Load Cell Prototype Design; Statistic Analysis

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Abstract- This article verifies the effectiveness of weighing with a load cell through a statistical analysis managing a reliability of 95%.

The load cell to be used is a prototype that was manufactured with PLA material [1], it uses a strain gauge as sensor which has a maximum resistance of one kilogram that was programmed through the Atmel 328A platform.

By means of a hypothesis test, the design of the prototype was verified by comparing it with digital and analog scales, taking a universe size of N = 100.

Keywords: Statistics, Data analysis, Hypothesis testing, Sampling, Balance.

1. INTRODUCTION

The strain gauge is a sensor, which measures deformation, pressure, load, etc. It is based on the piezo resistive effect, which is the property of materials to change the nominal value of their resistance when they are subjected to mechanical stress and deform in the direction of the axes. [1] Descriptive statistics provide a concise summary of the data, in which the data can be summarized numerically or graphically.

Inferential statistics use a random sample of data obtained from a population to describe and make inferences, which are valuable when it is not convenient or possible to examine every member of an entire population.

In this sense, it is understood to develop a statistical analysis of a prototype of a load cell (scale). To validate the data that will be obtained in the test; the tools of descriptive and inferential statistics will be used: hypothesis test, T Student distribution, Chi-square and standard deviation.

A hypothesis test examines two opposing hypotheses about a population: the null hypothesis and the alternative hypothesis. The null hypothesis is the statement to be tested. Generally, the null hypothesis is a "no effect" or "no difference" statement. The alternative hypothesis is the statement that want to be able to conclude is true according to the evidence provided by the sample data.

Based on the sample data, the test determines whether the null hypothesis can be rejected. The p-value is used to make that decision. If the p-value is less than the significance level (denoted as α or alpha), then can reject the null hypothesis.

Student T distribution is a probability distribution that arises from the difficulty that manifest of being able to estimate the mean of a normally distributed population, when the sample size is really small.

The chi-square statistic is a measure of the divergence between the distribution of the data and a selected expected or hypothetical distribution. It is used for:

• Test the independence or determine the association between categorical variables. If the p-value associated with the chi-square statistic is less than the selected significance level (α), the test rejects the null hypothesis that the two variables are independent.

• Determine if a statistical model fits the data adequately. If the p-value associated with the chi-square statistic is less than the selected significance level (α), the test rejects the null hypothesis that the model fits the data.

The standard deviation is the most common measure of dispersion, indicating how spread out the data is from the mean. The greater the standard deviation, the greater the spread of the data.

The symbol σ (sigma) is frequently used to represent the standard deviation of a population, while s is used to represent the standard deviation of a sample. [2]

Therefore, it seeks to affirm that the project is working correctly and if our hypothesis is fulfilled; which is "if the measurements made by our scale are comparable, identical and even equal to a digital one".

2. METHOLOGY

The prototype of the load cell is designed for weighing objects, ranging from 0.5 to 800 grams, which seeks to demonstrate 95% reliability with a margin of error of 0.5% compared to commercial mass measurement equipment that give measurements with wrong percentages depending on the brand.

In order to find the accuracy in the weighing of solid objects in the workplace, a data analysis was developed for the load cell or scale, using the tools of descriptive and inferential statistics; hypothesis test, T Student distribution, Chi-square and standard deviation.

Based on the following diagram (figure 1), it is shown how this investigation was developed.

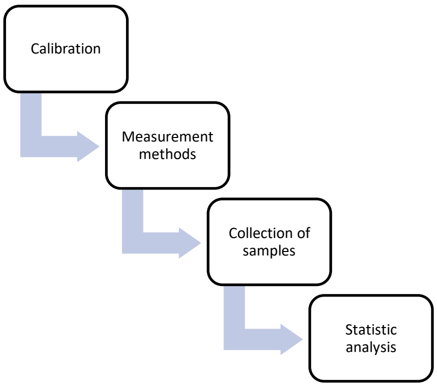

Fig. -1: Article development diagram.

2.1 CALIBRATION

To calibrate the scale; within the program a mass range is specified, which will help to have control to take the data, with the help of a set of weights the balance is calibrated

Fig. -2: Calibration weights.

