Substrate Correction in ISO 12647-2

Robert Chung* and Quanhui Tian**

Keywords: ISO 12647-2, solid, substrate, substrate-corrected aims, TVI, grey reproduction

Abstract

Currently, ISO 12647-2 (2004) specifies paper color with aim points and tolerances, but does not treat it as a normative requirement because more and more production papers are out of tolerance. This paper describes a printing experiment to investigate the effect of substrate-corrected colorimetric aims on solid, TVI, as well as on grey reproduction conformance. It concludes that (a) depending on the color of the ink, its ink film thickness, and the color of the paper, overall solid conformance may be improved when substrate-corrected colorimetric aims are used during press make-ready; (b) there is no difference between substrate-corrected TVI aims and target TVI aims; and (c) the tristimulus linear correction can be used to calculate the substrate-corrected grey ramp.

Introduction

There is a dilemma in printing standardization, i.e., substrate colors are specified in ISO 12647-2 standards; but more and more production papers, containing optical brightening agent (OBA), exceed the ISO tolerance limits. Such a quandary has caused concerns and confusions for printers. It also creates difficulties for certification bodies when certifying printing conformity according to ISO 12647-2.

* Rochester Institute of Technology, Rochester, NY, USA
** Shanghai Publishing and Printing College, Shanghai, China

There are two approaches to address the problem: (1) moving the substrate aim to a large negative b* value, and (2) adjusting colorimetric aims for substrate color difference. The first approach, while reducing color differences for some bluish substrates, does not solve the wide variance of substrate colors. The second approach is more promising than the first, but requires more understanding.

The authors studied OBA induced color measurement bias on printed colors and how these color differences may be modeled (Test Targets 10, 2011). While there is an overall reduction of color difference by using any one of the three correction methods, there is no clear understanding, to what extent, printed solid, TVI, and grey reproduction will improve.

Research questions

We wish to explore and answer the following questions: (1) What is the colorimetric effect of OBA on printed solids? (2) How should colorimetric aims for solids be corrected? (3) How should substrate-corrected solid aims be implemented? (4) What is the effect of substrate-corrected aims for TVI and grey conformance? In this research, some of the questions are answered by literature review; others are answered by designed experiments.

Experimental

Effect of OBA on printed solids and its conformance

Optical Brightening Agent (OBA) is a mixture of monomer and dimer. It absorbs UV energy from the light source and emits the energy back into short wavelength visible light. Figure 1 illustrates the spectral reflectance difference between paper with and without OBA. As a result, OBA increases the Z value significantly, and moves paper color towards increased L* and reduced b*, i.e., less yellowish or more bluish.

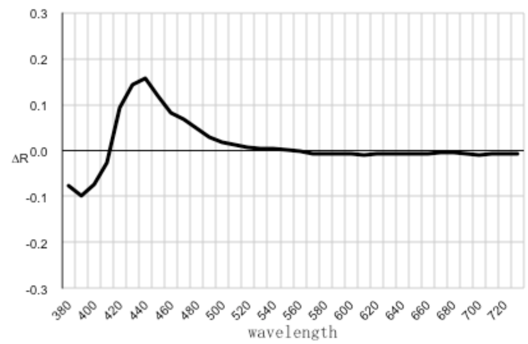


Figure 1. Spectral reflectance difference of paper with and without OBA.

If we print with certified process inks of cyan, magenta, and yellow solids on the two papers (with and without OBA) and measure them with a spectrophotometer under M0 conditions, their spectral reflectance differences are shown in Figure 2. The spectral difference is less pronounced for the yellow solid because yellow absorbs short wavelength visible light, thus, made yellow less chromatic (reduced yellowness), but without hue shift. However, neither cyan nor magenta absorbs short wavelength energies. Thus, the addition of short wavelength visible light makes magenta more bluish-red and cyan more bluish-green (more blueness). Appendix A describes spectral reflectance curves of paper and CMY inks on paper with and without OBA, their spectral reflectance difference, as well as their colorimetric differences.

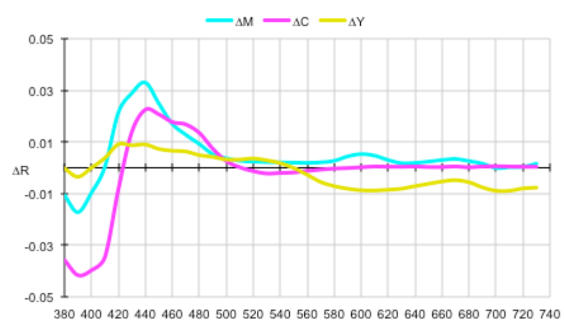


Figure 2. Spectral reflectance differences of CMY solids between paper with and without OBA.

