An Investigation of Factors Influencing Color Tolerances

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Abstract

Tolerance is the permissible difference between sample measurement and the aim and is used to determine the acceptability of a product. A well-known example is the color tolerance of printed solids in ISO 12647-2. The first edition of ISO 12647-2 was published in 1996. It has gone through two major revisions. In the 2004 revision, the magnitude of the color tolerance (ΔE^*_{ab}) was changed. In the 2013 revision, a new color tolerance metric (ΔE_{00}) was included. No justification was found regarding the ISO 12647-2 revisions. In this research, %Pass is used to study the effect of color tolerance in a database. Recognizing that tolerance is a man-made decision, if the tolerance is too tight, the %Pass will be low; and vice versa. This research also examines the use of the equal %Pass to determine the tolerance equivalency between the old (ΔE^*_{ab}) and the new (ΔE_{00}) parameter. The results show that there is no convergence between ΔE^*_{ab} and ΔE_{00} when using the boundary data approach. However, there is an equivalent tolerance between ΔE^*_{ab} and ΔE_{00} using the equal %Pass approach. The current ISO 12647-2 standard, using 3.5 ΔE_{00} for CMY and 5 ΔE_{00} for black, resulted in unequal %Pass. By using the equal %Pass approach, the black solid tolerance does not need to be different than cyan and magenta solids, but the yellow solid tolerance can be smaller than cyan and magenta solids.

Introduction

The commercial lithographic printing industry relies on industry standards for process control. This is because standards represent print buyers' quality expectations. Standards also enable printers to address productivity while reducing waste and spoilage.

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Printing associations, such as International Digital Enterprise Alliance (IDEAlliance) in the U.S, are notable for their efforts in developing regional standards, e.g., GRACoL, SWOP, etc. Meanwhile, the International Organization for Standardization (ISO) is developing international standards. ISO printing standards are adopted by thousands of printing companies worldwide. There is a synergy between regional standards and ISO standards. This is because the ISO standards often began as regional or national standards.

ISO Technical Committee (TC) 130, Graphic Technology, is responsible for developing international printing standards. According to McDowell (1996), the inaugural meeting of ISO TC130 was held on 2-4 June 1971 in Paris, France. TC130 soon became dormant. ISO TC130 was reactivated in Berlin, Germany in 1989. Today, there are 14 working groups (WGs). Working Group 3 (WG3) is responsible for developing and revising printing process control standards. A prime example of WG3 standard is ISO 12647-2 Graphic technology – Process control for the production of half-tone color separations, proof and production prints – Part 2: Offset lithographic processes. ISO 12647-2 has been widely accepted by the printing industry worldwide.

In regard to tolerances, ISO 12647-2 used ΔE^*_{ab} parameter to define tolerance values in 1996. As shown in Table 1, deviation tolerance values for CMYK solids are 4, 5, 8, and 6 ΔE^*_{ab} respectively.

	Black	Cyan	Magenta	Yellow
Deviation tolerance	4	5	8	6
Variation tolerance	2	2.5	4	3

Table 1. *CIELAB ΔE^*_{ab} tolerances for the CMYK solids in ISO 12647-2: 1996*

Source: ISO 12647-2: 1996

Tolerance values were changed in the 2004 edition (Table 2). Deviation tolerance values for CMYK solids are all 5 ΔE^*_{ab}.

	Black	Cyan	Magenta	Yellow
Deviation tolerance	5	5	5	5
Variation tolerance	4	4	4	5

Table 2. *CIELAB ΔE^*_{ab} tolerances for the CMYK solids in ISO 12647-2: 2004*

Source: ISO 12647-2: 2004

Since the introduction of ΔE*ab metric by CIE in 1976, limitations of ΔE*ab have been recognized by the graphic arts industry. ΔE00 metric was introduced by CIE in 2000 to provide a better correlation between the perceived color difference and color difference than ΔE*ab metric. In 2010, ISO/TC 130 resolved to use ΔE00, where appropriate, for all new ISO/TC 130 standards and revisions of existing standards. As a result, the revision of ISO 12647-2 (2013) included ΔE00 as the tolerance metric. The deviation tolerances for ΔE00 and ΔE*ab are shown in the Table 3.