Weights are the most frequently used and most important test equipment for testing scales and balances.

This will help to avoid weighing errors, save costs from having to repeat processes, dispose of residual materials, and recall products from the market.

2.2 MEASUREMENT METHODS

Measurement methods are used to identify how data will be collected to measure project progress.

Tests are usually done to determine:

- The repeatability of the indications.
- Errors in indications.
- The effect on the indication of eccentric application of a load.

For the analysis of this project, the repeatability test is used in the first place. Which consists of repetitively placing the same load on the load receptor, under identical load and instrument handling conditions, and under the same test conditions, as much as possible [3].

For this, it is necessary to determine the size of the sample in order to achieve the highest possible representativeness or precision in the estimation of population parameters [4].

Based on the above, the following formula is used (Equation 1), this equation determines the size of the real sample according to the type of population and the estimated parameter.

$$n = \frac{\frac{z^2pq}{E^2}}{1 + \frac{1}{N}\left[\frac{z^2pq}{E^2} - 1\right]}$$

Equation -1: Formula for sample calculation.

Therefore, this equation is solved, it is shown that to obtain a degree of reliability of 95% with a universe size N = 100, a sample size equal to 80 is needed (table 1).

Table -1: Sampling matrix for the experiment.

Matrix of sample sizes for a universe of N with a probability of p			
Confidence level	**d** [máximum estimation error]		
	5,0%	**4,0%**	**3,0%**
90%	73	81	88
95%	80	86	92
97%	83	88	93
99%	87	91	95

Now, in this sense, the eccentricity test is used in the same way, it consists of placing a load in different positions of the load receptor, in such a way that the center of gravity of the load occupies, as much as possible, the positions that they are indicated (figure 3) [3].

In this way, for this test, the load receiving stage is divided into quadrants in order to check the weight distribution, thereby attempting to demonstrate that the data to be obtained are similar or equal in all quadrants.

Fig. -3: Charging receiver.

2.3 COLLECTION OF SAMPLES

Depending on what was proposed, the sampling of 100 objects was carried out both with the load cell prototype and with a digital and analog scale, the study was developed in a laboratory of the facilities of the

Universidad Tecnológica de Tlaxcala, where a controlled environment was maintained for the experiment, later a comparative table was made where said weighings were recorded.

In this perspective, with the data obtained from the tests, eccentricity and repeatability, two line graphs are generated in order to compare the data, specifically to see if they are similar or different from each other.

The first graph (Chart -1) that is exposed comprises the data that were recorded in the quadrants (eccentricity test), as it can see the data are quite identical, it can be noted, in the same way, atypical data in the ranges 51 - 56, 71.96-100, without, however, these figures are within the maximum estimation error, which is 5%.

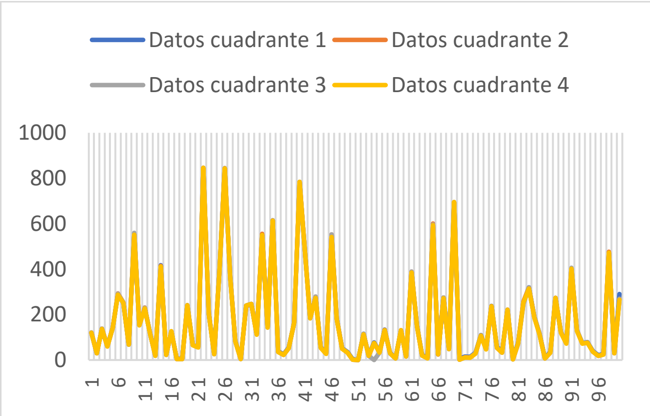

Chart -1: Quadrant comparison chart

From a more general perspective, the following graph (Chart -2) of lines is presented below, it projects the sampling figures on the digital scale, which is the main equipment with which it is compared, and the average of the quadrants (repeatability test), this with the aim of comparing them and observing their behavior.

