Appraisement of Equalization of Geodetic Observations Quality Applying Values of Defined Invariants Parameters

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Key words: equalization of geodetic measurements, geodetic networks, real estate

SUMMARY

Equalization of observations is one of the fundamental duties of geodetic measurements handling. Results depend degree on the way of gathering data in considered problem, i.e. on geodetic net structure or on real estates database formation to mathematical modelling of real estate market value. Determination of parameters, which may be objective indicators of database quality, obtained as result of projected definitely geodetic survey would be useful.

Two invariants parameters are proposed in this study. They were tested regarding the possibility of using them for appraisement of geodetic data quality.

This are following parameters:

– parameter calculated from trace of covariance matrix:

$$\sigma_{tr} = \frac{1}{\hat{\sigma}^2}\sqrt{\frac{tr\{Cov(W)\}}{n}}, \tag{1}$$

where:

$tr\{Cov(W)\}$ - trace of covariance matrix for adjusted observations,

$\hat{\sigma}^2$ - remainder variance estimator,

n - number of observations

– parameter calculated from determinant of covariance matrix:

$$\sigma_{det} = \frac{1}{\hat{\sigma}^2}\sqrt[u^2]{det\{Cov(W)\}}, \tag{2}$$

where:

$det\{Cov(W)\}$ - determinant of covariance matrix for adjusted observations,

$\hat{\sigma}^2$ - remainder variance estimator,

u - number of unknowns.

On the basis of these parameters criteria of database quality appraisement obtained from geodetic measurements can be formulated. These criteria have been formulated using enormous analyses of equalization different geodetic measurements.

STRESZCZENIE

Słowa kluczowe: wyrównanie obserwacji geodezyjnych, sieci geodezyjne, nieruchomości

Wyrównanie obserwacji jest jednym z podstawowych zadań opracowania pomiarów geodezyjnych. Wyniki zależą tu w dużym stopniu od sposobu zebrania danych w rozpatrywanym zagadnieniu, czyli np. od konstrukcji sieci geodezyjnej, czy też choćby od uformowania bazy danych o nieruchomościach, dla zagadnienia modelowania matematycznego wartości rynkowej nieruchomości. Cennym byłoby zatem zdefiniowanie wielkości, które mogłyby stanowić obiektywny miernik jakości bazy danych, uzyskanej w wyniku zaprojektowanego w określony sposób pomiaru geodezyjnego.

W niniejszej pracy zaproponowano do tego celu dwa parametry niezmiennicze, które przetestowano pod względem możliwości dokonania za ich pomocą oceny jakości danych geodezyjnych.

Są to następujące wielkości:

– Parametr określony ze śladu macierzy kowariancji, zdefiniowany wzorem:

$$\sigma_{tr} = \frac{1}{\hat{\sigma}^2}\sqrt{\frac{tr\{Cov\{W\}\}}{n}}, \tag{1}$$

gdzie:

$tr\{Cov\{W\}\}$ - ślad macierzy kowariancji dla wyrównanych obserwacji,
$\hat{\sigma}^2$ - estymator wariancji resztowej,
n - liczba obserwacji.

– Parametr określony z wyznacznika macierzy kowariancji, zdefiniowany wzorem:

$$\sigma_{det} = \frac{1}{\hat{\sigma}^2}\sqrt[u^2]{det\{Cov(W)\}}, \tag{2}$$

gdzie:

$det\{Cov\{W\}\}$ - wyznacznik macierzy kowariancji dla wyrównanych obserwacji,
$\hat{\sigma}^2$ - estymator wariancji resztowej,
u - liczba niewiadomych.

Na podstawie tych parametrów można sformułować kryteria oceny jakości bazy danych uzyskanej z pomiarów geodezyjnych. Kryteria te sformułowano na podstawie licznych analiz zagadnień wyrównania różnorodnych obserwacji geodezyjnych.

Appraisement of Equalization of Geodetic Observations Quality Applying Values of Defined Invariants Parameters

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1. INTRODUCTION

Adjustment of geodesic observations (like angles, lengths or heights) in order to determine e.g. unknown coordinates of points, is one of the fundamental tasks of geodesic measurements handling. Results depend here considerably on the method used to acquire data for an examined problem, as for example the structure of geodesic net or the configuration of real estates database for mathematical modelling of real estate market value.

