Quantitative Analysis of Tone Value Reproduction Limits

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Keywords: Standard, Tonality, Highlight, Shadow, ΔE^*_{ab}

Abstract

ISO 12647-2 (2004) defines "tone value reproduction limits" requirement as, half-tone dot patterns within 3% to 97% shall transfer onto the print in a consistent and uniform manner, but without a clearly stated test method. This research examines the definition of "tone value reproduction limits" closely and developed a test method that analyzes tone value reproduction limits from an input (tone value) and output (tonality change) point of view. The premise is that the tonalities of specified dots are verified if these dots, when printed, render sufficient tonal differentiation between these dots and their local references. The test method defines highlight contrast in terms of ΔE^*_{ab} between highlights (ranging from 2-10%) and the paper (0%). It defines shadow contrast in terms of ΔE^*_{ab} between shadow dots (ranging from 90-98%) and the solids (100%). In order to determine the tolerance, this research studied a database of 35 offset printed jobs. It was found out that (a) there is a linear relationship between ΔE^*_{ab} and tone values in both highlight and shadow region; and (b) by using the "mean minus one standard deviation" of ΔE^*_{ab} distributions, we can single out or fail one-sixth or 17% of the jobs with low tonality contrast. CIEDE2000 was also tested as a metric for tonal contrast determination, and it did not perform as effective as ΔE^*_{ab}. The proposed test method will improve the usability of the ISO 12647-2 by providing documented conformance in assessing tone value reproduction limits and can be adopted to specify tone value reproduction limits for other printing process, such as flexography.

Introduction

Printing standards specify requirements and metrics with aims and tolerances that define the acceptability of printed jobs. The test method should be quantitative, practical, and the requirements are achievable. While assessing printing conformance

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according to ISO 12647-2 (2004), we discovered that the test method for tone value reproduction limits assessment is missing (RIT, 2011). In a separate document issued by the ISO TC130 UK TAG, it also pointed out the same gap (ISO, 2011).

Literature Review

Clause 4.2.2 of the ISO 12647-1 (2002) defines tone value reproduction limits as the lowest and highest tone value in the data or on the colour separation film that transfers on to the print in a uniform and consistent manner. Clause 5.2 of the ISO 12647-1 (2002) only specifies how to assess tonal value on film. As for digital data, the application program specifies the tone value.

Clause 4.3.3 of the ISO 12647-2 (2004) specifies tone value reproduction limits as a normative requirement, i.e., 3 % to 97 % are specified for screen ruling between 40 cm-1 and 70 cm-1, but without a clearly stated test method, e.g., how to measure tonality as printed. Clause 4.3.3 of the ISO/DIS 12647-2 (2011) specifies tone value reproduction limits as an informative requirement, i.e., 2% to 98% are specified for screen ruling between 60 cm-1 and 80 cm-1, but without a clearly stated test method either.

Problem Statement

In terms of tone reproduction specifications, ISO 12647-2 (2004) defines midtone conformity by the tonal value increase of CMYK based on a 50% input value upon printing. The metrics describe input (tone value) and output (tonality) relationship. When ISO 12647-2 (2004) defines tone value reproduction limits requirement, it only describes the input (tone value) to be transferred onto the print in a consistent and uniform manner, but the metrics for output consistency and uniformity are not specified.

This research is aimed at developing a test method that analyzes tone value reproduction limits from an input (tone value) and output (tonality change) point of view. The premise is not about if the specified highlight dot or shadow dot is reproduced in a consistent and uniform manner. This is because “consistency” is a temporal issue and “uniformity” is a spatial issue. Rather, it is a tonal issue -- the tonality change between the specified dots and its local reference (paper for highlight and solid for shadow). When tonalities of these patches are differentiated from their respective references, we basically have the evidence that these limiting patches meet tone value reproduction limit requirements.

