Accuracy & Fidelity of Devices in a Workflow Integrating CMS

*G. Gonzalez**

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Abstract

Color Management aims for safe and reproducible communication of colors and assumes it can widely correct systematic errors introduced in prepress. Color measuring devices and the errors introduced in the production process are analyzed to gain information on their systematic/random behaviour. Origin, size and parameters influencing random errors introduced are discussed. Noise on the printing signal and intentionally addressable color levels are highlighted.

1. Introduction

Color management systems and their work have been described frequently and in great depth. A literature overview may be found in (1). Color management aims to be applied to devices located and operated in environments with non constant configurations - as they may not be calibrated as a whole configuration e.g. due to often occurring changes. The aim of color management is to avoid the characteristic systematic color reproduction errors which the devices under view perform.

However, color differences between originals and their reproductions may not only occure due to the different systematic behaviors but also due to stochastic errors on the signals as they are produced by the devices. Those errors are unavoidble and may have their origin in the physics of the materials involved (2,3) or in the characeristics of softwares.

*EFPG, Ecole Française de Papeterie et des Industries Graphiques,
B.P. 65, F-38402 Saint Martin d'Hères Cedex

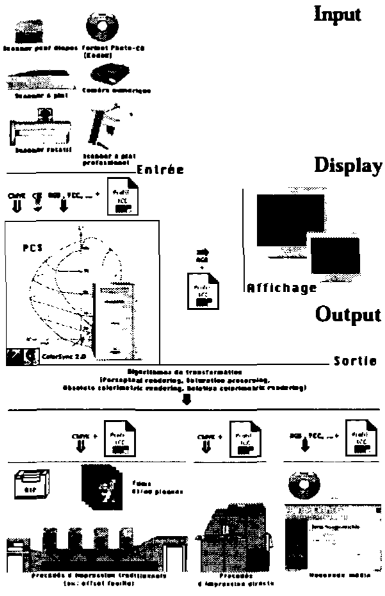


Figure 1 : Nowaday process including CMS.

In the past for users of color reproduction systems the question of color accuracy of the individual device or of software has been overlayed by the far more significant problem to communicate color doubtlessly. Now, since color communication works rather accurate with color management systems (Fig. 1), color accuracy of the devices and softwares need to be evaluated.

Here we first address the accuracy of color measurement devices as they are in use in the field, then the accuracy of scanners and printers is discussed.
As there are some characteristics in the noise on the color signals of offset presses this aspect is highlighted in a separate chapter.

Ahead of comparing the results on noise in device data, error propagation in the publication process is discussed.

2. Color measurement devices

Color measuring devices perform different with regard to several aspects like heat stability, performance of aging sensors etc. . In the following we concentrate on the reproducibility of the measured data and the accuracy of the results obtained by the devices.

In our approach we evaluated devices of a quality as they may usually be found in professional reproduction and printing environments. A further criteria was whether the devices under view would permit to obtain results according to CIE standards (4) and the ICC specification (5).

The accuracy and fidelity of three devices have been tested: the Gretag SPM100-II, the X-Rite 938 and the Digital Swatch Book from X-Rite (Tab. 1).

	Digital Swatchbook X-Rite	938 X-Rite	SPM100-II GRETAG
Dimensions in mm (width x height x depth)	76 x 69 x 137	76 x 81 x 197	83 x 90 x 270
Weight in g (app.)	380	1 100	1 300
Light source	Glow lamp	Glow lamp	Glow lamp
Output data formats	CIE XYZ, CIE xyZ, CIE LAB, CIE Luv, CIE LCh	CIE XYZ, CIE xyZ, CIE LAB, CIE Luv, CIE Lch, Hunter Lab, X%Y%Z%, ASTM E313 & D1925, TAPPI T452	CIE XYZ, CIE xyZ, CIE LAB, CIE Luv, CIE Lch, Hunter Lab, R(λ)
Illuminants	A, C, D50. D65, F2, F7, F11	A, C, D50. D65, F2, F7, F11, F12	A, C ,D30 à D300, F1 à F12 + 4 user
Angles	2°, 10°	2°, 10°	2°, 10°
Spectral Discretisation	400-700 nm every 20 nm (interpolation : 10 nm)	400-700 nm every 20 nm (interpolation : 10 nm)	380-730 nm every 10 nm
Measure domain	0-200% Reflexion	0-200% Reflexion	0-180% Reflexion
Geometry	45°/0°	0°/45°	45°/0°
Test pattern	4,0 mm transparent	4,0 mm black	3,5 mm black
Monochromator	interference	interference	diffraction
Sample	white polymer	bright ceramic	matt ceramique
Automatisation	no	no	no

Table 1 : Color measuring devices used in this work.

