

An Investigation of Factors Influencing Color Tolerances

Lufei Yu, Robert Chung, and Bruce Leigh Myers

Keywords: ISO 12647-2, deviation, tolerance, color difference

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. ΔE_{00} 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 ΔE_{00} , 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 ΔE_{00} as the tolerance metric. The deviation tolerances for ΔE_{00} and ΔE^*_{ab} are shown in the Table 3.

Process colour	Deviation tolerance		Variation tolerance		
	OK print		Production print		
	ΔE_{ab}	ΔE_{00}^a	ΔE_{ab}	ΔE_{00}^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

^aTolerance 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 ΔE_{00} , 3.5 ΔE_{00} , 3.5 ΔE_{00} , and 5 ΔE_{00} respectively. As noted in ISO 12647 (2013), tolerance values for ΔE_{00} 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 ΔE_{00} 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.

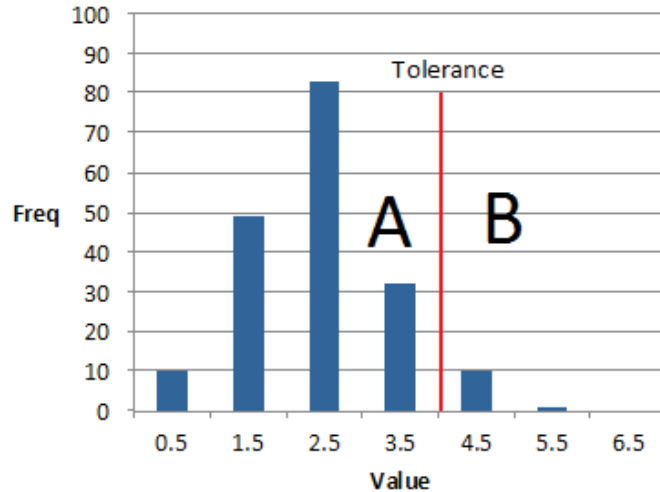


Figure 1. Frequency histogram

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.

$$\%Pass = \frac{A}{A+B} \times 100 \quad \text{Eq. (1)}$$

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.

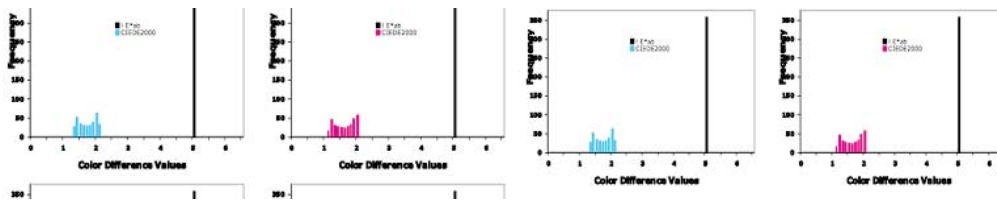


Figure 2. Samples with identical ΔE^*_{ab} but non-identical ΔE_{00} values

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.

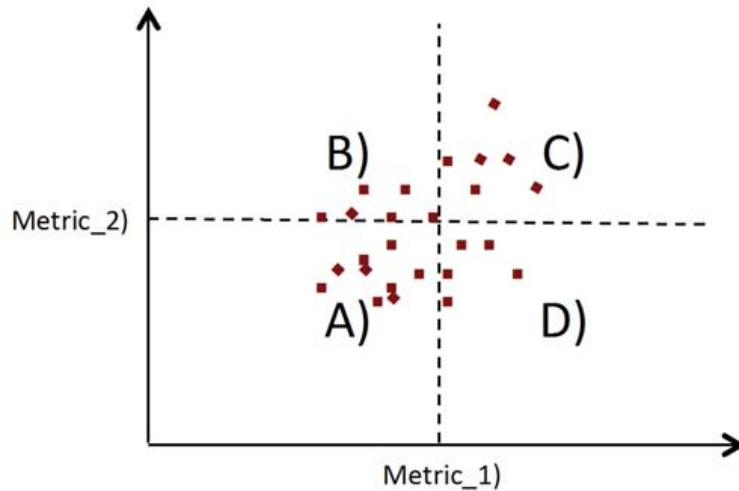


Figure 3. A generic description of two tolerance metrics in a database

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.

