COLOR DEVIATIONS AND VARIATIONS IN GRAVURE AND WEB OFFSET PRINTING

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Abstract: Customers and advertising agencies show an increasing interest in the magnitude of color tolerances within publication and catalogue printing on gravure and web offset presses. The variations between different production runs and the proof or OK sheet have been determined by statistical analysis. The measurements refer to a number of critical colors printed in the form of a color bar. It will be shown that gravure printing offers smaller color variation than web offset printing.

Introduction

Magazines and catalogs are critical products with respect to potential color variations and deviations. While magazines usually contain critical color ads, catalogs may consist of delicate colors where fashion articles or commodities are reproduced.
Customers and advertising agencies are therefore interested to know what color tolerances have to be accepted when a print order is given for a catalog or a color ad.

As magazines and catalogs can both be printed either in web offset or in gravure, one major question is what color variations and deviations are typically obtained with these processes. Another question is how color variations and deviations participate in the total color departure of a production with respect to a customer proof or OK sheet.

A further question is whether all colors occurring in a color ad or magazine are equally sensitive to variations, or whether it is possible to give a ranking list for more and less sensitive colors.

Definition of color variation and deviation

Color variations and deviations are distances in a three-dimensional space.
The deviation can be defined in two ways:

- either as the difference between the mean value of all samples (the center of production) and the reference or aim value,

- or as the average departure of all samples from the reference.

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In this investigation the difference between the production center and the aim value has been chosen to characterize the deviation.

The variation is defined as the range within which a certain percentage of all samples deviate from the production center. In this study the 95 % range (the so-called 95 % confidence interval) has been chosen. This value is obtained by multiplying the standard deviation with the factor of 1.96.

Both the variation and the deviation are color difference values ΔE. Since ΔE values show a non-Gaussian distribution, the variation and the deviation have to be calculated from the statistical values of the one-dimensional color coordinates, for instance from L*a*b* (details see appendix).

If the ΔE values of the variation and the deviation are added up, the resulting value describes the range within which 95 % of all samples deviate from the aim value (see figure 1).

Experimental

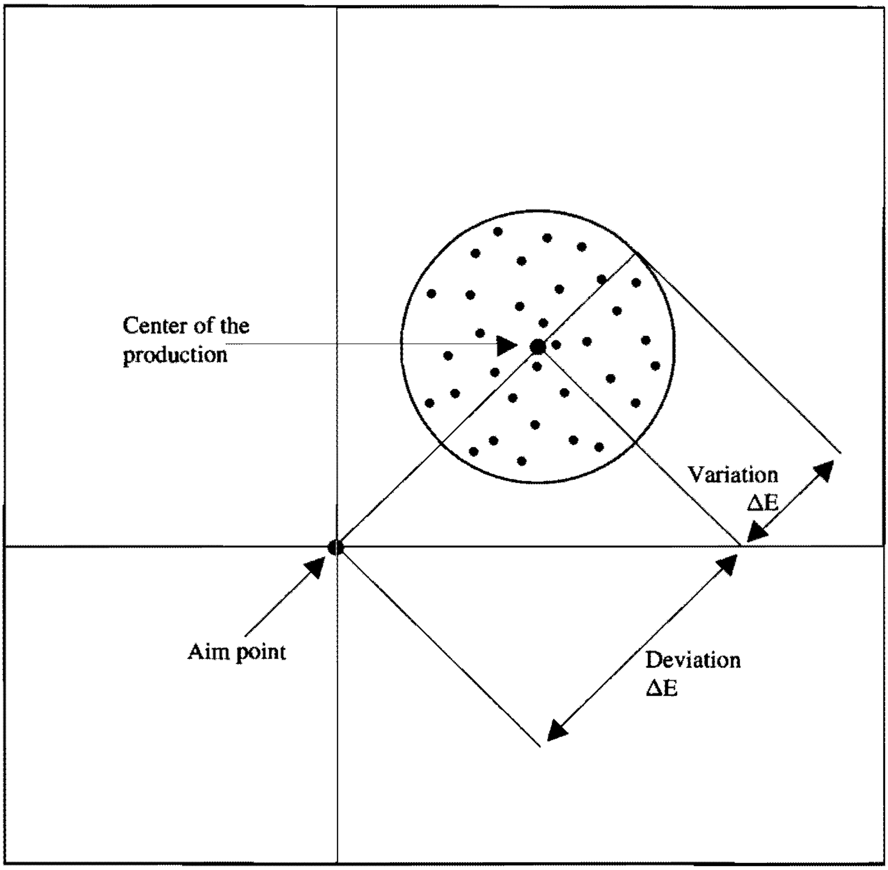
In order to investigate the color variations and deviations it was decided to print a special test element consisting of 24 color patches in each production to be tested. As all productions were printed on web-fed presses, the color patches could be placed outside of the page format where the signature is trimmed prior to the binding operation. Apart from the single colors, combinations of two and three chromatic single colors were chosen to measure the variations and deviations (see table 1).