In the case of geodesic nets – the model used to adjust observations is rigorously determined, so it has deterministic character. However, in the case of modelling real estate value, the selection of an appropriate model for a local market is a separate question. In the present analysis, this aspect, described largely in work [1], has been omitted. The author concentrated her mind on experiment planning, i.e. on preparing a geodesic measurement and influencing the adjustment of geodesic observations. Thus, it would be advantageous to determine quantities, which could be used as objective meters of quality of a database acquired by a determined geodesic measurement.

Two invariant parameters are proposed here. They have been tested regarding their usability for assessment of geodesic data quality.

2. DEFINITIONS OF INVARIANT PARAMETERS

To analyse the results of geodesic measurements adjustment, two following parameters are proposed:

- Parameter calculated from trace of covariance matrix, given by formula:

$$\sigma_{tr} = \frac{1}{\hat{\sigma}^2} \sqrt{\frac{tr\{Cov\{W\}\}}{n}}, \qquad (1)$$

where:

$tr\{Cov\{W\}\}$ - trace of covariance matrix for adjusted observations,

$\hat{\sigma}^2$ - estimator of remainder variance,

n - number of observations

- Parameter calculated from determinant of covariance matrix, given by formula:

$$\sigma_{det} = \frac{1}{\hat{\sigma}^2} \sqrt[u^2]{det\{Cov(W)\}}, \qquad (2)$$

where:

$det\{Cov\{W\}\}$ - determinant of covariance matrix for adjusted observations,

$\hat{\sigma}^2$ - estimator of remainder variance,

u - number of unknowns.

Analysing formula (1) and (2), it can be seen that these quantities are kind of measure for the relation of adjusted measurement average error to the remainder variance, determining inaccuracy of estimation of a model of unknowns. Thus, they can be used as objective indicators to formulate criteria of the designed measurement reliability.

3. METHODOLOGY OF INVESTIGATION

Information on land properties for housing, as the object of commercial traffic in Poland, was used as starting material for investigation. It comes from 10 different local markets of properties. Great differences of prices and variable dynamics of transactions are characteristic features of analysed markets. Gathered databases contain 20 to 130 properties. Information includes totally 530 land properties.

Another group of data included measurements applied to adjust different types of geodesic nets, containing both levelling nets, linear by their nature, and linearizated angular-linear nets. The number of measurements varied between 7 and 54, and the number of unknowns between 3 and 26.

In adjustment process – after lineariztion, when it was necessary – a multidimensional linear model was applied in form of linear multiple regression:

– in estimation of real estate value:

$$Y_i = a_0 + \sum_{k=1}^{u} X_{ik} * a_k \qquad (3a)$$

where:

Y_i - value of i-th estate in a given database,
X_i - attributes value vector for i-th estate ($1\times u$),
X_{ik} - value of attribute k for i-th estate,
a_0 - free term in the model,
a - vector of multiple regression coefficient ($(u+1)\times 1$),
a_k - coefficient of regression standing by attribute k

– in adjustment of geodesic nets:

$$L = AX + \delta \qquad (3b)$$

where:

L - vector of reduced values observed ($n\times 1$),
A - matrix of known coefficients ($n\times u$)
(partial derivatives after unknowns from observation formulas),
X - vector of unknowns ($1\times u$)
(corrections to approximated values of unknown coordinates),
δ - vector of random deviations ($n\times 1$).

Estimation of expected value of measured quantities model values vector was performed using least squares method, the estimator of unknowns $\hat{a}$ being determined by formula (3a) and $\hat{X}$ by formula (3b), such that:

$$\delta^T P \delta = \min \tag{4}$$

where:

P - matrix of observation scales/balance,

δ - vector of random deviations.

