Characterization of Multicolor Printing: Challenges and Solutions

Hanno Hoffstadt

Keywords: expanded color gamut, modeling, n-color, test charts

Abstract

Characterization of overprinted inks is the basis for color management. For multicolor printing beyond CMYK, a reliable characterization of the color of overprints is still a challenge in general. Also, thousands of different spot colors are used in packaging in changing combinations, each asking for another test print.

For the special case of Expanded Color Gamut (ECG), many spot colors can be replaced by a fixed set of 6 to 8 process inks. In that case, the effort of a carefully controlled test print for a full characterization is much more worthwhile, but also indispensable. This has led to an IDEAlliance® project to create a standard 7-color CMYKOGV test chart, in which the author participates.

The sampling of ink combinations has been done using incomplete regular grids of up to 4 overprinted inks. A layout has been developed where the first page alone should provide a good characterization, which can be augmented by using pages 2 – 4. The uncertainty from printing fluctuations can be estimated using many duplicate patches. For evaluation, two other charts have been created, one with patch combinations in the grid centers which maximizes interpolation error, and another which covers many overprints of more than 4 inks.

The paper presents the results from the first offset test prints, where all available overprints are predicted from a subset of patches using GMG OpenColor.

GMG GmbH & Co. KG

Introduction

Color management includes process calibration, color separation, and color conversions, with the help of profiles. Everything is based on **print characterization** – measuring the color of overprinted ink combinations –, from which calibration aims, and ultimately standards, can be developed. An ink combination consists of tone values per ink, each in the range 0–100 %. The produced color is sufficiently described by CIELAB values.

The standard procedure is to calibrate the printing process first, then to print and measure a test chart, and finally to make a profile which contains the characterization as a table which can be interpolated.

There are standard test charts for CMYK (IT 8.7/4-ISO 12642), but not for multicolor printing. Its combinatorics immediately lead to impractically high numbers of patches. A full characterization of all those ever-changing multicolor combinations that occur in day-to-day packaging production is therefore usually avoided. This makes overprints with arbitrary spot colors difficult to predict, so that they are often simply not used in the design.

In the so-called **expanded color gamut (ECG)** use case, which uses traditional **CMYK** process inks and **OGV** (or red/blue), most spot colors can be replaced by a fixed set of 6 to 8 process inks (CMYK + O (red/orange), G (green), V (blue/violet), and sometimes gray ink for dairy products, if the color of their overprints is known with sufficient precision (assuming a suitable calibration strategy, which is not covered by this paper).

The extra process inks can increase gamut size and hue stability in separations. So, with such a fixed ink set, the effort of a carefully controlled test print for a full characterization is easily justified. In the first part of this paper, general concepts are summarized to design a multicolor test chart. Then the focus will be on a 7-ink ECG test chart and its performance.

About the size of test charts

It is helpful to briefly cover the relation between amount of patches and reasonable real estate on a printing test form. Annex B in ISO 13655 relates minimum measurement diameter to screen ruling. It is recommended to have 15 periods in the aperture. For a 150 lpi screen, the diameter would be 2.5 mm. Including positioning tolerance, a feasible patch size is at least 4 mm × 4 mm. A typical A4 or US Letter page could then hold 3800 patches.

Many widespread instruments have a larger aperture, so that 6 mm × 6 mm are required for spot measurement mode (1900 patches/page). Scanning mode needs longer patches and contrast between patches which can be achieved by a special ordering or by optional gaps. A typical specification is 8 mm × 7.5 mm for scanning (allowing only about 1000 patches/page).

Test forms usually contain test charts and evaluation images to check the resulting characterization. Even for large format presses, more than 4 pages of test charts are usually too much.

Historical review: ideas behind CMYK test charts

The history of CMYK test charts started small. Because CMY is most important for color, a grid was used (e.g. 5×5×5 steps of 0–20–40–70–100 %). Such Cartesian grids are required by grid-based interpolation (like cellular Neugebauer meth- ods (Wyble and Berns, 2000). They can be easily interpolated, if all grid points are known.

For K, a separate wedge was added (e. g. LinoColor PrintOpen 135, GMG TC3). This required some model to add the effect of black on CMY.