Printing conformance to ISO 12647-2 requires the use of the correct ink printed at the correct ink film thickness. An efficient way of finding correct ink film thickness (or density) is to (a) provide even inking supply to all ink keys of an offset press, (b) print the ink starvation form (Figure 3), (c) generate a series of solid ink densities across the same press sheet due to uneven ink consumption of the test form, and (d) measure color difference (ΔE) as a function of ink film thickness (or density).

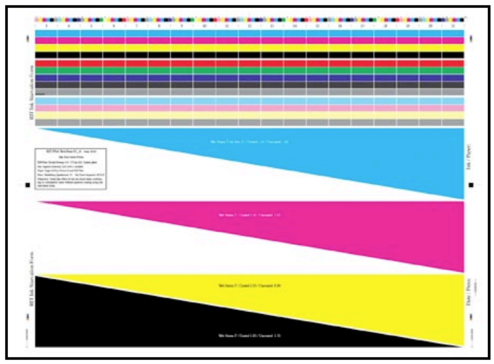


Figure 3. Ink starvation test form.

Figure 4 is the cyan inking conformance profile. The cyan solid density of 1.35 (Inking_1), producing the closest match to ISO 12647-2 (PT1) colorimetric aim, has a color difference of 3.9 ΔE.

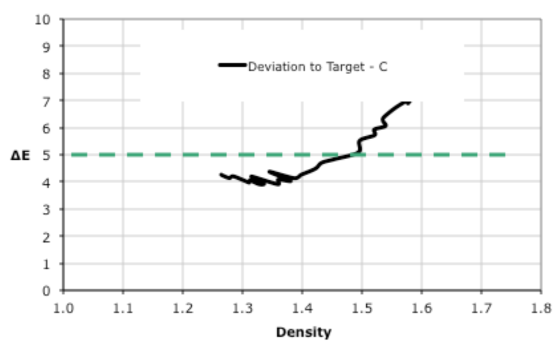


Figure 4. Relationship between ink film thickness and ΔE (published aim).

Table 1 summarizes CMYK solid conformance on paper containing OBA. ISO 12647-2 aims are shown in yellow-highlighted row. Here, (a) paper is out of conformance; (b) magenta solid is in conformance, and (c) cyan solid, at its optimum inking condition, has a color difference of 3.9 ΔE. The tolerance for solid is 5 ΔE. In other words, the OBA induced bias on solid is close to 80% of the tolerance allowed.

Table 1. Solid color conformance under Inking_1 and published aims.

	ISO 12647-2 (PT1)					ΔEab
	L*	a*	b*	C*	h	Inking_1
Paper	95	0	-2	2	270	5.5
	94.1	2.1	-7.0	7	286	
K	16	0	0	0	0	0.7
	16.3	0.4	-0.5	1	311	
C	55	-37	-50	62	233	3.9
	56.4	-33.8	-51.8	62	237	
M	48	74	-3	74	358	0.3
	48.3	74.0	-2.9	74	358	
Y	89	-5	93	93	93	1.5
	88.6	-3.6	92.7	93	92	

Substrate-corrected colorimetric aims

There are three topics of interest under the heading of substrate-corrected aims. First, we need to decide why apply substrate correction to the aim and not to the measurement. Second, we need to decide what equation to use to accomplish the result. Finally, we need to know if substrate-corrected aims alter the relationship between ink film vs. ΔE.

To answer the first question, printing with ink and paper is real. Thus, measurement of a real printed color results in an objective value that should not be changed. When the printed color does not conform to the target aim based on a different paper color, our only option is to mathematically adjust the target colorimetric aim to account for the effect of the paper on the printed color. The substrate-corrected aims or data set is, then, used to judge the printing conformity.

To answer the second question, one of the solutions for calculating substrate-corrected aims is based on the tristimulus linear equations for measurement backing correction (ISO 13655, 2010). The tristimulus linear correction equation is shown below:

$$X_2 = X_1(1 + C) - X_{\min}C$$
$$C = \frac{X_{w2} - X_{w1}}{X_{w1} - X_{\min}} \qquad \text{Eq. (1)}$$

X_1 is one of the tristimulus values of Substrate_1 or target aim.
X_2 is one of the substrate-corrected tristimulus values based on Substrate_2.
C is a constant.
X_{w1} is one of the measured tristimulus values of Substrate_1.
X_{w2} is one of the measured tristimulus values of Substrate_2.

