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THE METHODS OF SHOOTING EVALUATION

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Abstract: The Measurement Systems Analysis (MSA), unpaired t-test, factor analysis, normalized histogram, Z-score, and Mandel's statistics were used for estimation shooting accuracy capability of two spring air rifles, performed by two operators. The process of measuring the accuracy of the shooting, analysed by the MSA method, is not capable of the given measurement model (the value of %GRR is 96.32 for rifle V1 and 94.35 for V2).
Keywords: air rifle, capability, t-test, factor analysis, Z-score, Mandel's statistics

INTRODUCTION

Measurement in technical practice is affected by systematic, random, and possibly gross errors, which distort the measured value. To ensure accuracy and precision measurement results - the measured value must be measured in the system measurement management [1]. Standards ISO 5725-1 [2] and also ISO 3534-1 [3] define accuracy as describing a combination of both types of observational error above (random and systematic), so high accuracy requires both high precision and high trueness [1a].

Precision is the closeness of agreement between independent test results obtained under stipulated conditions. Less precision is reflected by a larger standard deviation. Precision is a description of random errors, a measure of statistical variability. Independent test results mean results obtained in a manner not influenced by any previous result on the same or similar test object. Quantitative measures of precision depend critically on the stipulated conditions. Repeatability and reproducibility conditions are particular sets of extreme conditions. Repeatability is the precision under repeatability conditions - the conditions where independent test results are obtained with the same method on identical test items in the same laboratory by the same operator using the same equipment within short intervals of time. [2][3].

The measurement management system requires that the measurement equipment must be confirmed and that the measurement process must be permanently controlled. An essential component of metrological confirmation is calibration. The calibrated measuring equipment is bound to the primary standard via an unbroken chain of comparisons with determined uncertainties. The requirement to control the measurement process stems from the fact that even the most accurate measuring equipment if used incorrectly, indicates incorrect results. The measurement process is performed in a system that includes, in addition to the measuring equipment of one or more operators performing the measurement, measurement conditions (e.g., temperature, humidity, pressure, vibration, noise, and lighting that may affect the operator), and properties of the measured samples.

The aim of the paper is the possibility of using some methods of evaluating the quality of measurement, commonly used in industrial and metrological practice to evaluate the accuracy of shooting. Due to the non-existence of relevant standards, in this case, we are limited only to the analysis of the control of the measurement process.

The first used method is based on the Measurement Systems Analysis (MSA), commonly used e.g. in the automotive industry [4]. It is based on the assumption that if the measuring process performs in a measurement system whose elements are capable, the process is also capable, i.e. of sufficient quality. This method has multiple approaches, the most used are repeatability and reproducibility analysis (GRR), and the analysis of variance (ANOVA). Due to the simpler approach, the GRR analysis will be used in the following. The results were confronted by t-test, factor analysis (ANOVA), and histogram of normalized values. The other two methods, Z-score and Mandel's statistics are used in practice to evaluate interlaboratory comparative measurements (round-robin tests), i.e. the quality of metrological, chemical, analytical work, etc. laboratories. The graphical output of both methods allows for quick orientation.

METHOD OF EXPERIMENTS

Two weapons were used - air rifles (pellet guns) type "Vostok" (IŽ-38), made in 1989 in the former USSR (in the following V1 and V2). Both have the original spring and seal, they have been used minimally. As the ammunition was used pellets Sport Diabolo caliber 4.5 mm (.177). It was verified according to the regulation of the Government of the Slovak Republic No. 397/1999 and its amendments (the last No. 269/2014). All pellets were from one package. The weight of 10 randomly selected pellets varied in the range of 0.5187 g - 0.5482 g (average 0.5328 g, standard deviation 0.0093 g). The measurement was performed in an enclosed space, the temperature fluctuated in the range of 25°C - 27°C, the illuminance of the target varied in the range of 94 lx - 253 lx. The "airgun" targets with a diameter of 120 mm (diameter of the outer circle of the scoring field with a hit value of 1, and were used hit value 1, and a diameter of 12 mm for an inner circle with a hit value of 10).

Two operators A (50 years) and B (36 years) shot at a distance of 10 m in a kneeling position. First, a rifle V1 and target No. 1 were used; both operators fired every five times in random order. It also fired at the targets No. 2 to No. 10. The same procedure was performed with the rifle V2.
As for the requirement for sufficient resolution (value of the smallest scale interval) of the measuring equipment, it is usually required to be able to read at least one-tenth from the variability of the monitored feature, which is represented by the standard deviation ST DEV. The target did not meet this condition, as the resolution was equal to 1 and the standard deviation of the measured values was 1.26 and 2.59. Fulfilling this requirement, i.e. dividing each scoring field of the target into tenth (to 1/10), would lead to the creation of a total of 100 scoring fields, separated by concentric circles. Such a target would be as confusing as possible.