Solving generalised linear model means:

- determining unbiased estimators of vectors of unknowns:

$$\hat{a} = (X^T X)^{-1} \cdot X^T Y \tag{5a}$$

or:

$$\hat{X} = (A^T PA)^{-1} A^T PL \tag{5b}$$

- determining unbiased estimator of remainder variance:

$$\hat{\sigma}_0^2 = \frac{Y^T Y - \hat{a}^T X^T Y}{n - u - 1} \tag{6a}$$

determining inaccuracy of parameters model estimation,
or:

$$\hat{\sigma}_0^2 = \frac{L^T PL - \hat{X}^T A^T PL}{n - u} \tag{6b}$$

determining estimation inaccuracy in correcting approximated unknowns,

- determining covariance matrix of vectors of unknowns:

$$Cov(\hat{a}) = \hat{\sigma}_0^2 \cdot (X^T X)^{-1} \tag{7a}$$

or

$$Cov(\hat{X}) = \hat{\sigma}_0^2 \cdot (A^T PA)^{-1} \tag{7b}$$

– determining covariance matrix of model values:

$$Cov(\hat{Y}) = \hat{\sigma}_0^2 \cdot X^T (X^T X)^{-1} X \tag{8a}$$

or

$$Cov(\hat{L}) = \hat{\sigma}_0^2 \cdot A(A^T PA)^{-1} A^T \tag{8b}$$

Thus, we find the essential – in the light of defined parameters – covariance matrix for observed model values of dependent variable.

4. DETERMINATION OF INVARIANTS VALUES

The last step was the determination of values of previously defined invariant parameters (1) and (2). For each estimated real estate assessment model and for each geodesic net, after determining covariance matrix for observation model values (prices of real estates, angles, lengths or height differences between points of measurement matrix), values of previously defined invariants have been calculated. As result, 134 sets of these two numbers were received. Results are presented in Table 1. Apart from invariants values, the Table contains as well: model type and values of constants characterising model and measurement database. These are:

- number of observations - *n*,
- number of unknowns - *u*,
- number of degrees of freedom - *k*,
- remainder variance - σ_0^2,
- radical of remainder variance (average error of determination of unknowns) - σ_0.

Table 1: Values of invariants

Nr	MODEL	VARIABILITY	*n*	*u*	*k*	σ_0^2	σ_0	σ_{tr}	σ_{det}
1	real estate	linear	18	13	4	2,807	1,675	0,526	0,16868
2	real estate	linear	18	7	10	5,206	2,282	0,292	0,00016
3	real estate	linear	18	8	9	5,364	2,316	0,305	0,00180
4	real estate	linear	18	9	8	5,930	2,435	0,306	0,00702
5	real estate	linear	18	10	7	4,643	2,155	0,363	0,02260
6	real estate	linear	18	11	6	4,762	2,182	0,374	0,04406
7	real estate	linear	18	12	5	4,750	2,179	0,390	0,07030
8	real estate	linear	18	4	13	4,286	2,070	0,254	0,00000
9	real estate	non linear	18	10	7	2,632	1,622	0,482	0,03190
10	real estate	non linear	18	14	3	0,325	0,570	1,602	1,58408
11	real estate	non linear	18	14	3	0,325	0,570	1,602	1,57550
12	real estate	non linear	18	12	5	0,355	0,596	1,370	0,66667
13	real estate	non linear	18	12	5	0,262	0,511	1,662	0,89908
14	real estate	non linear	18	13	4	0,266	0,516	1,709	1,35848
15	real estate	non linear	18	11	6	0,708	0,842	0,970	0,21128
16	real estate	non linear	18	10	7	0,834	0,913	0,856	0,08610
17	real estate	non linear	18	5	12	3,365	1,834	0,315	0,00000
18	real estate	non linear	18	5	12	3,365	1,834	0,315	0,00000
19	real estate	non linear	18	6	11	3,178	1,783	0,350	0,00000
20	real estate	non linear	18	8	9	3,064	1,750	0,404	0,00000
21	real estate	non linear	18	10	7	1,654	1,286	0,608	0,00003
22	real estate	non linear	18	8	9	0,986	0,993	0,712	0,00498
23	real estate	non linear	18	9	8	0,784	0,885	0,842	0,02908
24	real estate	non linear	18	8	9	0,715	0,846	0,836	0,00631
25	real estate	linear	31	15	15	37,875	6,154	0,117	0,00385
26	real estate	linear	31	13	17	38,515	6,206	0,108	0,00126
27	real estate	non linear	31	17	13	13,227	3,637	0,210	0,01980
28	real estate	non linear	31	17	13	11,151	3,339	0,228	0,02291
29	real estate	non linear	31	16	14	10,436	3,230	0,229	0,01753
30	real estate	non linear	31	18	12	9,954	3,155	0,248	0,03280
31	real estate	non linear	31	18	12	11,193	3,346	0,243	0,02962
32	real estate	non linear	31	16	14	9,116	3,019	0,245	0,01984
33	real estate	non linear	31	16	14	10,108	3,179	0,233	0,01821