Process colour	Deviation tolerance		Variation tolerance		
	OK print		Production print		
	ΔEab	ΔE00 [a]	ΔEab	ΔE00 [a]	ΔH
Black	5	5	4	4	-
Cyan	5	3,5	4	2,8	3
Magenta	5	3,5	4	2,8	3
Yellow	5	3,5	5	3,5	3
[a]Tolerance values for DE2000 are given for information only					

Table 3. *CIELAB ΔE*ab tolerances for the CMYK solids in ISO 12647-2: 2013*

Source: ISO 12647-2: 2013

Deviation tolerance values for C, M, Y, K solids are 3.5 ΔE00, 3.5 ΔE00, 3.5 ΔE00, and 5 ΔE00 respectively. As noted in ISO 12647 (2013), tolerance values for ΔE00 are given for information only.

There is no literature that explains how the magnitude of ΔE*ab tolerance was initially specified in 1996, why these magnitudes were revised in 2004, and how the magnitudes of the ΔE00 metric were determined in the 2013 revision.

Literature Review

This section reviews key concepts germane to this research: (1) the relationship between tolerance and %Pass, (2) determining new tolerance metric from the boundary data, and (3) determining new tolerance metric using %Pass and a database.

Relationship between tolerance and %Pass

ISO 12647-2 (2013) defines tolerance as the permissive color difference that determines whether a printed job passes or fails. Tolerance is a man-made decision. The consequence is that tolerance affects the %Pass in a database.

A job is in conformance when all normative requirements are met. The passing probability of a job, known as %Pass, is the percentage of jobs that conform to requirements. "If this probability is too low, very few printing jobs conform to requirements. If [the probability] is too high, most jobs conform to requirements" (Chung & Feng, 2012). We can also study the %Pass according to a normative requirement. Figure 1 illustrates the relationship between the frequency and tolerance values in a database.

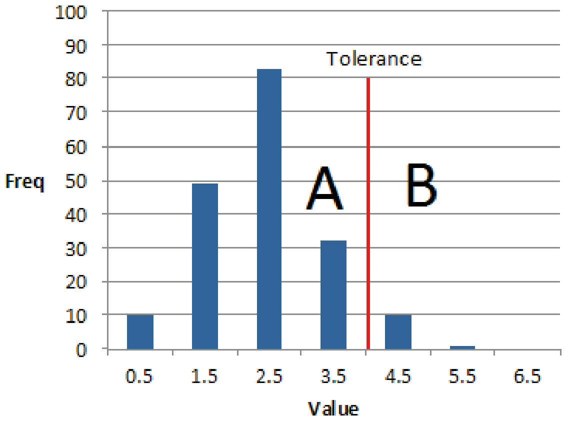

Figure 1. *Frequency histogram*

By placing the tolerance threshold in the histogram, the number in conformance (A), the number out of conformance (B), the %Pass is calculated using Equation 1.

$$\%Pass = \frac{A}{A+B} x100 \qquad \text{Eq. (1)}$$

Determining tolerance equivalency by the boundary data approach

In their research, Determining CIEDE2000 for Printing Conformance, Chung and Chen (2011) attempted to determine ΔE_{00} tolerance of CMYK solids based on the fact that a tolerance of 5 ΔE^*_{ab} encompasses a group of (L*, a*, b*) values on the circumference of a circle with an Euclidean distance of 5 ΔE^*_{ab} from the ISO aim for CMYK. They concluded that a single ΔE^*_{ab} did not map to a single ΔE_{00} when the ΔE_{00} values between the ISO aim and the group of (L*, a*, b*) values were calculated (Figure 2). In other words, there is no unique solution to determine the tolerance equivalency by the boundary data approach. The boundary data approach does suggest that K tolerance should be unequal to CMY tolerance. It is believed that ISO 12647-2 (2013) might have been influenced by the boundary data approach.

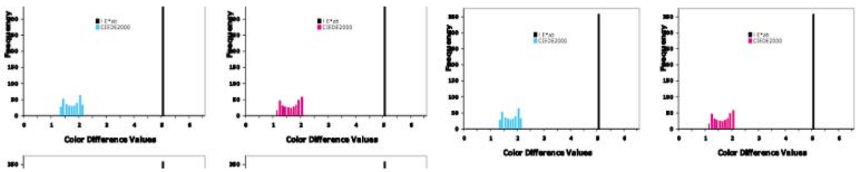

Figure 2. *Samples with identical ΔE^*_{ab} but non-identical ΔE_{00} values*

Determining tolerance equivalency by the %Pass approach

Chung, Urbain, and Sheng (2014) described a method to determine the equivalency between two parameters, midtone spread and ΔCh, with a printing database that included over 600 offset and digital printing jobs. This method is illustrated graphically in Figure 3.

