The estimation of the measurement results with using statistical methods

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Abstract. The row of international standards and guides describe various statistical methods that apply for a management, control and improvement of processes with the purpose of realization of analysis of the technical measurement results. The analysis of international standards and guides on statistical methods estimation of the measurement results recommendations for those applications in laboratories is described. For realization of analysis of standards and guides the cause-and-effect Ishikawa diagrams concerting to application of statistical methods for estimation of the measurement results are constructed.

Introduction

Technical measurement is the set of measurement activities used to provide the supplier and/or acquirer insight into progress in the definition and development of the technical solution. Technical measurement is planned early in the life cycle and then performed with increasing levels of fidelity as the technical solution is developed [1].

The important source of increase of production efficiency is a permanent increase of technical level and quality of the made products. The most complete and all-round quality evaluation is provided at taking into account of all properties of analyzable object that show up on all stages it life cycle: making, transporting, storage, application, repair and technical service.

Control of process envisages the exposure of causal factors that influence on the trouble-free functioning of productive process. Therefore the modern statistical methods of quality control of products and process now acquire all greater confession and distribution in industry. These methods can to use, first of all, for estimation of the technical measurement results in productive process.

For successful application of statistical methods for estimation of the technical measurement results a large role has corresponding normative documents and standards [2, 3].

Row of international standards describes various statistical methods that apply with the aim of realization of the analysis of measurement data. Having regarded to mark sufficiently actual is an analysis of those normative documents and standards for application of statistical methods for estimation of the measurement results. On the basis of the conducted analysis it is necessary to work out recommendations in concerning application of statistical methods in laboratories. Those recommendations and recommendations concerning application of general international guides and standards in the field of metrology [4] will be very profit for laboratories.
2. Application of statistical methods for estimation of measurement results

The term “statistics” is commonly associated with an idea of lists of numbers. It is thus advisable to make clear at the outset what in fact this statistical method is that may gainfully be applied in the field of quality, standardization, and metrology.

Statistical methods have numerous practical applications in the industries, research, laboratories and other spheres. Their effectiveness depends firstly on the suitability of the chosen method for the intended purpose and secondly on the application, the way it is used. Incorrect choice or poor application can lead to improper deductions and therefore to crucial errors.

International standard ISO/TR 18532 [2] describes the row of statistical methods, that apply for a management, control and improvement of processes, and international standard ISO 13528 [3] describes the detailed description of statistical methods and recommendations for estimation of the measurement results.

Untechnical resumes, as a rule, are short; the number of technical terms in this type resume is erected to the minimum. Technical resumes more long than untechnical resumes, for its use more technical terms. For many documents two resumes complement each other.

On Figure 1 a cause and effect Ishikawa diagram for application of statistical methods for estimation of the measurement results is represented. It applies where it is required to show, pictorially, cause and effect relationships. There are several types, based on the formation of the main branches (categories), including technical consideration. The primary factors on a diagram are included: terminology; describe; compare; explain; accept; follow in time; measurement control. Secondary and tertiary factors of diagram of Figure 1 are represented in the Table 1, standards and guides – in Table 2.

![Figure 1. Cause and effect Ishikawa diagram for application of statistical methods](image-url)

Practically all international standards (81) on a code 03.120.30 “Applications of statistical methods” International Classification for Standards (ICS) are developed by ISO/TC 69 “Applications of statistical methods”. Standards for conformity assessment are developed by Committee ISO on conformity assessment (CASCO); guidance for reference materials – Committee ISO on reference materials (REMC); Other international standards (10) are developed by IEC/TC 56 “Reliability” and subcommittee of IEC/SC 86B “Fibre optic interconnecting devices and passive components”. Guides ISO/IEC Guide 99 “International vocabulary of metrology” (VIM) and ISO/IEC Guide 98-3 “Guide to the expression of uncertainty in measurement (GUM)” [4] developed by eight international organizations in fields of metrology, standardization, accreditation, physics and chemistry.
### Table 1. Factors of cause and effect Ishikawa diagram for application of statistical methods

