MEASUREMENT SYSTEM UNCERTAINTY

By Elwyn Lewis (ASQC) CQT, CQE

It may seem peculiar to some that reference is made to a "Measuring System" as one automatically tends to think in terms of instrumentation only. The measuring instrument is invariably only one input into a total measuring system.

Even when used correctly a "Measuring System" will not always produce identical results, when repeat measurements on a single unit are taken with the same measuring system the results may vary, this is known as "Measuring Uncertainty". The questions are, however, how much variation is acceptable and how much can be eliminated? In order to understand the question we must first understand this variation and the different ways in which it can affect our measuring systems.

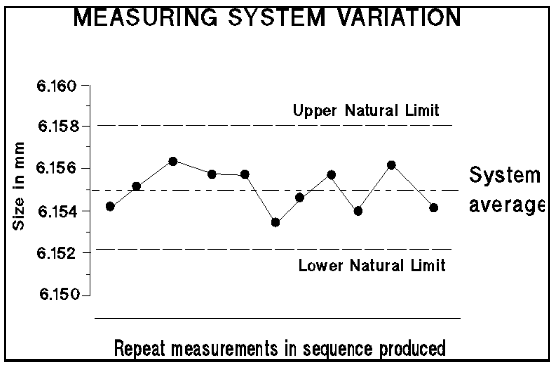

Figure 1 : Example of Measurement System Variation

The variation of repeat measurements (system output) can be graphically represented by a sequential plot as seen in figure 1.

The overall measuring system variation originates from the combined internal variation of each input element such as the analyst, his instrumentation and the various techniques utilised etc. Figure 2 graphically demonstrates this principle.

This output variation is inherent in all measuring systems and as long as the input elements vary within their natural limits, the variation of the system will be repetitive and predictable.
However, should any one of the input elements vary outside of its natural limits, it stands to reason that the system output will also tend to vary outside of its natural limits in an unpredictable fashion.

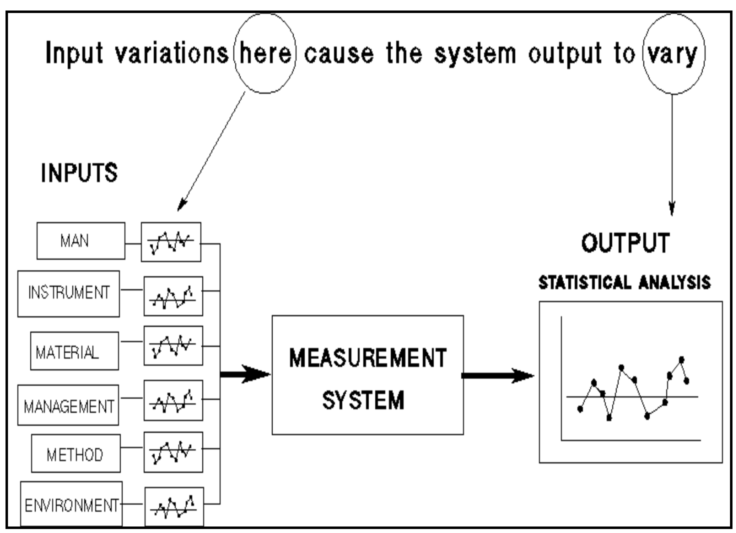

Figure 2 : Measurement system variation

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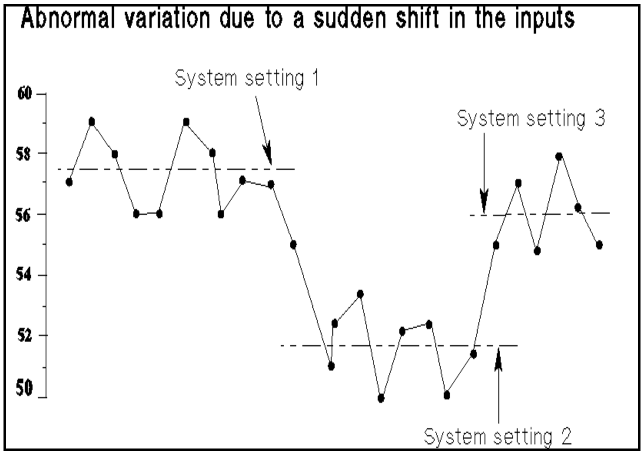

Figure 3 : Shift in System Average

In figure 3 it can be seen that there are three distinct levels at which the system has been operating - three system averages. This could be caused by three different analysts or inspectors, perhaps various shifts, three various calibration periods or a multitude of possible reasons. The system average has changed three times over the time scale of the X axis.

