Data Envelopment Analysis application in the evaluation of efficient measurement instruments

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(UPAEP 2018)

Abstract
The following article incorporates operational efficiency analysis in the context of dimensional metrology with a focus on technology selection- the objective is to evaluate measurement technologies under similar conditions and according to the physical characteristics of the instruments. The document proposes a selection of variables that allow comparing the attributes of the measurement process in different instruments for a specific piece – in such a way that the methodology shown can be applied to pieces with similar characteristics. The instruments are within the field of dimensional metrology and are representative of those commonly used in the industrial and the academic sector in the country. The contribution of this work consists of carrying a statistical tool normally used in managing organizational operations towards a technical environment such as dimensional metrology. The results present an opportunity for future research by combining the fields of metrology and efficiency analysis.

Keywords: *Data Envelopment Analysis, Analysis of the Measurement System, Measuring instrument.*

0 Introduction

To recognize the success or failure of a manufacturing company practically all production systems are evaluated in some way for example from technical, economic or even social indicators. There are different ways of assessing the efficiency of a manufacturing system and in all these forms it is necessary to measure the appropriate elements to generate data from the evaluation system. The importance of the measurement data lies in the fact that the decision to adjust a process is made based on the information acquired. If the data that result from measuring the behavior of a manufacturing system, bias and variation are considered as low quality data and condition the benefit of decision making. The magnitude of the variation and the degree of bias are factors included in an Analysis of the System of Measurement (MSA)

A measurement system involves 6 fundamental elements according to the Automotive Industry Action Group (AIAG); Pattern, Workpiece, Instrument, Person, Procedure and Environment. In this sense, the evaluation made by the measurement system is linked to the concept of error and the error measurement is nothing more than the cumulative analysis of the variations due to the 6 mentioned elements. The dilemma of assigning a numerical value to error consists in the usefulness of the results and in the similarity of the conditions of evaluation that tend to a just conclusion.

This work focuses on one of the elements of the measurement system: the instrument. The intention is to value each instrument from an efficiency analysis. Due to the different characteristics of each instrument applied to the same workpiece, we chose the use of a nonparametric statistical technique called Data Envelopment Analysis (DEA) which has the advantage of compressing information obtained from different types of variables to reach a single result [1]. In this way the present document focuses on the process of discerning the variables involved in the measurement system to relate them to an even more complex issue that is the correct selection of technology. Beyond choosing an instrument by characteristics such as price or availability, this work shows the application of a statistical tool commonly used in administrative areas and leads to a technical-technological environment.

1 Theoretical framework

1. 1 Measuring Instrument

Vernier type gauge

The Vernier scale in the traditional version allows obtaining three types of length measurements: exterior, interior and depth [2]. The Vernier (also called caliper or gauge) has a main scale and an additional one that facilitates the conversion of the units with which they are operated. For the calibration of the instrument, individual standard blocks are used. This instrument can perform readings with a metric approximation of up to 0.02 mm on the international scale and 1/128 or 0.001 inches on the English scale.

This instrument requires greater caution on the part of the operator who performs the readings specifically in the application of the measurement method, for example the pressure applied to the instrument, the contact made by the jaws on the object or the correct definition of a fixed reference. In general, Abbe's errors and the law of parallax are the main obstacles for this instrument. The measurements with this instrument should be repeated with more occasions, but in contrast it is quick and easy to use it.

Technical Publication CNM-INC-PT002 [10] of the National Metrology Center (CENAM) in Mexico describes Abbe's error (E) as the gap that exists between the surfaces that cross the scale of the vernier; this gap produces a reading error that can be quantified on the measurement line. The Abbe error establishes to align the measurement axes of the instrument with an imaginary axis of the piece from which the reading is taken.

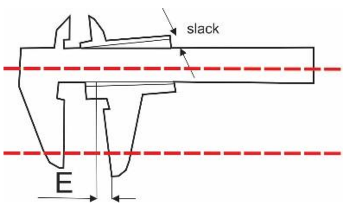

Fig. 1 Alignment of axes in the Abbe error (CNM-INC-PT002).

There is a parallax error because the scales of the vernier do not coincide, each one is in the front of two guides, of which one is movable, however, it transfers this effect directly to the types of the vernier. It can be said of this error as something inevitable, because the construction of a vernier is based on a fear by which a guide runs under certain restrictions of the positional relation with respect to other main guide CNM-INC-PT002 [11].