Methodology

The flow chart below illustrates a test method for determining tone value reproduction limits (Figure 1). It assumes a digital target containing highlight dots and shadow

dots, a database of printed samples with colorimetric measurements of these highlight dots and shadow dots.

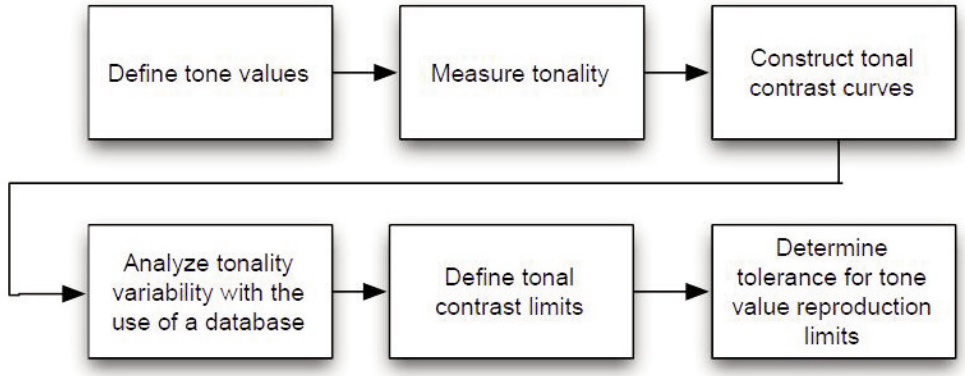

Figure 1. *Flow chart for determining tone value reproduction limits*

Define tone values

This research recognizes that the color characterization target, IT8.7/4, is the input. Input tone values of highlight dots and shadow dots, including their patch ID and coordinates in the randomized target, are shown in Table 1.

Tone Value	Patch ID	Position	Tone Value	Patch ID	Position
K0	1	N11	M0	1	N11
K2	1366	I9	M2	1326	X33
K3	1365	O38	M3	1325	C31
K5	1364	P45	M5	1324	G26
K7	1363	F36	M7	1323	V42
K10	1362	W19	M10	1322	L44
K90	1350	X36	M90	1310	D27
K95	1349	R14	M95	1309	G42
K98	1348	C48	M98	1308	F32
K100	1347	P24	M100	1307	P26
C0	1	N11	Y0	1	N11
C2	1306	2C42	Y2	1346	2A44
C3	1305	W29	Y3	1345	2F41
C5	1304	R48	Y5	1344	U27
C7	1303	S38	Y7	1343	H28
C10	1302	2F2	Y10	1342	K1
C90	1290	2G36	Y90	1330	V46
C95	1289	2G37	Y95	1329	C11
C98	1288	X23	Y98	1328	D46
C100	1287	P27	Y100	1327	P25

Table 1. *Input tone values of highlight and shadow dots*

Measure tonality and construct tonal contrast curves

The tonality of a patch in a single-color ramp is its CIELAB value. A highlight/shadow (H/S) tonal contrast curve is defined as a plot of tonality change between a tone value and its local reference (0% for highlight or 100% for shadow).

To construct the highlight contrast curve, compute and plot ΔE^*_{ab} and ΔC between the paper (reference) and the highlight tone values (2%, 3%, 5%, 7%, and 10%) as a function of %dot. To construct the shadow contrast curve, compute and plot ΔE^*_{ab} and ΔC between the solid (reference) and the shadow tone values (90%, 95%, and 98%) as a function of %dot.

Analyze tonality variability with the use of a database

The PSA database consists of 35 printed and measured IT8.7/4 color characterization targets, submitted for ISO 12647-2 printing conformance assessment (RIT, 2011). Variability is expected in the database and some jobs are expected to fail the tone value reproduction limits requirement. This research is aimed at developing a test method that analyzes tone value reproduction limits from an input (tone value) and output (tonality change) point of view.

