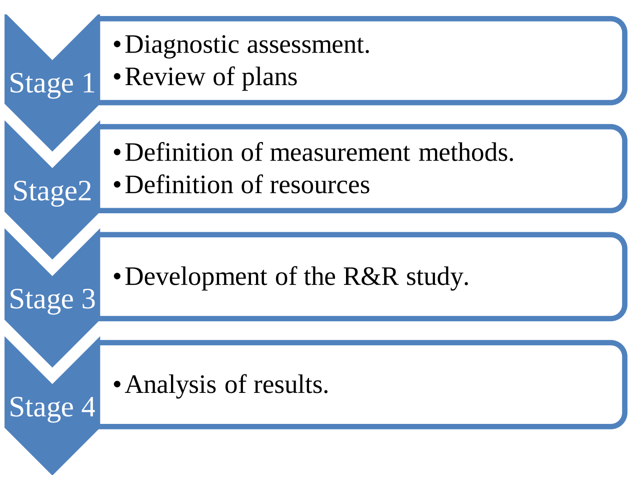


Figure 1 Methodology of analysis
Source: Own elaboration

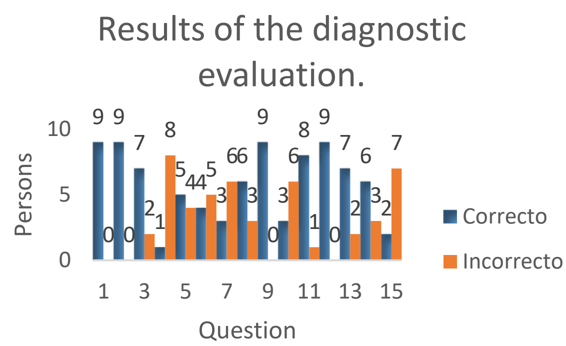
Stage 1

Diagnostic assessment of operators

Training is given to the personnel involved in the inspection process, a total of 6 operators and 3 inspectors, with emphasis on the following points:

- Components of a calibrator.
- Handling of the caliper.
- Parts that can be measured with the caliper.

The above points were identified on the basis of a diagnostic assessment, the following graph shows the results of this instrument:



Graphic 1 Diagnostic assessment results.
Source: Own elaboration

Review of plans

This process was used to determine the dimensional characteristics of the part numbers to be evaluated and to identify the measurement tolerances, it is worth mentioning that, due to company confidentiality, it is not possible to present these drawings, so we only present the tables indicating the tolerances of the three products evaluated in the study.

We limit ourselves to presenting the tables indicating the tolerances of the three products evaluated in the study, which, for practical purposes, we will call them A, B and C.

Cota	Tolerance
A	15mm +/- 1mm
B	50mm +/- 1mm
C	35mm +/- 1mm

Table 1 Dimensions of dimensional drawing component A
Source: Own elaboration

Cota	Tolerance
A	10mm +/- 0.5mm
B	434mm +/- 2mm
C	40mm +/- 2mm

Table 2 Dimensions of dimensional drawing component A
Source: Own elaboration

Cota	Tolerance
A	5mm +/- 0.5mm
B	166mm +/- 2mm
C	40mm +/- 2mm

Table 3 Dimensions of the dimensioned drawing component C
Source: Own elaboration.

Step 2.

Definition of measurement methods.

For the development of the study, the parts to be evaluated were randomly provided by the maquila area, including two parts above the upper specification and two parts below the lower specification, this applies to the three products to be evaluated. It is worth mentioning that the study is made up of 10 parts, three operators and each operator performs three repetitions.

Definition of resources

The following measurement instruments were defined as part of the study:

- Nine calipers model 500-196-30, resolution: 0.005, unit of measurement: inches.

- Three calipers model 500-196-30 with resolution: 0.0005, unit of measurement: inches.

- Data collection forms, identifying the measuring instrument, part number, characteristic to be measured, number of pieces, name of operators and number of repetitions.

Stage 3

Development of the R&R Study

The study was carried out in the following phases:

1. Preparation of the pieces. The sample pieces to be evaluated are prepared, maintaining their confidentiality during the study. The following image represents the part to be evaluated of product A.

Figure 2. Part number A
Source: Own elaboration

2. Inform area leaders. Area leaders are notified about the execution of the study, as well as about the participating operators and inspectors, in order to organise and manage the study in the best possible way.

3. Form teams of operators: These are defined by the leaders of the maquila and conversion area, bearing in mind that each participant belongs to the same process and that they have the necessary training for the proper handling of the measuring instrument.

4. Verification of the measuring instrument: This point is of vital importance as it must be verified that the measuring instrument to be used is calibrated, and that its date is valid, for this purpose the identification label must be checked.