Nr	MODEL	VARIABILITY	*n*	*u*	*k*	σ_0^2	σ_0	σ_{tr}'	σ_{det}'
34	real estate	non linear	31	15	15	10,212	3,196	0,225	0,01185
35	real estate	non linear	38	13	24	2324,053	48,208	0,012	0,00001
36	real estate	linear	131	12	118	779,711	27,923	0,011	0,00000
37	real estate	linear	127	12	114	469,446	21,667	0,015	0,00000
38	real estate	non linear	131	16	114	804,668	28,367	0,013	0,00000
39	real estate	non linear	127	16	110	473,673	21,764	0,017	0,00000
40	real estate	non linear	121	16	104	343,562	18,535	0,020	0,00000
41	real estate	linear	30	13	16	23,934	4,892	0,140	0,00218
42	real estate	linear	30	12	17	23,438	4,841	0,136	0,00101
43	real estate	linear	29	13	15	15,782	3,973	0,175	0,00371
44	real estate	linear	29	12	16	15,086	3,884	0,172	0,00181
45	real estate	linear	28	12	15	11,458	3,385	0,201	0,00282
46	real estate	linear	28	11	16	10,983	3,314	0,198	0,00110
47	real estate	non linear	30	16	13	21,975	4,688	0,160	0,01012
48	real estate	non linear	30	16	13	21,942	4,684	0,161	0,01005
49	real estate	linear	63	9	53	27,468	5,241	0,076	0,00006
50	real estate	linear	60	9	50	18,913	4,349	0,094	0,00117
51	real estate	non linear	57	10	46	8,016	2,831	0,155	0,00000
52	real estate	non linear	57	10	46	8,016	2,831	0,155	0,00000
53	real estate	non linear	57	9	47	9,610	3,100	0,135	0,00001
54	real estate	non linear	57	9	47	9,648	3,106	0,135	0,00000
55	real estate	non linear	54	9	44	5,284	2,299	0,187	0,00000
56	real estate	non linear	57	8	48	9,690	3,113	0,127	0,00001
57	real estate	non linear	54	8	45	5,296	2,301	0,177	0,00000
58	real estate	non linear	44	8	35	0,463	0,681	0,664	0,00000
59	real estate	non linear	57	8	48	9,560	3,092	0,128	0,00000
60	real estate	linear	30	15	14	1,006	1,003	0,728	0,10958
61	real estate	non linear	30	18	11	1,158	1,076	0,739	0,26293
62	real estate	linear	48	13	34	33,689	5,804	0,093	0,00006
63	real estate	linear	47	13	33	25,821	5,081	0,107	0,00009
64	real estate	linear	46	13	32	21,845	4,674	0,118	0,00121
65	real estate	non linear	48	13	34	34,447	5,869	0,092	0,00006
66	real estate	non linear	47	13	33	26,610	5,158	0,106	0,00009
67	real estate	non linear	46	13	32	22,785	4,773	0,116	0,00012
68	real estate	non linear	48	13	34	33,637	5,800	0,093	0,00006
69	real estate	non linear	47	13	33	26,123	5,111	0,107	0,00009
70	real estate	non linear	46	13	32	22,500	4,743	0,116	0,00012
71	real estate	non linear	48	13	34	33,522	5,790	0,093	0,00157
72	real estate	non linear	47	13	33	25,904	5,090	0,107	0,00009
73	real estate	non linear	46	13	32	22,196	4,711	0,117	0,00011
74	real estate	non linear	48	13	34	33,640	5,800	0,093	0,00064