The devices are exact to the degree that they obtain numbers as small as hundreth of numbers represented in CIEXYZ-Coordinates. When computing spectral values in CIELAB color space coordinates they refer to different standards (6,7).

Thus values obtained from the tested color measurement devices were first collected in CIEXYZ coordinates and then converted in CIELAB using DIN reference values (X_0, Y_0, Z_0) for D50 conditions.
For better matching with perceptions of human observers all color differences calculated are given in ΔE^*_{94}.

2.1. Reproducibility of color measurement devices

In order to evaluate the reproducibility of color measurement devices we did measure in different time sequences: the same target has been measured in six measuring cycles with 50 measurements per patch in a row with intermediate breaks of 24 hours and in three measuring cycles with 50 mesurements per patch in a row after 72 hours of use. In order to avoid problems due to warming up of the measuring devices under view, the devices remained to be switched on.

In addition we measured the influence of a renewed calibration on the reproducibility of the device.
The results are displayed in Fig. 2 (b).

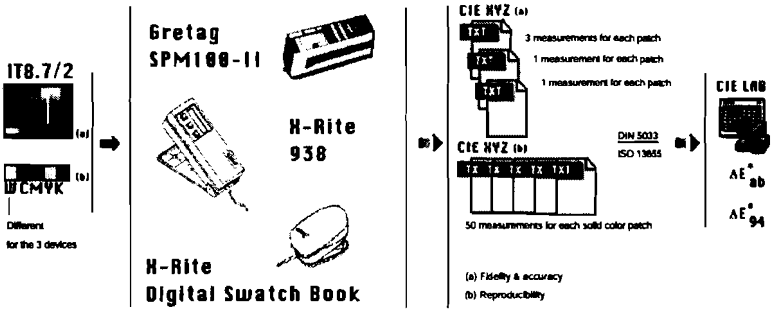


Figure 2 : Process for the tests on color mesuring devices.

As Fig. 3 indicates the effect of a renewed calibration turns out to be the most crucial parameter having an influence on the accuracy of the measured data. Relative to this number the other variances are small - that is in the range between ΔE^*_{94}= 0.1 and ΔE^*_{94}= 0.3.

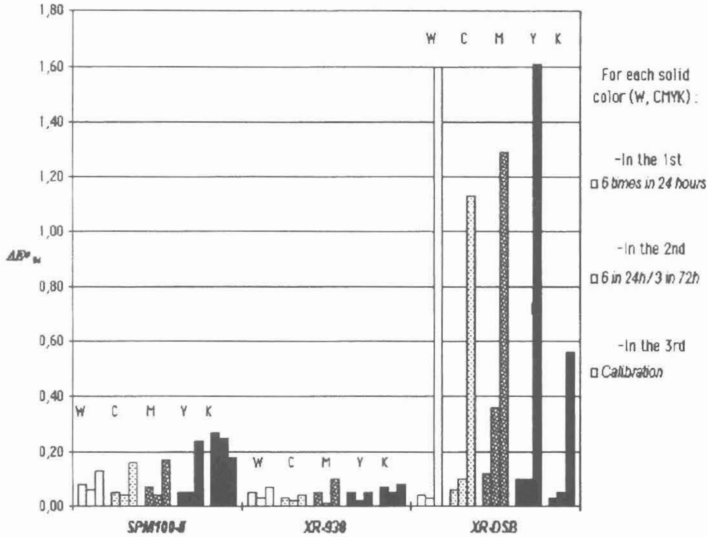


Figure 3 : Reproducibility of color measurement.
The different colums represent white reference and the primaries.

One should point out that the white references as they were used in the experiments, differ from device to device since the manufacurers of some of the measuring units provide the user with device specific targets (made of different materials). The exactness of the calibration depends on the sample and the range of wavelength taken into account by the devices. There has been some indication that the most inaccurate measurements occur in the very light and very dark patches.

2.2. Fidelity of color measurement devices

In order to acquire information on the fidelity of color measurement devices we used a printed sample of the KODAK IT8.7/2 as target. Three independent measurements have been obtained in all color patches defined by ISO and, in addition the CMYK and RGB values have been measured (Fig. 2 (a)).