X_{min} is one of the minimum tristimulus values of TAC_{Max} printed on Substrate_1.

The computational procedures are: (a) given printed colors on $Paper_1$ and the color of $Paper_2$ in CIELAB space; (b) convert CIELAB to CIEXYZ; (c) calculate the quantity, C, for X, Y, and Z using CIEXYZ of $Paper_1$, $Paper_2$, and Xmin (approximated as (10L*, 0a*, 0b*) in the CIELAB space.; (d) convert Color_1 to Color_2 in CIEXYZ space by Eq. (1); and (e) convert the substrate-corrected CIEXYZ (Color_2) back to CIELAB space.

Results

Substrate-corrected colorimetric aims for solid conformance

As shown in Figure 5, the relationship between cyan ink film and ΔE derived from the target aims (solid line) and the relationship between cyan ink film and ΔE derived from the substrate-corrected aims (dotted line) are different. A higher cyan solid density (1.50) is necessary in order to yield a lowered color difference of 2.1 ΔE from the substrate-corrected aims at Inking_2.

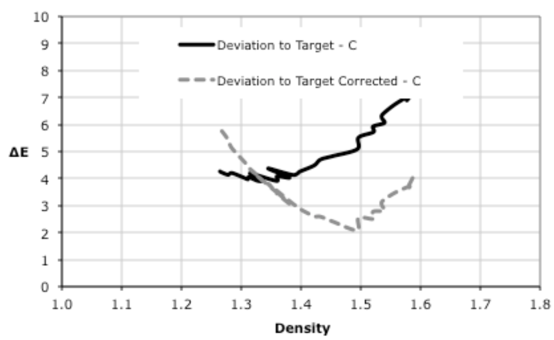


Figure 5. Relationship between cyan ink film thickness and ΔE (published and substrate-corrected aim).

Table 2 shows a number of important findings under Inking_2 conditions: (a) the paper difference is nulled, (b) cyan solid conformance is improved (from 3.9 ΔE to 2.1 ΔE), (c) black and yellow solid conformance remain the same, and (d) magenta conformance is worsened (from 0.3 ΔE to 2.5 ΔE). The relationship between black, magenta, and yellow ink film thickness and ΔE (target and substrate-corrected aim) can be found in the Appendix B.

Table 2. Solid color conformance under Inking_2 and substrate-corrected aims.

	ISO 12647-2 (PT 1) Corrected					ΔEab
	L*	a*	b*	C*	h	Inking_2
Paper	94	2	-7	7	286	0.0
	94.1	2.1	-7.0	7	286	
K	16	0	-1	1	292	0.2
	15.8	0.4	-0.5	1	304	
C	54	-36	-54	65	237	2.1
	54.0	-33.6	-53.6	63	238	
M	48	75	-6	75	356	2.5
	49.2	73.3	-4.8	73	356	
Y	88	-3	90	90	92	1.3
	88.8	-4.0	90.6	91	93	

One may wonder what will the result be if substrate-corrected colorimetric aims are compared to the press sheet under Inking_1? The results, shown in Table 3, indicate that (a) black continues to be immune from substrate correction, and (b) all three chromatic colors have larger ΔEs than Inking_2 sample. This points out the importance of correct inking (Inking_2) in order to lower ΔE between the measurement and substrate-corrected aims.

Table 3. Solid color conformance under Inking_1 and substrate-corrected aims.

	ISO 12647-2 (PT 1) Corrected					ΔEab
	L*	a*	b*	C*	h	Inking_1
Paper	94	2	-7	7	286	0.0
	94.1	2.1	-7.0	7	286	
K	16	0	-1	1	292	0.5
	16.3	0.4	-0.5	1	311	
C	54	-36	-54	65	237	3.5
	56.4	-33.8	-51.8	62	237	
M	48	75	-6	75	356	3.1
	48.3	74.0	-2.9	74	358	
Y	88	-3	90	90	92	2.6
	88.6	-3.6	92.7	93	92	

To sum up, ISO 12647-2 specifies aim point and tolerances for paper. Yet, substrate color is often non-conforming and it impacts conformance of printed solids. Substrate-corrected colorimetric aims will improve conformance of printed solids when color of the ink, its ink film thickness, and the paper color are accounted for.

