APPRAISAL OF PRODUCTION RUN FLUCTUATIONS FROM COLOR MEASUREMENTS IN THE IMAGE

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Abstract: Extensive measurements of representative samples drawn from both web and sheet fed illustration printing showed that certain colors are particularly prone to variations, among them dark gray and brown. During 19 production runs, the variations of these colors were followed in CIELAB color space and their deltaE distances from the production center were determined. They followed a chi^2 statistic, characterisable by a single parameter, which could be linked to the standard deviations in L^*, a^* b^* space. As a basis for quality appraisal, the distribution of the parameter over the sampled production runs is given.

INTRODUCTION

In the control of production printing the densitometer is still the preferred instrument. Recommendations for production tolerances are thus expressed in terms of tone value (dot area) and solid density variations, both quantities to be measured in control strip patches. For a variety of reasons, however, control strips are often omitted, even on high quality jobs. In this case, there is no objective basis for settling disputes on production run variations between print buyer and printer. This was the starting point for several investigations where colorimetric measurements in the image were used for process control and quality assessment purposes, Schläpfer (1984, 1985, 1992), Dolezalek et al. (1987, 1990).

Looking at the variability of various halftone colors in the field, it was found, surprisingly, that there were no discernible product specifics. For instance, skin colors of cosmetics catalogs did not fluctuate less from copy to copy than did skin colors in furniture catalogs of similar quality. Rather, the magnitude of the fluctuation was tied to the individual color shade and its lightness, Dolezalek et al. (1987). The highest fluctations were found with tertiary colors in the mid-tone, Pietzsch et al. (1992). A surprising fact had previously been observed by Schläpfer et al. (1985), namely that the variation within 100 successive copies amounted already to one half of the total variation within the production run.

When 20 halftone colors were tested by Pietzsch et al. (1992) for the size of their fluctuations in printing, the following five colors were found to be particularly prone to variations, listed here in the order of descen-ding variability:

	$L^*/a^*/b^*$	
Gray	(51/-3/-2)	K 9 C52 M41 Y36
Brown	(34/20/23)	K 0 C60 M90 Y90
Earth	(54/ 6/31)	K14 C31 M41 Y67
Siena	(51/20/12)	K11 C44 M76 Y48
Ivy	(57/-18/0)	K 3 C59 M23 Y42

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The tone value percentages quoted were found to produce the listed colors under average printing conditions on coated paper with positive-working plates. Other compositions are, of course, possible.

As has been pointed out by Schläpfer (1984, 1985), that for the study of production run fluctuations, it is useful to distinguish between the deviation of the production center (or mean) from the OK sheet (OK) and between the variations of the individual sheets around the production center (PC), see Fig. 1. This work is concerned with the latter case and it is here where gaussian statistics show certain shortcomings, see the Appendix. If, however, the deltaE values are calculated with reference to the OK sheet, higher numbers may result where gaussian statistics would then be a good approximation.

The present work is a field test of the use of the mentioned colors as monitors of production run variation.