Nr	MODEL	VARIABILITY	*n*	*u*	*k*	σ_0^2	σ_0	σ_{tr}’	σ_{det}’
75	real estate	non linear	47	13	33	25,669	5,066	0,108	0,00009
76	real estate	non linear	46	13	32	21,648	4,653	0,118	0,00013
77	real estate	linear	42	11	30	30,296	5,504	0,097	0,00002
78	real estate	linear	41	11	29	25,487	5,048	0,107	0,00002
79	real estate	linear	41	7	33	27,622	5,256	0,084	0,00000
80	real estate	linear	40	7	32	24,308	4,930	0,091	0,00000
81	real estate	linear	40	10	29	22,262	4,718	0,111	0,00000
82	real estate	linear	40	9	30	21,527	4,640	0,108	0,00000
83	real estate	non linear	41	13	27	25,092	5,009	0,117	0,00029
84	real estate	non linear	40	13	26	21,775	4,666	0,127	0,00039
85	real estate	non linear	41	13	27	24,974	4,997	0,117	0,00029
86	real estate	non linear	40	13	26	20,615	4,540	0,130	0,00041
87	real estate	non linear	40	14	25	16,437	4,054	0,151	0,00114
88	real estate	non linear	40	16	23	15,671	3,959	0,165	0,00407
89	real estate	non linear	40	15	24	15,515	3,939	0,160	0,00240
90	real estate	non linear	39	15	23	15,671	3,959	0,162	0,00276
91	real estate	non linear	39	14	24	15,515	3,939	0,157	0,00145
92	real estate	linear	50	13	36	1,864	1,365	0,388	0,00034
93	real estate	non linear	50	18	31	1,192	1,092	0,564	0,02838
94	real estate	non linear	49	18	30	0,853	0,923	0,674	0,04265
95	real estate	non linear	48	18	29	0,580	0,761	0,826	0,06656
96	real estate	non linear	50	14	35	1,289	1,135	0,482	0,00138
97	real estate	non linear	46	14	31	0,523	0,723	0,790	0,00570
98	levelling	linear (P≠I)	54	26	28	2,768	1,664	1,971	0,05062
99	levelling	linear (P≠I)	54	26	28	95,76	9,786	0,025	0,00146
100	levelling	linear (P≠I)	54	26	28	2,170	1,473	0,939	0,06457
101	levelling	linear (P≠I)	54	26	28	542,500	23,292	0,005	0,00026
102	levelling	linear (P≠I)	54	26	28	23,149	4,811	0,133	0,00605
103	levelling	linear (P≠I)	54	26	28	63,663	7,979	0,040	0,0022
104	levelling	linear (P≠I)	54	26	28	2,910	1,706	0,933	0,04815
105	levelling	linear (P≠I)	7	4	3	1,220	1,105	2,017	0,00500
106	levelling	linear (P≠I)	7	4	3	0,942	0,971	3,601	0,00648
107	levelling	linear (P≠I)	7	4	3	0,799	0,894	2,696	0,00764
108	levelling	linear (P≠I)	7	4	3	3,387	1,840	0,974	0,00180
109	levelling	linear (P=I)	7	4	3	3,142	1,772	1,128	0,00194
110	levelling	linear (P=I)	7	4	3	21,993	4,690	0,161	0,00028
111	levelling	linear (P=I)	7	4	3	1,294	1,137	2,740	0,00472
112	levelling	linear (P=I)	7	3	4	109,667	10,472	0,024	0,00000
113	levelling	linear (P≠I)	7	3	4	1,898	1,378	1,423	0,00000
114	levelling	linear (P=I)	7	3	4	15,667	3,958	0,166	0,00000
115	levelling	linear (P=I)	7	3	4	266,333	16,320	0,010	0,00000

