DETERMINE NDT LABORATORY INSPECTION UNCERTAINTY BY ROBUST ISOGUM METHOD

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Abstract: In order to fulfil the requirement of ISO 17025 laboratory accreditation requirement, NDT laboratory inspection uncertainty evaluation must be done for each NDT laboratory. This paper introduce a Robust ISOGUM model by adding Z_score and robust CV coefficient check to original ISO-GUM model, the advantage of this model is able to identify bad performance operator and improve laboratory uncertainty, and is also very easy to apply compare with ISO 5725 model. Both ISO 5725 and Robust ISO-GUM models use a UT weld inspection example to demonstrate the application results.

Introduction: The purpose of determining NDT laboratory inspection uncertainty is to evaluate inspection capability and also to fulfil the requirement of ISO 17025 laboratory accreditation requirement of evaluating laboratory performance capability. Two evaluation models were proposed , they are ISO 5725 mode and ISO-GUM model. ISO 5725 model is sophisticated is calculation but has the advantage of finding poor inspection operators, while ISO-GUM is easy to apply but without the function of identifying bad inspection data. This paper introduce a new Robust ISO-GUM model to achieve the goal of good and easy operated laboratory inspection uncertainty evaluation..

Model 1 ISO 5725 Accuracy of measurement method:

(1)Original Data Set

n_{ij} = Number of Inspections by operator i on defect j.

y_{ijk} = The kth data on defect j by operator i.

p_j = Number of operators on defect j inspections.

$$y_{ij} = \left[\sum_{d=1}^{n_{ij}} y_{ijd}\right] \Big/ n_{ij}$$ Average data on defect j by operator i.

$$y_j = \left[\sum_{d=1}^{P_j} y_{dj}\right] \Big/ p_j$$ Average data of defect j.

$$S_{ij} = \sqrt{\left[\sum_{d=1}^{n_{ij}} (y_{ijd} - y_{ij})^2\right] \Big/ (n_{ij} - 1)}$$ Sample variance of defect j by operator i.

(2)Outlier data check

Single outlier observation

$$Gc_j = S_{dj,\max} \Big/ \sum_{d=1}^{P_j} S_{dj}$$ = ratio of maximum S_{dj} to total sum of S_{dj}

$$S_b = \sqrt{\left[\sum_{d=1}^{P_j} (y_{dj} - Y_j)^2\right] \Big/ (P_j - 1)}$$ = Variance between NDT operators

$$G_{p1} = \left[(y_{ij})_{\max} - y_j\right] \Big/ S_b$$

$$G_{p2} = \left[y_j - (y_{ij})_{\min}\right] \Big/ S_b$$

G_{p1}, G_{p2} represent contribution of max and minimum yij to deviation.

Dual outlier observation

$$S_o^2 = \sum_{d=1}^{p_j} (y_{dj} - y_j)^2$$

$$S_L^2 = \sum_{d=1}^{p_j-2}\left[y_{dj} - \left(\sum_{d=1}^{p_j-2} y_{dj}\right) \Big/ (p_j - 2)\right]^2$$

$$G_{p3} = S_L^2 \Big/ S_o^2$$ = Variance ratio of two smallest data.

$$S_h^2 = \sum_{d=3}^{p_j}\left[y_{dj} - \left(\sum_{d=3}^{p_j} y_{dj}\right) \Big/ (p_j - 2)\right]^2$$

$$G_{p4} = S_h^2 \Big/ S_o^2$$ = Variance ratio of two largest data check.

Compare with 1% and 5% critical value of Cochran's table and Grubb's table to determine the operator's data is accepted, suspected or rejected.

Mandel's suspected data re-check

$$H_{ij} = [y_{ij} - y_j] \Big/ S_b$$ = average deviation ratio of suspected data

$$S_a = \sqrt{\sum_{d=1}^{p_j} S_{dj}^2 \Big/ p_j}$$

$$K_{ij} = S_{ij} \Big/ S_a$$ = variation deviation ratio of suspected data

Compare with 1% and 5% critical value of Mandel's H and K Test to determine the operator's data is either accepted or rejected. Operator of rejected data is considered to be incompetent operator, data should be deleted from laboratory data set for uncertainty evaluation.