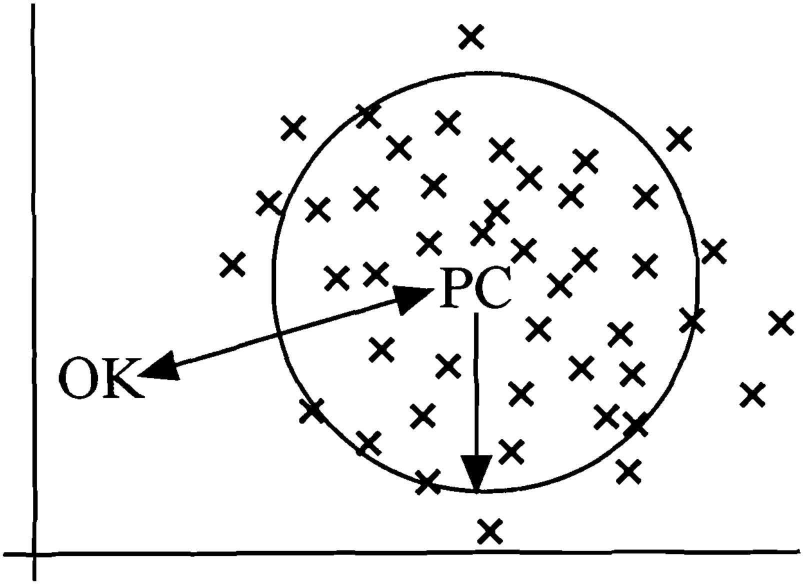

Figure 1. Scatter of samples in color space around their mean, the production center (PC), which is at some distance from the OK sheet

EXPERIMENTAL

Print samples were pulled from 19 production runs of four-color offset illustration jobs on coated paper, totalling 2.5 million copies in all. Of these, 900 000 were sheet-fed and the remainder heat-set web. For the latter, about one copy per 5000 was withdrawn and with sheet-fed jobs one per 1000. The sample size per run ranged from 20 to 30 copies. The nominal halftone screen frequency was 60/cm throughout, two sheet-fed jobs had been printed with waterless offset.

The illustrations were screened visually for the occurrence of the five colors listed in the introduction. While it was not possible to find a single job where all colors could be found it was equally hard to find a job which did not show a suitable gray or brown shade. An image spot was first located using a specially prepared colored mask, then the color was verified with a hand-held spectrophotometer. A value within deltaE = 6 of the required color was regarded as acceptable. A thin transparent overlay paper was prepared and a hole punched at the required spot. The remaining copies were measured through the hole with the paper placed in register.

The color measurements were performed on a black backing in accordance with ISO 5/4 with a hand-held spectrophotometer (Gretag SPM 100) under the conditions 45/0 geometry, no polarisation, 2° observer, D50, CIELAB-system. The diameter of the measured spot was 3.5 mm. Surprisingly, the reproducibility of the measurements on the same spot was indeed much better than the variation from sheet to sheet. Only spots with a strongly visible structure had to be rejected for lack of reproducibility.

From the L^*, a^*, b^* co-ordinates, the standard deviations and the mean values L^*_0, a^*_0, b^*_0 were calculated, the latter defined the center of the production. Taking the latter as the reference, the deltaE values of the remaining sheets were calculated. The results were plotted in diagrams of the type depicted in Fig. 4. Here, the vertical axis is graduated such that a three-dimensional Chi^2 distribution (i.e. the integral of $x^2exp(-x^2/2)$, see Table A1) is rendered as a straight line. The distributions are characterizable either by the median deltaE value, i.e. the value which represents the upper limit for half of the samples or the individual standard deviations of L^*, a^*, b^*.

Where possible, the deviation of the center of production from the OK sheet was also determined. For the gray and brown colors this quantity amounted to deltaE = 2 on the average.

RESULTS AND DISCUSSION

Typical results are depicted in Figs. 2 to 4 for a long web run with 159 samples. Some wild excursions can be spotted in Fig. 2 but there are also quiet periods and drifts. In Fig. 3 the data are plotted in a diagram in which a gaussian distribution would be rendered as a straight line. As can be seen, the line cannot represent the data points very well. The diagram of Fig. 4, however, is better in this respect, both to the low and the high side. Here, the vertical axis was graduated such that the 3-dim data of Table A1 would give a straight line. The sample data can be characterized by a single number, the median deltaE value which is read in Fig. 4 at 50 % as 2.0. It was found that the median values of the various runs correlate well with their average standard deviations of L^*, a^*, b^*. In our case, the standard deviations were 1.20, 1.48 and 1.42. The average is 1.37, the ratio of the median value to the deviation average is 1.46.