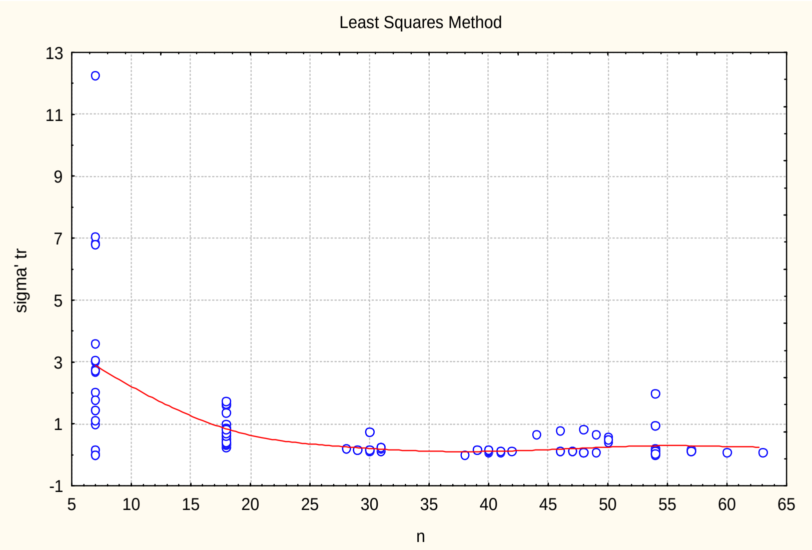
Nr	MODEL	VARIABILITY	*n*	*u*	*k*	σ_0^2	σ_0	σ_{tr}'	σ_{det}'
116	levelling	linear (P=I)	7	3	4	423,000	20,567	0,006	0,00000
117	levelling	linear (P≠I)	7	3	4	238,553	15,445	0,013	0,00000
118	levelling	linear (P≠I)	7	3	4	1,135	0,065	1,771	0,00000
119	levelling	linear (P≠I)	7	3	4	1,020	1,010	2,716	0,00000
120	levelling	linear (P≠I)	7	3	4	1,898	1,378	1,423	0,00000
121	angular-linear	non linear	7	4	3	1,178	1,085	12,252	0,00345
122	angular-linear	non linear	7	4	3	4,714	2,171	3,028	0,00094
123	angular-linear	non linear	7	4	3	2,095	1,447	6,834	0,00206
124	angular-linear	non linear	7	4	3	2,091	1,446	7,039	0,00271
125	angular-linear	non linear	7	4	3	0,523	0,724	27,445	0,00888
126	angular-linear	non linear	7	4	3	0,524	0,724	27,147	0,00732
127	angular-linear	non linear	7	4	3	4,710	2,170	3,063	0,00087
128	angular-linear	non linear	7	4	3	0,295	0,543	48,290	0,01106
129	angular-linear	non linear	7	4	3	2,095	1,447	6,797	0,00197
130	angular-linear	non linear	7	4	3	0,344	0,586	41,286	0,01169
131	angular-linear	non linear	7	4	3	0,213	0,461	66,975	0,01500
132	angular-linear	non linear	7	4	3	2,095	1,447	6,797	0,00197
133	angular-linear	non linear	7	4	3	0,524	0,724	27,186	0,00789
134	real estate	linear	49	12	36	56,208	7,497	0,069	0,00001

5. ANALYSIS OF RELATION BETWEEN INVARIANTS AND QUANTITIES CHARACTERISTIC FOR MEASUREMENT DATABASE AND RESULTS OF ESTIMATION OF THE MODEL

In order to formulate criteria for quality estimation of geodesic measurement data, several scatter diagrams of invariants dependence on constant quantities describing measurement database and applied adjustment model have been made. On each of these diagrams, a trend line, estimated with least squares method, has been put on. It enables to confirm the occurrence or non-occurrence of any relations between these quantities and, in consequence, to draw conclusions concerning the model or the results of measurement.

Diagrams of invariants dependence on following parameters have been made:
- number of observations
- number of unknowns
- number of degrees of freedom,
- remainder variance,
- average error of determination of unknowns

Selected diagrams of the whole set are presented below.