Results and Discussion

Tonal contrast curves from the database

Figures 2-5 show ΔE^*_{ab} and ΔCs as a function of dot areas for the highlight and shadow regions for KCMY channels of all 35 jobs. We shall refer the plot as the highlight/shadow contrast curves. Initial observation of these curves suggests that the change in tonality is linear with varying slopes.

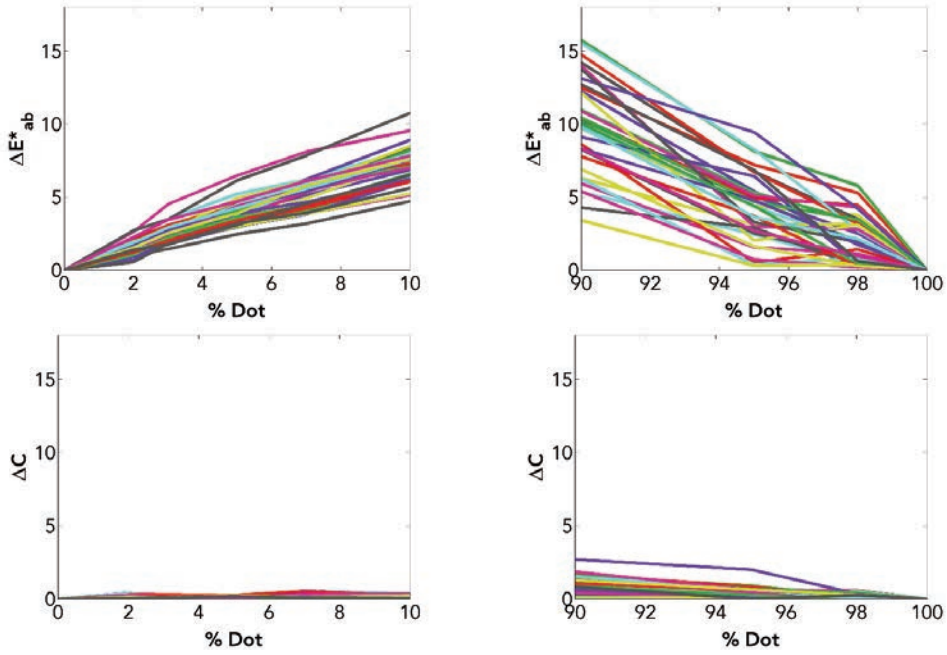

Figure 2. *E*ab and ΔC as a function of K dot areas for the highlight (left) and shadow (right)*