In the Appendix, the mathematical value for the conversion factor is given as 1.53 for the 3-dimensional case and identical standard deviations σ (sigma) for L^*, a^*, b^*. The experimental data showed, however, that this factor is also a good approximation in cases where the standard deviations differ up to a factor of 2.

The distribution of the average standard deviations the 19 sampled production runs is shown in Table 1 for the colors gray and brown. For other colors there was too little data.

Close inspection of the two production runs of Table 1 which showed wider variations than the other 17 (=90 %) revealed that their dot gain variations were well outside the tolerances recommended for normal (i.e. standardized) printing. The variations of the others runs were borderline cases or well within tolerances. It was thus concluded that the 90 % values of Table 1 represent a suitable upper limit for four-color quality printing. The corresponding median values for delta E are obtained by multiplying the 90 %-values of Table 1 with 1.53. Fig. 5 shows the sum percentage graphs for the 90 % borderlines.

Percent of runs:	Average standard deviation of L^*, a^*, b^* gray	brown
50%	≤0.89	≤1.15
60 %	≤1.02	≤1.30
70 %	≤1.15	≤1.42
80 %	≤1.33	≤1.56
90 %	≤1.57	≤1.75

Table 1. Percentage of production runs with averaged standard deviations below the tabled value

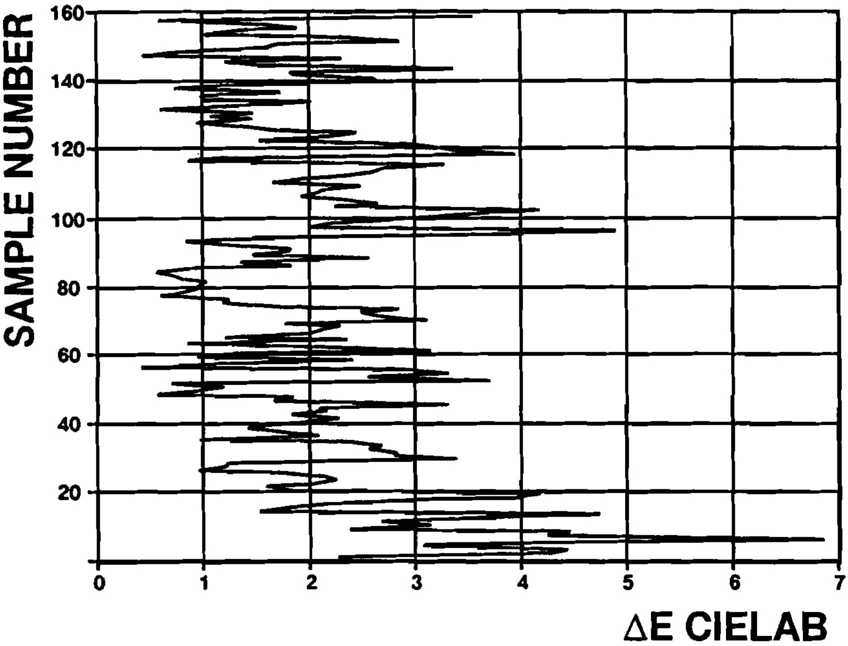

Figure 2. Scatter of 159 heat-set web samples, deltaE was calculated from the production center