The first improvements were to help the model by guiding "black lines", adding increasing K to a few CMY combinations (Logo ProfileMaker™ TC2.9, LinoColor PrintOpen 210). But higher precision was needed for GCR and UCR separations, which led to "black planes" with complete CMY grids (ColorBlind, GMG TC4, Monaco Profiler). A model was now less important, since these black planes provided a good basis for interpolation.

Looking at the first standardized CMYK test chart, the IT8.7/3 (ISO 12642), this principle can be easily recognized, because complete CMY grids are contained for six levels of black (0, 20, 40, 60, 80, 100%). The later versions ECI2002 and IT8.7/4 mostly extended the CMY grid resolution but not the concept.

Finally, gradation detail was captured with dedicated wedges (IT8.7/3, Logo ProfileMaker™ 3 TC6.02). Automated measurement devices became common and imposed a practical limit of one A4 or US Letter page. The standard IT8.7/4 test chart has 1617 patches at a size of 6×6 mm, which are arranged in a rectangle of 33×49 patches in the standard visual and randomized layouts.

The "black planes" of the IT8.7/4 have the following CMY grids (Tab. 1). With increasing K, the resolution of the CMY grids can be decreased, because black ink compresses the gamut of the remaining inks (toward a small dark lump), so that the CMY grid resolution does not have to be kept at 9 steps. Note how higher K levels have CMY grids which are subsets, which isolates the effect of K at constant CMY (like black lines do).

In addition, there are single-ink wedges every 5 % (plus 2,3,7, and 98 %), and gray balance patches on the same 6 K planes with the following CMY values:

(5,3,3) – (10,6,6) – (20,12,12) – (40,27,27) – (60,45,45) – (80,65,65) – (100,85,85).

K plane	CMY grid steps									number
0	0	10	20	30	40	55	70	85	100	9x9x9
20	0	10	20		40		70		100	6x6x6
40, 60	0		20		40		70		100	5x5x5
80	0				40		70		100	4x4x4
100	0				40				100	3x3x3

Table 1: *CMY grids of the black planes of the IT8.7/4. Some other grids have been omitted here.*

Additional aspects for more than 4 inks

The most obvious problem arises from combinatorics. The naïve intention is to achieve a uniform sampling of press behavior. One might start by treating all inks with equal rights, and ignoring the reduction by K levels. The highest CMY resolution of the IT8.7/4 is 10–15 % (9 steps), which needs $9^3 = 729$ patches. For 4 inks, we get $9^4 = 6561$ patches, and for 7 inks, $9^7 \approx 5$ million patches.

As said above, the practical limit is 1–4 pages, or 1000–5000 patches for scanning. Even with only 4 steps, we have $4^7 =$**16384** patches at a rather poor grid resolution of 33 %, which is too much. So all opportunities to exclude less useful patches must be exploited. Printing limitations can help to reduce that number, in particular the amount of ink, and the available screens for halftoning.

Usually 7 × 100 % ink is too much ink to be printed. Depending on process and substrate, a limit on the total area coverage (TAC) is imposed, which removes some patches.

Considering that device space is the unit hypercube $[0, 100\ \%]^n$, and a TAC limit L means that the ink sum $\sum x_i \leq L$. For equality, this is a plane $\perp$ to the main diagonal. So the volume of the hypercube is cut by the plane. By symmetry, cutting at half point (half TAC) removes the darker half of the patches. The counted number of patches for equidistant steps are shown in Fig. 1 for the 4-color and 7-color case.

For simplicity, consider that a TAC of 350% is often just printable. For 7 inks and 4 steps, the 16384 patches are reduced to **8192** patches.

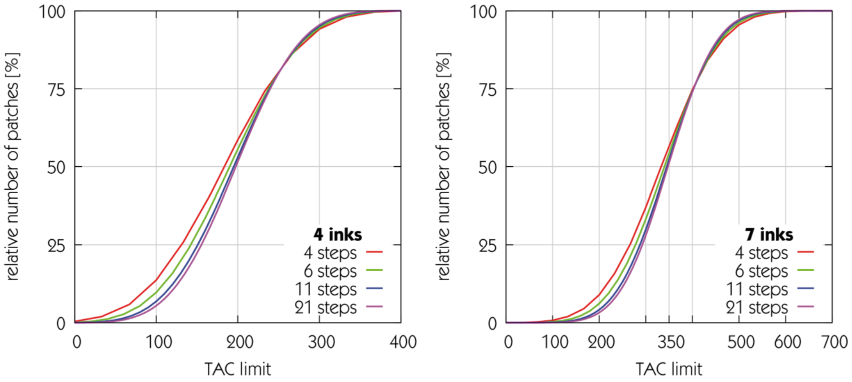

Figure 1: *Counted number of patches, which decrease with TAC limit.*
In a continuous device color space, half TAC means half volume (see text).
This relation is approximated by increasing discrete steps in an equidistant grid.