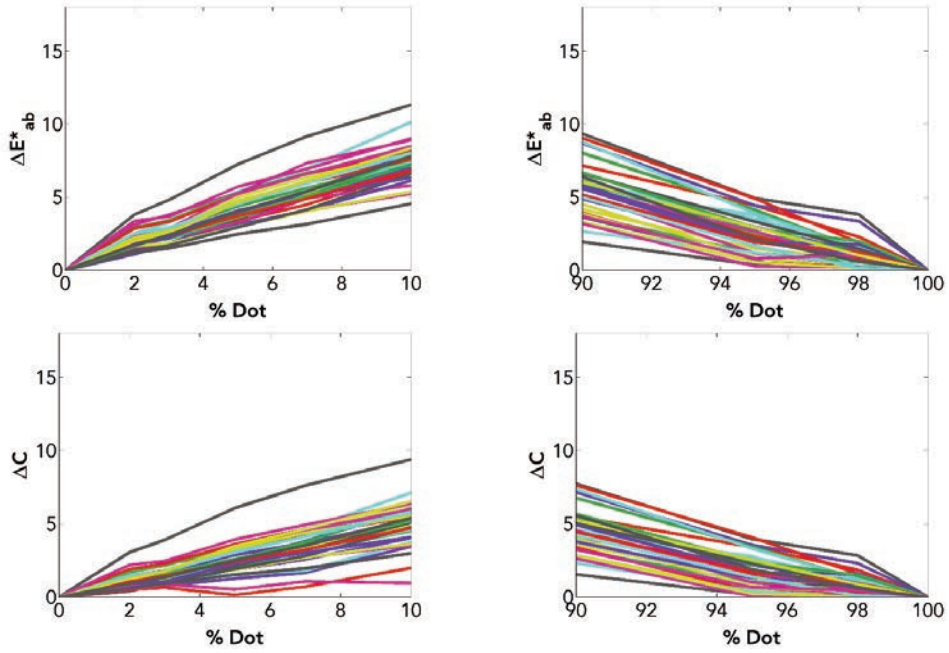

Figure 3. *ΔE^*_{ab} and ΔC as a function of C dot areas for the highlight (left) and shadow (right)*

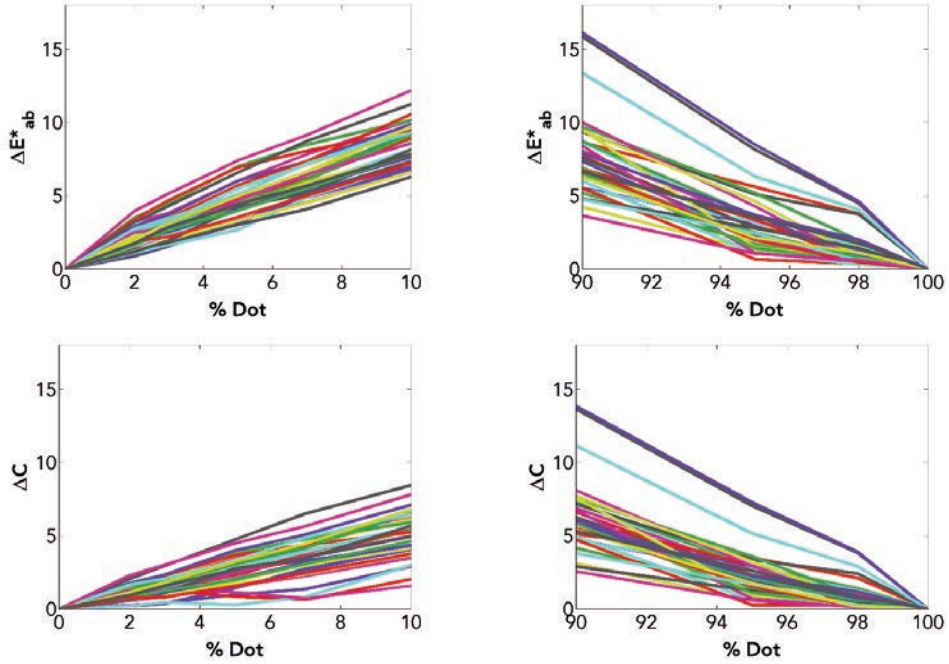

Figure 4. *ΔE^*_{ab} and ΔC as a function of M dot areas for the highlight (left) and shadow (right)*