$$\%Pass_{Metric_1} = \frac{A+B}{A+B+C+D} \times 100 \quad \text{Eq. (2)}$$

$$\%Pass_{Metric_2} = \frac{A+D}{A+B+C+D} \times 100 \quad \text{Eq. (3)}$$

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			M100	L* Aim	a* Aim	b* Aim										
BB			0	48	72	-5										
WB			1	48	74	-3										
Job_ID	Sample_ID	* Backing Desc	L* sample	a* sample	b* sample	C* sample	L* OK	a* OK	b* OK	C* OK	h OK	AE*ab Dev.	Tol (0.1)7	AE*00 Dev.	Tol (0.1)7	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	47.25	76.39	-0.59	76.39	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	-6.82	74.83	356.21	3.04	0	1.54	0	0
184	1	0	46.39	74.94	-6.12	75.19	46.36	75.38	-5.57	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	Altab	AE00	Equal %Agreement										
			76.4	2.0	0.9	81										
			74.9	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	76										
			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 (AEab)	Deviation (AE00)											
			# of solids exceed to:	Tolerance	5.0	3.5										
			%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.

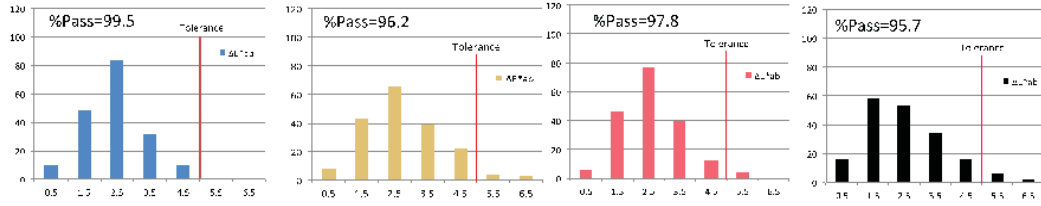


Figure 4. Frequency vs. ΔE^*_{ab} tolerance

Figure 5 illustrated the ΔE_{00} distribution of CMYK solids and %Pass at 3.5 ΔE_{00} for CMY and 5 ΔE_{00} 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.

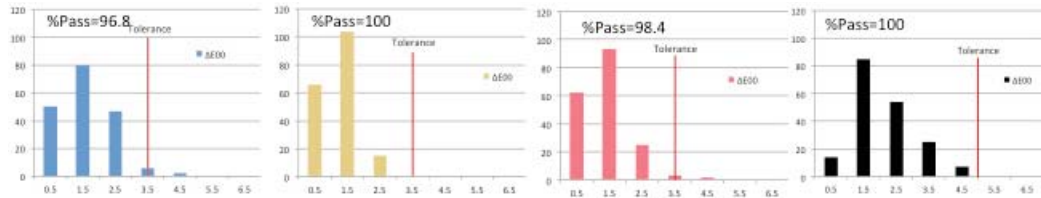


Figure 5. Frequency vs. ΔE_{00} tolerance using a real database

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			
%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.

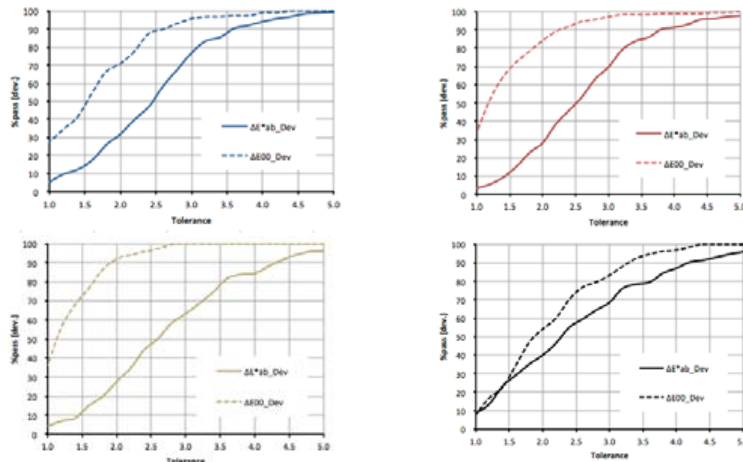


Figure 6. %Pass as a Function of Tolerance (ΔE^*_{ab} & ΔE_{00})

A ray-tracing technique is used to determine the equivalent tolerances between ΔE^*_{ab} and ΔE_{00} 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. ΔE_{00} curve, and (3) drawing a downward arrow until it intersects with the x-axis. In other words, the initial ΔE^*_{ab} and the resulting ΔE_{00} are the equivalent tolerances between ΔE^*_{ab} and ΔE_{00} . There are many equivalent tolerance pairs between ΔE^*_{ab} and ΔE_{00} .