The increase of system variation as shown in figure 4 usually indicate that an input element of the measuring system requires investigation and possibly repair or maintenance. Input variation has increased thereby causing the measuring system variation to also increase.

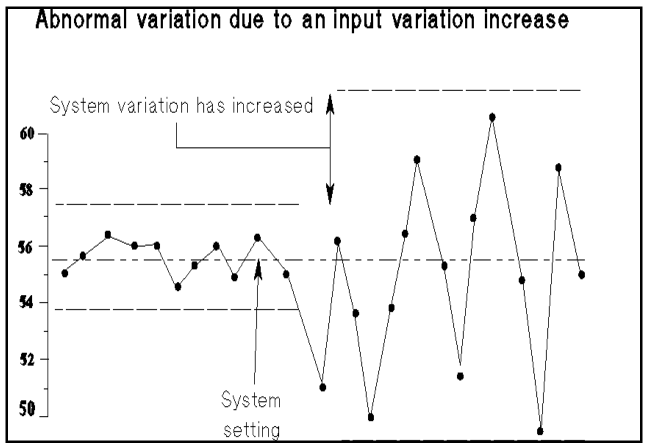

Figure 4 : Change in System Variation

The two most commonly used terms that describe measurement system variation are Accuracy and Precision and both need to be measured, evaluated and controlled if we wish to maintain an effective Laboratory or Inspection service. In simplistic terms, Accuracy is the difference between our measuring system average and the true value of the item being measured, whereas the precision is the amount of variation around the system average.

The text book definitions are:

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Accuracy: The accuracy of a measuring system is defined as the extent to which the average of a long series of repeat measurements made on a single unit of product differs from the true value. In most cases the difference can be assigned to the system being out of calibration.

Precision: The precision of a measuring system is the extent to which the system repeats the results when making repeat measurements on the same unit of product. The variation (scatter) of the measurements is also known as the **"Measuring Uncertainty"** and may be designated σ_{MU}, meaning the standard deviation of measurement uncertainty.

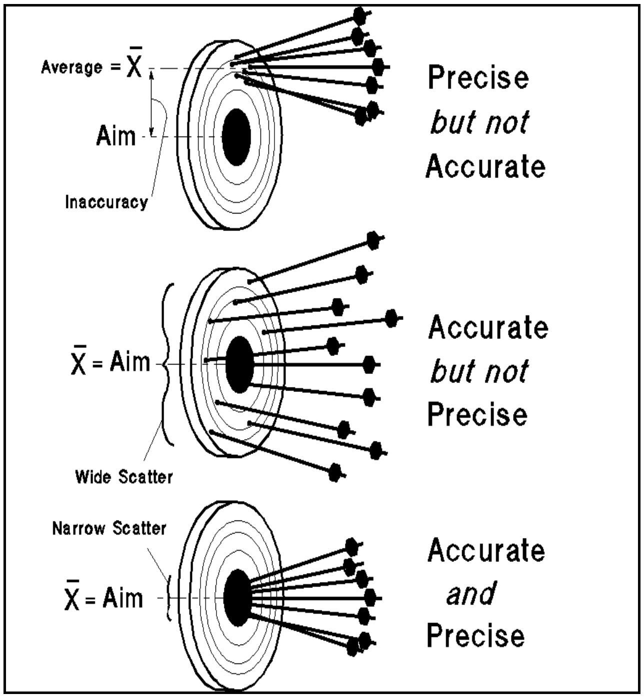

Figure 5 : Archer Analogy

The terms accuracy and precision can be illustrated by figure 5 where we can clearly see the difference between accuracy and precision. The three targets represent the results of an archer whose aim is to hit the "bull's-eye". The top target shows that the archer has a good scatter around his average but that his average is not near his aiming point - the bull's-eye. The second target shows that the average of the archer's arrows is close to the bull's-eye, but his scatter or variation around his average is wide. The third target shows the ideal situation, accurate and precise, the archer's average is equal to the bull's-eye and his scatter is close to his average.

There has long been much confusion about the use of the terminology - accuracy and precision, in most literature these terms are used interchangeably. For example table 1 show the statements on error of measurement as listed in three categories none of which define the word "accuracy".