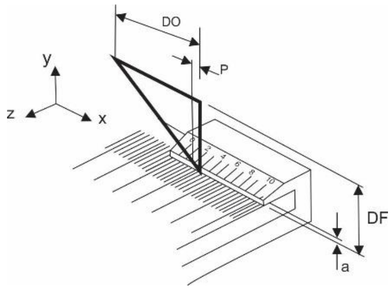

Fig. 2 Deviation of vernier scales (CNM-INC-PT002)

Where:
Do is at the front distance considering the eye of the one who takes the reading.
P is the parallelism that exists as a difference between the location of the human eye and the scale of the instrument.
DF is the vertical distance from the scale of the instrument and the position of the reader's eye
a is the thickest in the construction of the scale of the instrument versus the guidelines of the instrument.

The operator must adopt the ability to obtain readings regarding the limitations of data recognition, visual acuity and resolution power. In the parallax error in the position of the operator's eye is very important, for example, when both eyes are used to take the reading, it will be known that at least one will have the effect of parallax. Whether the view is to the right or left there is a variation that is related to the height of the mismatched planes within the front mechanism of the instrument.
This type of error can be minimized if the height ("a") that separates each of the fixed and mobile scales of the calibrator is reduced even in the hypothetical case of becoming zero.

There are more than 20 vernier models that can be used in specific cases, in figure 3 the examples of vernier models that were evaluated in this work are shown according to the characteristics of the piece to be measured *[9]*.

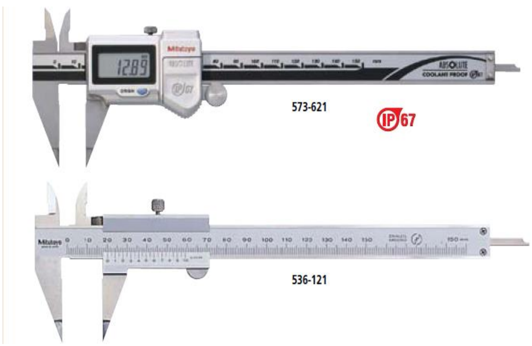

Fig. 3 Tip gauge types. Source Mitutoyo®.

Laser scanner

The technology of laser scanner allows in a short time to acquire with a high level of detail the geometric relief of the object that is scanned. When the laser light emitted by a computer is reflected on the object it is possible to create constructions in three dimensions and transfer them by means of software to a system with greater possibility of use [3].

What can be highlighted in laser scanning technology is the versatility of this type of instruments to adapt to the measurement conditions, the effectiveness of a laser is the precision with which elements are captured in a limited context where for other tools it would be difficult not only achieve an accurate record but get a reading. The use of the laser technique for measurement brings with it a characteristic that can be considered as a virtue or defect; as a virtue in the case of taking advantage of the enormous amount of information that is translated as a point cloud and that is reflected in a high-level detail of the object that is to be represented, as a defect because the same large amount of information makes the processing slow of images, so that not any computer equipment can be considered suitable for this type of work [4].

The basic principle of operation of the laser scanner is supported on two elements; while a mechanism is responsible for measuring the distance to where the laser beam reaches the other mechanism is responsible for scanning the laser light on the body that is scanned. The result of laser scanning is the generation of a cloud of points organized according to a simple coordinate system, in some equipment the reference of origin is in the center of the equipment in such a way that the points obtained by scanning are positioned within a three-dimensional system.

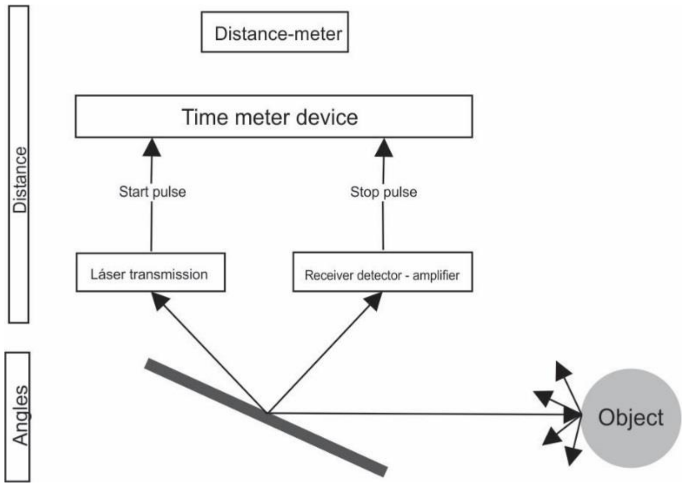

Fig.4 Principle of Laser Operation (I. García-Gómez).

Optical Comparator.