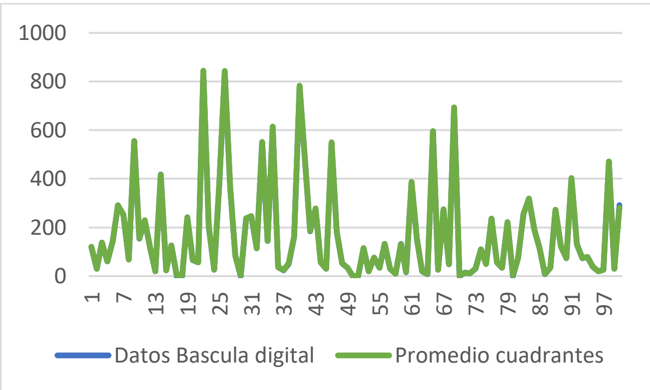

Chart -1: Graph comparison of average quadrants vs Digital scale data.

An almost exact similarity can be perceived, the atypical data are very little perceived, demonstrating its accuracy graphically.

2.4 STATISTIC ANALYSIS

For the statistical analysis, hypothesis testing is performed, in the same way it is corroborated with the T Student distribution, Chi-square and standard deviation.

Within this order of ideas, it began with the hypothesis test in which it is necessary to establish what is a null hypothesis (H0) where it is the one that tells us that there are no significant differences between the groups and an alternative hypothesis (H1) which in the same way is an alternative assumption to the null hypothesis formulated in an experiment and / or investigation.

Based on what has been stated, the null hypothesis says that: the measurements made by our scale will vary significantly compared to other measurements made, whether analog or digital, and therefore the alternative hypothesis establishes that: the measurements made by our scale, made up of a load cell are comparable, identical and even equal to a digital one [5].

Which can be translated as: the null hypothesis will have an effectiveness less than 95%, and consequently an alternative hypothesis will have an effectiveness greater than 95%.

$H_0=\mu<95\%$

$H_1=\mu\geq 95\%$

Consequently, a level of significance is established, which is determined through the following (Equation 2).

$$\alpha = 1 - nivel\ de\ confianza$$

Equation -2: Significance level

Where the degree of confidence is 95% that it is the one that is sought to be obtained.

$$\alpha = 1 - 95\% = 0.05\%$$

In addition, in turn there is a critical value equal to 1.645.

Second, we proceed to a test value calculation depicted below (Equation 3).

$$Z = \frac{X - \mu}{\frac{\sigma}{\sqrt{n}}}$$

Equation -3: Population variance.

$$Z = \frac{\mathbf{172.731475} - 95}{\frac{\mathbf{197.48762447781}}{\sqrt{100}}} = 8.75$$

In this sense, it is concluded that any Z score higher than the critical value (1.645) will be rejected, or rather, the null hypothesis is declined and the alternative hypothesis enters instead.

On the other hand, it is worth considering the uniformity test, which is the most important property that a set of random numbers must fulfill, and statistical tests such as the Chi-square test have been developed to verify its compliance.

This test is one of the most useful and widely used in statistics, to determine how significant is the difference between the observed and expected frequencies of one or more categories. The difference between the expected and observed frequencies are considered as the sampling error. The observed frequencies are calculated from a count of the numbers that coincide in a determined sub-interval, and the expected frequencies are based on a theoretical probability distribution.

Procedure:

1. Generate the sample of random numbers of size N. 2. Subdivide the interval into n subintervals.
2. For each sub interval, count the observed frequency F.
3. Calculate the test statistic (Equation 4). [5]

$$X_0^2 = \sum_{i=1}^{m} \frac{(E_i - O_i)^2}{E_i}$$

Equation -4: Chi-square test

Within this framework of ideas, it is possible to observe the population of data that has been collected in graph 2, specifically the section of "Average load cell quadrants". To continue to the second step, the data shown in table 3 was collected, establishing maximum and minimum values, number of intervals and their amplitude, which are:

Table -3: Uniformity test data

Data number	Number of intervals	Minimum value	Maximum value	Interval width
100	10	0.39	844.5675	85

Now, continue with the elaboration of the Chi-square calculation in which start from the intervals, the range that they cover and in turn the observed and expected frequencies as indicated by the procedures.