Manufacturer			
Instrument	A	B	C
Outside micrometer (0-25mm)	Accuracy 0.0025mm	Accuracy is maintained at 0.00127mm	No statement
Dial calliper	Accuracy to 0.0254mm per 152.4mm	Accuracy guaranteed within 0.0254mm	No statement
Electronic comparator	Repeatable accuracies to 0.000101mm	It repeats to within 0.0000508mm	Total error is less than 1½% of full-scale reading

*Table 1

* Extracted from Quality Planning and Analysis - Juran / Gryna second edition

It is important to know the difference between accuracy and precision as the following actual example will demonstrate:

During 1986 whilst walking through the workshop I happened to notice one of my inspectors measuring a very expensive component on the "3 Dimensional (3 D) machine". This machine was a modern three dimensional measuring machine and could produce a read out to 0.001mm. After greeting the inspector I curiously asked him: "How accurate is this machine, Daan?". "To the micron" (0.001mm) he replied in a surprised manner. I then asked: "What is the precision of this instrument?" now looking very dubious he said "to the micron!". "Show me?" I challenged, handing him a component which he duly set up and measured.

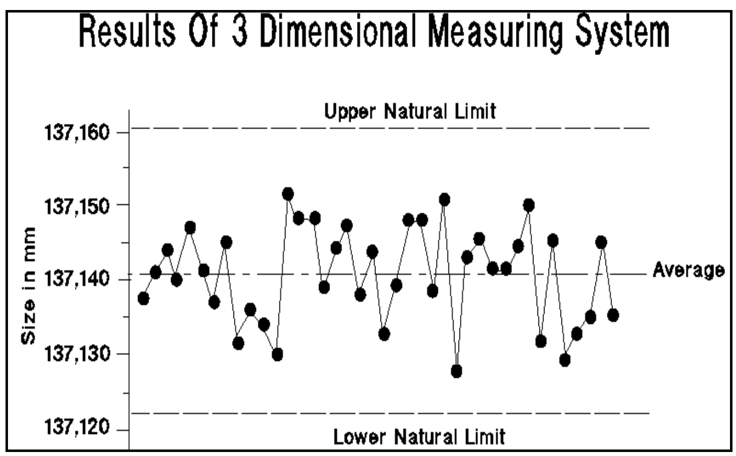

Figure 6 : Measuring a Component Ø137,150 ± 0,050mm

The measurement was of the inside diameter of a Component (headlight bell housing) with a specification of

∅137,10 ± 0,050mm. Upon finishing the measurement Daan read the result from the display, "137,138mm" he stated with a smile. "Would you mind repeating the measurement?" I asked. Confused with my request Daan grudgingly repeated the measurement, only this time the display showed a different result of 137,141mm. "Which one is the correct one?" I enquired, "The first one" answered Daan.

Based on this discrepancy I was able to convince Daan to take a further 38 measurements to make a total of 40 measurements made on the same component. We plotted the results and analysed the chart by searching for abnormal variation in the data (the analysis methods will be discussed at a latter stage).
The results of our charting the data is seen in figure 6. What conclusions can you make about the accuracy and precision of this measurement process?

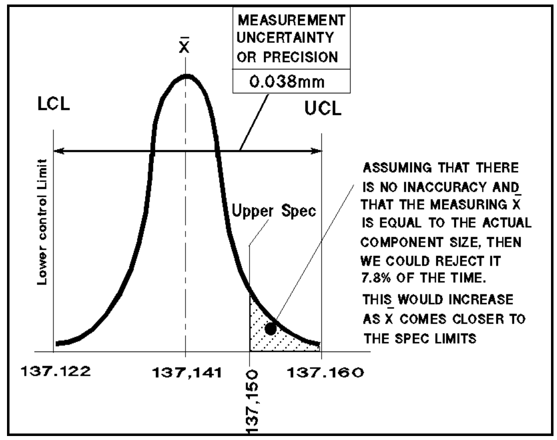

Figure 7 : Measuring System from figure 6

Daan was quick to volunteer the reasons for such a large variation (precision) and explained that the component could have been oval, the surface finish too rough and numerous other possible reasons.