5. Data collection. For this point, each operator performs the measurements in random sequence according to the following table, for reasons of confidentiality only the order of collection for part A is presented:

Measurement sequence Part A										
1st attempt	6	9	1	2	5	10	4	3	7	8
2nd attempt	4	3	9	6	10	8	5	1	2	7
3rd attempt	3	2	6	8	4	10	7	5	9	1

Table 4 Measurement sequence of component A
Source: Own elaboration.

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1. Once the data collection has been completed, the data are sorted according to the following template, only the data from part A are presented:

ESTUDIO R&R POR VARIABLES REPETIBILIDAD Y REPRODUCIBILIDAD DE DISPOSITIVOS TOMA DE DATOS									
No. de parte y descripción:					**No. del dispositivo**				
Parte A					CAL010				
Característica:					**Dispositivo de medición:**				
-Cut convertido de forma manual (anc					Vernier Digital				
Intentos	**Operadores**		**Piezas**				**Fecha de estudio**		
r = 3	j = 3		n = 10				15/12/2022		
Operador	A			B			C		
Pieza	1	2	3	1	2	3	1	2	3
1	9.87	9.3	9.73	9.76	9.76	9.92	9.81	9.7	9.74
2	10.02	9.21	9.92	9.7	10.1	9.82	9.78	9.76	9.97
3	9.65	9.88	9.67	10.1	9.8	9.81	9.64	9.76	9.68
4	9.6	9.88	9.8	9.82	10.1	9.85	9.84	9.82	9.87
5	9.67	9.66	10	9.84	9.76	9.85	9.82	9.83	9.73
6	10.3	9.72	9.89	9.8	9.76	10.52	9.86	9.88	9.85
7	9.92	9.42	9.99	10.1	10.1	9.72	9.94	9.66	9.6
8	9.77	9.9	9.93	9.9	9.88	10.52	9.9	9.78	9.69
9	9.89	9.75	9.81	10.2	9.68	10.18	9.77	9.72	9.78
10	9.73	9.53	10.1	9.95	9.98	10.17	9.78	9.69	9.71

Table 5 Component A data collection.
Source: Own elaboration.

It is worth mentioning that, due to company confidentiality, only the data collected for component A is presented, and in the same sense the results obtained from the study will be presented.

Results

Analysis of results

With the results obtained from the measurement system, it was determined that it is adequate with respect to the processes that are carried out in the different work areas, such as the conditioning and inspection of the finished product. But it must be improved if we want a system of excellence as demanded by the automotive industry worldwide; this is nothing more than the updating of measuring equipment such as gauges that have a pressure valve.

In this study we have a 21.484% of Repeatability (EV) which indicates that the variability that exists in the measurement system is caused by the device, the variation that exists on the part of the operators in the measurement system is 5. 818% of Reproducibility (AV); as part of the estimated combined variation of Repeatability and Reproducibility (GRR) we have 22.258% which is within the range of acceptance of the measurement system (between 10% and 30%) established by the AIAG, so it is acceptable but work must be done to achieve a percentage of less than 10%.

However, it is concluded that when working with this type of materials (adhesive and soft) and in order to have the most reliable measurement possible, it depends not only on the measuring equipment but also on a good training and recruitment programme, which is explained in the recommendations.

As far as the quality department is concerned, there are no problems with non-conforming products, as they are within their permissible limits, but there is always room for improvement and these improvements would have a positive impact on the organisation.

Funding

This research did not obtain funding from any public or private institution.

Conclusions

This research developed an analysis for active gauges within the measurement system in an automotive components manufacturing company, through direct observations of the production process and information provided by production operators, as well as through data collection and analysis. It was possible to identify the performance level of the measurement system, which, according to the results shown in the previous section, is evaluated as acceptable with areas for improvement, which validates the hypothesis of this research, since the company guarantees the level of reliability of its products for its customers.

Therefore, the factors influencing the variability of the process show that the behaviour of the production depended on the conditions of the measuring instrument, as well as the operators on shift and the methods used by each one of them, since the personnel with less time in the company presented a greater deficiency in their measurements.

With the analysis of the Repeatability and Reproducibility studies, failures were identified in the measurement system, which placed 7% of the studies at an unacceptable level and 80% of the studies at an acceptable level with reservations, i.e. subject to improvement, and 13% with a degree of excellence.

The measuring instrument is not suitable because, in the company, it is used for soft material measurements and there are personnel who use a lot of force when taking measurements or, on the contrary, less force, which was reflected in the repeatability component, since the personnel were not constant in their measurements.

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