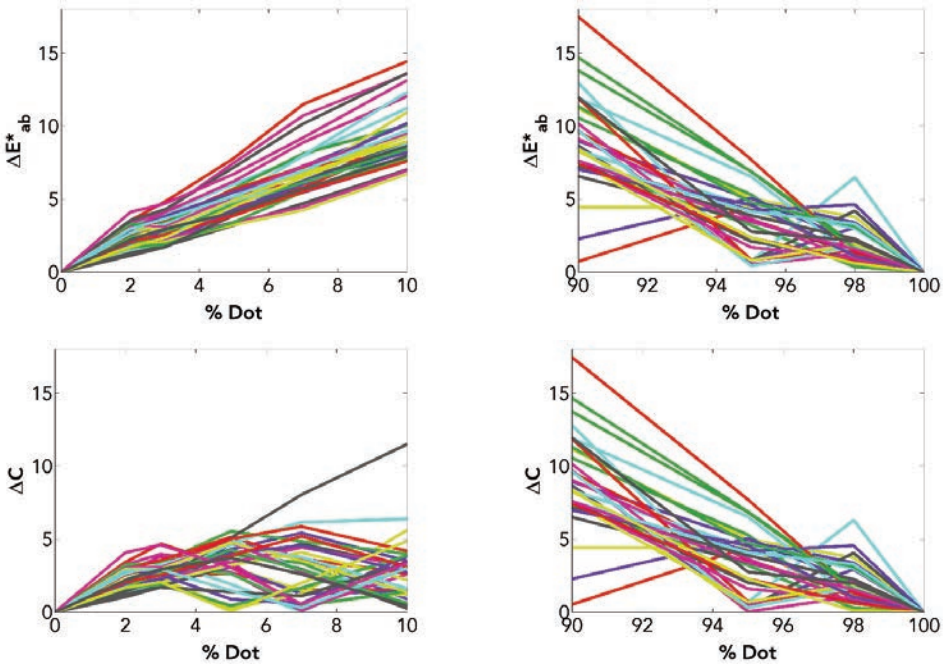

Figure 5. *ΔE^*_{ab} and ΔC as a function of Y dot areas for the highlight (left) and shadow (right)*

ΔE^*_{ab} is a much better metric for judging tonal contrast of the black channel than ΔC. While ΔL^* may be a possible candidate, ΔL^* would perform poorly for the yellow channel. Thus, ΔE^*_{ab} is chosen as the single metric for specifying tone value contrast from all CMYK channels.

Figure 5 shows more shadow tonality noises in the Y channel than in any other channels. While no specific cause is identified, it is recommended that a dedicated highlight/shadow scale, consisted of 12 patches, with (0%, 2%, 4%, 6%, 8%, 10% dot) as the top row, and (90%, 92%, 94%, 96%, 98%, and 100% dot) as the second row, be used so that these patches are clustered instead of dispersed randomly that are subject to spatial variation.

Specifying tonal contrast limits curve in ΔE^*_{ab}

Tables 2 and 3 show the mean and standard deviation of ΔE^*_{ab} for all channels of the 35 jobs. The line of "mean values minus one standard deviation" specifies the highlight and shadow contrast limits, i.e., it identifies 1/6 or 17% of jobs having low tonal contrast for further scrutiny.

The tonal contrast limits curves, formed by "mean value minus one standard deviation," are shown in Figures 6-9 (n=35). It is interesting to note that the magnitude of tonal contrast limit curves (CMYK) converges to 6 ± 1 ΔE_{00}. The tonal contrast limit curve (in red) is helpful to either flag jobs with low tonal contrast or to fail these jobs based on the documented evidences.

% Dot	K		C		M		Y	
Reference:0	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
0	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
2	1.5	0.53	2.0	0.64	2.1	0.79	2.3	0.77
3	2.4	0.63	2.5	0.70	2.8	0.91	2.9	0.87
5	4.0	0.86	4.2	0.98	4.6	1.20	5.0	1.16
7	5.3	1.07	5.5	1.14	6.2	1.26	6.9	1.65
10	7.2	1.24	7.5	1.31	8.6	1.40	9.5	2.02

Table 2. *Mean and standard deviations of ΔE^*_{ab} from 0 – 10% tone reproduction*

% Dot	K		C		M		Y	
Reference:100	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
90	9.9	3.25	5.5	1.82	7.8	2.82	9.0	3.21
95	4.2	2.35	2.3	1.38	3.2	1.89	3.4	2.06
98	2.2	1.57	1.1	0.87	1.4	1.23	2.0	1.33
100	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00

Table 3. *Mean and standard deviations of ΔE^*_{ab} from 90 - 100% tone reproduction*