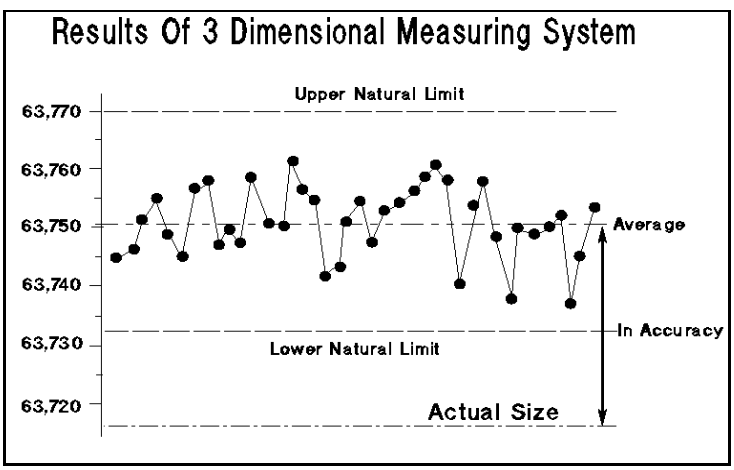

Figure 8 : Calibration Ring ∅63.7159mm

From figure 7, another graphical view point of figure 6, we could only conclude that although there were no abnormalities shown on the chart, the measuring uncertainty or precision of 0.038mm (38 microns) was much too large for that specific 3 D machine's capability. As for the accuracy, we could not comment as we did not know the actual size of the component. With this in mind we decided to repeat the exercise but this time using a calibration ring. This ensured that the surface finish and ovality factors would not play a role in the system variation. The size of the calibration ring is ∅63,7159mm. Figure 8 illustrates that the measurement system precision of 0,0367mm (at 99% confidence) has not reduced significantly from our previous precision of 0,038mm. Figure 9 is an alternate graphical presentation of figure 8 and is useful in highlighting the alarming inaccuracy which existed between the measuring system average and the actual size of the calibration ring, an inaccuracy of 0,0347mm, as well as the large precision.

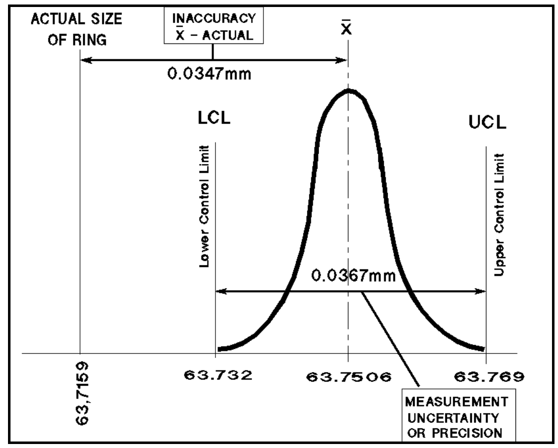

Figure 9 : Measuring System from figure 8

This was a very expensive error. Imagine the situation, a 3 dimensional machine costing approximately R175 000, back in 1986, being used to inspect machined gearbox casings with tolerances of ± 0,010mm, which cost about R18 000 each, accepting nonconforming products whilst ensuring that conforming products are reworked until they too are out of specifications. All manufacturing processes were geared up and rely upon the results supplied by the 3 D machine for input into their machine settings and first off samples. This played absolute havoc with the interchangeability of parts used on assembly lines as well as the spares sold separately.

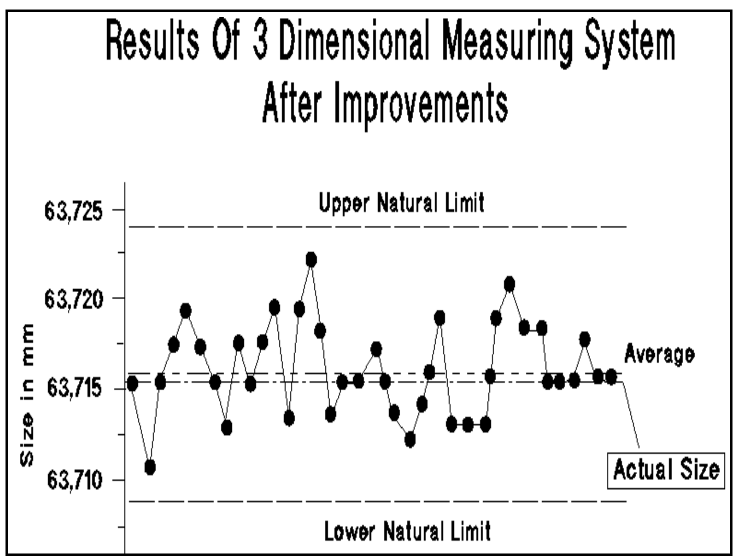

Figure 10 : After measurement system improvement

It was clear that there was a serious problem and that immediate management action should be taken to correct the situation. After an intensive study and investigation it was discovered that the compressed air, used to supply the pneumatics, was saturated with oil. This was due to the piston rings in the compressor being worn allowing oil to be pumped into the pneumatic system, thus overloading the filtering system which was not able to cope with the increased oil levels in the air. This resulted in excess oil being penetrated into the mechanics, optics and electronics of the 3 D machine.