Indicating as the last step the calculation of formula 4. Chi-square test shown in the last boxes of table 4: Chi-square calculation.

Table -4: Chi square calculation.

Interval		Observed Frecuency	Expected Frecuency	(Ei-Oi)^2/Ei
0	85	49	10	152.1
85	170	17	10	4.9
170	255	12	10	0.4
255	340	6	10	1.6
340	425	5	10	2.5
425	510	2	10	6.4
510	595	3	10	4.9
595	680	2	10	6.4
680	765	1	10	8.1
765	850	3	10	4.9
				192.2
				16.91876

To finalize this uniformity test, a summation of the last section was carried out, as can be seen, which gives a total of 192.2, an amount which is greater than the value of Chi square (16.91876). In other words, it is concluded that the data analyzed are rejected, because the sum is greater than the Chi-square test, that it is does not follow a uniform distribution.

3. RESULTS

With the help of statistical software, different types of analysis were carried out to compare and graph the data obtained with the scales: analog, digital and the prototype.

3.1 CHART INTERACTION BETWEEN QUADRANTS

Within this order of ideas the first analysis is projected (Chart -3) in which the data of the quadrants are compared, interpreting the graph it is observed that the data of each quadrant are very similar to each other. That it is not observed some significant difference, deducing that by placing the piece on either side of the scale, the data that it will give will be correct.

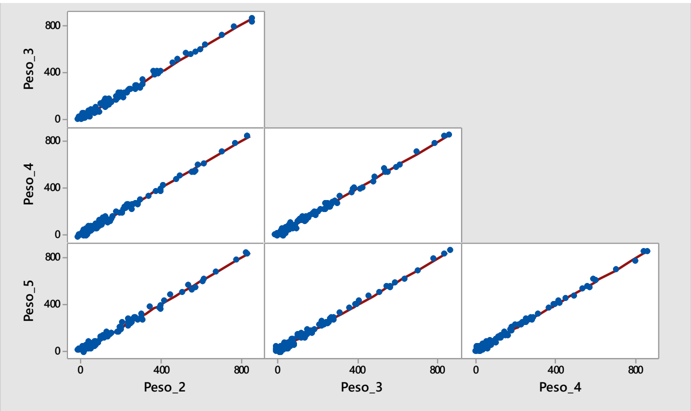

Chart -3: Data matrix for quadrants

With reference to the previous ones, comparisons between these same quadrants are shown through various methods, all with the purpose of pointing out the similarity that they show.

This first analysis is quantitatively affirmed with the following tables, which are provided by the statistical software.

First, a correlation matrix is observed (Table 6) which shows the Pearson correlation values; these data measure the degree of linear relationship between each pair of elements or variables. In order to interpret the matrix, a relationship of values is used (Table 5) which indicates the type of relationship that we can find, immediately it can be seen that all the quadrants have a perfect correlation or, in other words, wherever are place the load the data that we will obtain will be correct.

Table -5: Relationship of correlation matrix values

0,00	0,09	Null correlation
0,10	0,19	Very weak correlation
0,20	0,49	Weak correlation
0,50	0,69	Moderate correlation
0,70	0,84	Significant correlation
0,85	0,95	Strong correlation
0,96	1,00	Perfect correlation

Table -6: Pearson's correlation matrix

	Cuadrant_1	Cuadrant_2	Cuadrant_3
Cuadrant_2	1.000		
Cuadrant_3	1.000	1.000	
Cuadrant_4	1.000	1.000	1.000

Subsequently, the following table is studied (Table 7), which shows us the mean and standard deviation of the variables (quadrants), it can be seen that the means of each variable are very similar, without on the other hand they tend to change their values minimally. Regarding the standard deviation of the elements, it is used to determine how dispersed the scores are with respect to the mean of each element, which, in the same way, the values are very close to each other, thus concluding that the weight is distributed according to proportionally throughout the receiving stage.