The optical comparator is also known as a profile projector and is used to measure small parts by amplifying its image on a screen. It is useful when there is interest in the piece being measured in the angles between the faces of the piece. Its operation is based on a projection lens, a piece clamping system and a translucent screen. They are classified according to their type of lighting in horizontal and vertical without a significant difference in the result of the measurement. This lighting system allows the measurement focused on the counter or on the surface (or even both simultaneously).

The part's clamping system is part of the measurement method itself since in this instrument in the initial calibration settings reference lines of the projection screen are used to align the piece with respect to a point of origin denoted by the position of the path within the fastening system.

An advantage of this instrument is that it can be equipped, for example, with linear scales, templates or some other addition that give comfort in the measurement work, especially in repetitive jobs.

1. 2 Data Envelopment Analysis (DEA)

Data Envelopment Analysis is an iterative method based on linear programming that aims to measure the efficiency of a system in relation to an optimal value. The iterative process is actually an optimization model guided by historical values and that reflect the performance of the system under study. This process of optimization presents problems when more than one measure of performance is required or between the performance indicators of the system, there are conflicts; The solution to this type of problems is not concentrated on obtaining a single optimal solution, but on creating a set of favorable solutions called the efficient frontier [5]. The efficient frontier of the DEA shows the relation between the products of the System (Outputs) given the inputs involved (Inputs).

The utility of the DEA technique is that it allows to recognize in the units of measurement (DMU's) used, those that are below the efficient frontier, moreover, this technique allows to recognize the distance and location that separates the DMU. Ordinary of those that behave as the efficient frontier of the System, this concept gives rise to the so-called orientation towards Outputs or towards Inputs as working models of the DEA [12].

Combining the knowledge of the DEA technique, it is relevant to consider the problem of the technique when working with system evaluation variables that do not represent the performance of the system, either because not all the representative variables of the system are included or because too many have been included. this generates that the technique is not discriminating enough and the decision making based on the results of the AED is biased.

2 Methodology

The selection of variables was obtained through an analysis of the general conditions of dimensional measurement equipment proposed in the previous section. The analysis of the instruments in question not only involved a review of literature, but also a review of websites, product catalogs and manuals and operating instructions that show the specific technical characteristics of the instruments, this review determined the variables considered in this study [6-9].

The variables that were not applicable for the study were filtered, either due to their technical or economic characteristics. Although an analysis of efficiency between different technologies is intended, the focus of this work is oriented towards a technical field rather than the commercial one, for this reason the variables of economic type such as the cost of the instrument, maintenance cost or cost of calibration are not considered within the study.

The categorization of the variables involved in inputs and outputs used the error in the measurement as the main axis of this efficiency analysis. The error is defined as the difference between the nominal or the true value of the object and the measured value. There will always be errors in the measurement since it is not possible to separate the imperfection of the instruments, the means of observation, the staff's senses or environmental causes, this definition originates what is known as "absolute error". There is also the relative error defined as the ratio of the absolute error between the nominal value or true value. Typically, the relative error is expressed as a percentage, which favors the understanding of the reading taken and provides better information to quantify the seriousness of the error [2].

The variables in the study are not statistically affected by the presence of multicollinearity between the data of the variables, this reason justifies that no correlation and multivariate statistics studies were performed, unlike other studies associated with the DEA technique.

The variables considered for this study are:

Tolerance.
Defined as the total amount in which it is allowed to vary to a certain dimension, this is that once it is known that there is no process or perfect product the owner of the piece allows a difference by up or down or the nominal value of the measure which is called upper and lower specified limits. The intention to define a tolerance lies in allowing the manufacturing process a real and fair comparison between the dimensional characteristics of the element to be measured and the effectiveness of the measurand.

Precision.
It is defined as the absence of systematic errors and is related to the degree of similarity between two or several consecutive measurements of the same object with the same device and the same procedure. Even a series of measurements that are far from the nominal value, but close to each other reflect a high level of accuracy.

Resolution of the instrument.
It is defined as the smallest division or the smallest reading that can be done with a measuring instrument. For the specific case of 3D scanners, the resolution does not change even though

the software used as an interface is modified because the resolution of the instrument is attached to the instrument and not to the peripheral elements.

Environmental conditions.
They are defined for this study as the temperature in the workstation where the measurements are obtained. At times, humidity, height at sea level or atmospheric pressure could also be considered.

Repeatability
It is defined as the variation of the measurements made by the same operator on different occasions, but using the same measurement conditions, same instrument and the same piece of work.

Accuracy.
It is defined as the agreement of a measurement with the known true value for the quantity that is being measured, the term is related to the concept of error defined as the deviation between the measured value and the value of a reference pattern taken as true.

Speed in results.
They are defined in this study as the minutes needed to obtain a measurement from the moment in which both equipment, part and measurement conditions are suitable to start the measurement.