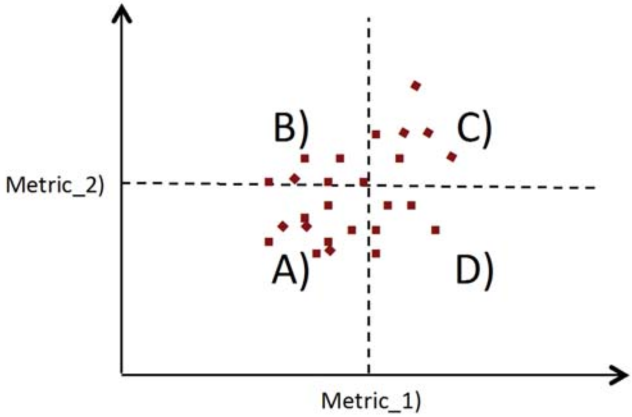

Figure 3. *A generic description of two tolerance metrics in a database*

As shown in Figure 3, A, B, C, and D are regions where passed and failed jobs with metric_1 and metric_2 in a database reside. The vertical dotted line is the tolerance for metric_1 and the horizontal dotted line is the tolerance for metric_2. The %Pass according to a normative requirement as a function of tolerance of the two metrics can be calculated using Equations 2 and 3.

$$\%Pass_{Metric\_1} = \frac{A+B}{A+B+C+D} x100 \quad \text{Eq. (2)}$$

$$\%Pass_{Metric\_2} = \frac{A+D}{A+B+C+D} x100 \quad \text{Eq. (3)}$$

Research questions

There are two research questions in this study: (1) What justifies for equal or unequal tolerances for CMYK solids, and (2) is there a method to determine the tolerance equivalency between ΔE^*_{ab} and ΔE_{00}?

One might argue that the same ΔE_{00} tolerance represents visual agreement for all colors. This means that there is no point to determine the ΔE^*_{ab} and ΔE_{00} equivalency. Thus, the issue of visual agreement is outside the scope of the study.

Methodology

In this research, the methodology is described into two parts: (1) determining %Pass in a database according to the ISO 12647-2 (2013) specifications, and (2) determining the tolerance equivalency using the equal %Pass approach.

Part 1 — %Pass according to the ISO 12647-2 (2013) specifications

This research uses the Process Standard Offset (PSO) database, courtesy of the Fogra PSO, to investigate how the magnitude of color tolerance influences %Pass. The PSO database, containing 185 jobs, provides CIELAB values of samples and the OK sheets. An example of the Excel spreadsheet for magenta solids is shown in Table 4.

* Backing description	
BB	0
WB	1

M100	L*_Aim	a*_Aim	b*_Aim
M100_BB	46	72	-5
M100_WB	48	74	-3

Job_ID	Sample_ID	* Backing Des.	L*_sample	a*_sample	b*_sample	C*_sample	L*_OK	a*_OK	b*_OK	C*_OK	h_OK	ΔE*ab_Dev.	OK_Dev Tol. 5 Tol (0/1)?	ΔE*00_Dev.	OK_Dev Tol. 3.5 Tol (0/1)?	Pass/Fail Agreement (0/1)
1	1	0	47.82	74.35	-3.71	74.44	48.32	73.74	-5.01	73.91	356.11	2.90	0	2.30	0	0
2	1	1	49.20	72.55	-4.42	72.68	49.08	72.59	-4.81	72.75	356.21	2.54	0	1.35	0	0
3	1	1	47.26	76.29	-0.50	76.29	46.66	76.63	0.19	76.63	0.14	4.35	0	1.93	0	0
4	1	1	48.69	74.10	-7.89	74.52	47.45	74.39	-6.64	74.69	354.90	3.70	0	1.53	0	0
5	1	1	46.46	76.79	-4.08	76.90	46.85	76.02	-4.69	76.16	356.47	2.87	0	1.38	0	0
182	1	0	48.93	71.49	-3.91	71.60	50.37	68.89	-5.63	69.12	355.33	5.40	1	4.40	1	0
183	1	0	48.44	73.88	-5.93	74.12	47.44	74.67	-4.82	74.83	356.31	3.04	0	1.54	0	0
184	1	0	46.39	74.94	-6.12	75.19	46.36	74.34	-6.57	74.63	354.95	2.84	0	0.86	0	0
185	1	1	47.26	74.90	-1.33	74.91	47.15	75.04	-1.22	75.05	359.07	2.23	0	1.13	0	0