Reduction by number of overprinting inks

Another possible reduction is inspired by printing only combinations that would be used in separation. Less overprinting inks also mean less color variation and better process control. Historically, Küppers (1985) suggested to use only 3 overprinting inks: YOK, OMK, MVK, VCK, CGK, GYK. Boll (1994) also used six subspaces, but with 4 overprinting inks: GYOK, YOMK, OMVK, MVCK, VCGK, CGYK, of which today mainly YOMK, MVCK, and CGYK are actively used (no combinations of O, G, V).

MVCK is a difficult case for AM screening where only 3 screening angles can be printed without offending Moiré patterns, and a fourth ink must be very light (like yellow) so that the pattern is not very visible. But in MVCK, all 4 inks are dark. So if V is overprinted both with C and with M, it has to use the same screen angle as K. Then, Y can still be used, and the subspace is CMYV instead. In fact, Esko's Equinox™ approach combines four 4-channel test charts printed with CMYK, OMYK, CGYK, and CMYV, so that 4 pages are sufficient, at the expense of not knowing anything about, and therefore not using, overprints of C+O, M+G, and V+K.

So four overprinting inks are sufficient (like CMYK). This reduces TAC too (to at most 400%). For s steps per ink excluding 0, and up to m overprints, the number of patches for n inks is $\sum_{i=0}^{m} \binom{n}{i} s^i$, which is shown in Fig. 2.

For 7 inks, 4 steps (s=3) and 4 overprinting inks (m=4), **3991** patches remain. This gets us the feasible range, so we will continue to focus on this example case.

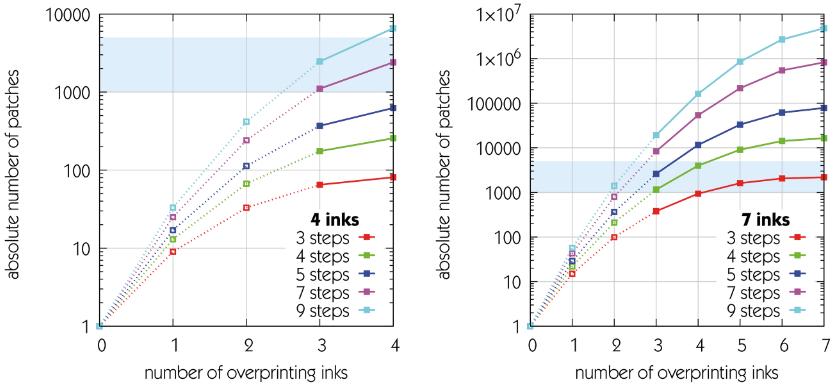

Figure 2: *Number of patches decreases with number of overprinting inks. Less than 3 overprinting inks are shown only for completeness (dotted line). The fea- sible region of 1000–5000 patches is marked blue. For 7 inks and 4 overprinting inks, not more than 4 steps are feasible.*

Reduction by avoiding screen clash

AM halftoning causes screen clash for ink pairs with same raster parameters (typically C+O, M+G, K+V). Such overprints are very sensitive to register variations. Differences can easily reach 20 ΔE_{00} (example in Fig. 3).

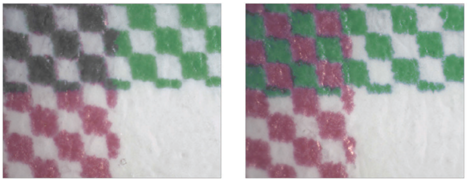

Figure 3: *M+G with same screen. Left: perfect register. Right: worst shift, much darker.*

If we follow the suggested list of subspaces above, C+O and M+G are not used simultaneously in separations, while K+V can occur but is problematic. If we remove all patches which contain such pairs, we end up with **1372** patches in our example case. We might also remove Boll's O+G, G+V, V+O, leading to **832** patches. This is a number which easily fits on a single page. Adding single-ink wedges, it now seems possible to have a relevant one-page test chart.