(3)Laboratory inspection uncertainty evaluation

$$S_{rj}^2 = \left[\sum_{i=1}^{p_j}(n_{ij} - 1)S_{ij}^2\right] \Big/ \left[\sum_{i=1}^{p_j}(n_{ij} - 1)\right]$$ =repeatability variance

$$S_{dj}^2 = \left[\sum_{i=1}^{p_j} n_{ij}(y_{ij} - y_j)^2\right] \Big/ (p_j - 1) = \left[\sum_{i=1}^{p_j} n_{ij} y_{ij}^2 - y_i^2 \sum_{i=1}^{p_j} n_{ij}\right] \Big/ (p_j - 1)$$

=Variance within operators

$$S_{Lj}^2 = (S_{dj}^2 - S_{rj}^2) \Big/ \left[\left(\sum_{i=1}^{P_j} n_{ij} - \sum_{i=1}^{p_j} n_{ij}^2 \Big/ \sum_{i=1}^{p_j} n_{ij}\right) \Big/ (p_j - 1)\right]$$

$$S_{Rj} = \sqrt{S_{Lj}^2 + S_{rj}^2}$$

$U_j = 2 \cdot S_{Rj}$ = Uncertainty of Defect j

$$U = \left(\sqrt{\sum_{d=1}^{j} U_d^2 / j}\right)$$ = Laboratory test uncertainty

Model 2 Robust ISOGUM Method:

(1)Outlier data check

Median = middle data of y_{ij}

Normalized interquartile-range(IQR) = Q_3 (upper quartile) – Q_1(lower quartile), by align y_{ij} in increasing series.

Deviation = y_{ij} – median

Z_score = (y_{ij} – median)/ Normalized IQR

|Z_score| ≤ 2 accepted, 2 < |Z_score| < 3 suspected, |Z_score| ≥ 3 rejected

From Z_score data to decide the operator's data is acceptable or not, suspected or rejected. Operator of Z_score greater than 3 is considered to be incompetent operator, this data should be deleted from laboratory data set for uncertainty evaluation.

(2) Robust CV coefficient

Coefficient of variance of all operators(CV_{all}) = Standard deviation of all y_{ij} / Average of all y_{ij}

Coefficient of variance of good operators(CV_{good}) = Standard deviation of good y_{ij} / Average of good y_{ij}

Robust CV coefficient (R-CV)= $|CV_{all} -- CV_{good}| / CV_{good}$ X 100%

Inspection data is improved obviously if R-CV is greater than 50%.

(3) Laboratory inspection uncertainty evaluation

System modelling equation

$M_j = F(y_{1j}, y_{2j}, \ldots y_{pj}) = (y_{1j} + y_{2j} + \ldots + y_{pj}) / p_j$

$= [(y_{1j} + \Delta_{1j}) + (y_{2j} + \Delta_{2j}) + \ldots + (y_{pj} + \Delta_{pj})] / p_j$

$= [y_{1j} + y_{2j} + \ldots + y_{pj}] / p_j + (\Delta_{1j} + \Delta_{2j} + \ldots + \Delta_{3j})] / p_j$

$= \underline{y_j} + \underline{\Delta_j}$

$\sigma(M_j)^2 = (\partial M_j)/\partial\sigma(\underline{y_j}) \square \sigma(\underline{y_j})^2 + (\partial M_j)/\partial\sigma(\underline{\Delta_j}) \square \sigma(\underline{\Delta_j})^2$

$= \sigma(\underline{y_j})^2 + \sigma(\underline{\Delta_j})^2$

$\sigma(\underline{y_j})$ comes from reading error, by square distribution

$\sigma (y_j) = (1 / \sqrt{3}) = 0.577$ mm

$\sigma(\underline{\Delta_j})$ comes from covariance of data of y_j

$\sigma(\underline{\Delta_j}) =$

$$S_j = \sqrt{\left[\sum_{i=1}^{p} \sum_{d=1}^{n_{ij}} (y_{ijd} - y_j)^2 \right] \Big/ (\sum_{i=1}^{p_j} n_{ij} - 1)}$$