The results obtained may be structured as follows: 1. The measurement results as they are derived with different devices differ significantly as can be seen when comparing Fig. 4 and Fig. 5.

4. The differences of the measurment results become larger as the saturation of the colors under view increases.

5. The inaccuracy of magenta turns out to be the largest.

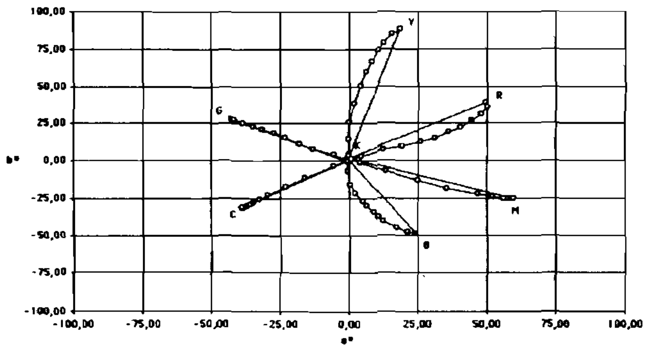


Figure 4: Gamut obtained with Gretag SPM100-II using the Kodak IT8.7/2 target fixed color patches as well as CMYK and RGB patches.

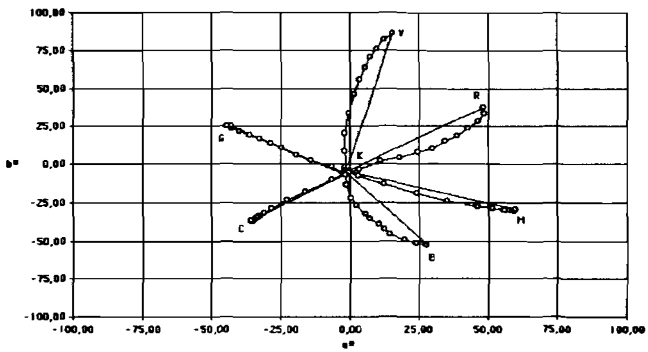


Figure 5: Gamut obtained with X-Rite digital swatch book using the Kodak IT8.7/2 target fixed color patches as well as CMYK and RGB patches.

3. Reproducibility of color signals of devices in color reproduction

3.1. Scanners

The accuracy and fidelity of two flatbed scanners were tested: the Saphir (by Linotype-Hell) office scanner and the Topaz scanner (also by Linotype-Hell), which aims for professional jobs as target groups. These two were chosen since they cover both the low and the medium price market segments and are equipped with scanner-adapted software.

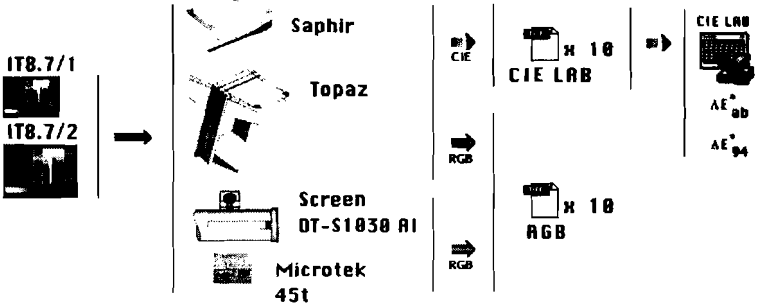


Figure 6 : Process for the tests on scanners (with their built in software).

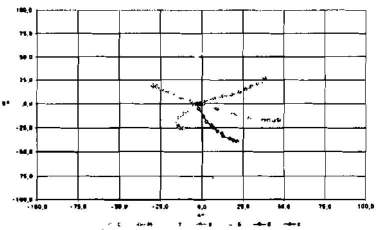
The experiments (Fig. 6) were performed in the following way: the target (IT8.7/1 and IT8.7/2 Kodak targets) has been fixed on the scanner and scanned 10 times under standard options and without any scanner profile. The transformation from RGB (of the CCD chip) to Lab is then performed by the scanner software, using an internal „generic" calibration.
The resulting data were saved as TIFFLAB files in LinoColor and analysed using a software tool. This software tool is a home made C program running on UNIX platform.

As for the tested color mesurement devices, the results are presented in ΔE^*_{94} for the IT8.7/2 target with an accuracy of only one thenth of CIELAB coordinates. This accuracy has been chosen to take into account that the data obtained in one scan vary from pixel to pixel within the same patch scanned. We were unable to learn wether this variance occurs due to the scanner or to the target. The limits of the accuracy of the data collected by the scanner ranged within the boundaries of tenth of CIELAB coordinates.