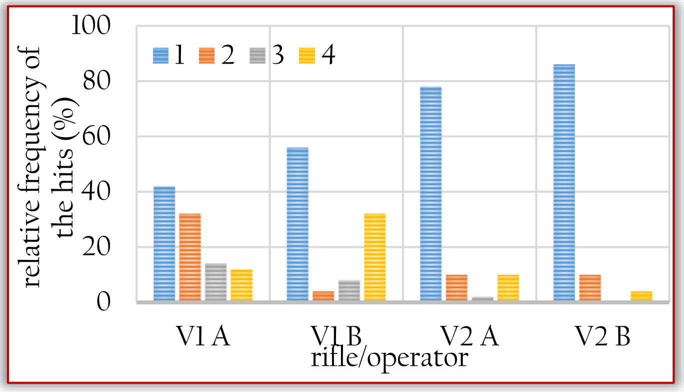

Figure 1 - Distribution (relative frequency of the hits) in individual sectors of the target

Outliers were determined using the Grubbs test at the significance level α = 0.05, they did not occur. Normality was determined according to a normal probability plot using the Freeware Process Capability Calculator software. The normality of all files was confirmed (all hits of one operator with one weapon represented one file). If the measured results have a different distribution than normal, using standard methods for the calculation of capability results in an underestimation of the results. These usually seem worse than they are.
The repeatability and reproducibility analysis (GRR), the method used to evaluate the capability is described in more detail in the literature [4, 5]. Numerical calculations were performed at a 99% significance level with a 99% coverage interval (5.15) by the MSA module of the Palstat CAQ software. Ten targets represent ten samples with hits of both operators (model with 10 samples), the value of the hit represented the repetition of the measurement on the sample (model with 5 repetitions). The capability was evaluated separately for each of the rifles (V1 and V2).

RESULTS

As can be seen from Figure 1, both rifles, independent of the operator, takes to the top right (sector 1, Figure 2).
The parameter "ndc" - the number of separate classes (Wheeler's classification ratio) is related to the question of the resolution of measuring equipment. It indicates the number of different categories that can be reliably distinguished by the measuring system. The number "ndc" should be at least 5 (for rough estimates in it should be at least 2). The low value of the index (Table 1) corresponds to the above-mentioned low resolution.

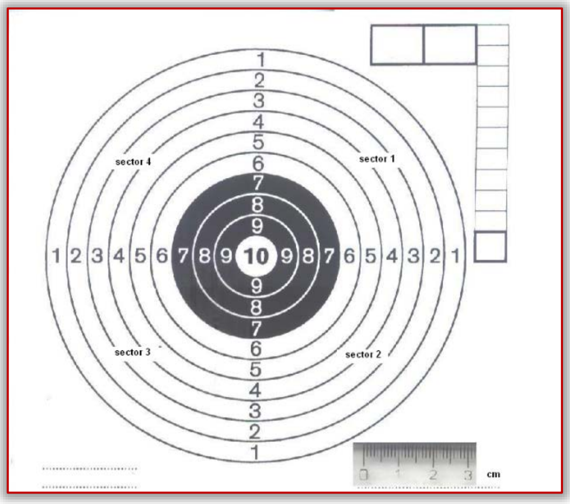

Figure 2 - The target and sectors

Table 1 - Basic statistics and competency indices

rifle	V1	V1	V2	V2
operator	A	B	A	B
average value of hits $\bar{x}$	7.44	7.4	6,46	6,88
standard deviation ST DEV	1.53	1.26	2,14	2,59
%EV	96.3		93.98	
%AV	0		8.252	
%PV	26.85		33.15	
%GRR	96.32		94.35	
ndc	0.333		0.435	

The% EV index is a function of the average variation range of repeated measurements - hits of all operators. Its high value is due to the low resolution of the target as measuring equipment, which practically represents the measuring means. The% AV index expresses the operator's influence on variability, e.g. his approach or abilities. It is a function of the variation range of arithmetic averages of hits of individual operators. For the V1 rifle, the influence of the operator on the capability was negligible. The increase in the value of the% AV index for the V2 rifle can be attributed to the different properties of both rifles. It proves, as follows from the Table 1, approximately the same decrease in the mean value of the hits $\bar{x}$ and an increase in the variance of STDEV in both operators. The % GRR index represents the ratio of the influence of the measuring equipment on the variability. Its value practically expresses the capability of the measuring process. If it is up to 10%, the process and also system are acceptable, up to 30% conditionally acceptable. The analyzed measurement process is unacceptable - ineligible, as the values of the% GRR index exceed 90%. The % PV index is a function of variation between individual targets - samples. Its low value indicates the low sensitivity of the measurement model used to capture these differences, but also the stability of the performance of both operators.