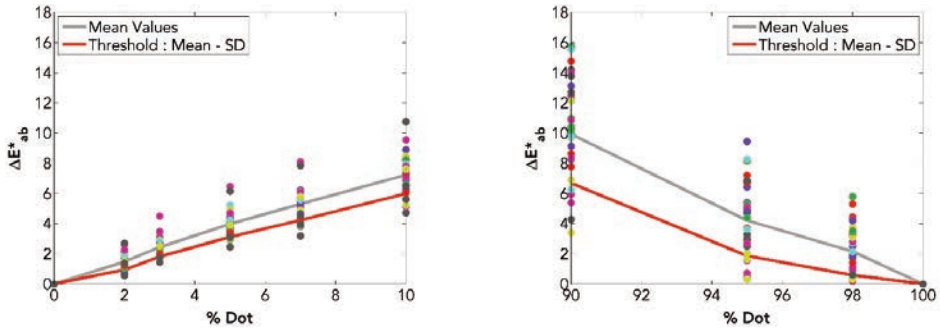

Figure 6. *K tonal contrast limit curves (red) for highlight (left) and shadow (right)*

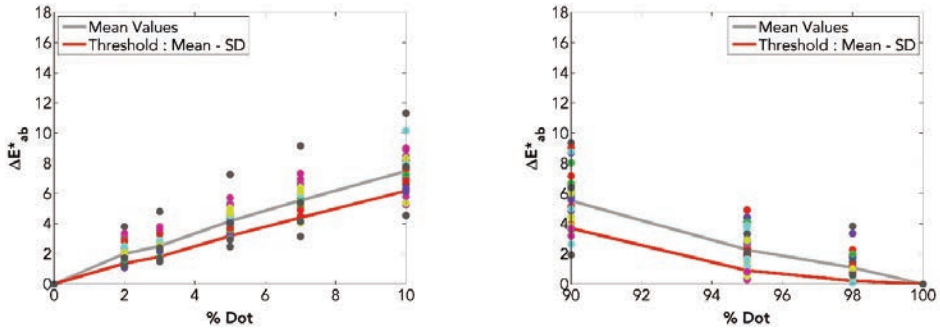

Figure 7. *C tonal contrast limit curves (red) for highlight (left) and shadow (right)*

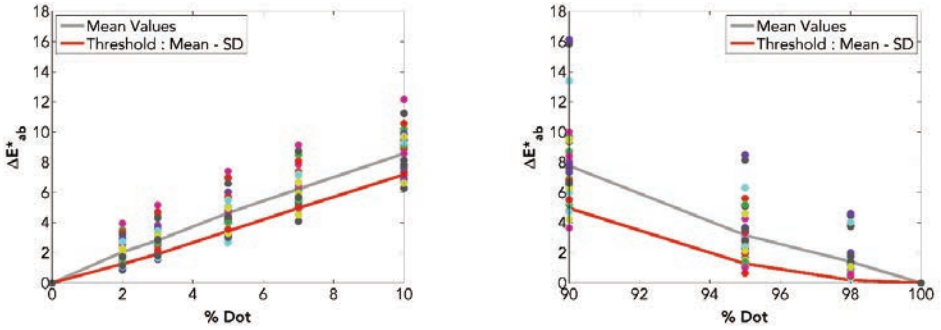

Figure 8. *M tonal contrast limit curves (red) for highlight (left) and shadow (right)*

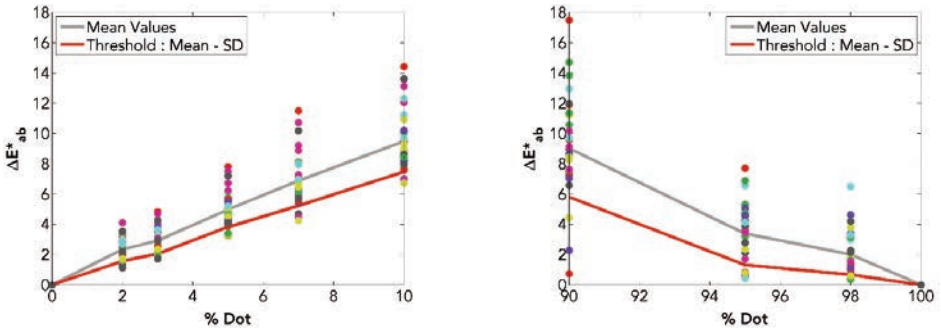

Figure 9. *Y tonal contrast limit curves (red) for highlight (left) and shadow (right)*