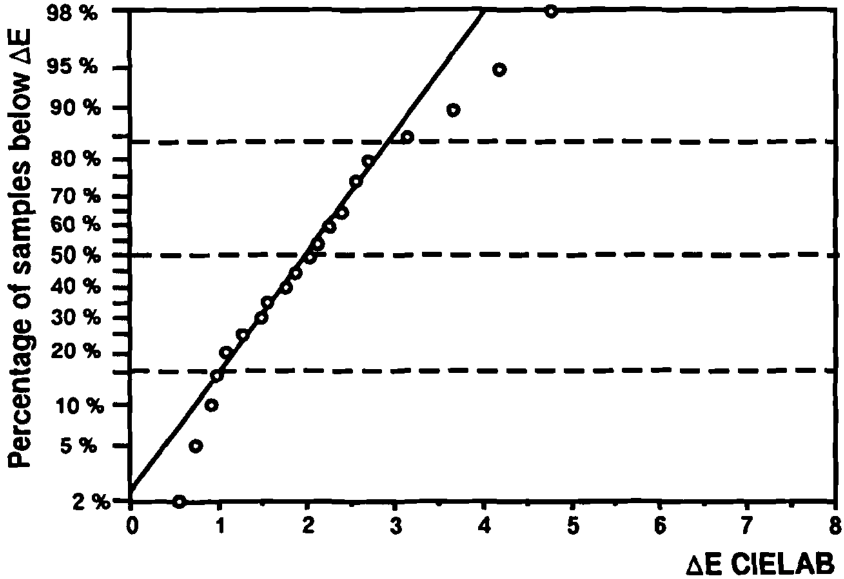

Figure 3. Data of Fig. 2 plotted in a diagram where a gaussian distribution results in a straight line

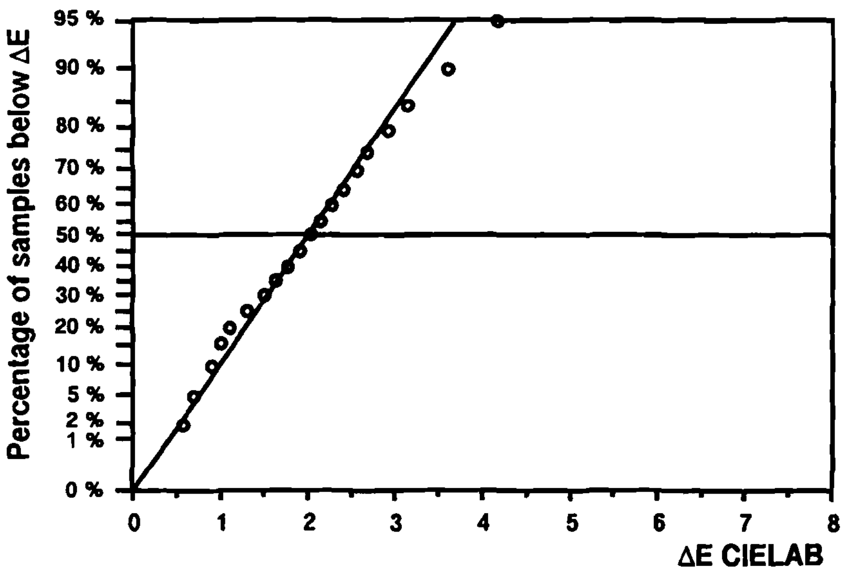

Figure 4. Data of Fig. 2 plotted in a diagram where a chi² distribution results in a straight line