The color patches were printed in 9 web offset runs and 9 gravure runs 7 of which were catalog productions and 11 were magazines (see table 2).
The print runs were made at 9 different production sites. The run lengths varied between 50'000 and 450'000 copies. In case of each production 10 to 20 samples were measured.
The test program included:

- colorimetric measurements of 24 colors (as described in table 1)

- densitometric measurements of 8 primary color patches (solid-tone density and dot gain at 50 %).

The measured colorimetric values were L*, a*, b* (CIELAB) based on illuminant D65, 2 ° observer, 45/0 geometry and black backing. From the single L*a*b* values the mean and the standard deviation were calculated.
To obtain deviation values it was necessary to have for each production run a reference sample which was in this investigation an OK sheet pulled at the beginning of the print run.



Deviation: Distance between the center of the production and the aim point

Variation: Range within which 95 % of all samples are located with respect to the center of the production

Figure 1 **Definition of variation and deviation**

Patch No.	C	M	Y	K	Type of color patch
1	100				Primary colors
2	50				100 % + 50 %
3		100			
4		50			
5			100		
6			50		
7				100	
8				50	
9	100		100		Secondary colors
10	100	100			100 % + 100 %
11		100	100		
12	50		50		Secondary colors
13	50	50			50 % + 50 %
14		50	50		
15	50	50	50		Tertiary color 50 %
16	100		50		Secondary colors
17	100	50			100 % + 50 %
18		100	50		
19	50		100		
20	50	100			
21		50	100		
22					Plain paper
23	50	50	100		Tertiary colors
24	50	100	50		100 % + 50 % + 50 %
25	100	50	50		

Table 1 **Composition of the color patches used to measure the variation and deviation**

Process	Code	Product	Number of printed copies	Paper weight g/m²	Press speed (copies per hour)
Gravure	A	Magazine	273'000	60	40'000
	B	Magazine	52'000	60	27'000
	C	Magazine	147'000	90	28'000
	D	Magazine	220'000	56	34'000
	E	Magazine	110'000	80	23'000
	F	Catalog	280'000	60	39'000
	G	Magazine	190'000	60	35'000
	H	Magazine	140'000	60	34'000
	I	Magazine	450'000	60	35'000
Web offset	J	Catalog	60'000	100	20'000
	K	Catalog	204'000	54	35'000
	L	Catalog	203'000	80	40'000
	M	Magazine	120'000	70	25'000
	N	Catalog	145'000	48	35'000
	O	Catalog	150'000	60	40'000
	P	Catalog	130'000	60	47'000
	Q	Magazine	400'000	60	51'000
	R	Magazine	350'000	60	35'000

Table 2 **List of the tested production runs**

Densitometric variations

Looking at the densitometric measurements, the variation values deserve the most interest, because they illustrate the fluctuation of the ink film thickness in both printing processes. As can be seen from figure 2, the variations in web offset printing are more than twice as high as those in gravure printing, although the density levels are comparable in both processes (see table 3). These results suggest that the color variations may differ in the same order of magnitude.