The reduction steps are summarized in Tab. 2 for the example case of 4 steps (0–33–67–100%) and 7 inks. We still have the option to further reduce the number of patches with high amounts of K. Whether the extremely low resolution of only 4 steps is enough remains to be seen. The guiding principles can be applied for other multicolor cases as well, even if the patch counts will be different.

combinations	TAC	Exclusions	count
all 7 inks (4^7)	700	—	16384
all 7 inks (4^7)	350	—	8192
any 4 out of 7 inks	400	—	3991
any 4 out of 7 inks	400	C+O, M+G, V+Y	1372
any 4 out of 7 inks	400	C+O, M+G, V+Y, G+O, O+V, G+V	832

Table 2: *Systematic test chart reduction and resulting number of steps for the example case of 4 steps (0–33–67–100%) and 7 inks.*

The IDEAlliance ECG test chart project

Within IDEAlliance®, a project has been created to propose a standard ECG test chart (7c, CMYKOGV) which is supported by all major profiling software vendors. Such a test chart should be as universal as possible, not only suitable for offset, flexo, gravure, and digital printing, which also means that no color combinations should be excluded a priori (e. g. O+G). It is recognized that in practice, screen exclusion rules often apply (no C+O, M+G), but screen limitations can be removed by using FM screens.

The test chart should also provide a reasonable CMYK characterization, so that a separate IT8.7/4 chart is not needed. As expected, everybody agreed that K should get a special treatment, meaning less grid steps at higher K values. The result should be a patch list which can be turned into various layouts (max. 4 pages).

Regarding different profiling strategies, there is also the case of approximation (as opposed to interpolation; e. g. in the Argyll Color Management System), which prefers evenly distributed, but otherwise unstructured data and morphs a (thinplate spline based) model to follow the mapping from device space to CIELAB space. If precision is understood as the reproduction of the input training data by the profile, grid-based interpolation has an advantage over approximation. Maybe that is why most profiling vendors preferred to work with a regular Cartesian grid (it is the case for GMG). Also, several preferred a subset of grids at higher K.

A critical aspect is the total ink limit, which does not allow to print some of the grid corners in a 7-ink ECG process (like 5, 6, or 7×100%), so they must be somehow guessed (extrapolated), before interpolation can be used. Incomplete grids thus cannot be avoided. TAC was limited to at most 400%.

The ingredients for the current version 4 combine the ideas from CMYK with the findings from the last sections. There are up to 4 overprinting inks, regular grids, and reduced steps at higher K. The basic 4-step grid was chosen to be 0–40–70–100 for CMYOGV and 0–40–80-100 for K. To achieve a more precise CMYK characterization, a 6-step grid was used with 0–20–40–70–85–100 for CMY and 0–20–40–60–80–100 for K. Other aspects have been considered, for example the inclusion of the G7 gray balance and the Fogra multicolor media wedge.

Near-gray wedges with C=M=Y are placed on the higher-resolution grid of the IT8.7/4 test chart (0–10–20–30–40–55–70–85–100). Grid neighbors are added around this wedge for better gray interpolation.

The gradation is captured with single-ink wedges at 15 steps, which are also aligned with the grid. Finally, there is a complete 2-step 7c grid at 0,40 (not 100). It has up to 7 overprinting inks, so it can lead to screen clashes.

Example layout and staggered pages

An example layout was provided by GMG using 4 pages with 35×30 patches (Fig. 4). It is suitable for many devices and meets the requirements for the X- Rite i1iO2 scan mode. The first page alone is meant to provide reasonable quality (excluding complementary colors). Supplemental pages can be added to improve quality.

Figure 4: *Example layout for the ECG v4 test chart (4 pages)*

Pages 1–3 have repeated single-ink wedges. They record print variation in the single inks and can thus provide a better average behavior. For the same reason, page 4 has repeated overprints of 40 %.