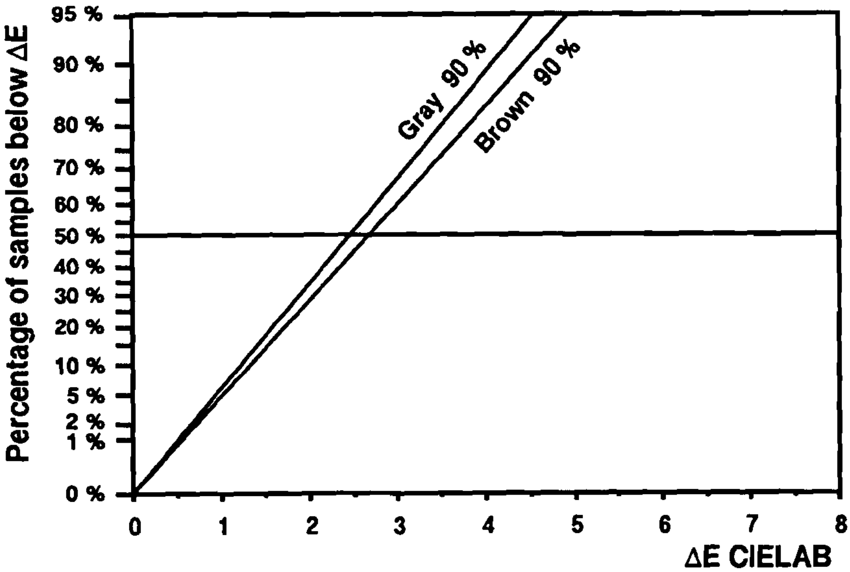

Figure 5. Sum percentage lines which correspond to the 90 % values in Table 1

In a practical application, the diagram Fig. 5 would be used to plot the deltaE sum percentages of, say, 20 samples pulled from a production; the deltaE calculation to be based on the production center (defined by the mean values of L^*, a^*, b^*). All is well if the data points remain to left of the sloping line corresponding to the measured color. An alternative criterion would be that the average standard deviation of L^*, a^*, b^* for brown or gray is below the corresponding 90 % value of Table 1.

As mentioned in the Introduction, this work is concerned with variation of color loci around their mean, see Fig. 1., where gaussian statistics are less adequate. If, however, the deltaE values are referred to a color locus at some distance from the mean, gaussian statistics may be less inadequate. In this work σ (sigma) was found to lie in the range 0.9 to 1.6 for most jobs, this translates into deltaE median values of 1.4 to 2.4 (factor 1.53). Gaussian statistics could thus be applied with confidence only if the production had drifted away from the OK sheet by, say, deltaE = 6 to 10.

CONCLUSIONS

Color measurements in three- or four-colored gray or brown spots of an image may be used for the appraisal of production run variations. For a range of colors between ($L^*/a^*/b^*$) = (50/0/0) and = (35/20/20), the maximum median deltaE values considered to be compatible with quality printing range between 2.4 and 2.7, respectively. The statistics of color distances from the center of production (the mean) is not gaussian. Gross errors may result especially in the one- and two-dimensional cases if gaussian statistic formulae are used for calculating confidence intervals or the probability of values well beyond the median value.

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LITERATURE CITED

Dolezalek, F. and Besson, K.-H.
1987. "Color measurement at the printer" (In German)
FOGRA Research Report 3.251
(FOGRA, Munich)

Dolezalek, F.; Fuchs, T.; Schlütken, J.
1991. "Do control strips indeed mirror the quality of the work?" (In German)
FOGRA Research Report 3.280
(FOGRA, Munich)

Dolezalek, F., and Pietzsch, R.
1990. "The use of color measurements in the image for make-ready and production run control" (In German)
FOGRA Research Report 3.251
(FOGRA, Munich)

Pietzsch, R. and Dolezalek, F.
1992. "How can color measurement be used for matching prints on differently colored substrates?" (In German)
FOGRA Research Report 3.287
(FOGRA, Munich)

Schläpfer, K.
1984. "The appraisal of color deviations in production printing" (In German)
UGRA-Mitteilungen, Nr. 3

Schläpfer, K.; Flüeli, G.; Fässler, K.
1985. "Color deviations in gravure printing and web offset" (In German)
UGRA-Bericht 80/2
(St. Gall, Switzerland)

Schläpfer, K.
1992. "The maximum color deviations in standardized offset printing" (In German)
UGRA-Mitteilungen, Nr. 2, 1992

Võlz, H.G.
1990. "Color assessment of pigments and colorants"
(In German) (Verlag Chemie, Weinheim)

Appendix: DELTA-E STATISTICS

Let us assume that the color coordinates L^*, a^*, b^* are distributed with gaussian statistics around the mean values L^*_0, a^*_0, b^*_0. What is the distribution of the deltaE and deltaC values calculated from

$$\text{deltaE}^2 = (L^* - L^*_0)^2 + (a^* - a^*_0)^2 + (b^* - b^*_0)^2 \text{ and}$$

$$\text{deltaC}^2 = (a^* - a^*_0)^2 + (b^* - b^*_0)^2 \text{ ?}$$

A gaussian distribution requires like probabilities for like deviations from the center value. This is obviously not the case for deltaE or deltaC because both quantities are limited to positive numbers. Therefore, both distributions must be asymmetrical; hence they cannot be gaussian. It has been shown by Völz (1990) that the deltaE distribution is represented by the three dimensional chi^2 function.