Description of the piece.
A suitable piece was chosen to be used with the different instruments, both in size and shape. The path is part of an assembly so the true value is defined according to the manufacturer's specifications.

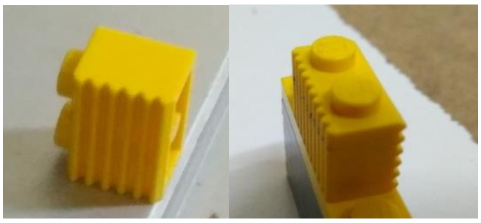

Fig. 5 Sample piece for measurement.

2.1 Readings with Vernier.

It is the most common instrument in the industrial sector because of the ease with which it can be transported and the speed of measurement. The study did not require more preparation than activating it with a movement and although the conversion between millimeters and inches was not used, the digital screen does the conversion immediately. As shown in Figure 6, the care and protection of the instrument are important to the reliability of future data.

Fig. 6 Vernier protection.

Specifically, in this work we opted for the tip vernier model because it facilitates reading between "valleys and ridges" that the piece that is the object of measurement has. Figure 7 shows that unlike a conventional vernier, the instrument used in this work acquires an advantage both in the speed of obtaining measurements and in the quality of the data it yields.

The measurement of the piece did not require the tuning of the equipment or complementary peripheral equipment, although this vernier model has an interface to carry the data to a computer equipment. The taking of readings did not follow any method out of the convention, so the results were given instant.

Fig. 7 Mitutoyo ® Vernier tips.

Readings with optical comparator.

An optical comparator of the horizontal type Mitutoyo model PH-14 was used. The taking of readings initially requires what is known as "Commissioning" of the equipment so that the referential corner was defined in the work piece, it was ensured at each reading start the placement in zero on both the X and Y axis, the 0 ° profile of the rotary screen was adjusted and the type of lighting of the equipment was adjusted.

The measurement method included positioning the piece in the same way to start the data collection always with the same working pattern. Given the physical characteristics of the workpiece, it was not necessary to fix the piece or mechanical adjustments to fasten the piece. Figure 8 shows the take both the measurement panel and the reader board.

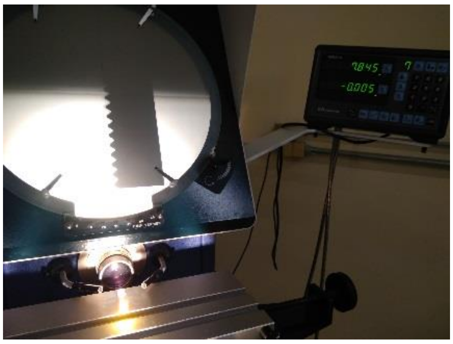

Fig. 8 Initial setting of the optical comparator.

Readings with the laser scanner.
The laser scanner requires complements for the operation that consist of the software that transfers the readings made to the piece and takes them to the computer in the form of a mesh or a cloud of points by which other software recognizes this cloud of points in positions in 3D so you can measure the virtual distance existing in the piece obtained.

The 3D scanner uses as a reference targets that are positioned on the piece and the main planes of the workstation. Once the work area is defined, the scanner is activated to find the points that will be your reference throughout the different measurements. To follow the configuration of the software-scanner, 4 elements are defined: the laser power, the level of the shutter, the ram memory with which it will be worked and the level of detection that feeds the operator to know if it is too close or too far from the piece as to lose sight of the targets with which the scanner is located and takes reference.

Fig. 9. A 3D Scanner equipment used in the measurement.

The image no. 9 shows the Scanner 3D model Handy Scan Exascan 30635 from Creaform, the scanning software that the creative company includes for this equipment is VX elements. The software requires an initial configuration to ensure the optimum performance of the parts to be scanned. Initial equipment configuration tests were performed from the VX elements software resulting in optimal levels in:
65% laser power.
Shutter: 12.6 milliseconds.
Detection and cover image: 85%.

Once the equipment is configured as shown in figure 10, a first "sweep" of the work area is performed where the scanner detects the points or targets that will be referenced in subsequent measurements.

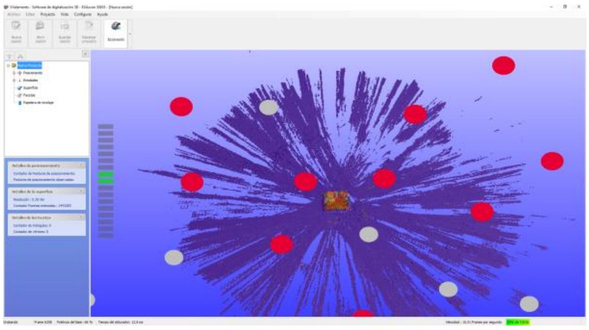

Fig. 10 Scanning reference targets for the scanner.