The content of the pages is as follows:
Page 1: basic 7c grid, CMY grid at K=0, wedges, CMY gray at K=0,40,80
Page 2: more 7c, CMY grids at K=20,40,80,100
Page 3: more 7c, CMY grids and near-neutral patches
Page 4: more 7c, CMY grid at K=60, overall rather dark
The additional pages place more emphasis on ECG (see Tab. 3).

page	with ECG	CMYK only	1	2	3	4	5	6	7
p1	608	442	105	201	444	289	0	7	1
p2	811	239	105	60	547	316	21	0	0
p3	675	375	105	63	392	488	0	0	0
p4	914	136	7	27	128	879	6	1	0

Table 3: *Patch counts per page and by number of overprinting inks*

Verification charts

To evaluate the ECG test chart, two other 7-color test charts have been created (Fig. 5). The two-page "**Centers**" test chart has patch combinations in the grid centers, similar to a body-centered cubic grid. At the centers of the grid cells, the interpolation error is maximal. E. g. for 7c, the grid 0,20,55,85 is centered in the grid 0,40,70,100.

The one-page "**Random**" test chart (by ColorLogic and Kodak) contains extra patches with 5 and 6 overprinting inks, and non-grid patches (Tab. 4).

page	with ECG	CMYK only	1	2	3	4	5	6	7
c1	494	556	106	143	638	162	0	0	0
c2	526	524	9	166	715	160	0	0	0
r1	955	95	133	91	119	184	454	66	0

Table 4: *Patch counts per page and by number of overprinting inks*

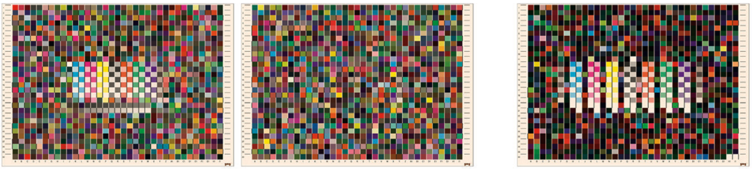

Figure 5: *Verification test charts "Centers" (2 pages) and "Random"*

Test Prints

The performance of the current version 4 has been verified by test prints (Fuji FinalProof, 3 Offset Prints, 1 Flexo Print until end of 2018). One of the offset prints was printed by MAN Roland for the Fogra Multicolor Event (October 2018). The other American printers are anonymized here (Offset 2, Offset 3).

Due to problems with the flexo print, results are only shown for the offset prints (Tab. 5).

print	ink rotation	screening	comments
Fogra	KCMYBOG	C=O, M=G, K=B	only ECG v4
Offset 2	KCMYOGV	C=O, M=G, V FM	ECG v4 + Centers
Offset 3	KCGOVMY	C=O, M=G, V FM	ECG v4 + Centers + Random

Table 5: *Offset test prints conducted in 2018*

Use duplicate patches to see printing variation

There are the same ink wedges on ECG p1, p2, p3, Centers page c1, Random page r1. Often, midtones vary more than solids. For single inks, an average uncertainty of 1–2 ΔE_{00} must be expected (data not shown).

Duplicates of 40 % overprints of 2–4 inks from p1 are on p4 and c1, some on r1. For overprints, an average uncertainty above 2 ΔE_{00} is typical (Tab. 6).

Fogra			
Q_{50}	Q_{95}	N	pair
2.5	5.5	52	p4-p1-op

Offset 2			
Q_{50}	Q_{95}	N	pair
2.1	3.7	35	c1-p3-op
2.4	5.2	52	p4-p1-op

Offset 3			
Q_{50}	Q_{95}	N	pair
2.2	4.1	35	c1-p3-op
1.8	4.5	52	p4-p1-op
2.4	5.1	20	p2-r1-op
2.4	5.1	20	p2-r1-op
4.3	6.4	18	p3-r1-op
5.9	6.6	18	c1-r1-op
1.9	4.2	19	c2-r1-op

Table 6: *ΔE00 percentiles Q50 and Q95 for duplicates of 40 % overprints*

Creating Profiles (1)

The testing procedure was to measure the ECG v4 test chart and the other evaluation charts ("Centers", "Random") using an X-Rite i1iO2 table, then to create profiles from various subsets of the ECG v4 test chart (e. g. from page 1 only). Then all the measurements were compared individually to the profile output using ΔE_{00}.

This way of testing depends strongly on the profiling software. In this paper, GMG OpenColor was used. It uses process-based modeling with spectral data, which describes the mosaic of overprinting dots deposited on a substrate with ink trapping. Model details depend on the process (in this case, offset lithography). The parameters have a physical correspondence and can therefore be measured in principle.