Table -7: Total and item statistics

Variable	Total count	Mean	St. Dev.
Cuadrant_1	99	174,59	198,54
Cuadrant _2	99	173,89	200,01
Cuadrant _3	99	173,41	199,81
Cuadrant _4	99	172,42	199,25
Total	99	694,31	797,59

Cronbach's alpha = 1,000

Now, the analysis of statistics of omitted elements is proposed (Table 8) which serves to determine if the elimination of an element substantially improves the internal uniformity of the test. Therefore, if an omitted item has a low multiple squared correlation value, a low adjusted total item correlation value, and a substantially higher Cronbach's alpha value, then this is where you can consider removing the item from the survey or test to improve its internal uniformity.

Table -8. Omitted item statistics

Omitted variable	Adjusted total mean	St. Dev Adjusted total	Total Correlation adjusted by item	Square multiple Correlation	Cronbach´s alpha
Weight_2	519,7	599,1	0,9999	0,9998	1
Weight_3	520,4	597,6	1	0,9999	1
Weight_4	520,9	597,8	1	0,9999	1
Weight_5	521,9	598,3	1	0,9999	1

Following the previous conditioning factors, it is shown that, in these results, the adjusted total correlation of the element and the square multiple correlation values are uniformly high for all the elements. Taking into account that Cronbach's alpha for all omitted elements is also uniform. Therefore, it could be summarized that all the elements measure the same characteristic and therefore removing an element would not substantially improve the internal uniformity.

3.2 Test and CI for two variances: Digital Scale Data; Average Quadrants

Concerning other types of tests performed, it was sought to be able to determine if the variances or standard deviations of two groups differ and through this to calculate a range of values that includes the existing population relationship of the variances or standard deviations of the two groups such results are shown below (Table 9).

Tabla -9. Statistics

Variable	N	St. Dev	Variance	IC of 95% for S.t Dev
Digital Scale Data	100	197,908	39167,675	(173,765; 229,905)
Cuadrants average	100	198,483	39395,315	(174,269; 230,572)
	Standard deviation ratio = 0,997			
	Variance ratio = 0,994			

It should be noted that the results obtained from Table 9 and consequent will be useful for the analysis and subsequent tests, since from here they start comparisons and observations of the behavior shown by the data obtained.

The following analysis (Chart 4) consists of a CI test for two variances which consists of detecting differences that are less than or greater than the hypothetical relationship.

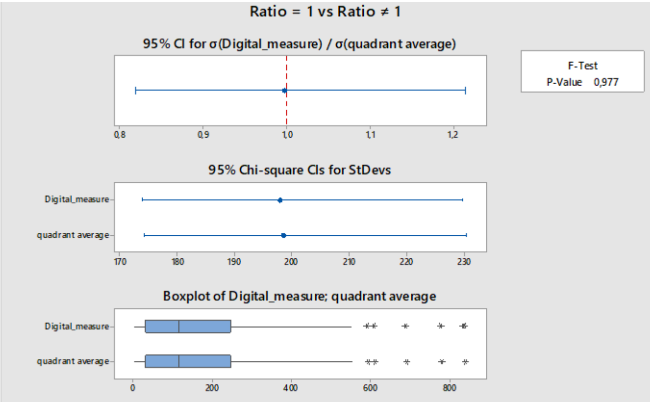

Chart -4: Test and CI for two variances.

In these results previously shown, it can be observed that the estimate of the ratio of the standard deviations of the populations is 0.997, where it can be 95% sure that the ratio of the deviations is between “0.818; 1,216” (Table 10 and Table 11).

Table -10: 95% Confidence intervals

Method	IC for St. Dev. ratio	IC for variance ratio
F	(0,818; 1,216)	(0,669; 1,478)

Method	GL1	GL2	Standard test	Value p
F	99	99	0,99	0,977

Table -11: Tests

Which means if the p-value is less than or equal to the significance level, the decision is to reject the null hypothesis. Therefore, it can be concluded that the ratio of the standard deviations or variances of the populations is not equal to the hypothetical relationship.

Problems with data, such as skewness and outliers, can negatively affect results. Therefore, the analysis carried out through graphs to look for asymmetry will be shown (examining the dispersion of each sample) and to identify possible atypical values.

Moreover, this means that when the data is skewed, most of the data is located at the top or bottom of the graph. It is often easy to detect skewness with a histogram or boxplot.

