



Determining CIEDE2000 for Printing Conformance

Robert Chung and Ping-hsu Chen
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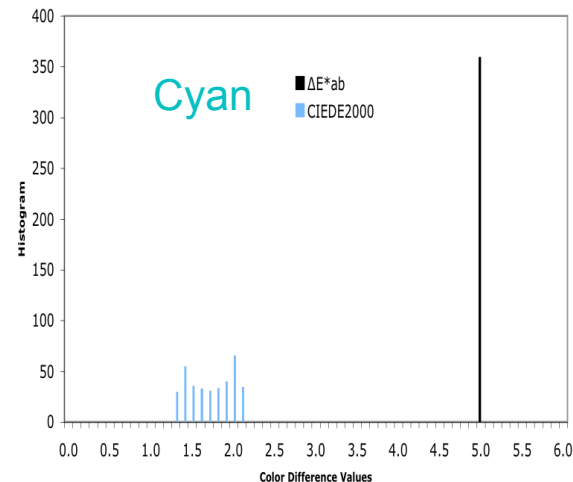
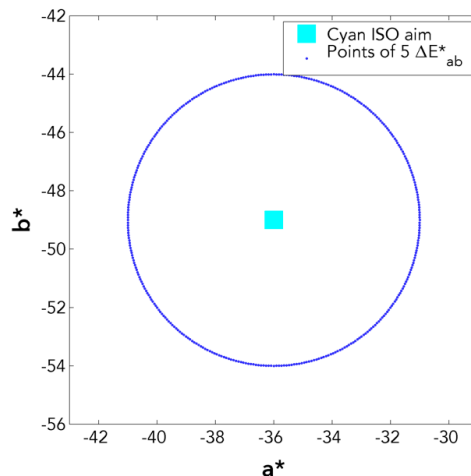
Rochester Institute of Technology
Rochester, NY, USA

Introduction

- CIELAB is approximately a uniform color space.
 - The Euclidean distance in CIELAB color space, ΔE^*_{ab} , provides a quantitative definition of color difference.
 - Several color difference metrics, such as CIE94, CMC, and CIEDE2000 (ΔE_{00}), were proposed in order to provide a better correlation between perceived color difference and instrument color difference.
- ISO/TC130 used ΔE^*_{ab} metric to specify tolerances for many years.
 - TC130 plenary meeting in Sao Paulo, Brazil resolved to use CIEDE2000 for all new ISO/TC130 standards and revisions of existing standards.

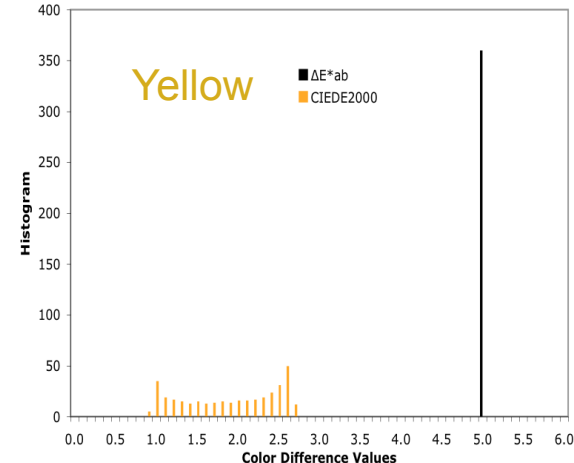
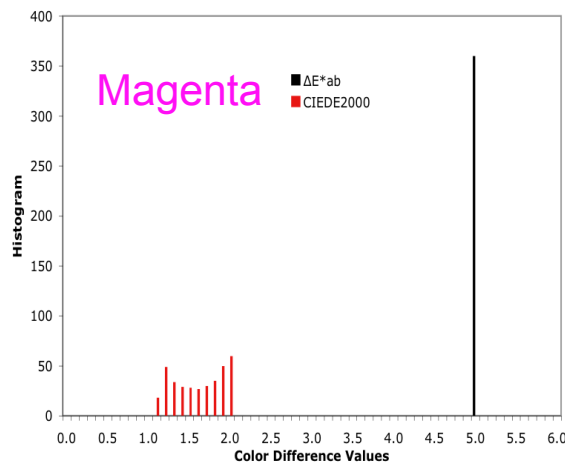
Problem Statement

- A major difficulty in adopting ΔE_{00} is that there is no single tolerance value in ΔE_{00} metric that matches exactly the outcome with ΔE^*_{ab} metric.
 - Using cyan solids as an example, the ΔE_{00} values of those equal ΔE^*_{ab} points around the circle are (1) smaller in magnitude, and (2) not converging.