	Web offset	Gravure
C	1.27	1.45
M	1.44	1.38
Y	1.28	1.43
K	1.80	1.85

Table 3 **Average solid-tone densities measured in 9 runs for each process**

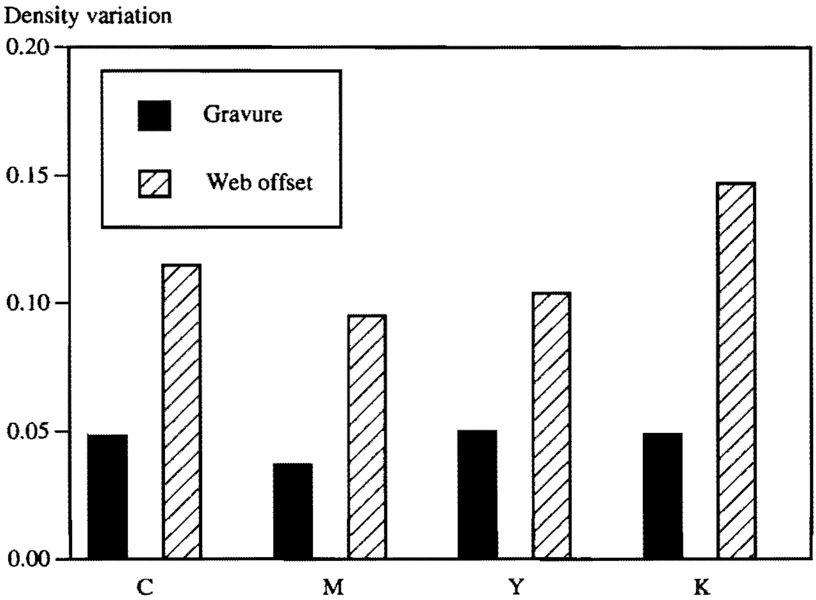


Figure 2 **Density variation of the process inks measured in 9 runs for each process**

Color deviations

When discussing colour deviations, different reference points are possible: First, the customer proof, second the OK sheet signed at the beginning of the production run and third a numerical specification for an original. Depending on how close the proof matches the production conditions, the deviation from the proof may be small. An even better result can be expected, when the deviation from the OK sheet is measured. If the printing conditions show no departure from the initial press setting, the deviation may be close to zero. As no proofs were available for the present study, the reference point was in all cases an OK sheet. The measured deviations can be seen from figure 3. The deviation values found for 9 runs range from $\Delta E = 0.84$ to $\Delta E = 1.65$ in case of gravure, while the range for web offset goes from $\Delta E = 1.34$ to $\Delta E = 2.67$.

The mean value for the 9 gravure runs was $\Delta E = 1.24$ and $\Delta E = 2.01$ for the 9 web offset runs. The latter value is in good agreement with a study of Dolezalek (1994) who found an average deviation of $\Delta E = 2$ for offset productions, when tertiary colours are measured.

Comparing gravure and web offset, it can be seen that the gravure deviation is only about 60 % of the web offset deviation.

Altogether the deviation values found in this study must be regarded as small, if the ΔE values are judged according to the scale shown in table 4.

ΔE value	Magnitude of color difference
Below 0.2	not visible
0.2 – 1.0	very small
1.0 – 3.0	small
3.0 – 6.0	medium
Above 6.0	large

Table 4 **Interpretation of ΔE values**

However, much higher values may be found, if single deviation values (maximum values measured in a single sample) are regarded. These can go higher than ΔE = 10 in case of web offset printing and as high as ΔE = 8 for gravure printing.