Least Squares Method
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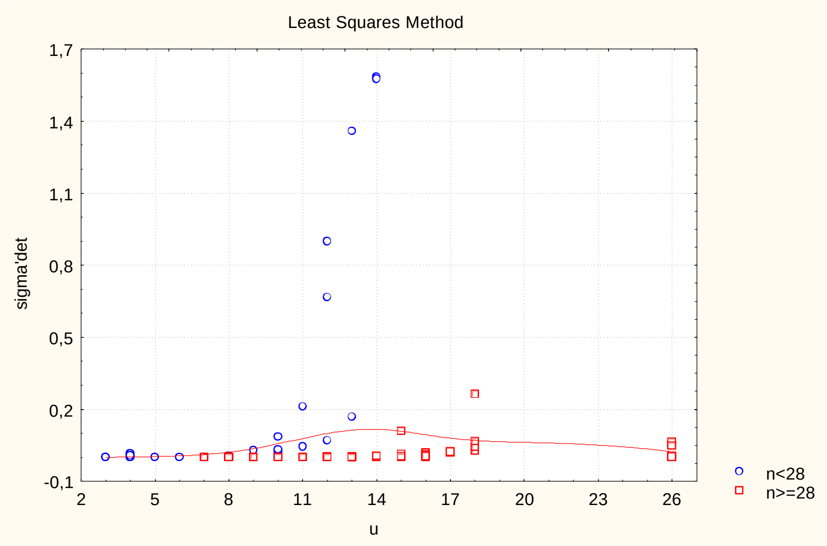
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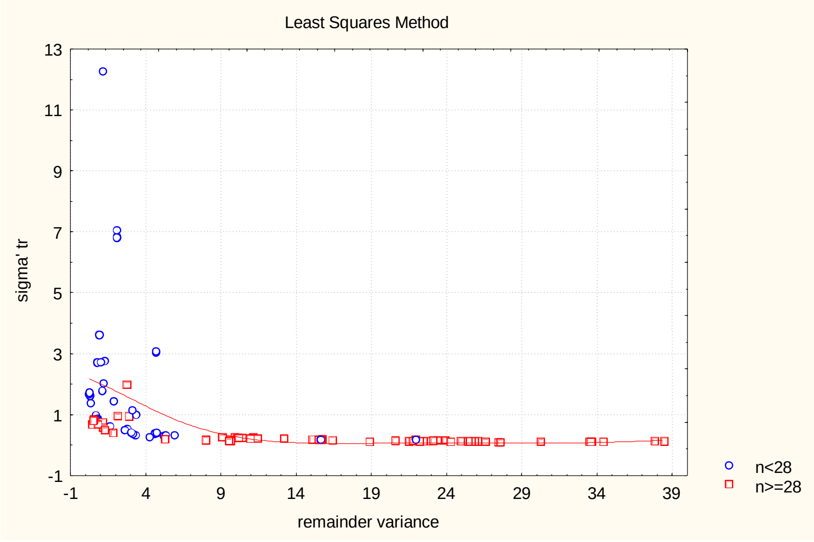
Least Squares Method
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34
39
n<28
n>=28

6. CONCLUSIONS

The principal purpose of the study was to present usability of defined parameters for assessment of a geodesic measurement designing method and its influence on the effect of adjustment of geodesic measurements. It is closely connected with pre-setting of the number of measurements as well as the number of unknowns, and consequently, the number of degrees of freedom.

After the defined invariants σ_{tr}, σ_{det} have been determined for about 130 models of different number of observations (7 to 132) and of different number of unknowns (3 to 26) – on the basis of these invariants scatter diagrams in conjunction with characteristics of databases and models, the following conclusions can be formulated:

- The behaviour of both parameters is similar considering number of observations, number of degrees of freedom, remainder variance and average error of determination of unknowns. Thus, in the case of these quantities, analysing quality of measurement data and estimating adjustment model, there is no need to take into account the covariances between adjusted measurements (→ determinant of covariance matrix), we only need to consider their variances (→ trace of covariance matrix).
- In principle, increase of number of observations and of number of degrees of freedom results in decreasing invariant value. However, it is visible that a large increase of number of measurements as well as their number in relation to the number of unknowns, does not improve the results.
- In the case of number of degrees of freedom, a stabilisation of both parameters is visible for a number of observation equal to, at least, twice as large number of unknowns.
- Too small number of observations disturbs relationship of invariants with remainder variance; it is however less important in the case of average error of estimators of unknowns.
- Optimum number of measurements should be equal to threefold number of unknowns (e.g. parameters of estimation model or corrections to approximated coordinates). It should be pointed out that this number must be equal to, at least, twice as large number of unknowns, and that its rise (above quadruple number of unknowns), generally, does not improve the results.
- In the case of examining the influence of number of unknowns on the quality of the whole adjustment of geodesic observations, the parameter based upon the determinant of covariance matrix for adjusted observations is positively more legible. When the number of unknowns exceeds 10, appropriately high number of observations (30 at least) is necessary to keep stability of parameter σ_{det}.
- A choice of database acquired by a determined geodesic measurement can be recognised as optimum if the value of invariant σ_{det} is contained in range: $\sigma_{det} \in (0{,}02368; 0{,}09262)$, resulting from range estimation for σ_{det} at confidence level 0,95.

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