Substrate-corrected colorimetric aims for TVI conformance

Regardless measured TVI, the question is, "Is there difference between dataset-based TVI and substrate-corrected TVI?" By calculating colorimetrically computed TVIs per Eq. (2) ~ (4) (ISO 10128, 2008), we found there is no difference between target TVI values and those calculated with the use of substrate-corrected aims. This is because (a) the Murray-Davies equation for TVI calculation uses solid and tint that are tristimulus-based, (b) the substrate correction is linear in the tristimulus color space, and (c) the ratios of solid and tint remain the same.

$$\text{TVI} = 100\left(\frac{Y_p - Y_t}{Y_p - Y_s}\right) - TV_{Input}$$

Eq. (2) for magenta and black

$$\text{TVI} = 100\left(\frac{Z_p - Z_t}{Z_p - Z_s}\right) - TV_{Input}$$

Eq. (3) for yellow

$$\text{TVI} = 100\left[\frac{(X_p - 0.55Z_p) - (X_t - 0.55Z_t)}{(X_p - 0.55Z_p) - (X_s - 0.55Z_s)}\right] - TV_{Input}$$

Eq. (4) for cyan

Substrate-corrected colorimetric aims for grey reproduction conformance

There is plenty awareness regarding the fact that paper color influences grey reproduction. ISO/WD 12647-2 (2010) proposes the use of Eq. (6) for calculating a substrate-corrected grey ramp. Here, (L^*_{paper}, a^*_{paper}, b^*_{paper}) is the substrate color and (L^*_{cmy}) is the color of the CMY-overprint.

$$a^* = a^*_{paper}\left(1 - 0.85\frac{L_{paper}^* - L^*}{L_{paper}^* - L_{cmy}^*}\right)$$
$$b^* = b^*_{paper}\left(1 - 0.85\frac{L_{paper}^* - L^*}{L_{paper}^* - L_{cmy}^*}\right) \quad \text{Eq. (5)}$$

Figure 6 is the comparison of substrate-based grey ramp between Eq. (1) and Eq. (5). In order to show there is complete agreement between the two methods, the grey ramps are slightly shortened on either end for the Eq. (5).

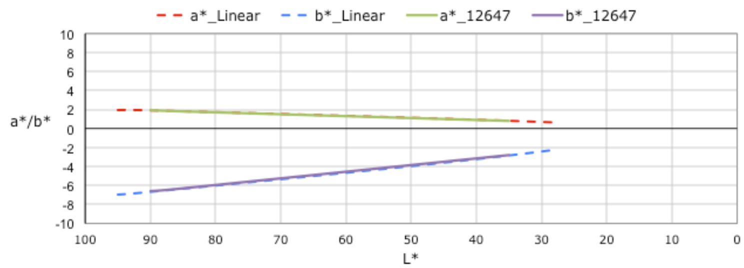


Figure 6. Substrate-based grey reproduction ramp.

ANSI/CGATS Committee is developing a G7 (IDEAlliance, 2009) or greyscale-based press calibration method to achieve specified printing aims (CGATS/TR, 2011). The specification defines grey balance as a function of paper color (expressed in CIE a* and b*) where a* and b* values for each greyscale step are reduced towards zero as the grey scale darkens (Eq. 6). Because it starts with the paper color and the transition is linear, there is complete agreement between the method and the use of Eq. (1) to derive substrate-corrected grey ramp.

$$a^* = a^*_{paper} \times \frac{100 - C\%}{100}$$
$$b^* = b^*_{paper} \times \frac{100 - C\%}{100} \qquad \text{Eq. (6)}$$

The lesson learned here is that (a) there is awareness that substrate color impacts grey reproduction, and (b) there is less awareness that substrate color impacts printed solids. In addition, Eq. (5), as proposed in ISO/WD 12647-2 (2010), and Eq. (6), as proposed in G7 Master Pass/Fail (2011), can only generate a substrate-corrected grey ramp. Yet, Eq. (1) can generate substrate-corrected aims, including solids and grey ramp.