$Uj = 2 \square \sigma(Mj)$

$$U = (\sqrt{\sum_{d=1}^{j} U_d^2 / j}) = \text{Laboratory test uncertainty}$$

Results: The test sample is from inside company weld UT inspection by 16 operators following AWS D1.1 code. Table 1 is original data set. Table 2 is uncertainty calculation by ISO 5725 model, operator No.9 and No.12 are identified as incompetent operator form Grubb's test check and H and K test. After remove these two operator's data, laboratory uncertainty is 8.38. Table 3.1 and 3.2 is uncertainty calculation by Robusted ISO-GUM Model, operator No.9 and No.12 are identified as incompetent operator form Z_score test and re-confirmed by robust CV coefficient. After remove these two operator's data, laboratory uncertainty is 8.29.

Discussion: Both Robust ISO-GUM model and ISO 5725 model get similar results in poor operator identification and laboratory uncertainty evaluation, but Robust ISO-GUM model is much easier to apply. The ISO-GUM model is modified by adding Z_score and robust CV coefficient to identify bad performance operator and keep the advantage of easy calculation of laboratory inspection uncertainty . The advantage of Robust ISO-GUM model to original ISO-GUM model is to kick off poor operators for further training and to improve laboratory uncertainty value at the same time.

Conclusions: The robust ISOGUM model by adding Z_score and robust CV coefficient check to original ISOGUM mode has the advantage of identifying bad performance operators to improve laboratory uncertainty, and is also very easy to apply for calculating NDT laboratory uncertainty for fulfilling the requirement of ISO 17025 laboratory accreditation requirement.

References:

1. ISO Guide to the Expression of Uncertainty in Measurement (ISO-GUM).
2. ISO 5725 Accuracy (trueness and precision) of measurement methods and results.
3. ISO 17025 Guide for laboratory Accreditation

Table 1 Original data set

Operator #		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Def L1	y_{i11}	12.4	11.9	12.8	12.3	9.0	11.8	12.1	16.0	25.0	12.4	11.9	12.8	12.3	9.0	11.8	12.1
	y_{i12}	11.9	12.5	13.6	13.1	8.6	12.6	11.7	17.1	22.9	11.9	12.5	13.6	13.1	8.6	12.6	11.7
	y_{i13}	10.6	11.9	13.4	12.9	8.2	11.0	14.5	16.5	27.0	10.6	11.9	13.4	12.9	8.2	11.0	14.5
	y_{i1}	11.6	12.1	13.3	12.8	8.6	11.8	12.8	16.5	25.0	11.6	12.1	13.3	12.8	8.6	11.8	12.8
	S_{i1}	0.9	0.4	0.4	0.4	0.4	0.8	1.5	0.6	2.0	0.9	0.4	0.4	0.4	0.4	0.8	1.5
Def L2	y_{i21}	37.5	41.4	36.1	44.2	30.6	44.2	45.2	43.2	38.9	43.7	41.7	47.6	48.9	28.5	30.5	43.5
	y_{i22}	38.4	45.7	36.2	46.0	31.5	42.0	45.0	41.2	39.8	36.0	42.2	37.4	50.5	30.6	31.6	43.3
	y_{i23}	37.6	41.3	36.1	46.2	32.0	42.4	45.0	40.6	38.6	35.8	46.9	37.3	53.0	29.8	35.5	45.3
	y_{i2}	37.8	42.8	36.1	45.5	31.4	42.8	45.1	41.7	39.1	38.5	43.6	40.8	50.8	29.6	32.5	44.0
	S_{i2}	0.5	2.5	0.0	1.1	0.7	1.2	0.1	1.3	0.6	4.5	2.9	5.9	2.1	1.0	2.7	1.1
Def L3	y_{i31}	63.4	65.4	62.3	60.1	58.3	62.7	59.3	63.3	77.5	57.8	61.1	78.1	58.9	61.2	60.2	62.7
	y_{i32}	60.3	67.1	65.3	60.0	58.9	62.3	61.5	64.2	72.9	54.8	61.8	71.0	59.7	61.6	64.1	63.9
	y_{i33}	61.8	61.3	63.4	62.0	59.6	62.6	62.6	64.0	71.1	52.7	59.8	76.5	60.4	61.6	63.0	62.1
	y_{i3}	61.8	64.6	63.6	60.7	59.0	62.6	61.1	63.9	73.8	55.1	60.9	75.2	59.7	61.5	62.4	62.9
	S_{i3}	1.6	3.0	1.5	1.1	0.6	0.2	1.6	0.5	3.3	2.5	1.0	3.7	0.7	0.2	2.0	0.9
Def L4	y_{i41}	100.2	98.6	96.4	98.3	90.2	95.5	96.3	89.5	101.3	99.9	91.1	106.0	100.9	100.6	95.1	93.5
	y_{i42}	100.7	98.8	100.6	98.9	91.7	90.2	95.1	88.3	103.8	98.2	91.0	104.9	100.5	95.2	94.6	92.6
	y_{i43}	104.4	98.9	98.2	96.3	91.4	93.3	99.9	87.2	98.5	96.3	89.0	104.4	101.4	95.1	99.8	95.0
	y_{i4}	101.8	98.8	98.4	97.9	91.1	93.0	97.1	88.3	101.2	98.2	90.4	105.1	100.9	97.0	96.5	93.7
	S_{i4}	2.3	0.2	2.1	1.4	0.8	2.7	2.5	1.2	2.7	1.8	1.2	0.8	0.4	3.2	2.8	1.2