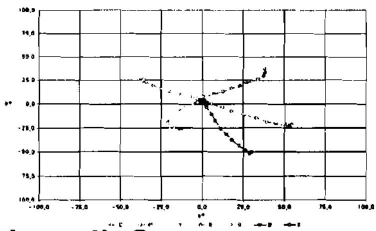
ΔE^*_{94}	mean	max.	min.
Saphir	0.2	1.0	0.1
Topaz	0.1	0.9	0.0

Table 2 : Results in ΔE^*_{94} obtained with the both scanners in reflexion mode.

As the results indicate (Tab. 2), both scanners have an alike accuracy. Nevertheless, when looking at the color gamut obtained from the IT8.7/2 taget, the white and black point of the Topaz scanner are slightly better centered in an (a*,b*) representation than the data generated with the Saphir Scanner we used. This results into a better fidelity in the color dataset acquired with the Topaz (Fig. 7).



*Linotype-Hell Topaz :
CMYK and RGB color gradations
of an IT8.7/2 (reflexion mode).*



*Linotype-Hell Topaz :
CMYK and RGB color gradations
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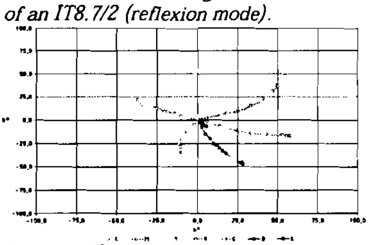
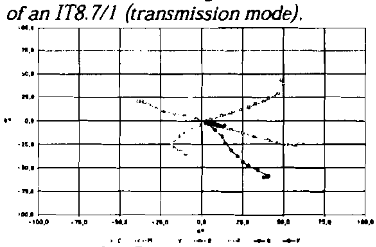


*Linotype-Hell Saphir :
CMYK and RGB color gradations
of an IT8.7/2 (reflexion mode).*



*Linotype-Hell Saphir :
CMYK and RGB color gradations
of an IT8.7/1 (transmission mode).*

Figure 7 : Gamut obtained using the Kodak IT8.7/2 and IT8.7/2 targets fixed color patches as well as CMYK and RGB patches.

3.2. Printers

In order to gather insight into the reproducibility of color signals of printers the following experiments have been performed with several presses and printers. The ability of three printing processes (sheet-feed offset, gravure and non impact-Xeikon) to reproduct 8 bit colorlevels in CMYK as well as in secondary and tertiary colors (C+Y, C+M, M+Y and C+M+Y) was evaluated.

The test target we used contained 256 patches with increasing color level of the primary, secondary and tertiary color under view. The field contained patches which have been placed in a square of 16 by 16 fields with different colors. A sketch of the target it has been printed with the different devices is displayed in figure 8 (a & b).

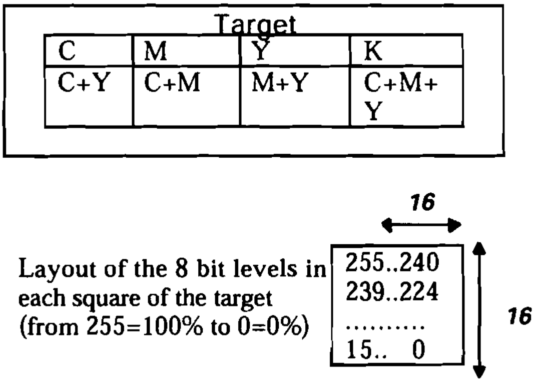
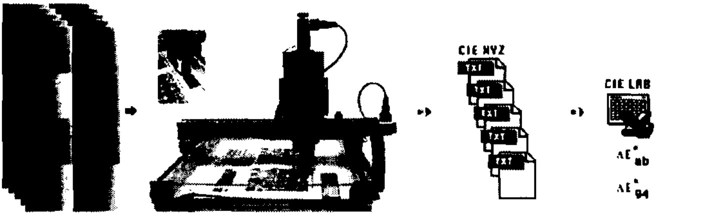


Figure 8 a : Organisation of the test target.