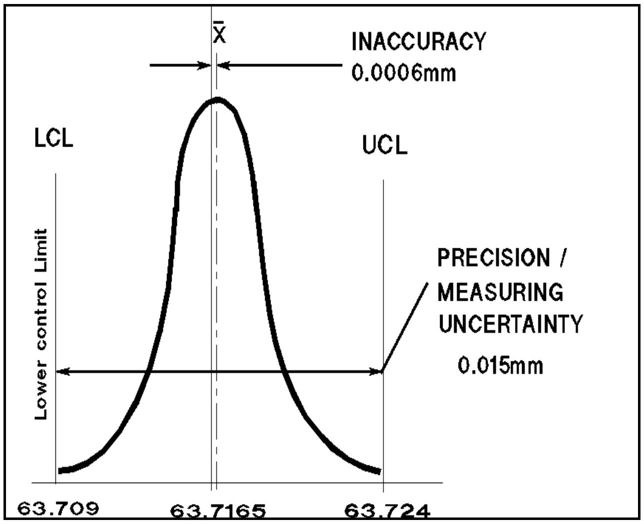

Figure 11 : After measuring system improvement

The solution was simple, fix the compressor. However, budgets were low and money tight with no one willing to pay for the expensive repairs to the compressor. The only other alternative was to improve the filtering system. Once this had been upgraded the 3 D machine underwent a full service and recalibration. Another statistical analysis was performed to ascertain whether there had been an improvement or not. The same calibration ring of ∅63.7159mm or ∅2.5" was used and another 40 results were taken and plotted on a chart. Figure 10 shows the results with no sign of abnormal variation in the data. Figure 11 highlights the significance of the improvements to the accuracy and precision of the measuring system precision. After further analysis and under test conditions we were able to improve the precision to ± 0,002mm. However the smallest we could maintain the precision under normal operating conditions, with a 99% confidence, was to ± 0,0075 (0,015mm).

Figure 12 illustrates the improvements made to the accuracy and precision.

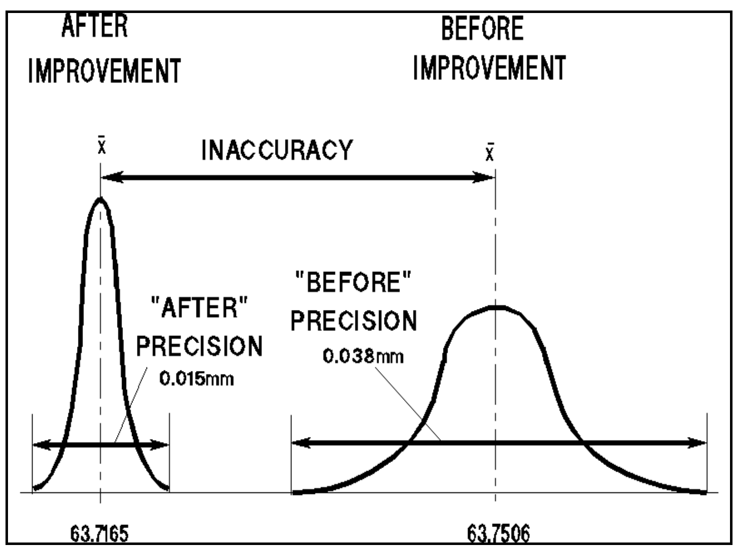

Figure 12 : Comparison of Improvement

It should be noted that this is but one true example of many expensive measuring errors, and it has been my experience that 3 dimensional measuring machines are grossly over rated. People tend to just accept a result because of the complexities of the system, assuming that it must be right.

Understanding and monitoring of "Measurement Uncertainty" is an important aspect of any process and/or product, and management should know, with confidence, that they have supplied a system capable of meeting the requirements consistently.

References:

1. J.M. Juran and Frank M. Gryna "*Quality Planning and Analysis*": Press - McGraw-Hill 1980

2. Elwyn Lewis "*Managing with System Analysis Methods*": The Institute of Quality Assurance (London) - The Quality Forum Vol.17 No.3 pages 101 to 105.

Biography - Elwyn Lewis

Elwyn Lewis is currently employed by Mossgas (Pty) Ltd, a South African petrochemical company which will produce oil from gas once commissioned. He is responsible for the development and implementation of Statistical Quality Control methods.

Elwyn has been certified, as both, a Quality Technician (CQT) and a Quality Engineer (CQE - 1983) by the American Society for Quality Control (ASQC). He is also a dual tradesman, a Fitter Machinist (1980) and an Armourer (Gunsmith - 1978).

Although a British Citizen, Elwyn lived in Rhodesia until 1980, thereafter moving to the Republic of South Africa.

His experience covers Military, Armaments, Mining, Automotive and currently the Petrochemical industry. Elwyn has been actively compiling and presenting numerous Quality courses in the field of Statistical Quality Control since 1984.