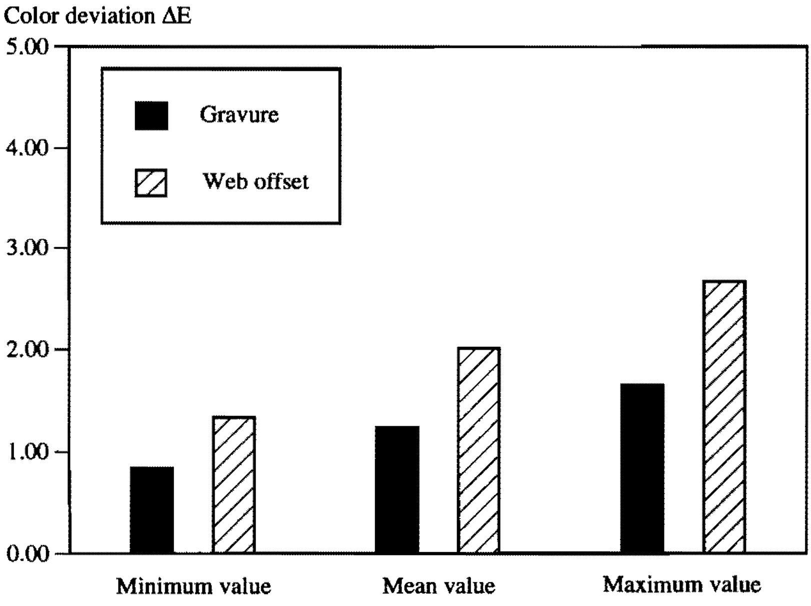


Figure 3 **Color deviations ΔE measured in 9 runs**

Colour variation

The measured values for the color variation are illustrated in the same way as those for the deviation. As can be seen from figure 4, the variation ranges from ΔE = 1.67 to ΔE = 2.30 for 9 gravure productions and from ΔE = 2.69 to ΔE = 4.57 for 9 web offset productions. The gravure variation is on the average only about 60 % of the web offset variation, again indicating that gravure printing is obviously the more stable process compared with web offset printing.
The mean values found for the two processes are ΔE = 2.02 for gravure and ΔE = 3.54 for web offset. The highest variations occurring in a single run in any color, however, can be substantially higher.
The highest value found for web offset printing was ΔE = 10.0 and for gravure printing ΔE = 4.35.

An important question to be answered is whether or not a distinction is possible between colors being more or less sensitive to color variations. In a first attempt, all 24 colors measured in this investigation were ranked according to their magnitude of variation.
However, an analysis of this ranking list shows that the variations of different colours are overlapping to such a large extent that a statistically significant classification of more and less sensitive colors is not possible. In figure 5 three groups of colors are distinguished, i.e.
- primary colors (solid-tones, 50 % halftones)
- secondary colors (solid-tones, 50 % halftones and combinations of them)
- tertiary colors (combinations of 50 % halftones and solid-tones).