Conclusions

This research investigates the effect of substrate correction on solid color conformance as well as its effect on TVI and grey reproduction conformance. This research concludes that (a) fixed paper aim points and tolerances in ISO 12647-2 (2004) cause non-conformance due to OBA; (b) paper color also impacts printed solid conformance; (c) substrate-corrected colorimetric aims can be calculated using the tristimulus linear correction method, described in ISO 13655; (d) depending on the color of the ink, its ink film thickness, and the color of the paper, overall solid conformance may be improved when substrate-corrected colorimetric aims are used during press make-ready; (e) substrate-corrected TVI aims is the same as the initial TVI aims; and (f) the tristimulus linear correction can be used to calculate the substrate-corrected grey ramp.

Looking ahead, ISO 15339 (ISO, 2010) uses substrate-corrected aims to make printing aims relevant, i.e., (a) the designer picks the appropriate gamut (characterization dataset), and (b) the printer/client chooses the substrate. Once the dataset and substrate are known, substrate correction is applied to each patch in the target dataset (including solids and neutrals) and the resulting substrate corrected aims is used as the target for conformance of both contract proofing and printing.

Acknowledgments

The authors wish to express their appreciation to the following individuals and organizations: Mr. David McDowell, Standards Consultant, for his encouragement and helpful discussion on substrate correction; Mr. Fred Hsu of RIT for his experimental support; and Mr. Robert Eller, RIT Visiting Scholar, for his review of the paper.

References

ANSI CGATS/TR (2011) Graphic technology — Methodology for Establishing Printing Aims Based on Shared Neutral Greyscale Appearance.

Chung, R. and Tian, Q. (2011), Effect of Paper Containing OBA on Printed Colors, Test Targets 10, 2011 (to be published).

IDEAlliance (2009) G7 How-To Guide.

ISO 10128 (2008) Graphic technology — Methods of adjustment of the colour reproduction of a printing system to match a set of characterization data.

ISO 13655 (2009) Graphic technology-Spectral measurement and colorimetric computation for graphic arts images.

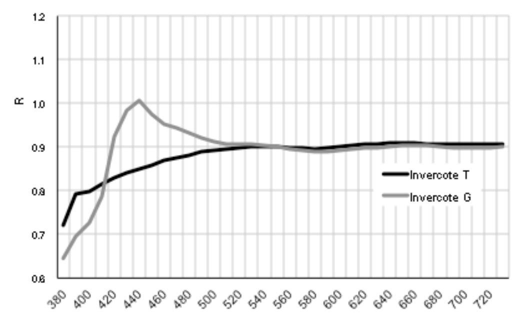
ISO/CD 15339 (2010) Graphic technology — Printing of digital data — Part 1: Basic principles.

ISO/WD 12647-2 (2010) Graphic technology — Process control for the production of half-tone colour separations, proof and production prints — Part 2: Offset lithographic processes.

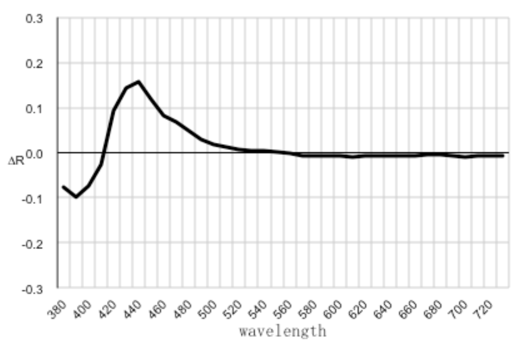
Appendix A.

Spectral reflectance curves of CMYK solids and
their spectral reflectance between paper with and without OBA

Spectral reflectance curves of paper with and without OBA



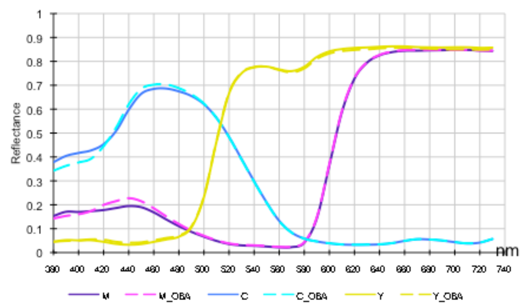
Spectral reflectance difference between paper with and without OBA



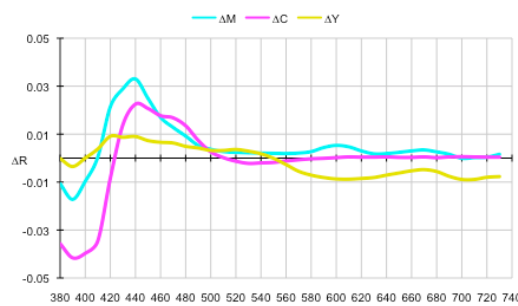
CIEXYZ and CIELAB difference between paper with and without OBA