Equal %Pass	ΔEab	ΔE00	Equal %Agreement
70.4	2.0	0.9	81
74.3	2.2	1.0	74
72.7	2.4	1.1	74
73.4	2.6	1.3	70
72.1	2.8	1.4	72
73.3	3.0	1.5	78
72.0	3.2	1.8	82
72.1	3.4	2.0	83
71.6	3.6	2.1	84
76.3	3.8	2.3	89
71.9	4.0	2.4	89
75.1	4.2	2.5	92
76.6	4.4	2.8	94
74.0	4.6	2.9	95
73.6	4.8	3.0	97
71.5	5.0	3.1	98

M100	Deviation (ΔEab)	Deviation (ΔE00)
Tolerance	5.0	3.5
# of solids exceed tol.	4	3
%Pass by color	97.8	98.4

Table 4. *An Example of the Excel spreadsheet for Extended Research (Magenta)*

The Excel spreadsheet computes ΔE^*_{ab} and ΔE_{00} values between measurements and printing aims for each solid color. The spreadsheet then determines whether a job passes or fails and computes %Pass according to the specified requirement.

Part 2 — Determining tolerance equivalency using the equal %Pass approach

Part 2 utilizes the %Pass of metric_1 and the %Pass of metric_2 as a function of tolerance, ranging from 2~5; to define the equal %Pass with the use of a ray-tracing technique to address the tolerance equivalency between ΔE^*_{ab} and ΔE_{00}. A detailed description of the ray-tracing technique is included in the Results section.

Results and Discussion

Part 1 — %Pass according to the ISO 12647-2 (2013) specifications

Based on the PSO database and the tolerances in ISO 12647-2 (2013), the frequency distribution and %Pass by color, using the 5 ΔE^*_{ab} tolerance, is shown in Figure 4.

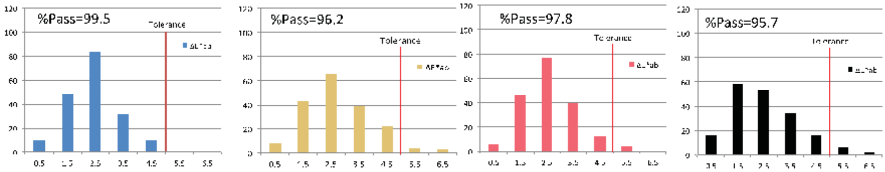

Figure 4. *Frequency vs. ΔE*ab tolerance*

Figure 5 illustrated the ΔE00 distribution of CMYK solids and %Pass at 3.5 ΔE00 for CMY and 5 ΔE00 for K. The results show that %Pass is proportional to tolerance magnitude that varies from color to color. Also, the magnitude of color tolerance is influenced by the metric.

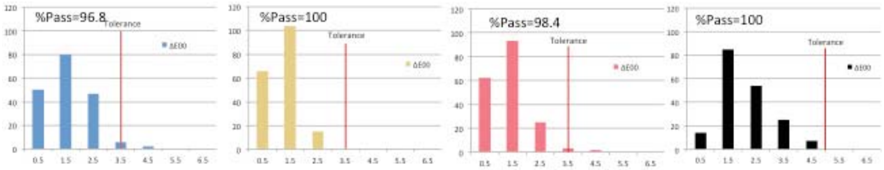

Figure 5. *Frequency vs. ΔE00 tolerance using a real database*

Table 5 summarizes the %Pass according to ISO 12647-2 (2013) specified tolerances. The %Pass ranges from 96.8 to 100 among CMYK solids. The high %pass is due to the fact that the database contained little or no nonconforming jobs.

ISO 12647-2	C	M	Y	K
ΔE^*_{ab}	5			
%Pass	99.5	97.8	96.2	95.7
ΔE_{00}	3.5			5
%Pass	96.8	98.4	100	100

Table 5: *ISO 12647-2 (2013) specified tolerances and their %Pass values*

Part 2 — Determining the tolerance equivalency using equal %Pass approach

Figure 6 indicates the %Pass vs. tolerance values for each color in the database. Specifically, as the tolerances for CMYK solids increase, higher %Pass will result.