Table 2 Laboratory Inspection Uncertainty Evaluation by ISO 5725 model

	Def-1	Def-2	Def-3	Def-4	5% value	1% l value
Gc	0.129	0.209	0.151	0.116	0.319	0.388
Gp1	3.196*	1.881	2.424	1.818	2.585	2.852
Gp2	1.232	1.860	1.587	1.873	2.585	2.852
Gp3	0.183*	0.667	0.201*	0.660	0.3603	0.2767
Gp4	0.794	0.555	0.760	0.580	0.3603	0.2767
Outlier	Op-8(Susp.) Op-9(RJ)		Op-9(Susp.) Op-12(Sus.)			
Hij recheck	Op-8=0.916 (OK)		Op12=2.424 (RJ)		1.86	2.33
Kij recheck	Op-8=0.487 (OK)		Op12=1.987 (RJ)		1.70	2.05
Srj	1.04	1.96	1.49	1.91		
SLj	1.96	5.96	2.26	3.87		
Uj	4.44	12.56	5.41	8.63		
U	8.38	Un-qualified Operator		Op-9, Op-12		

Table 3.1 Laboratory Inspection Uncertainty Evaluation by Robusted ISO-GUM model (Z_score for finding poor inspection data)

Operator #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Def L1	-0.5	-0.2	0.6	0.2	-2.6	-0.4	0.2	2.8	8.6*	-0.9	-2.3	0.8	1.0	-0.4	-0.6	1.7
Def L2	-0.6	0.3	-0.9	0.8	-1.8	0.3	0.7	0.1	-0.4	-0.5	0.4	-0.1	1.7	-2.1	-1.6	0.5
Def L3	-0.1	1.2	0.7	-0.6	-1.5	0.2	-0.5	0.8	5.4*	-3.3	-0.6	6.1*	-1.1	-0.3	0.1	0.4
Def L4	1.0	0.3	0.2	0.1	-1.5	-1.0	-0.1	-2.2	0.9	0.2	-1.7	1.8	0.8	-0.1	-0.2	-0.9
Un-qualified Operator					Op-9, Op-12											

Table 3.2 Laboratory Inspection Uncertainty Calculation

	Def-1	Def-2	Def-3	Def-4
CV-all	28.12	14.10	7.96	4.69
CV-good	17.73	15.28	4.33	4.41
R-CV	58.6*	7.7	83.7*	6.4
Sj	2.177	6.318	2.658	4.231
S(yj)	0.577	0.577	0.577	0.577
Uj	4.50	12.33	5.44	8.54
U	8.29	Un-qualified Operator: Op9, Op12		