Invercote T (NoOBA)			Invercote G (OBA)		
X	Y	Z	X	Y	Z
86.4	89.9	71.3	87.2	90.1	78.8
L*	a*	b*	L*	a*	b*
95.9	-0.53	2.56	96.0	0.76	-3.82
ΔX			0.87		
ΔY			0.18		
ΔZ			7.57		
ΔE			6.52		

Spectral reflectance curves of CMY solids printed on paper with and without OBA



Spectral reflectance difference of CMY solids between paper with and without OBA



CIEXYZ and CIELAB difference of CMY solids between paper with and without OBA

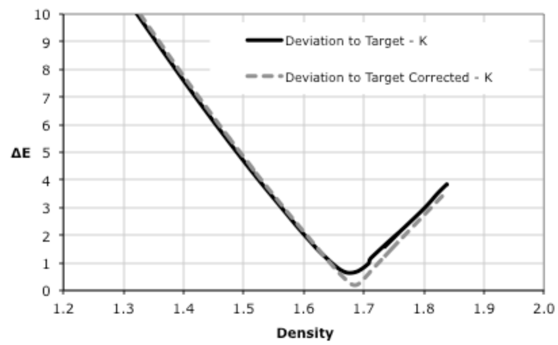
Color	X	Y	Z	L*	a*	b*	ΔX	ΔY	ΔZ	ΔE
M	32.5	16.4	13.0	47.4	74.6	1.4	0.55	0.32	1.57	3.51
M_OBA	33.1	16.7	14.6	47.8	74.8	-2.1				
C	14.8	22.5	51.6	54.5	-36.2	-49.4	0.19	0.00	1.18	1.74
C_OBA	15.0	22.5	52.7	54.5	-35.0	-50.7				
Y	68.5	71.7	5.96	87.8	-1.43	95.74	-0.43	-0.24	0.56	2.76
Y_OBA	68.1	71.5	6.52	87.7	-1.86	93.01				
K	1.82	1.88	1.53	14.82	0.23	0.19	0.00	-0.01	0.00	0.18
K_OBA	1.82	1.87	1.53	14.78	0.39	0.12				

Appendix B

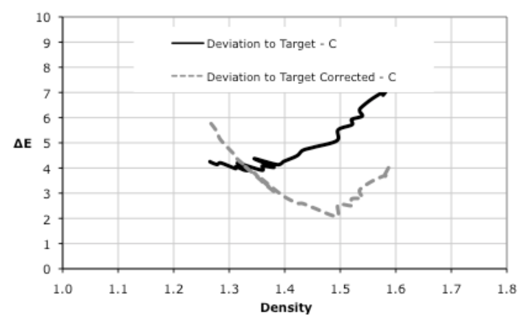
Relationship between ink film thickness and ΔE

The following graphs are produced by (1) printing the "ink starvation" test form, (2) measuring a series of cyan, magenta, yellow, and black solid ink films colorimetrically, (3) calculating color difference between the measurement and two kinds of printing aims, i.e., (a) published aims as solid lines, and (b) substrate-corrected aims in dashed lines.

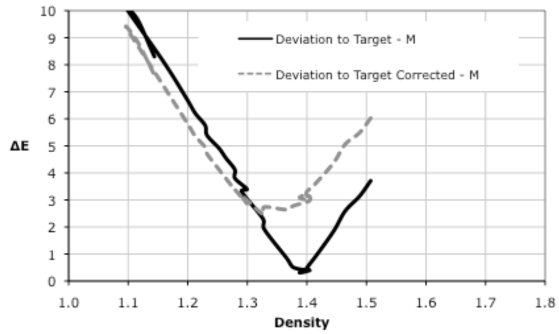
Black solid — No difference in ink film between published and substrate-corrected aims



Cyan solid — A large ink film difference between published and substrate-corrected aims.
The substrate-corrected aim improves the conformance significantly.



Magenta solid — Some ink film difference between published and substrate-corrected aims.
The substrate-corrected aim does not improve the conformance.



Yellow solid — A small ink film difference between published and substrate-corrected aims.
The substrate-corrected aim improves the conformance slightly.