The Role of Distributions and Control Charts in Metrology

Yu Adler, T Polkhovskja, V Filichkina, V Shper

NIST “MISIS”, Moscow, Leninskij prospect, 4
e-mail: vlad.shper@gmail.com

Abstract. In this paper it is suggested to change radically the existing metrology paradigm for measurement data analysis, namely to reject from searching the appropriate Distribution Function (DF) and use nonparametric methods for uncertainty estimation in all circumstances. This let to avoid using limiting and unprovable assumptions that lead to invalid conclusions. In the paper it is offered to use Shewhart Control Charts (ShCC) as an indispensable method to monitor the current state of measurement system. And this method does not require any assumptions about specific type of DF.

Papers on metrology give much attention to the role of Distribution Functions (DF) for measurement treatment and interpretation. However most often it is impossible to estimate which specific DF relates to a sample. Besides this requires big resources and much time. That’s why practitioners use the idea of normality so permanently. More than two centuries it seemed quite acceptable to them. As a result many are used to consider it as something natural and obvious. Great reduction of cost for calculations and rapid growth of computer power and data volumes let people to create empiric estimates of sample distributions. Consequently, it turned out that something like normal DF is a very rare event. So we suggest here to change radically the existing metrology paradigm for measurement data analysis, namely to reject from searching the appropriate DF and use nonparametric methods for uncertainty estimation in all circumstances. While DFs are being discussed by metrologists often and with enthusiasm they talk about Shewhart Control Charts (ShCC) much more rare and – we think – not to the point. Meanwhile this is an indispensable method to monitor the current state of measurement system. And this method does not require any assumptions about specific type of DF. Besides we suggest using ShCC in order to check data homogeneity and to estimate widened uncertainty. Such procedures turn out to be much simpler than those described in many metrology standards.

Why normal distribution [1]? There are many reasons for metrologists to adhere to normal distribution. First of all, it is an old tradition sanctified by the name of outstanding Gauss. He was simply looking for an approximation to describe parallel observations of trajectories for astronomy measurements. But his grateful customers accepted his result as the great law of Nature, and they persuaded themselves in this. So all this started in 1806. This tradition was growing, widening, became more sound and successfully reached our days. And when you have the Law you do not need anybody, all you need are formulas to calculate and tables to simplify results and to accelerate the procedure. An useful additional result is that learning simple formulas and algorithm does not require notable time and
efforts – this means that one can improve his mastering in his own profession where there are always many problems. But these are not all advantages.

It is not mandatory to know the theory which formulas are based on but anyone wants to be sure that these formulas give him the best result. And the theory claims that if you know that the DF is normal then these formulas give us the best optimal result. And if one uses some detour way – there are always many detour ways because statisticians need to earn for their living – the result will always be worse. This means that under the same efforts one will obtain wider confidence limits, the result will have greater uncertainty, its reliability will be lower, in short, everything will be much worse. Simultaneously efficiency of using resources will be suffering as well as waste of time will be significant. Some estimates show that average worsening will be about three times.

Obviously, the choice is clear. But there is a “little” difficulty. The thing is that all above-mentioned is absolutely true only under assumption that normality is unquestionable. Alas, the doubts do exist. And not little ones. In real life we are not interested in asymptotics and limiting theorems because we can’t live until the time to use them will come. And the idea of normality at best cannot be rejected for real samples especially for little ones as well as many other ideas. That’s why normality becomes the symbol of belief. It is dangerous to build important conclusions on such base.

Sometimes the practitioners are trying to use a priori information about some may be not normal distributions. Then one can estimate the uncertainty by the maximum likelihood method. It is clear that if we are sure that our data relate to, for example, Poisson DF, or Weibull, or lognormal distribution, then it will be wrong not to use this knowledge because it always will improve results and make them cheaper though not always this will make their extraction more simple. Unfortunately these cases are rare and exotic and do not change general picture.

If we can’t rely on reliable information about DF maybe it is worth start to think about the estimates which do not afraid to break any assumptions. Such methods do exist and are called “robust” [2]. Their using is quite possible and is based on intensive use of computers and is difficult for interpretation. One can remember the robust estimate of mean, which was created by Tukey and was named “gopher estimate” by him. It pretends to be as sustainable to breaking assumptions as “gopher wood” – the material for Noath’s Ark – had been during the Flood.