Testforms : 8 bit gradations in CMYK, C+Y, C+M, M+Y, C+M+Y

Measurements carried out with a SPM100-II using an XY table(*) to key in the 256 XYZ CIE triplets in each of the 8 gradations (~ 3:48 per testform)

(*) Dr. A. Paul, FOGRA

Datafiles processing : conversion to CIELAB space, ΔE calculations, color levels calculation

Fig. 8 b : Processing mode.

Here the results for sheet-feed offset with AM and FM screening and paper class 1 as well as for non impact-Xeikon with paper class 2 (as specified in (8)) are presented. As Fig. 9 indicates, none of the printing processes tested were able to reach the 256 color levels contained in the initial digital document.

Parameters influencing those results are numerous: screening (e.g. screening method, dot shape and size), properties of paper involved (e.g. gloss, whiteness) and of course the way the printing process runs.

The coordinates of the colors measured in the patches do not devolope linearily in the CIE space. In order to evaluate the real length in ΔE^*_{94} from level 0 (color at 100%) to 255 we used a step of 5 levels which estimates the shape of the curve rather well. Due to artefacts in the color levels, steps smaller than 5 could not be choosen.
We used the ΔE^*_{94} calculation to take the difficulties and limits of the human observers to differenciate colors in some parts of the CIELAB color space into account.

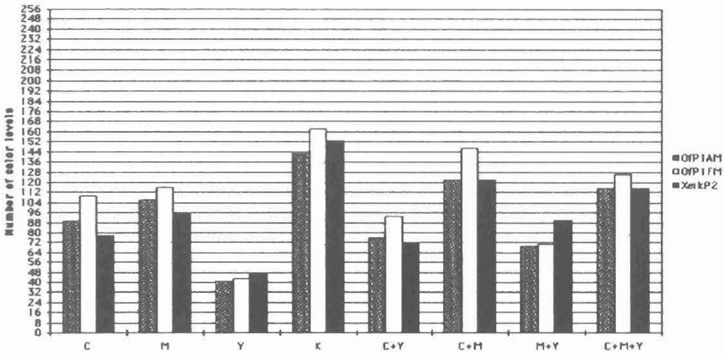


Figure 9 : Number of colorlevels obtained from adressed 8 bit levels in C, M, Y, K, C+Y, C+M, M+Y and C+M+Y.

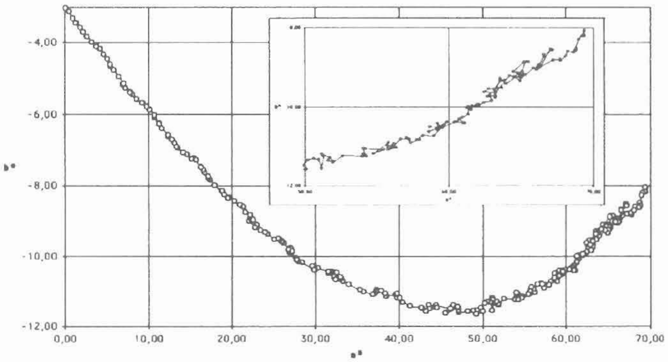


Figure 10 : Adressed 8 bit Magenta levels in sheet-feed offset with AM screening.

Fig. 10 displays the number of color levels measured on the patches on one sheet under view. As can be seen the curve is not linear and - as displayed in the enlarged segment of the curve - the measurements do not follow each other in a clear direction - meaning one color level may e.g. be darker than the following one despite its encryption in the data set would indicate a darker point. This interpretation also holds in the three dimensional representation of the measurement results.

This effect leads to the insight that, despite a large number of color levels may physically be printed on a printer or a press, only a limited number within a certain accuracy may be *intentionally* reproduced. Fig. 6 displayes the number of color levels as they may intentionally be reproduced in this sense by the different devices (see tables in appendix). As can be seen the numbers of color levels displayed in the primary colors ranges around 200 depending on the screening method and the paper under view. The overprints of different primaries as it leads to secondary and tertiary colors gain a number of around 80 to 100 color levels which may intentionally be addressed (Tab. 3, Tab. 4 and Tab 5).

	C	M	Y	K
Global ΔE^*_{94}	47.74±0.48	56.53±0.27	41.25±0.52	77.02±0.24
Nb. of levels	89±5	106±3	41±5	142±2
	C+Y	C+M	M+Y	C+M+Y
Global ΔE^*_{94}	68.00±1.57	78.59±0.69	69.14±0.52	95.60±3.43
Nb. of levels	76±13	122±7	69±5	115±18

Table 3 : Number of colorlevels obtained from addressed 8 bit levels in C, M, Y, K, C+Y, C+M, M+Y and C+M+Y for sheet-feed offset with AM screening.