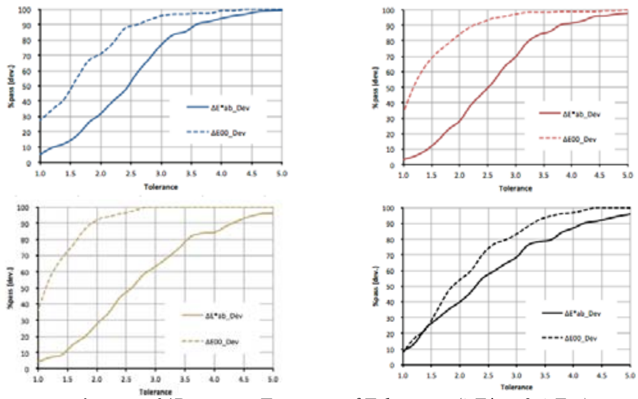

Figure 6. *%Pass as a Function of Tolerance (ΔE*ab & ΔE00)*

A ray-tracing technique is used to determine the equivalent tolerances between ΔE*ab and ΔE00 for each color (Figure 7, left). This is done by (1) drawing an upward arrow from a tolerance value in the x-axis until it intersects with the %Pass vs. ΔE*ab curve, (2) drawing a horizontal arrow until it intersects with the %Pass vs. ΔE00 curve, and (3) drawing a downward arrow until it intersects with in the x-axis. In other words, the initial ΔE*ab and the resulting ΔE00 are the equivalent tolerances between ΔE*ab and ΔE00. There are many equivalent tolerance pairs between ΔE*ab and ΔE00.

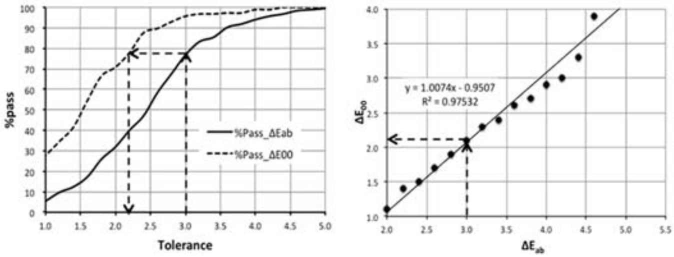

Figure 7. *ΔE*ab vs. ΔE00 yielding equal %pass of CMYK solids*

Figure 7 (right) shows the linear relationship, including the coefficient, between the ΔE*ab and its equivalent ΔE00. In other words, the equal %Pass approach provides us with a unique solution between two tolerance metrics that yields equal %Pass.

As shown in Table 6, ΔE*ab tolerances for CMYK solids are all 5, according to ISO 12647-2 (2013). The equivalent tolerances of printed solids for CMYK are 4.1, 3.2, 2.4, and 3.8 ΔE00 respectively. The %Pass for CMYK solids range from 95.7 to 98.9.

Proposed Method	C	M	Y	K
ΔE^*_{ab}	5			
Equivalent ΔE_{00}	4.1	3.2	2.4	3.8
% Pass	98.9	97.8	95.7	96.2

Table 6. *ΔE00 tolerances that are equivalent to 5 ΔE*ab tolerances*

Figure 8 illustrates the distribution of all 185 jobs by color in relation to the ISO 12647-2 (2013) tolerances and the equivalent tolerances. The results indicate that the tolerance for yellow solid could be smaller than cyan and magenta solids. In addition, the black solid tolerance does not need to be different from cyan and magenta solids.

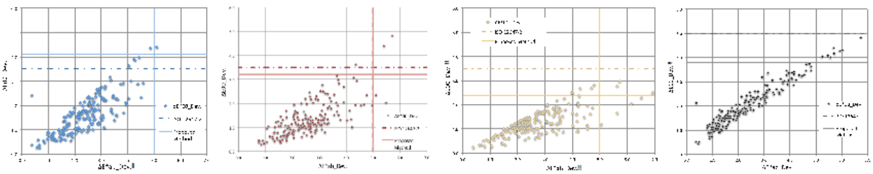

Figure 8. *ΔE*ab vs. ΔE00 using the PSO database*

Conclusions

This research devised a method that uses the %Pass approach in a database to determine the equivalent tolerances between ΔE^*_{ab} and ΔE_{00}. This research also examined the merit of specifying equal or unequal ΔE_{00} tolerances among CMYK solids. The findings indicate that (1) equal %Pass is likely to result in unequal E_{00} tolerances among CMYK solids, (2) contrary to the boundary data approach, ΔE_{00} tolerance for K solid does not have to be larger than Cyan and Magenta solids, and (3) ΔE_{00} tolerance for Yellow solid can be smaller than Cyan and Magenta solids.

Printing standardization and certification bodies are encouraged to apply the methodology with larger databases, including non-conforming jobs, to assess the performance of current printing specifications in the graphic arts industry. Their findings are the best impetus for future revision of printing standards.

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