3.3 2-SAMPLE T-TEST FOR AVERAGE DIGITAL SCALE DATA AND AVERAGE QUADRANT

As is evident, different tests, comparisons and results obtained were carried out; this is how, not excepting this case (Chart 5), the data about two samples and their comparison of the means of two independent groups and if they are different are shown.

From the aforementioned, the 2-sample t-test for the mean emerges, which is a method used to test whether the unknown population means of two groups are equal to each other or not.

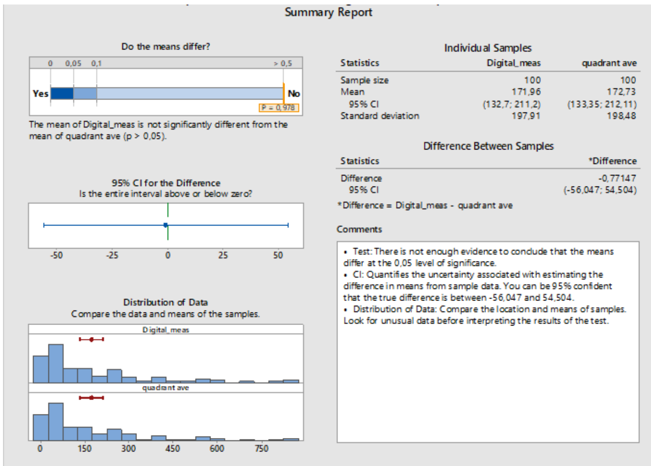

Chart -5: 2-sample t-test for the mean

As shown previously in Chart 5, there is no significant difference in the means, that is, the dispersion of values from one data to another is not significant when altering the results.

In addition, regarding the quantification of the uncertainty associated with the estimation of the difference between means from the data of the samples, there is a 95% certainty that the true difference is between 56.047 and 54.504.

At the same time, in the two-sample t test for the mean, those atypical values present in the collected population were analyzed (Chart 6), that is, those values numerically distant from the rest of the data, since these in certain cases could be misleading.

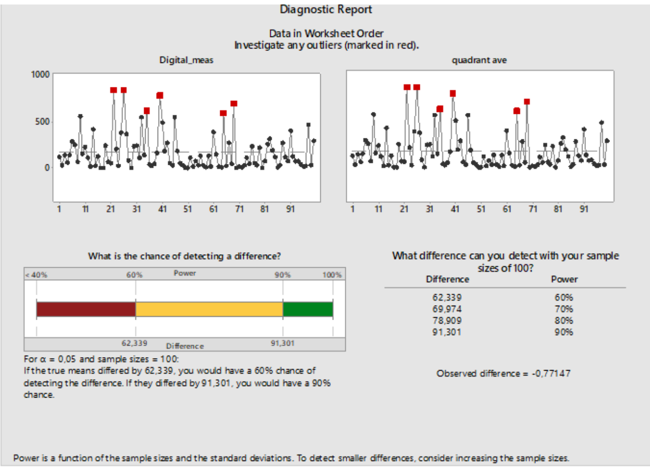

Chart -6: 2-sample t-test diagnostic report for the mean; atypical values

Seen which is analyzed above, six atypical values per graph are observed which in comparison is the same because the data collected is with a mass greater than the rest, so it means that it is correct, but even so it exceeds parameters compared to the rest of the data.

Likewise, Chart 6 shows us that it is a comparison, which states that if the means varied from 62,339, there would be a 60% probability of detecting the difference, that is, it would be more perceptible, and likewise if the difference between means were 91,301 would have a probability of 90%.

3.4 STANDARD DEVIATION TEST FOR ANALOG SCALE DATA; DIGITAL SCALE DATA; AVERAGE QUADRANTS

Under the same objective, a standard deviation test was carried out, which helps us to estimate the variability of the process and to compare it with an object value (Chart 7).