| Secondary factor | Tertiary and other factors |
|------------------|---------------------------|
| 1 – terminology   | 1.1 – statistics probability; 1.2 – metrology; 1.3 – design of experiments; 1.4 – applied statistics |
| 2 – describe      | 2.1 – prediction interval; 2.2 – median; 2.3 – difference of 2 median; 2.4 – mean; 2.5 – variance; 2.6 – proportion; 2.7 – tolerance interval; 2.8 – normal distribution |
| 3 – compare       | 3.1 – variances; 3.2 – means; 3.3 – proportion; 3.4 – power of test |
| 4 – explain       | 4.1 – design of experiments |
| 5 – accept        | 5.1 – sampling (5.1.1 – guide); 5.2 – process performance |
| 6 – follow in time| 6.1 – reliability (6.1.1 – maintainability; 6.1.2 – adjustment; 6.1.3 – estimation; 6.1.4 – sampling plan); 6.2 – evolution (6.2.1 – statistical process control, SPC); 6.2.2 – control charts; 6.2.3 – process capability |
| 7 – measurement control | 7.1 – accuracy; 7.2 – laboratory capability; 7.3 – measurement uncertainty; 7.4 – reference materials |

### Table 2. Factors for application of statistical methods and international standards or guides

| Tertiary and other factors | International standards or guides |
|----------------------------|----------------------------------|
| 1.1 – statistics probability | ISO 3534-1, 2 |
| 1.2 – metrology            | ISO 5725-1; ISO 11843-1 |
| 1.3 – design of experiments | ISO 3534-3 |
| 1.4 – applied statistics   | ISO 3534-2 |
| 2.1 – prediction interval   | ISO 16269-8 |
| 2.2 – median                | ISO 16269-7 |
| 2.3 – difference of 2 median| ISO 2854 |
| 2.4 – mean                 | ISO 2854; ISO 2602 |
| 2.5 – variance              | ISO 2854 |
| 2.6 – proportion            | ISO 11453 |
| 2.7 – tolerance interval    | ISO 16269-6, ISO 3207 |
| 2.8 – normal distribution   | ISO 5479 |
| 3.1 – variances             | ISO 2854 |
| 3.2 – means                 | ISO 2854; ISO 3301 |
| 3.3 – proportion            | ISO 11453 |
| 3.4 – power of test         | ISO 3301; ISO 3494 |
| 4.1 – design of experiments | ISO 3534-3 |
| 5.1 – sampling              | ISO 2859-0…5, 10; ISO 3951-1…5; ISO 8422; ISO 8423; ISO/TR 8550-1…3; ISO 10725; ISO 11648-1, 2; ISO 13448-1, 2; ISO 14560; ISO 18414; ISO 21247 |
| 5.2 – process performance   | ISO 21747 |
| 6.1.1 – maintainability     | IEC 60706-2, 3, 5 |
| 6.1.2 – adjustment          | IEC 60605-6; IEC 61649 |
| 6.1.3 – estimation          | IEC 61073-1; IEC 60605-4 |
| 6.1.4 – sampling plan       | IEC 60410; IEC 61123; IEC 61070 |
| 6.2.1 – statistical process control | ISO 11462-1, 2 |
| 6.2.2 – control charts      | ISO 7870-1, 3, 4; ISO/FDIS 7870-2, 5; ISO 8258; ISO 7873 |
| 6.2.3 – process capability  | ISO 21747; ISO 22514-1…4, 6…8 |
| 7.1 – accuracy              | ISO 5725-1…6; ISO 15725-1, 2; ISO/TR 22971 |
| 7.2 – laboratory capability | ISO/IEC 17043; ISO 13528 |
| 7.3 – measurement uncertainty | ISO/IEC Guide 98-1, 3, 4; ISO/IEC Guide 99; ISO TS 17503; ISO/TR 21748; ISO/TS 21749 |
| 7.4 – reference materials   | ISO 11095; ISO Guide 31, 33, 35, ISO 10576-1, ISO 11843-1…5; ISO 11843-6 |
3. Standards for measurement control in laboratory
Among the presented standards most interest for laboratories is contained by the standards concerning of measurement control in laboratories (primary factor “measurement control” for diagram on Figure 1).
Features of introduction in the international guides and standards for evaluation of measurement uncertainty (secondary factor for diagram on Figure 1 “measurement uncertainty”) and for reference materials (“reference materials”) described in [5–10]. Having regard to it is expedient to be more in detail stopped for the feature of introduction in international guides and standards for evaluation of accuracy (“accuracy”) and for laboratory capability (“laboratory capability”).
The detail cause and effect Ishikawa diagram concerning primary factor of diagram for “measurement control” is resulted on Figure 2. The secondary factors for “measurement control” are: accuracy; laboratory capability; measurement uncertainty; reference materials. Tertiary and other factors for diagram on Figure 2 are driven in Table 3.