Table 2 - T-test and factor analysis

unpaired t-test			
together: rifle	together: operator	P	difference betwen files
V1	A, B	0.1892	is not statistically significant
V2	A, B	0.2670	is not statistically significant
V1, V2	A	0.0095	is statistically significant
V1, V2	B	0.0719	is not statistically significant
one factor analysis			
1 – rifle and operator		0.0092	the influence of the factor is statistically significant
two factor analysis without repetition			
Factor 1 – rifle		0.5604	the influence of the factor is not statistically significant
Factor 2 – operator		0.1894	the influence of the factor is not statistically significant

The unpaired t - test of the assessment of the diameters of the two sets was compared to the sets of values of interventions of both operators from both weapons at the level of significance □ = 0.05%. As can be seen from Table 2, the difference between the operators when firing a weapon V1 or V2 is not statistically significant, on the other hand, the difference between the weapons is on the border of statistical significance for operator B, and statistically significant for operator A.

The Analysis of Variance – ANOVA, the part of the Microsoft Excel software package was used as another comparison method. Average values measured on individual targets were compared in one - or two-factor analysis with the first type error 0.05.

We assume that the variability of the values of the variable reaction Y is influenced by the factor 1 (rifle or operator) in the case of one-factor analysis or by factors 1 (rifle) and 2 (operator) in the case of two-factor analysis without repetition. We want to test whether the influence of factor 1 (or 1+2) on the variability of the hits values is statistically significant. If the p-value >0.05, the factor does not significantly affect the values of the hits [6]. The values of p for individual combinations are given in the Table 2. The cumulative influence of the rifle and the operator on the values of hits is statistically significant, although its share on the overall variability is relatively low - 5.6%. Separately, both components of the factor (as separate factors of the rifle and the operator) are not statistically significant.

The histogram of normalized values is a graph that shows the distribution of the frequency of measurement errors of individual operators. It makes it possible to obtain quick visual information on how the error, i.e. the difference between the observed and the normalized value, is divided. The ideal case is the maximum number at point 0 (on the x – axis). As can be seen from Figure 3, the error rate is higher for the rifle V2 and operator A.

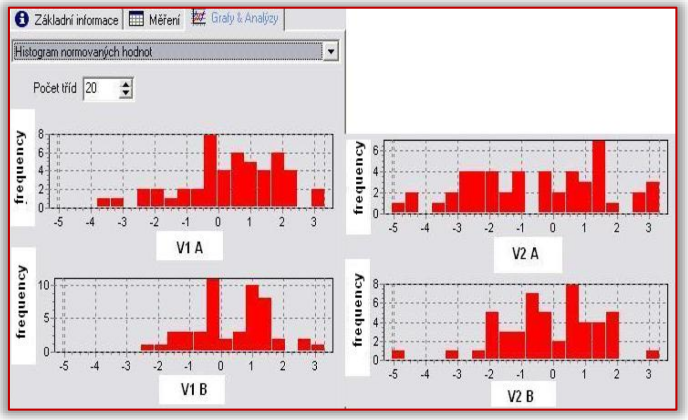

Figure 3 - Histogram of normalized values

When calculating the Z - score and Mandel's statistics, we used a simplification, the laboratory corresponds to the values of the hits of one operator with one rifle. For individual repetitions, the Z-score is calculated:

$$z_i = \frac{x_i - \bar{x}}{ST\ DEV} \quad (1)$$

where x_i the average of the values of the hits of one operator with one rifle on one target, $\bar{x}$ is the average of the values of all hits, and "s" is the standard deviation of the values of all hits. Z-scores whose absolute value $z_i \leq 2$ are satisfactory, whose absolute value exceeds 3 are unsatisfactory [6]. The Z-score values are shown in Figure 4.

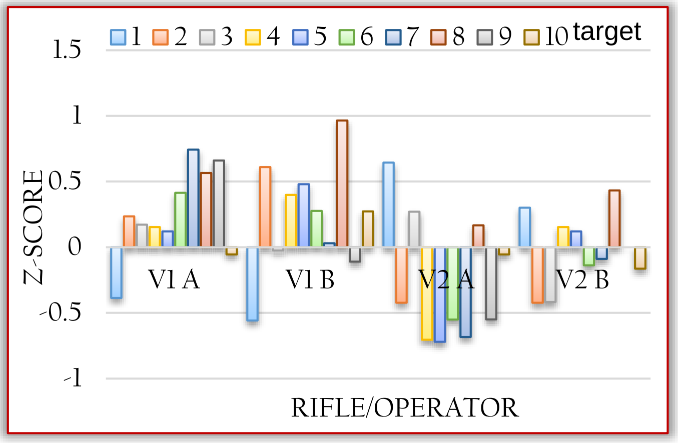

Figure 4 - Z - score

Mandel's statistic h is based on the mean, statistic k on the variance:

$$h_i = \frac{\bar{x}_i - \bar{\bar{x}}}{\sqrt{\frac{1}{p-1}\sum_{i=1}^{p}(\bar{x}_i - \bar{\bar{x}})^2}} \quad (2)$$

$$k_i = \frac{s_i\sqrt{p}}{\sqrt{\sum_{i=1}^{p} s_i^2}} \quad (3)$$

where $\bar{x}_i$ is the average of the values of one operator's hits with one rifle on one target, $\bar{\bar{x}}$ is the average of the values of all hits, s_i is the standard deviation of one operator's hits with one rifle on one target, and $p = 4$ (two rifles and two operators, i.e. four analysed files). Statistics k acquires only positive values. Lines corresponding to critical values are plotted in the graphs of Mandel statistics, at the significance level $\alpha = 0.05$ (strugglers) and at the significance level $\alpha = 0.01$ (outliers) [6].

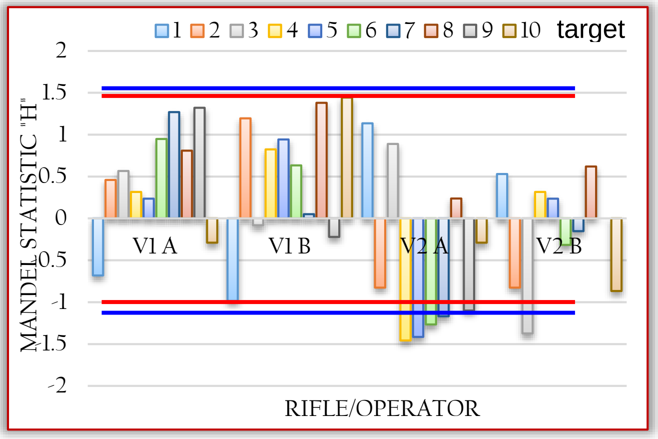

Figure 5 - Mandel's statistics „h"

In the analysis of Z - score and Mandel's statistic "h", Figure 5we notice outliers - these did not occur, but outside the set V1- A there are struggle values. Mandela's statistics are more sensitive in this respect than the Z - score. Symmetrical distribution of the values of individual samples - targets around the axis, which is approached only by the set V2-B, is suitable. As can be seen from Figure 6, this file shows the largest variance with the occurrence of an outliers. Operator A shows a larger variance on both rifles than operator B, this fact corresponds to the results of the histogram of normalized values.

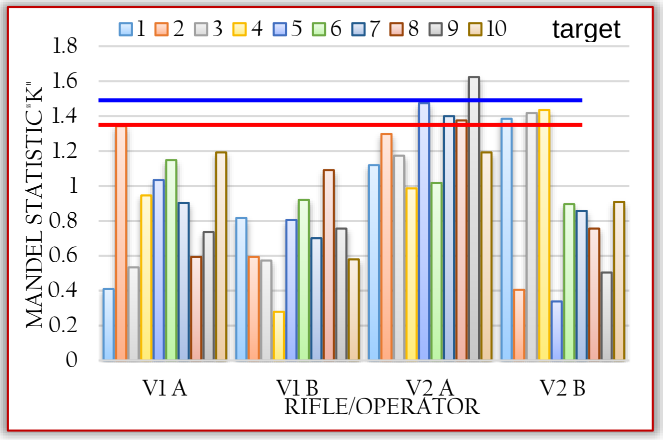

Figure 6 - Mandel's statistics „k"

DISCUSSION

The process analysed by the MSA method appears to be not capable, i.e. insufficiently sensitive to the evaluation of the quality of shooting. Insufficient resolution of the measuring equipment was identified as the cause. However, a finer division of the target would ultimately lead to a more complicated reading of the value of the hits. Likely, the MSA method is not suitable for evaluating the quality of shooting (similar to, for example, for measuring of the hardness [7] or the pressure of the blood [8]).

CONCLUSIONS

1. The process of measuring the accuracy of the shooting, analysed by the MSA method, is not capable of the given measurement model.
2. The statistical significance of the effect of the rifle used was confirmed by an unpaired t-test.
3. The statistical significance of the cumulative influence of the operator and the rifle on the accuracy of shooting was confirmed by one-factor analysis of variance.
4. The histogram of the normalized values and the Mandel statistic "k" confirmed a larger variance for operator A.
5. The results of MSA, t-test, and factor analysis show that the differences between the quality of the two operators are negligible. More sensitive graphical methods indicate that operator A is of lower quality than operator B.

Acknowledgment

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