In general, there can be a considerable correlation between any two of the co-ordinates L^*, a^*, b^*. If we look at the variations of a single-color solid, it is natural for L^* to rise if either a^*, b^* or both rise. If we look only at fluctuations of four-color halftones near the gray axis, however, we can make the simplifying assumption that the fluctuations in the L^*, a^*, b^* directions are independent of each other. With the above assumption, the probability distributions can be calculated. The results are shown in Figs. A1 to A3 for the one-, two- and three-dimensional cases.

One-Dimensional Case

In the one-dimensional case, only one of the three co-ordinates L^*, a^*, b^* fluctuates with a standard deviation σ, the others are constant. Fig. A1 depicts the probability distribution. It is the typical bell-shaped gaussian but with the lower half cut off. It is useful to graduate the horizontal axis in terms of (deltaE)/σ because deltaE scales with σ. Towards the right, the probability function drops off as $\exp(-x^2/2)$, where x is short for (deltaE)/σ. The broken curve is the integral of the probability distribution, it gives the proportion of samples whose deltaE values are smaller than the abscissa multiplied by σ. The deltaE of one half of the samples is below 0.67σ, the median value (50 %). The data for the broken curve are tabulated in Table A1 under "1-dim".

Let us now see what happens if we ignore the fact that the distribution is not gaussian. We use the probability data to calculate the mean value, 0.78, and the standard deviation, 0.61. These values are not independent of each other, their ratio is 1.28. The dotted curve in Fig. A1 shows a gaussian calculated from these values. It drops off much more rapidly than the solid curve. It follows that, in a practical situation, it would be grossly misleading to calculate 95 % or 99 % confidence intervals from gaussian statistics. Also, it might be overlooked that standard deviation and mean are related by a constant factor. Rather, the data should be plotted like the broken curve in Fig. A1 or in a diagram where this curve would be rendered as a straight line, see Fig. 4.

One-dimensional cases are not uncommon: Consider presses with a doubling problem in one unit. The color excursions in the corresponding direction would be the overriding component of deltaE. Another case is the register dependence of the yellow/black moiré of some halftone screen patterns, here the movement is essentially along the b^* axis.

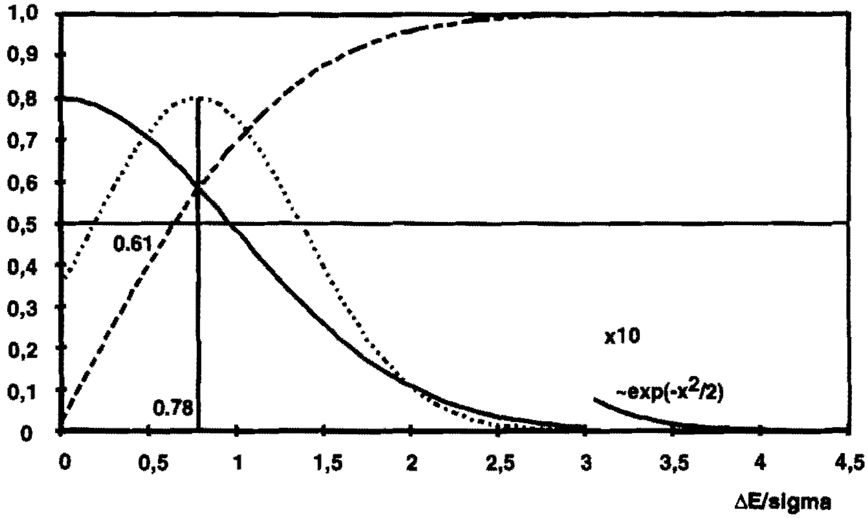

Figure A1. Probability distribution (solid), corresponding gaussian (dotted) and sum percentage (broken) for the 1-dimensional case