![Figure 2. Cause and effect Ishikawa diagram for the secondary factors for “measurement control”](image)

| Secondary factor | Tertiary and other factors |
|------------------|----------------------------|
| 7.1 – accuracy   | 7.1.1 – accuracy (trueness and precision) of measurement methods and results; 7.1.2 – repeatability and reproducibility standard measurement method; 7.1.3 – intermediate measures of the precision of a standard measurement method; 7.1.4 – trueness of a standard measurement method |
| 7.2 – laboratory capability | 7.2.1 – qualification of laboratory; 7.2.2 – participating in interlaboratory comparisons |
| 7.3 – measurement uncertainty | 7.3.1 – estimation method; 7.3.2 – expression; 7.3.3 – use of repeatability, reproducibility and trueness estimates; 7.3.4 – repeated measurements and nested experiments |
| 7.4 – reference materials | 7.4.1 – technical limit; 7.4.2 – capacity for exposure (7.4.2.1 – methodology of determination for the cases of linear and nonlinear calibration; 7.4.2.2 – methodology of determination in default of calibration data) |
The most essential international standards for measurement control in laboratories are standards ISO 5725 with the group name “Accuracy (trueness and precision) of measurement methods and results” (6 parts) [5–10].

The international standard ISO/TR 22971 [11] provides users with practical guidance to the use of ISO 5725-2 [6] and presents simplified step-by-step procedures for the design, implementation, and statistical analysis of inter-laboratory studies for assessing the variability of a standard measurement method and on the determination of repeatability and reproducibility of data obtained in inter-laboratory testing.

The standard ISO/IEC 17043 [12] specifies general requirements for the competence of providers of proficiency testing schemes and for the development and operation of proficiency testing schemes. These requirements are intended to be general for all types of proficiency testing schemes, and they can be used as a basis for specific technical requirements for particular fields of application.

International standard ISO 13528 [3] contains the detailed descriptions of statistical methods, that use for data analysis, which got by means of charts of qualification verification, and gives to recommendation concerning using by the participants of such charts and authorized persons. It is appointed as adding to the standard ISO/IEC 17043 concerning verification of abilities by means of interlaboratory comparisons.

The International standard ISO 21748 [13] gives guidance for evaluation of measurement uncertainties using data obtained from studies conducted in accordance with standard ISO 5725-2 and comparison of collaborative study results with measurement uncertainty obtained using formal principles of uncertainty propagation. This standard is applicable in all measurement and test fields where an uncertainty associated with a result has to be determined. It does not describe the application of repeatability data in the absence of reproducibility data.

The standard ISO 21748 assumes that recognized, non-negligible systematic effects are corrected, either by applying a numerical correction as part of the method of measurement, or by investigation and removal of the cause of the effect. The recommendations in this standard are primarily for guidance. It is recognized that while the recommendations presented do form a valid approach to the evaluation of uncertainty for many purposes, it is also possible to adopt other suitable approaches. In general, references to measurement results, methods and processes in this standard are normally understood to apply also to testing results, methods and processes.

The International standard ISO 21749 [14] follows the approach taken in the GUM and establishes the basic structure for stating and combining components of uncertainty. To this basic structure, it adds a statistical framework using the analysis of variance (ANOVA) for estimating individual components, particularly those classified as Type A evaluations of uncertainty, i.e. based on the use of statistical methods. A short description of Type B evaluations of uncertainty (non-statistical) is included for completeness.

The standard ISO 21749 covers experimental situations where the components of uncertainty can be estimated from statistical analysis of repeated measurements, instruments, test items or check standards. It provides methods for obtaining uncertainties from single-, two- and three-level nested designs only. More complicated experimental situations where, for example, there is interaction between operator effects and instrument effects or a cross effect, are not covered.

When results from interlaboratory studies can be used, techniques are presented in the companion standard ISO/TS 21748. The main difference between standards ISO/TS 21748 and ISO 21749 is that the standard ISO/TS 21748 is concerned with reproducibility data (with the inevitable repeatability effects), whereas standard ISO 21749 concentrates on repeatability data and the use of the analysis of variance for its treatment.

Main approaches for uncertainty assessment in environmental and metrological guides are considered in [15–17]. The use of GUM in development of new and reconsideration of old international environmental guides is recommended.
Summary
Plenty of international standards and guides regulate various statistical methods that apply for the analysis of technical measurements. Practically all these standards are developed by the specialized technical committee of ISO concerning application of statistical methods.
Having regard to plenty of standards that regulate application of statistical methods expedient and necessary development of the special recommendations concerning their application in laboratories. For realization of analysis of these standards the useful to use of cause and effect Ishikawa diagram.

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