The examined subsets of the data were labeled **p1234, p123, p12, p1**. The labels correspond to the included pages of the ECG v4 test chart, starting from the complete testchart, then skipping the dark page p4, etc., until only page 1 was used.

The average ΔE_{00} by number of overprints was taken and again averaged. These average ΔE_{00} values are shown for each combination of training data subset and measurement file in Tab. 7, and for the "Offset 3" test print in Fig. 6.

training set	p1	p2	p3	p4	c1+c2	r1
fogra-p1234	0.18	0.25	0.25	0.97	–	–
fogra-p123	0.18	0.25	0.25	1.61	–	–
fogra-p12	0.18	0.25	1.98	1.71	–	–
fogra-p1	0.18	1.91	2.13	2.26	–	–
offset2-p1234	0.15	0.14	0.14	0.72	1.24	–
offset2-p123	0.15	0.14	0.14	1.49	1.26	–
offset2-p12	0.15	0.14	1.42	1.62	1.28	–
offset2-p1	0.15	1.92	1.67	2.44	1.38	–
offset3-p1234	0.15	0.15	0.16	0.57	1.33	1.77
offset3-p123	0.15	0.15	0.16	1.38	1.33	2.03
offset3-p12	0.15	0.15	1.71	1.51	1.39	2.21
offset3-p1	0.15	2.45	2.03	2.07	1.47	3.11

Table 7: *Average ΔE₀₀ by training set (rows) for each measurement file (columns)*

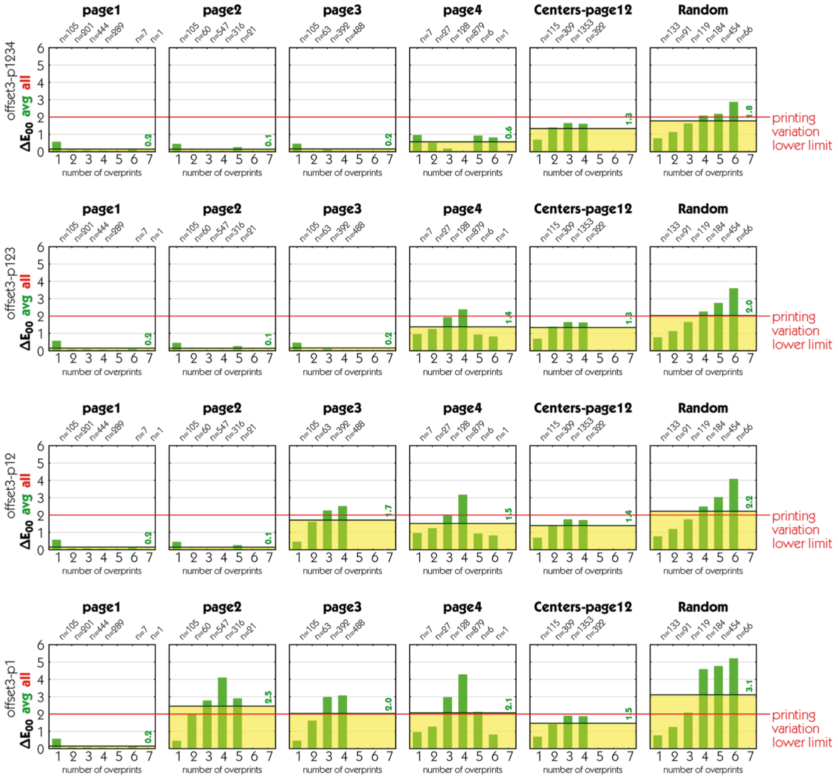

Figure 6: *Average ΔE₀₀ by number of overprints (vertical bars), and their averages (green lines and numbers) for the "offset3" training set, by measurement file*

Discussion (1)

By design of the verification test charts, the result for “Centers” is dominated by interpolation error, which is about 1.4 on average and almost independent of the training data set.

For the “Random” test chart, only available in the “Offset 3” test print, the result is dominated by prediction error, because the “Random” test chart contains many dark combinations which are not covered by the combined grids of ECG v4 pages 1–4. Furthermore, when the dark page p4 is removed from the training data, this error increases, as well as the error for the p4 page itself.

OpenColor internally averages all duplicate patches spectrally. This means that p123 has an average of three single-ink gradations, while p12 only has the average of the gradations from pages 1 and 2, and p1 has only the one gradation of page 1.