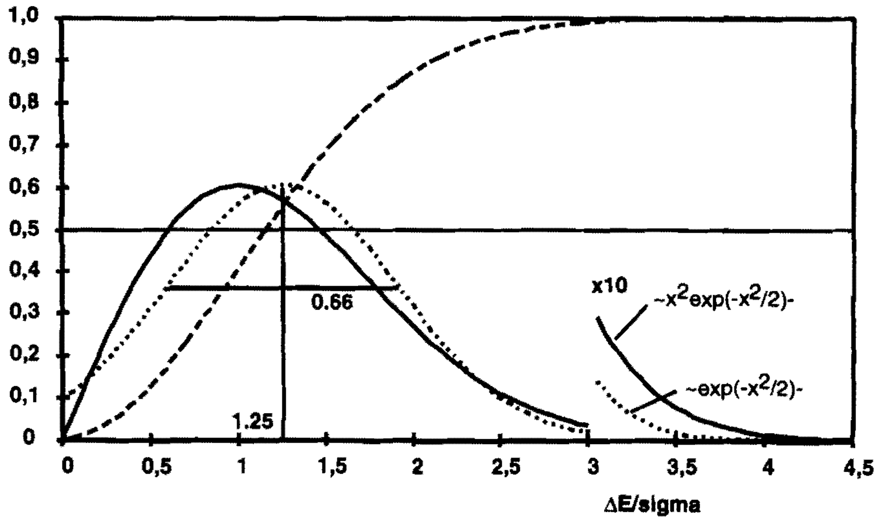

Figure A2. Probability distribution (solid), corresponding gaussian (dotted) and sum percentage (broken) for the 2-dimensional case

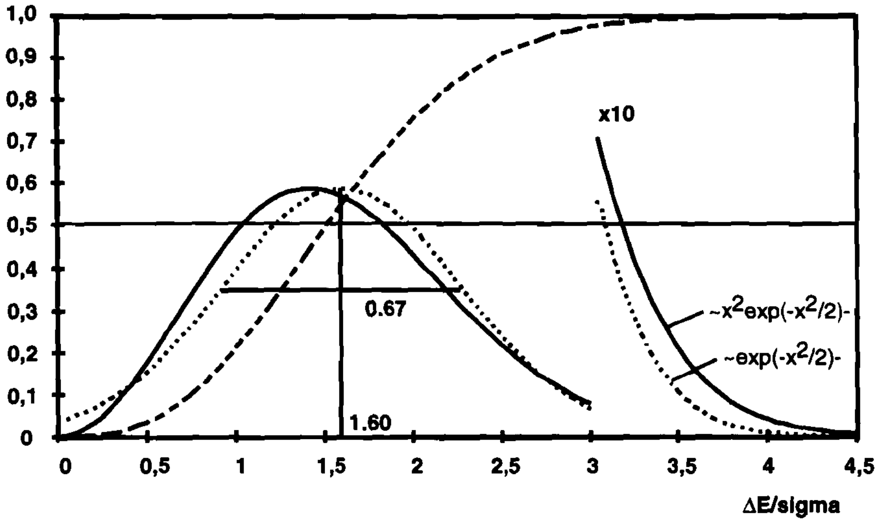

Figure A3. Probability distribution (solid), corresponding gaussian (dotted) and sum percentage (broken) for the 3-dimensional case

Two-Dimensional Case

The following applies to deltaE statistics where of the three co-ordinates L*, a*, b* only two fluctate independently though with a standard deviation σ, the third is constant. In addition, it applies to the deltaC values. The solid curve in Fig. A2 shows the probability distribution plotted over (deltaE)/σ. It has a maximum at 1 and drops off as $x\exp(-x^2/2)$, where x is short for (deltaE)/σ. The dotted curve depicts again the gaussian curve that corresponds to mean and standard deviation values calculated from the probability distribution. It falls off more rapidly than the correct probability curve. The broken curve represents the integral of the solid curve, it is tabulated in Table A1 under "2-dim". The median value (50 %) is located at 1.17.