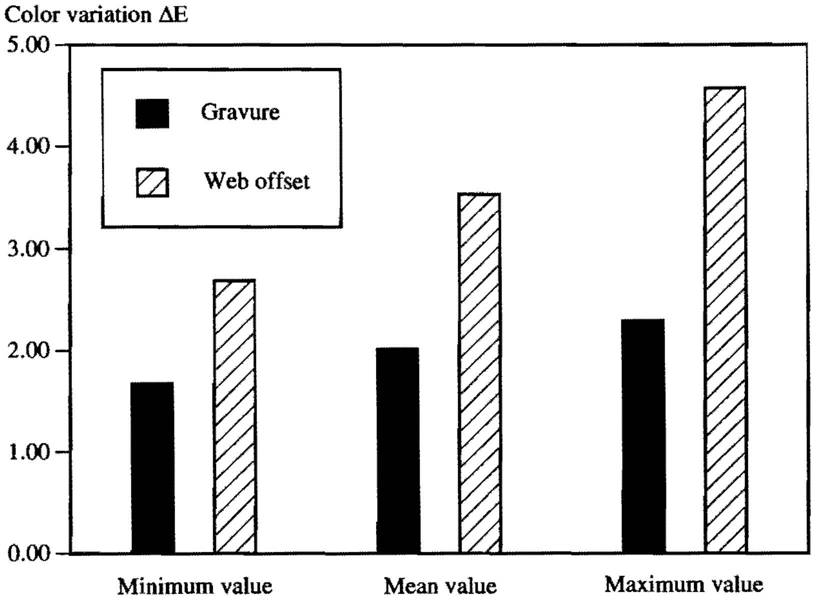


Figure 4 **Color variations ΔE measured in 9 runs**

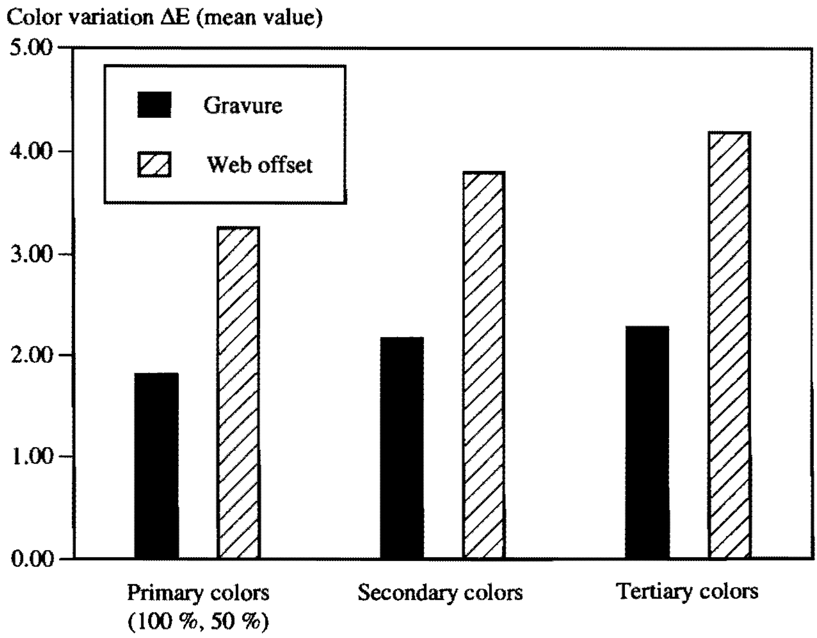


Figure 5 **Mean values for the color variation ΔE measured in 9 runs for different colors**

As can be expected, tertiary colors are more sensitive than secondary colors, the primary colors being the least sensitive group. The differences between these groups are, however, not so substantial. On the average, tertiary colors are only 25 % to 30 % more sensitive than primary colors.
The average ΔE values found for tertiary colors in offset printing are again in good agreement with findings of Dolezalek (1994). Based on standard deviation values specified by Dolezalek for tertiary colors, an average variation of ΔE = 3.90 can be calculated which compares with ΔE = 4.19 found for tertiary colors in this study.

The average value ΔE only represents the limit below which approximately 50 % of all production runs may be found. More interesting is the 90 % limit, because this variation may be regarded as a tolerance value for customers and advertisement agencies. As 9 runs are not a sufficient base to statistically derive a 90 % range, a statistical analysis was made for all secondary and tertiary colors measured in the 9 production runs. From these 144 colors the following 90 % limit was found:
ΔE = 3.0 for gravure printing
ΔE = 5.5 for web offset printing.

The limit for web offset may again be compared with the results of Dolezalek (1994). His 90 % limit specified particularly for brown tones is expressed as average standard deviation s = 1.75. From this a ΔE = 5.94 can be calculated.

Conclusions

The most important conclusions from this analysis of 9 gravure productions and 9 web offset productions are:

1. Gravure printing gives substantially lower color variations and deviations than web offset printing. The average ratio of gravure vs web offset is 0.6 : 1.

2. The deviations of the productions from the OK sheet are clearly smaller than the variations within the production runs. This ratio (deviation vs variation) is also about 0.6 : 1.

3. Primary colors show only 20 % less variation compared with tertiary colors. Secondary colors are about 15 % below the variation of tertiary colors.

4. For the variation within a production run, the following tolerances can be proposed:
   - for gravure printing: $\Delta E = 3.0$
   - for web offset printing: $\Delta E = 5.5$.

5. As tolerance for the deviation of the center of the production from the OK sheet a value of $\Delta E = 1.8$ is proposed for gravure printing and $\Delta E = 3.3$ for web offset printing.

Reference

Dolezalek, F. K.
1994 «Appraisal of production run fluctuations from color measurements in the image», TAGA Proceedings, pp 154 - 164.

Appendix: Statistics of ΔE values

As ΔE values are three-dimensional quantities, their statistics obey particular laws. The correct treatment of statistical ΔE values is explained by using a series of L*a*b* values as example (see Table A).

The example is chosen in such a way that the values L*, a*, b* show a nearly Gaussian distribution. (An exact Gaussian distribution cannot be illustrated with only 21 values.) In addition an aim point L^*_0, a^*_0, b^*_0 is specified from which the deviation of the measured values can be calculated as follows:

$$\Delta L^* = L^* - L^*_0$$
$$\Delta b^* = a^* - a_0^*$$
$$\Delta b^* = b^* - b_0^*$$
$$\Delta E^* = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}}$$

Now, for each column in table A two basic statistic values can be obtained, i.e.
- the mean value $\overline{x}$
- the standard deviation s.

As can be seen from table A, the calculated values for $\overline{x}$ and s are identical for L*a*b*. Although this has been deliberately chosen, it is not an unrealistic example for colorimetric values. Moreover, it can be seen that the delta values for L*a*b* have the same standard deviation as the absolute values. This identity is statistically given and therefore not only found in this example.

If the standard deviation is multiplied by the factor of 1.96, the resulting value describes, in the case of a Gaussian distribution, the range within which 95 % of all samples are located: this range is called the 95 % confidence interval.