For “Offset 3”, the test form layout is shown in Fig. 7. It can be seen that p1 is in the top right part of the sheet. It is likely that this area alone is less representative for the rest of the test form. In fact, the statistics for p2 and r1 (both on the left side) with the training set p1 alone are worst. At the same time, statistics for the neighboring c1 page are not getting worse. This supports that the inking or TVI conditions in the left and right ink zones are different.

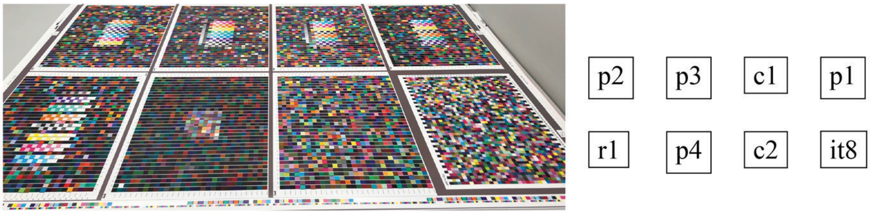

***Figure** 7: Test form arrangement of “Offset 3” across ink zones*

To summarize: with a full characterization (pages 1–4), the model results for the remaining pages are around 2 ΔE_{00} on average. About the same quality is achieved with pages 1–3. Ink zones can have a noticeable influence. Errors for the dark charts (page 4 and “Random”) tend to be highest. However, those patches are less relevant for image separations.

Does this mean that a full or almost full characterization (p1234, p123) is needed and more truthful to the average press result? Given the variation along the ink zones, what is the **ground truth** to compare against?

Creating Profiles (2)

There are two possible problems with the measured data sets. They have shown printing variations of 2 or more ΔE_{00} for overprints, and they contain patches with screen clashes (depending on the different screenings used for Fogra, Offset 2, and Offset 3).

A better ground truth would be to remove the ink zone variation. As an approximation, the average single ink gradations from p1, p2, p3 are calculated. Using the GMG OpenColor prediction technology, the individual pages p1, p2, p3, r1 are then linearized (normalized) to these average gradations, which affects (shifts) all overprints likewise. The procedure is similar to what was used in the construction of the FOGRA51 data set (Hoffstadt, 2016). The other pages p4, c1, c2 have not been adjusted. (p4 and c2 do not contain the needed single-ink wedges. For c1 it would have been possible to do so.)

The examined subsets of the data were labeled as follows:

p1adj	ECG v4 page 1 only, adjusted to average gradation of p1,p2,p3
scw	single-ink wedges of average gradation (21 steps per ink + white)
scw6	subset of single-ink wedges (5 steps 20–40–70–85-100 + white)
scw4	subset of single-ink wedges (3 steps 40–70–100 + white)

To avoid the unstable variations due to the patches with screen clashes, those patches were determined from the respective screening conditions and excluded from the evaluation. Results are shown in Tab. 8 and Fig. 8.

no-clash data	p1adj	p2adj	p3adj	p4	c1+c2	r1adj
fogra-p1adj	0.04	1.22	0.90	1.23	–	–
fogra-scw	1.67	1.96	1.81	1.96	–	–
fogra-scw6	1.88	2.16	2.17	1.98	–	–
fogra-scw4	1.98	2.29	2.26	1.98	–	–
offset2-p1adj	0.00	1.66	1.31	2.05	1.14	–
offset2-scw	1.89	2.68	1.82	2.88	1.94	–
offset2-scw6	1.97	2.73	1.92	2.87	1.87	–
offset2-scw4	1.99	2.7	1.97	2.86	1.91	–
offset3-p1adj	0.04	1.90	1.31	1.80	1.35	1.93
offset3-scw	2.02	2.84	1.86	2.71	2.19	2.79
offset3-scw6	2.12	2.93	2.12	2.71	2.36	2.89
offset3-scw4	2.25	2.95	2.38	2.66	2.71	3.02

Table 8: *Average ΔE_{00} by training set (rows) for each no-clash data set (columns)*