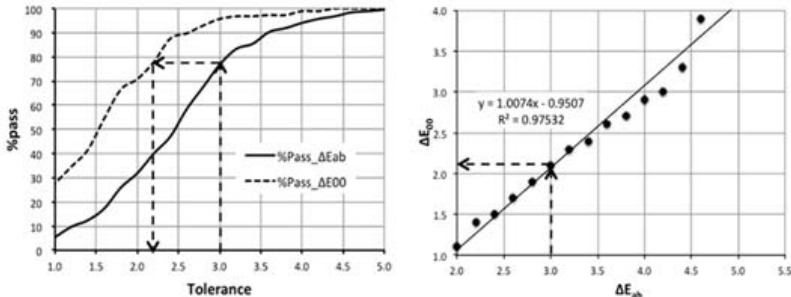


Figure 7. ΔE^*_{ab} vs. ΔE_{00} yielding equal %pass of CMYK solids

Figure 7 (right) shows the linear relationship, including the coefficient, between the ΔE^*_{ab} and its equivalent ΔE_{00} . 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 ΔE_{00} 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. ΔE_{00} 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.

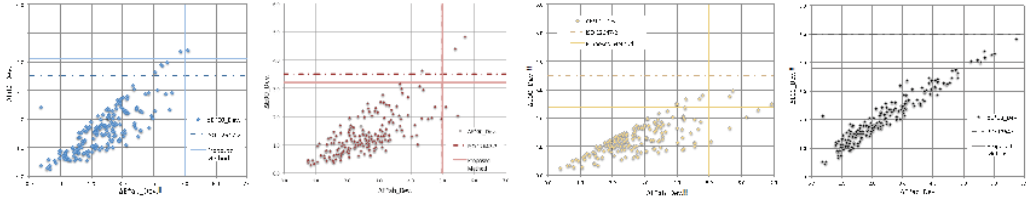


Figure 8. ΔE^*_{ab} vs. ΔE_{00} using the PSO database

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.

Acknowledgments

The authors wish to express their appreciation to Mr. Jürgen Gemeinhardt, Fogra for making the PSO Database available. They also want to recognize RIT School of Media Sciences for providing the academic environment that enable students and faculty to excel and learn.

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An Investigation of Factors Influencing Color Tolerances

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R-I-T 

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Introduction


- Print buyers demand quality printing.
 - Quality printing means conformance to specifications
- Specifications are developed by standardization bodies.
 - Regional standards are developed by printing associations, e.g., IDEAlliance in the U.S.
 - International standards are developed by ISO TC130.

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History of ISO TC130

- TC130 Graphic technology started in 1971.
 - TC130 was reactivated in 1989.
 - TC130 has 14 Working Groups.
 - WG3 is responsible for developing and revising specifications in printing standards.
 - A good example is the ISO 12647 series of printing standards.

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History of ISO 12647-2

- Originally published in 1996.
 - ΔE^*_{ab} metric was used to define color tolerances of CMYK solids. Density of solids are specified as informative.

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

Source: ISO 12647-2:1996

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History of ISO 12647-2

- Revised in 2004.
 - Magnitudes of tolerance for CMYK solids were changed from unequal to equal.

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

Source: ISO 12647-2:2004

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History of ISO 12647-2

- The most recent revision was in 2013.
 - ΔE^*_{ab} remained as the normative metric. ΔE_{00} was added as an informative metric.

Process colour	Deviation tolerance		Variation tolerance		
	OK print		Production print		
	ΔE_{00}	ΔE_{ab}	ΔE_{00}	ΔE_{ab}	ΔE_{sc}
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

* Tolerance values for D50 illuminant are given for information only.
Source: ISO 12647-2:2013

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Problem Statements

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- There is a lack of understanding or documentation as to
 - How was the magnitude of ΔE^*_{ab} tolerance initially specified in 1996?
 - Why were these magnitudes revised in 2004?
 - How was the magnitude of ΔE_{00} tolerance specified in relation to ΔE^*_{ab} tolerance?

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Research Questions

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- What factors influence the magnitude of color tolerance?
- Is there tolerance equivalency between the old metric (ΔE^*_{ab}) and the new metric (ΔE_{00})?

Note: The same ΔE_{00} tolerance may represent visual agreement for all colors. This means there is no point to determine the ΔE^*_{ab} and ΔE_{00} equivalency. But, this is outside the scope of the study.