Determining tolerances for H/S tone value reproduction limits

Overall, the tonal contrast limit (red) curves are quite straight and are similar in magnitude, i.e., 6 ± 1 ΔE_{00}. The conformity criterion for the highlight region is a tonality change of 0.6 ΔE^*_{ab}/dot between 2% - 10%. For example, 3% highlight dots should exceed (3 x 0.6) or 1.8 ΔE^*_{ab} relative to paper; or 5% highlight dots should exceed (5 x 0.6) or 3.0 ΔE^*_{ab} relative to paper.

The conformity criterion for the shadow region is a tonality change of 0.6 ΔE^*_{ab}/dot between 90% - 98%. For example, 97% shadow dots should exceed (3 x 0.6) or 1.8 ΔE^*_{ab} relative to its solid; or 95% shadow dots should exceed (5 x 0.6) or 3.0 ΔE^*_{ab} relative to its solid.

What about using CIEDE2000?

Instead of specifying tonality change in ΔE^*_{ab}, we were curious if the analysis would provide any advantages by using ΔE00 as the metric. Appendix A illustrates the tonal contrast limits curve in ΔE00. There are three observations: (1) ΔE00 describes all highlight contrast limits similar to those of ΔE^*_{ab}, (2) ΔE00 describes the shadow contrast limits of black similar to that of ΔE^*_{ab}, and (3) ΔE00 describes shadow contrast limits of cyan, magenta, and yellow with significantly less magnitude

than ΔE^*_{ab} does. Based on these observations, there is no distinct advantage to use $\Delta E00$ as the metric in the assessing tone value reproduction limits.

Conclusions

The test method for tone value reproduction limits assessment in ISO 12647-2 (2004) is missing. This research used the linear relationship between input (%dot) and output (ΔE^*_{ab}) to assess highlight contrast and shadow contrast. A highlight/shadow target with (0%, 2%, 4%, 6%, 8%, 10% dot) in the top row, and (90%, 92%, 94%, 96%, 98%, and 100% dot) in the second row is recommended as input for tone value reproduction limit assessment. The proposed test method will improve the usability of the ISO 12647-2 by providing documented conformance in assessing tone value reproduction limits. It can be adopted to specify tone value reproduction limits of other printing processes, e.g., flexography.

References

Chung, Robert and Chen, Ping-hsu, Statistical Analysis of PSA Press Sheet Check-up Database, RIT Printing Industry Center, Rochester, NY, PICRM- PICRM-2011-08, 2011

ISO/TC 130/WG 3 N 1154 (2011) — ISO 15311 Print Quality Attributes Table Summary v13

ISO 12647-1 (2002) Graphic technology — Process control for the production of half-tone colour separations, proof and productions prints — Part 1: Parameters and measurement methods

ISO 12647-2 (2004) Graphic technology — Process control for the production of half-tone colour separations, proof and production prints — Part 2: Offset lithographic processes

ISO/DIS 12647-2 (2011) Graphic technology — Process control for the production of half-tone colour separations, proof and production prints — Part 2: Offset lithographic processes