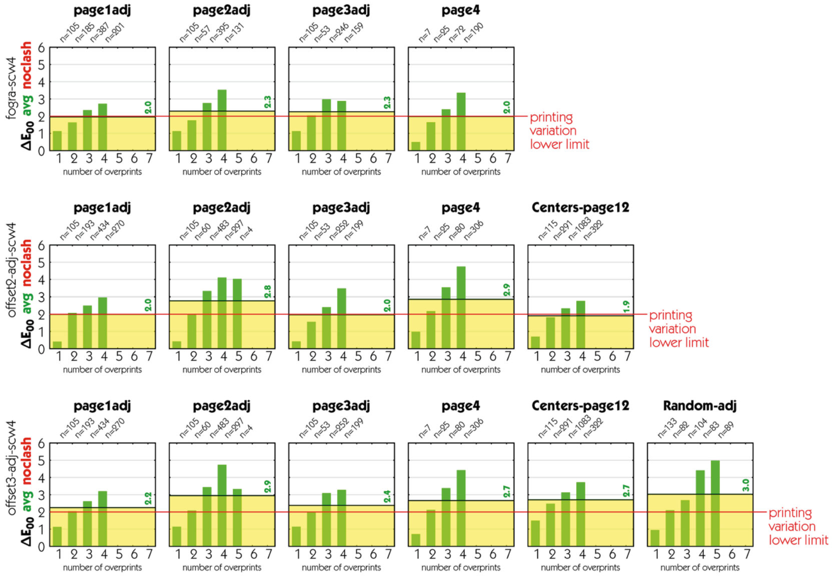

Figure 8: *Average ΔE_{00} by number of overprints (vertical bars), and their averages (green lines and numbers) for the smallest (scw4 22 patch) training sets, by no- clash measurement file, where p1,p2,p3,r1 are adjusted to average gradations.*

Discussion (2)

When only the first – but adjusted – page is fed into OpenColor, all errors for the no-clash data are lower than 2 ΔE_{00} on average. This means that the adjusted p1 is now much more representative and sufficient to achieve a characterization quality which has a lower average than the estimated printing variations.

When only the average single-color wedges (scw) from p1,p2,p3 are used, there are no overprints in the training data set anymore. All corners of the test chart grid except the solid single inks are missing and must be predicted. For these three offset lithography test prints, the errors increase by less than 1 ΔE_{00} for the test data sets, when going from the p1adj to the scw training condition.

Reducing the training data set further to 6 or 4 steps per ink (to 36 or 22 patches, respectively), the errors increase only slightly and mostly stay below 3 ΔE_{00} on average. This means that the test prints have a sufficiently smooth gradation to describe the gradation of each ink in detail with just the steps 0–40–70–100.

This extremely small test chart is like a **print control strip** with multiple patches of 40–70–100 which can be averaged across ink zones to provide the average, representative behavior.

Conclusions

A flexible multi-vendor multi-process ECG test chart was created. Page 1 covers the regular ECG use case (without screen clash) quite well.

It was shown that printing variations must be taken into account (a typical average is $\Delta E_{00} > 2$.

GMG OpenColor can predict to a similar accuracy (shown for offset). If mini-strip test charts are used (down to print control strips), a very consistent, smooth profile is generated which is still quite accurate (average $\Delta E_{00} < 3$) and well achievable on press within printing tolerance.

To get representative data from a test print, it is therefore advisable to use a small chart multiple times, and not to use a single test chart with many pages.

References

Wyble, D. R., Berns, R. S.,
2000 "A Critical Review of Spectral Models Applied to Binary Color Printing," *Col. Res. Appl., Vol. 25*, p. 4–19

Küppers, H.,
1985 "Die Farbenlehre der Fernseh-, Foto- und Drucktechnik," DuMont, Cologne, Germany. ISBN 3-7701-1726-3.

Boll, H.,
1994 "A Color to Colorant Transformation for a Seven Ink Process," *Proc. SPIE, Vol. 2170*, p. 108ff

Hoffstadt, H.,
2016 "How to Create Characterization Data for a Printing Standard," *TAGA 68th Annual Technical Conference*, Memphis, TN.
http://www.eci.org/_media/en/fred15/hanno_hoffstadt_taga2016_v2.pdf

Acknowledgments

Many thanks to Ron Ellis for leading the project, and to the other contributors, especially the printing companies which provided the test prints (remaining anonymous here). The participating profiling software companies have been Alwan, ColorLogic, Esko, GMG, Heidelberg, Kodak, and X-Rite.