We think that the best choice for today is the approach, which admits that DF just exists for the random variable under consideration and which is limited with only this weak hypothesis. Such approach is usually named as nonparametric [3]. It is minimally pretentious. Simultaneously it let us to do everything we need and all calculations are much easier and interpretation is simpler.

What is the price for these advantages?

The price is that we cannot indicate the exact probabilities of measurement errors. But if we look at the exact values of uncertainties attentively we will understand that they emerge in classical metrology only under the hypothesis of normality, but we do not belief in it. That is the values of 95% or 99% are fictions, which mislead us. What for the exact values are necessary if we never can reliably estimate them? And rough estimate is always possible.

Why we need to use Shewhart Control Charts (ShCC) [4]? The application of ShCC encounters constantly on different misunderstandings. One of the reasons is that during monitoring the measurement process inside a process of manufacturing of some product we need to follow two interconnected processes. One is the production process itself and ShCC is necessary to find out the moment of the loss of stability in order to return the process into stable state. Another is the measurement process, which can also become unstable and needs to be returned into stable state. Measurement professionals usually used to consider that production process can go out from stable state. But they often think that measurement process cannot behave in such way. They consider it to be stable. But our experience shows that measurement processes can be unstable as often as production processes. Surely monitoring of measurement process should be organized separately from monitoring production process. To this end it is necessary to include into production process in randomized order the reference measures which then will be used for construction additional ShCC. The choice of the structure for this process, the frequency of including standard samples and other organization problems – all these are the
ordinary tasks of design of experiment (DOE). The analysis of the corresponding chart will show if the loss of stability took place or not. And if this has happened we need to do everything we are doing for technological process. Namely, we need to create a team of professionals to search and remove the root causes of unstability, and this team should include those who measure as well as experts in metrology, statistics, equipment, economics, management. They need to learn to understand each other, i.e. to create common terminology, and become a team, that is to learn to work for their common goal while do not forgetting their professional purposes. Of course, this team must use the same tools as the team of technological process.

So, our suggestions may be presented as the following simple algorithm:

1. A rejection of searching the DF
2. The use of median (or any other nonparametric estimate of data centre) instead of mean
3. The use of sample range or interquartile range instead of sample variance (or sample error or sample standard deviation)
4. Visualization of measurement data by using the Tukey’s “box-and whisker” and corresponding analysis of data for outliers [5]
5. Construction of histograms
6. Monitoring of measurement process by using ShCC (which do not require the normality)
7. The analysis of homogeneity of measurement data by using the rules for interpretation of ShCC
8. The estimate of measurement process stability
9. The creation of team for searching the root causes of unstability, and if it is found
10. Continuous improvement (kaizen) [6] of measurement process by using the Shewhart-Deming cycle (PDSA)
11. The estimate of widened uncertainty as the distance between the upper and lower limits of ShCC for the process in stable state
12. The search for new possibilities to improve measurement process by using better equipment, new technologies, and so on.

In our opinion there is nothing above that contradicts the requirements of ISO 17025 standard and ISO 9000 standards.

As a whole the thing is that it is high time to change the paradigm of that section of science which is called metrology. It is well and long ago known that paradigm change is a difficult and tiresome process taking usually a big period of time. We understand that our suggestions will be - most probably - rejected or admitted partly. So at this moment we suggest to organize a broad discussion about all above-mentioned problems and discuss not the abolition of traditional approach but only the possibility of application the suggested approach in parallel with traditional procedures. Surely, we are ready to participate actively in such discussion and work. The examples of analysis of real data and comparison with traditional approach are presented in our papers [7].

References.

[1] Adler Yu 2013 The Statistics: Past, Present, and Future (A New Paradigm in Statistics) Proc. 13th Annual ENBIS Conference (Ankara, Turkey)
[2] Huber P J 1981 Robust Statistics (NY, John Wiley & Sons)
[3] Adler Yu, Shper V 2019 Practical Guide for Statistical Process Control (Moscow: Alpina Publisher)
[4] Mosteller F, Tukey J 1977 Data Analysis and Regression (USA: Addison-Wesley Publishing Company)
[5] Kume H 1985 Statistical Methods for Quality Improvement AOTS
[6] Adler Yu, Shper V 2019 Assessment in an Era of Changes: Is There Any Use to Change? Part 1: Why Does Uncertainty Need Normality? Product Quality Control 9 30-36
[7] Adler Yu, Shper V 2019 Assessment in an Era of Changes: Is There Any Use to Change? Part 2: Analysis of Results of Interlaboratory Comparisons Product Quality Control 10 27-35