As the statistical example in table A is based on 21 values, theoretically 1 or 2 of all values should be outside of the calculated 95 % interval. A comparison with table A shows that this is the case except for the ΔE values.

The ΔE values in the last column show a non-Gaussian distribution meaning that the values for the standard deviation and for the 95 % confidence interval, as calculated in table A, have no statistical significance and have to be ignored. The correct ΔE value for the 95 % confidence interval is obtained from the 95 % values calculated for ΔL*, Δa* and Δb* by using the formula:

$$\Delta E = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}}$$

Based on the values of table A this yields

$$\sqrt{2.641^2 + 2.641^2 + 2.641^2} = 4.574$$

Due to the non-Gaussian nature of the ΔE values, the mean value ΔE calculated from the single values ΔE is statistically equally misleading.

	L*	a*	b*	ΔL*	Δa*	Δb*	ΔE*
Aim Value	39.0	39.0	39.0	–	–	–	–
Sample 1	42.7	39.9	37.3	3.7	0.9	-1.7	4.2
2	42.1	40.9	37.9	3.1	1.9	-1.1	3.8
3	41.8	41.1	38.2	2.8	2.1	-0.8	3.6
4	41.5	38.7	38.5	2.5	-0.3	-0.5	2.6
5	41.3	39.5	38.7	2.3	0.5	-0.3	2.4
6	41.1	38.2	38.9	2.1	-0.8	-0.1	2.2
7	40.9	41.3	39.1	1.9	2.3	0.1	3.0
8	40.7	41.5	39.3	1.7	2.5	0.3	3.0
9	40.5	40.7	39.5	1.5	1.7	0.5	2.3
10	40.3	37.9	39.7	1.3	-1.1	0.7	1.8
11	40.2	40.2	39.8	1.2	1.2	0.8	1.9
12	40.1	42.7	39.9	1.1	3.7	0.9	4.0
13	40.0	40.0	40.0	1.0	1.0	1.0	1.7
14	39.9	37.3	40.1	0.9	-1.7	1.1	2.2
15	39.8	40.3	40.2	0.8	1.3	1.2	1.9
16	39.7	39.8	40.3	0.7	0.8	1.3	1.7
17	39.5	40.5	40.5	0.5	1.5	1.5	2.2
18	39.3	38.5	40.7	0.3	-0.5	1.7	1.8
19	39.1	39.3	40.9	0.1	0.3	1.9	1.9
20	38.9	41.8	41.1	-0.1	2.8	2.1	3.5
21	38.7	39.1	41.3	-0.3	0.1	2.3	2.3
22	38.5	42.1	41.5	-0.5	3.1	2.5	4.0
23	38.2	38.9	41.8	-0.8	-0.1	2.8	2.9
24	37.9	39.7	42.1	-1.1	0.7	3.1	3.4
25	37.3	40.1	42.7	-1.7	1.1	3.7	4.2
Mean	**40.000**	**40.000**	**40.000**	**1.000**	**1.000**	**1.000**	**2.74**
Standard deviation	**1.347**	**1.347**	**1.347**	**1.347**	**1.347**	**1.347**	**0.864**
95 % confidence interval	**2.641**	**2.641**	**2.641**	**2.641**	**2.641**	**2.641**	**1.693**

Table A **Example of values L*a*b* with a nearly Gaussian distribution**

The correct value results from the mean values of ΔL^*, Δa^* and Δb^* using the already mentioned ΔE formula.

For the values in table A this is

$$\sqrt{1.0^2 + 1.0^2 + 1.0^2} = 1.73$$

This value describes the distance of the production centre from the aim value.

If the already calculated value for the 95 % confidence interval is added to this mean value, the sum describes the 95 % confidence interval with respect to the aim value.

To summarize, there are two statistically meaningful ΔE values. They describe:

- **the distance of the production center from the aim value:** This ΔE value is obtained from the mean values ΔL^*, Δa^* and Δb^*.

- **the 95 % confidence interval:** This value is obtained from the standard deviations of ΔL^*, Δa^* and Δb^* multiplied by 1.96.

In both cases the ΔE is calculated with the formula

$$\Delta E = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}}$$

No statistical significance, however, have both the mean value and the standard deviation calculated from the single ΔE values.