	C	M	Y	K
Global ΔE^*_{94}	46.72±0.13	55.60±0.12	40.56±0.49	78.51±0.52
Nb. of levels	109±2	116±2	43±6	162±5
	C+Y	C+M	M+Y	C+M+Y
Global ΔE^*_{94}	65.02±0.61	73.19±0.47	65.31±0.54	85.37±1.54
Nb. of levels	93±7	147±4	71±5	126±10

Table 4 : Number of colorlevels obtained from addressed 8 bit levels in C, M, Y, K, C+Y, C+M, M+Y and C+M+Y for sheet-feed offset with FM screening.

	C	M	Y	K
Global ΔE^*_{94}	48.64±1.58	54.11±0.58	42.02±0.35	68.65±0.38
Nb. of levels	78±6	96±3	47±3	153±2
	C+Y	C+M	M+Y	C+M+Y
Global ΔE^*_{94}	96.61±3.54	75.85±2.15	67.43±3.14	97.68±5.38
Nb. of levels	72±8	122±6	90±12	115±12

Table 5 : Number of colorlevels obtained from addressed 8 bit levels in C, M, Y, K, C+Y, C+M, M+Y and C+M+Y for sheet-feed offset with non-impact Xeikon.

4. Accuracy in color management and conclusion

Our search did not indicate any literature available pointing out adaptable methods to understand error propagation between the devices used in the color reproduction chain. Traditional methods used to evaluate the resulting errors in interacting signals overlayed by random errors do not apply in our case since they base on the assumption that one can add the fourier transforms of the (11). Since the noise under view is both time and dot area dependent such an is inappropriate and we can just estimate the resulting errors in the process.

As pointed out, spectrometers and scanners perform both reproducible to a degree of a mean $\Delta E^*_{94}=0.2$.

In an ongoing study we evaluate the accuracy of the ICC approach (12). It turns out that the inaccuracy obtained between using and not using color management systems is significant. However, using color management for the scanners under view we still obtained a medium $\Delta E^*_{94}=5.0$ using an ICC profile and up to $\Delta E^*_{94}=9$ without.
That is why, studying scanners, the calculation of a profile should also be taken into account. In addition to the out-pointed errors, there may be quantization errors of the software used. We have no numbers describing those errors.

Thus one cannot not expect the ICC approach to lead to an accuracy better than ΔE^*_{94}=0.4 in scanner reproduction. In addition, even when not taking quantization errors into account, significantly higher errors may randomly occure for this device type. The fact that the medium errors obtained are signifivantly higher than that may point to weaknesses in the softwares used or weaknesses in the ICC approach.

Dealing with presses and drivers, our results indicated that they were able to reproduce between 80 and 200 color levels on the basis of 8 bit data. Tests with profiles for offset printing conforming to the BVD/FOGRA standard (8) resulted in an average color deviation of ΔE^*_{ab}=3 to ΔE^*_{ab}=5 and a maximum deviation of ΔE^*_{ab}=9 to ΔE^*_{ab}=10 for the basic patches of the IT8/7.3 test plate (13) when simulated on a dye sublimation printer. The results published in reference (14) of the bibliography result into the same range of color deviation. They are also comparable with results presented in reference (15) of the bibliography.

As for scanners, the calculation of a profile should also be taken into account. The profile should be based on overaged measurements in order to reduce the error due to deviation during a run. As indicated by the reproducible color levels, the presses are not able to print color depths of 8 bit.

Given measurement errors and errors occuring when producing the profiles are to be taken into account in the case of printers, too, one has to at least average the random errors in the production of the profile by measuring a significant amout of targets or estimate an inaccuracy of the profile in the region of at least a medium ΔE^*_{ab}=3.0. Averaging over a larger amount of sheets may lead to the creation of more accurate profiles, but to expect color management for printers to lead to an accuracy significantly higher than a medium DE^*_{94}=5 +/- 2 on an individual sheet under view depending on the CMM and printer or presses involved in reproduction is asking too much.

Concluding one may say that the results presented for printers indicate that if appropriately using ICC profiles and the CMMs and if the profiles were generated with the fidelity of printers, the printers used in the color reproduction may produce a reproducibility close to the random error. Scanners perform better in this respect. However, there is a need to create theory that results into means to calculate error propagation in subsequent processes like in the reproduction of color data.

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