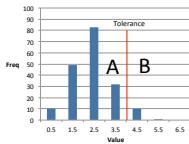
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Tolerance & %Pass

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- Tolerance is the permissive color difference that determines whether a printed job passes or fails.
- The passing probability of a job, known as %Pass, is the percentage of jobs that conform to all normative requirements in a database (Chung & Feng, 2012).



$$\%Pass = \frac{A}{A+B} \times 100$$

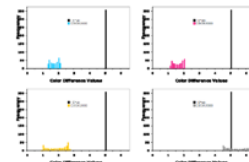
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Boundary Data Approach

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- Using the boundary data to determine the new tolerance metric (ΔE_{00}) from the old metric (ΔE^*_{ab})
 - No unique solution -- Single ΔE^*_{ab} will map to a range of ΔE_{00} (Chung & Chen, 2011).



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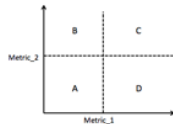
Real Database Approach

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- Finding %Pass of two metrics using a database (Chung, Urbain & Sheng, 2014)

$$\%Pass_{Metric_1} = \frac{A+B}{A+B+C+D} \times 100$$

$$\%Pass_{Metric_2} = \frac{A+D}{A+B+C+D} \times 100$$



- If the relation between %Pass and tolerance can be determined, the equivalent tolerance is when both tolerance metrics produce the same %Pass.

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Methodology, Part 1

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- To determine the relation between tolerance & %Pass,
 - Select Fogra PSO database (185 jobs for CMYK solids)
 - CIELAB values of the ISO 12647-2 aims
 - OK sheet for each job

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Methodology, Part 1

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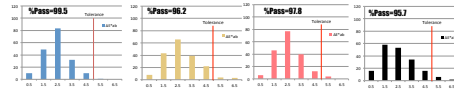
- Compute ΔE_{ab}^* and ΔE_{00} for each job in the database.
- Compute %Pass according to ISO 12647-2 (2013) specified tolerances.

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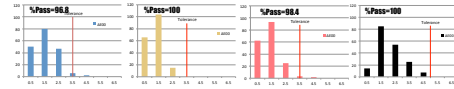
Results, Part 1

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- ΔE_{ab}^* distribution of CMYK solids and %Pass at 5 ΔE_{ab}^* tolerance.



- ΔE_{00} distribution of CMYK solids and %Pass at 3.5 ΔE_{00} for CMY and 5 ΔE_{00} for K.



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Methodology, Part 2

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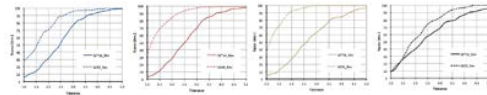
- To determine the tolerance equivalency between the old metric and the new metric,
 - 1) Determine %Pass by varying ΔE_{ab}^* and ΔE_{00} tolerances.
 - 2) For each metric, plot %Pass as a function of tolerance.

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Results, Part 2

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- The graphs of %Pass vs. tolerance show that
 - %Pass is proportional to tolerance magnitude.
 - ΔE_{00} is a larger metric than ΔE_{ab}^* .
 - There is a larger $\Delta E_{ab}^*/\Delta E_{00}$ ratio for Yellow solid than for Black solid.

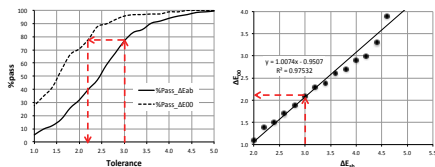


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Results, Part 2

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- By using the ray-tracing techniques, we can find the equivalent ΔE_{00} that would yield the same %Pass as the specified ΔE_{ab}^* color by color.



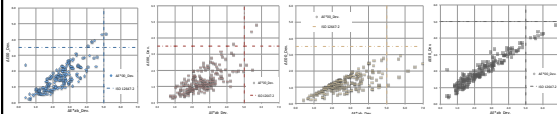
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Discussions

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- %Pass for both metrics according to ISO 12647-2 are high.

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	96.4	100	100



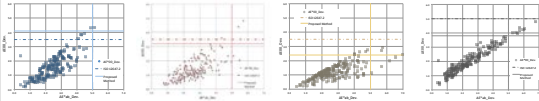
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Discussions

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- Using the equal %Pass as the tolerancing criteria, it will yield unequal tolerances.

Proposed Method	C	M	Y	K
ΔE_{00}^*			S	
%Pass	99.5	97.8	96.2	95.7
ΔE_{00}	4.1	3.2	2.4	3.8
%Pass	98.9	97.8	95.7	96.2



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Conclusions

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- The proposed method, using equal %Pass in a real database, provide us a solution to find the equivalent tolerances between ΔE_{ab}^* and ΔE_{00} .
- Regional printing associations and certification bodies should apply the methodology with larger databases, including non-conforming jobs, to assess how tolerances and %Pass perform in the industry.

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Acknowledgments

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Thank you
Q&A

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