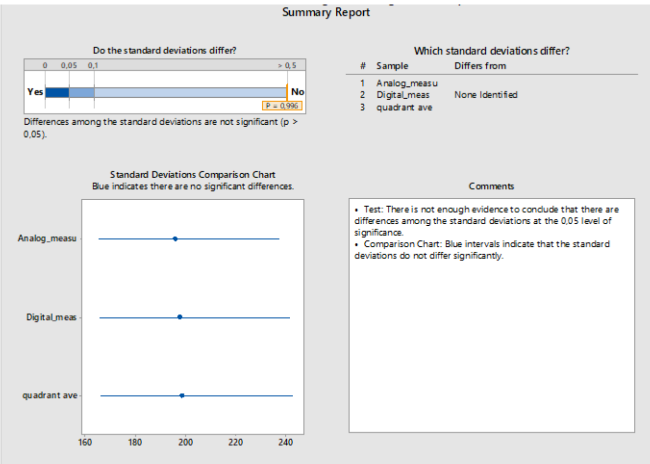

Chart -7: Standard deviation test report

Under an exhaustive analysis and multiple comparisons through the standard deviation test, agreed with the results obtained in the comparison of means, where it was shown that there are no significant differences with respect to the population that has been shown and that the dispersion. The number of values in the data collected is almost nil, where it is also worth mentioning a smaller or minimum number of values, which can be denoted as atypical, resulting in high peaks in our following graph (Chart 8).

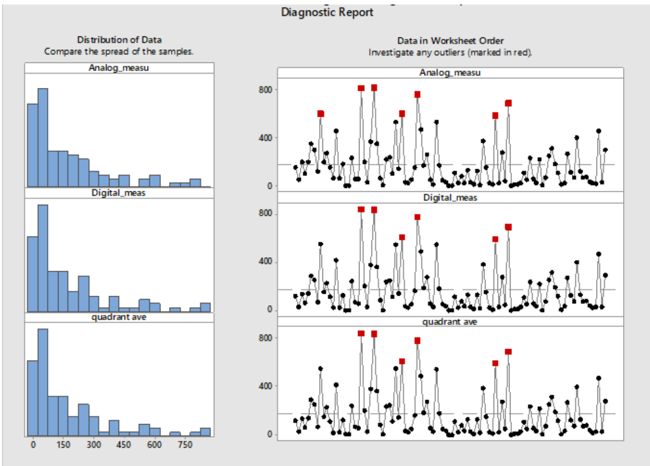

Chart -8: Diagnostic standard deviation test

In accordance with what was presented above, it is possible to observe that the data distribution is similar between digital and analog scale data and our load cell prototype. Comparing the data dispersion by means of histograms and the detection of atypical values, these same being reviewed, thus checking that they are correct and equal to each other, except for the analog scale.

On the other hand, Table 12 is shown which presents data for the mean, standard deviation and individual 95% IC in order to conclude its similarity and equality between data, serving in turn as an argument for the aforementioned.

Table 12- Deviation test

Descriptive Statistics Report

Statistics

Sample	Sample Size	Mean	StDev	Individual 95% CI for StDev
Analog_measu	100	173,8	195,85	(158,96; 246,13)
Digital_meas	100	171,96	197,91	(159,19; 250,96)
quadrant ave	100	172,73	198,48	(159,50; 251,92)

4. CONCLUTIONS

In relation to the above analysis, it can be concluded that the null hypothesis, which says that the measurements made by our scale will vary significantly, compared to other measurements made, whether analog or digital, has been rejected due to the tests carried out on hypothesis testing and uniformity testing contemplating dispersion of data and results that they yield, for which the alternative hypothesis establishes that: the measurements made by our scale, made up of a load cell, are comparable, identical and even equal to a digital one, it has been accepted, assuming or summarizing that the prototype of the scale has reached the objective set, having an efficiency of 95% and consequently yielding a margin of error of 5% or less.

Adding in turn that through the tests carried out such as t-test for two samples, test and IC among the rest, the equality of values between the digital scale with our load cell prototype has also been demonstrated, which although they are not exactly they are reduced if equality to hundredths or even thousandths, demonstrating whether the effectiveness of the load cell. Likewise, it is worth highlighting the uniformity in the data behavior also demonstrated through multiple tests, assuming its correct operation.

Finally pointing out that the prototype is suitable to be implemented in a manufacturing didactic cell that will help to give a more accurate weighing in a simulated production process.

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