Three-Dimensional Case

Finally, Fig. A3 refers to deltaE values where all three coordinates L*, a*, b* fluctuate independently, though with a common standard deviation σ. Again, the horizontal axis is graduated in terms of deltaE/σ. The probability distribution function reaches a maximum at $\sqrt{2}$ and drops off as $x^2\exp(-x^2/2)$, x=deltaE/σ. The broken curve shows the integral of the probability distribution, the data are given in Table A1 under "3-dim". the median value is reached at 1.53.

If the data are treated as a gaussian distribution, we calculate a mean value of 1.60 and a standard deviation of 0.67. These values are linked, their ratio is 2,37. A gaussian curve that corresponds to these values is shown with a dotted line. Again the gaussian falls off much more steeply than the probability distribution. Thus, the probability of finding samples that are way out may be underestimated by using gaussian statistics. Rather, it is recommended to plot the sum percentage data in a diagram of the type depicted in Figs. 4 and 5, where the broken curve in Fig. A3 is rendered as a straight line.

The probability distribution and its integral can be characterized by a single parameter, for instance σ, the average standard deviation of L*, a*, b* , or the median deltaE value which constitutes an upper limit for 50 % of the samples. This value equals to

0.67σ in the one-dimensional case,
1.17σ in the two-dimensional case,
1.53σ in the three-dimensional case.

Table A1. Probability for finding deltaE values below delta E_0

deltaE_0	1-dim	2-dim	3-dim
0.00σ	0.020	0.000	0.000
0.05σ	0.060	0.002	0.000
0.10σ	0.099	0.007	0.000
0.15σ	0.139	0.015	0.001
0.20σ	0.178	0.025	0.003
0.25σ	0.217	0.037	0.005
0.30σ	0.255	0.051	0.009
0.35σ	0.292	0.068	0.013
0.40σ	0.329	0.086	0.019
0.45σ	0.365	0.106	0.027
0.50σ	0.400	0.128	0.035
0.55σ	0.435	0.152	0.046
0.60σ	0.468	0.177	0.058
0.65σ	0.500	0.203	0.071
0.70σ	0.532	0.231	0.087
0.80σ	0.591	0.288	0.122
0.90σ	0.645	0.348	0.164
1.00σ	0.695	0.408	0.211
1.10σ	0.739	0.469	0.263
1.20σ	0.779	0.528	0.318
1.30σ	0.815	0.584	0.375
1.40σ	0.846	0.638	0.434
1.50σ	0.873	0.687	0.492
1.60σ	0.896	0.733	0.550
1.70σ	0.916	0.774	0.605
1.80σ	0.932	0.811	0.657
1.90σ	0.946	0.843	0.705
2.00σ	0.957	0.871	0.749
2.10σ	0.966	0.895	0.789
2.20σ	0.974	0.916	0.825
2.30σ	0.980	0.933	0.856
2.40σ	0.985	0.947	0.882
2.50σ	0.988	0.959	0.905
2.60σ	0.991	0.968	0.925
2.70σ	0.994	0.975	0.941
2.80σ	0.995	0.981	0.954
2.90σ	0.997	0.986	0.964
3.00σ	0.998	0.989	0.973
3.10σ	0.998	0.992	0.979
3.20σ	0.999	0.994	0.985
3.30σ	0.999	0.996	0.989
3.40σ	0.999	0.997	0.992
3.50σ	1.000	0.998	0.993