The Crux of the ndc

Dipl-Ing. Stephan Conrad, TEQ® Training & Consulting GmbH

Since the third edition of the AIAG Core Tool MSA 2002 manual has been published in 2002, the subject of ndc keeps haunting the world. It almost seemed like this statistic will continue to have a ghostlike, unremarkable presence and might even disappear slowly but surely. But then came the fourth edition of this manual in 2010 and the ndc gained in importance once again.

By now, people have had enough time to gather sufficient experience to apply this statistic; however, most of them have rather had a bad experience. This is the reason why we will have a closer look at whether the "number of distinct categories (ndc)" makes sense or not.

TV, PV and GRR

First of all, it is important to clarify one of the main issues of the AIAG MSA manual. How do total variation (TV), part variation (PV) and gauge repeatability and reproducibility (GRR) relate to one another? This question is actually about the fact that the observed process variation is always a (quadratic) combination of the actual process variation and the gauge repeatability and reproducibility. In case of normally distributed values, this fact leads to

$$\sigma^2_{\text{observed process variation}} = \sigma^2_{\text{actual process variation}} + \sigma^2_{\text{gauge repeatability and reproducibility}}$$

The AIAG MSA manual puts it as follows:

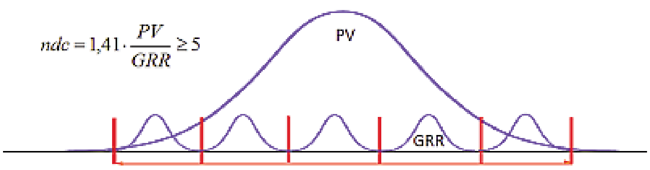
$$\sigma^2_{\text{Total}} = \sigma^2_{\text{Process}} + \sigma^2_{\text{MSA}} \quad \text{or}$$

$$TV^2 = PV^2 + GRR^2$$

This relationship provides the essential basis for understanding the AIAG MSA manual perfectly.

ndc according to AIAG MSA

The AIAG MSA manual defines the ndc as the number of categories of measured values that can be reliably distinguished. To put it simply, you may count how many times the gauge repeatability and reproducibility GRR fits into the actual process variation.



You always truncate the ndc, unless it is less than 1. If it is less than 1, you have to round it up. The factor of 1,41 (=√2) does not refer to the 97% confidence interval as described in the MSA manual. It is calculated from the variation ratios given in the ISO plot.

The AIAG MSA manual says the ndc should be greater than or equal to 5. The thought behind this specification is that process control only makes sense in case you are able to divide the process into at least 5 distinct categories of measured values based on the ndc.

The AIAG MSA manual lists the ndc under "additional width error metric". However, the actual and main evaluation of the measurement system is based on the GRR value. The manual demands a GRR value being less than or equal to 10% of the reference value.

$$\%GRR = \frac{GRR}{TV} \cdot 100\%$$

Together with the relationship between total variation, part variation and GRR you obtain the following three equations.

$$ndc = \sqrt{2} \cdot \frac{PV}{GRR}$$

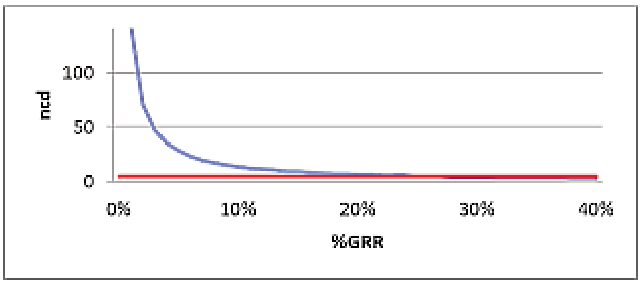
$$\%GRR = \frac{GRR}{TV} \cdot 100\%$$

$$TV^2 = PV^2 + GRR^2$$

These equations clearly illustrate that ndc and %GRR interdepend. So you may convert ndc directly to %GRR and vice versa.

$$ndc = \sqrt{2 \cdot \left(\frac{1}{\%GRR^2} - 1\right)}$$

With the help of %GRR, you may find the ndc directly in the diagram.



So the ndc amounts to 14 in case %GRR = 10% and the ndc is 4 when %GRR = 30%. Unfortunately, the limit ndc = 5 as found for %GRR = 27,2% does not match the limits for %GRR.

By using the tolerance as a reference, the following formulas apply to TV and PV according to AIAG MSA Chapter III - Section B (p. 122).

$$TV = \frac{USL - LSL}{6} = \frac{T}{6}$$

$$PV = \sqrt{TV^2 - GRR^2} = \tfrac{1}{6}\sqrt{T^2 - (6 \cdot GRR)^2}$$

The part variation PV calculated here, of course, does not concern the real process variation at all. It is nothing but an auxiliary quantity in order to calculate the ndc. With the tolerance as a reference, the ndc is calculated from the following formula.

$$ndc = \sqrt{2} \cdot \frac{PV}{GRR} = \sqrt{2} \cdot \frac{\sqrt{T^2 - (6 \cdot GRR)^2}}{6 \cdot GRR}$$

Roughly speaking,

- the %GRR specifies how many times the GRR fits into the tolerance
- the ndc specifies how many times the GRR fits into the tolerance reduced by (the square of) GRR.

You notice that the information is redundant. The calculation of two statistics is not required and, when considering the different limits of %GRR and ndc, it is even counterproductive.

Common Practice and the Meaning of ndc

In order to make sense of these methods, you generally use an approach different from the AIAG MSA manual. %GRR is related to the tolerance (TV=T/6) whereas ndc refers to the actual part variation (PV) gained from the measured parts. Now you realize quickly that evaluating the measurement system based on the ndc does not make sense. The %GRR shows that a measurement system is applicable with respect to the corresponding tolerance whereas the ndc only indicates that the parts used in the inspection can be divided into a minimum number of categories. The ndc thus depends directly on the variation of the 10 parts and rather provides information about the applied parts than the measurement system.

You may also question the meaning of the ndc when thinking of SPC as an issue usually dealing with quality control charts and sampling. The larger the sample size, the more precise the control chart. How is it possible to decide whether the measurement system is appropriate for process control based on the ndc alone?

What Does the Author of the ndc Say?

The doubts about the benefits of the ndc continue to arise when reading the AIAG MSA manual more carefully. The third edition of the manual still referred to the origin of the ndc in Chapter III - Section B, i.e. it mentioned the book ″Evaluating the Measurement Process“ (1984) by Donald J. Wheeler and Richard Lyday. This piece of information is missing completely in the fourth edition. So the question arises why the authors and the reference were deleted from the footer.

The background of this strange fact becomes clear when reading Wheeler's blog on Quality Digest from March 2011. Please find the article online on the website http://www.qualitydigest.com/inside/quality-insider-column/problems-gauge-rr-studies.html. Wheeler makes it very clear that the formula the AIAG MSA manual uses to calculate the ndc does not determine the ″number of distinct categories“ at all. He says "… nowhere in that text did we ever suggest that this ratio would define the number of distinct categories." But what is it this formula defines? Wheeler: "Unfortunately, as I has discovered after much effort, there is no simple interpretation for the classification ratio in practice." Or even more clearly: „The number of distinct categories value (…) does not represent anything that can be expressed in practical terms." This value is of no relevance in practice!

How shall we deal with the ndc given in the AIAG manual now? Wheeler's answer: "So even though I may be the author of this ratio, it is useless in practice. I personally quit using it back in the 1980s. I suggest that you do the same, starting immediately."