The result of the measurement is a cloud of points according to the piece worked, with the scale 1: 1 and with the resolution, accuracy and other variables shown in table 11 of results. The resulting file is of type.jt which allowed it to be taken to other design software to determine the distances from one point to another.

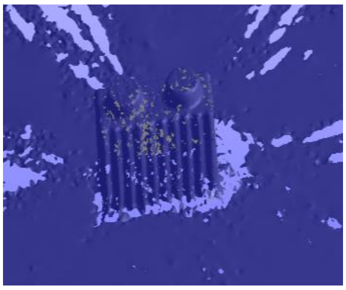

Fig. 11 Mesh resulting from 3D scanning

Once the readings of the different teams were gathered, the information concentrate was made in the calculation table no. 1 were 3 main points stand out; first the categorization of the variables involved in inputs and outputs, second the value of the variable of environmental conditions is a dummy type like 0 to denote that the temperature does not affect the measurement and 1 for the opposite case. The third point to note is that the value of accuracy and repeatability result of a statistical calculation process under the guidelines of the AIAG manual for the analysis of the Measurement System, of which the repeatability study is a part [11] the first is a difference of the nominal value and in the second case a variance exercise is performed to determine the degree of Affectation of the same operator measuring the same piece. Both accuracy and repeatability are dimensionless and absolute.

Instrument	Inputs					Outputs	
	Tolerance mm.	Precision mm.	Resolution of the instrument mm./ m	Environmental conditios (dummy)	Repeatability	Speed in Results (minutes)	Accuracy
Vernier	0.020	0.010	0.100	0	0.73	1	0.0350
Optical Comparator	0.020	0.001	0.001	0	0.45	3	0.0330
Lases Scanner	0.020	0.040	0.100	1	0.65	45	0.0378

Table 1. Result lectures.

The DEA analysis was performed on the Excel® platform and is presented in table 2 in a summary that indicates efficient entities; Both the optical comparator and the laser scanner are part of the efficient frontier from the technical aspect of the variables included in the study. It has occupied the CCR model that is a DEA model focused on the use of inputs as a means to reach an optimal result.

What is shown in the table is that the only instrument that does not reach an efficiency level in any aspect is the vernier, that is, in the relationship formed by tolerance versus accuracy or for example the combination of repeatability, precision and resolution versus speed in results did not indicate that the vernier had any advantage over the other two teams in the study. In fact, what the DEA technique has done is a series of iterations always looking for the best result from the restrictions posed in the teams involved.

			Virtual inputs	Virtual inputs	Virtual inputs	Virtual inputs	Virtual inputs	Virtual outputs	Virtual outputs	
	DMU	Eff. score	Tolerance mm.	Precision mm.	Resolution mm./ m	Environmental Conditions	Repeteability	Speed in results	Accuracy	Pears --->
1	Vernier	0.333333	0.00667	0.00033	0.00033	0.00000	0.15000	1.00000	0.00000	2(.333)
2	Optical comparator	1	0.02000	0.00100	0.00100	0.00000	0.45000	3.00000	0.00000	2(1)
3	Laser Scanner	1	0.02000	0.04000	0.10000	1.00000	0.65000	45.00000	0.00000	3(1)

Table 2 of efficiencies results.

This solution is interesting if one considers that the vernier for its practicality and its low economic value is the most used instruments in the work environment. It is possible to consider improvements in the study for the vernier and make it reach an efficient state if improvements are observed in the measurement method with a view to improving the repeatability factor, something that coincides with reality since being such an easy tool in its use is also common that the method of taking a piece to measure it is done with freedom for the operator.

3 Conclusions

The result of applying this DEA study to the technical field allowed us to observe that it is possible to improve a complete measurement system from the most basic actions such as the correct choice of measuring instrument. The initial idea of incorporating a statistical management tool, as in the case of the DEA tool to the field of technology selection, also results in the benefit of research, since it gives results in terms of the fact that it presents a vision of the way in which it can be applied. improve not only the production scope, but the measurement system that is a fundamental axis in manufacturing companies.

This research contributes both in the practice of statistical tools and in the field of metrology since it allows visualizing techniques that converge in a clear intention of a production organization that is to optimize and be more efficient and productive.

The continuation of this work would include the adoption of other types of instruments in a possibly more complex system that addresses the issue of technology selection in strategic business planning.

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