Appendix A. Tonal contrast limits curve in CIEDE2000

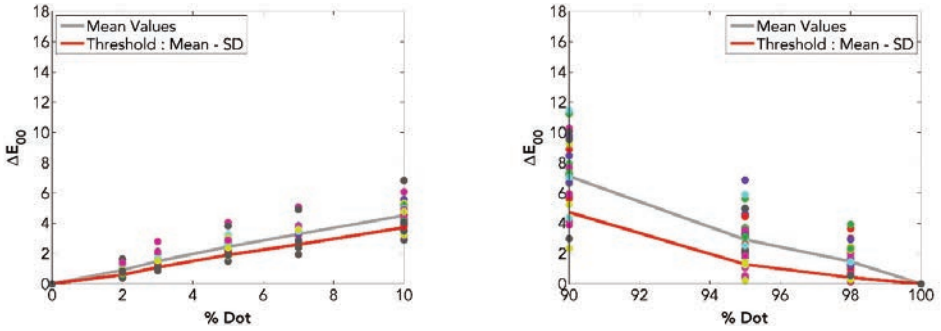

Figure A1. *K tonal contrast limit curves*

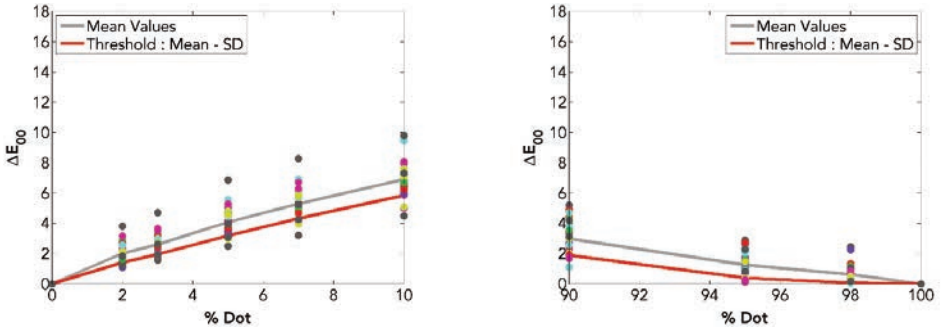

Figure A2. *C tonal contrast limit curves*

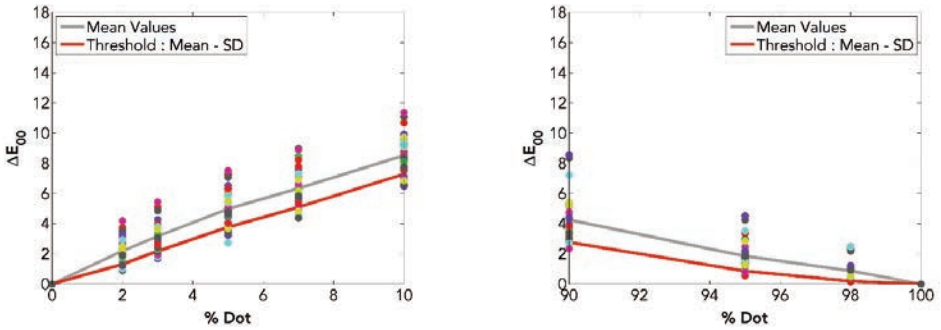

Figure A3. *M tonal contrast limit curves*

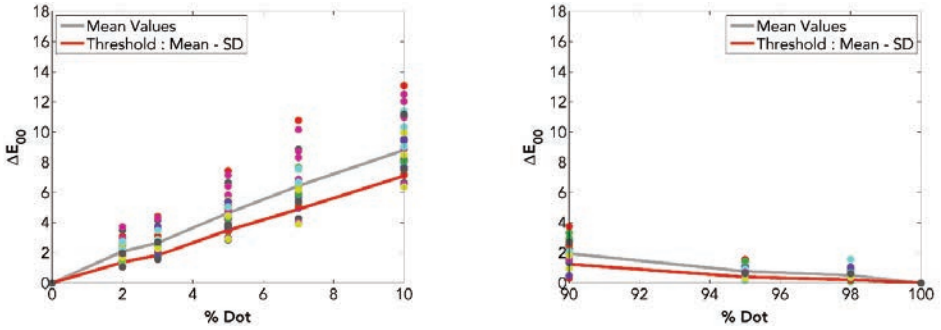

Figure A4. *Y tonal contrast limit curves*