Research Question

- Lack of convergence between ΔE_{00} and ΔE^*_{ab} are common in all three (CMY) solids.
- The research question becomes:
 - Is there a way to determine color tolerance as a single CIEDE2000 metric for CMYK solids that represent the best compromise in ΔE^*_{ab} ?



Literature Review

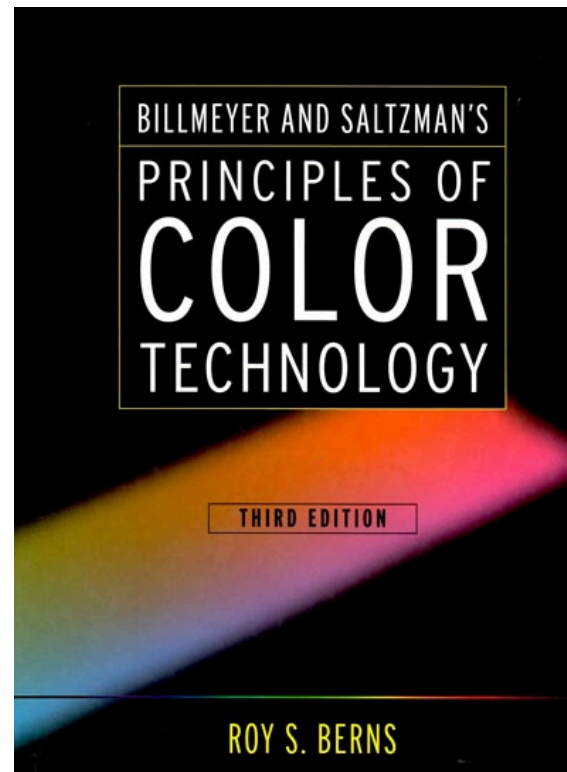
- Relationship between ΔE^*_{ab} into ΔE_{00}
 - Kraushaar used CIELAB measurements of CMYK solids from the bvdM/Fogra (filtered) database.
 - $5 \Delta E^*_{ab}$ for cyan solid is equivalent to $2.6 \Delta E_{00}$.
 - Rich used simulated data that passed the ISO criteria.
 - $5 \Delta E^*_{ab}$ for CMY solid is equivalent to $2 \sim 2.5 \Delta E_{00}$.
 - K solid is equivalent to $3 \sim 4 \Delta E_{00}$.
 - McDowell studied ratios between ΔE^*_{ab} and ΔE_{00} from solids and tints measured from proofing samples of IT8.7/4 target.
 - Ratio is proportional to CMY ink amount.
 - There is no single ratio between ΔE^*_{ab} and ΔE_{00} .

Methodology

- To 'optimize' often means to 'compromise.'
 - Is there a single ΔE_{00} that passes as many samples that ΔE^*_{ab} also passes and, at the same time, fails as many samples that ΔE^*_{ab} also fails?
 - If so, we will call it the optimized ΔE_{00} tolerance.
- What we need is an optimization model plus a database with a large amount of printed samples, including samples that pass and fail the 5 ΔE^*_{ab} criterion.

Optimization Model

- Berns describes an optimization method that derives color tolerances between instrumental and visual historical data.
- A step-by-step adaptation of the optimization is used in this research.
 - $5 \Delta E^*_{ab}$ is used as the pass/fail criterion instead of the visual historical data.



Step-by-Step Optimization

- 1) Given a database with 35 L* a* b* measurements for cyan solids, their ΔE^*_{ab} values and conformance outcomes, compared to tolerance (5 ΔE^*_{ab}), are shown.

Sample	ΔE^*_{ab}	Conformance
#1	5.0	Fail
#2	2.5	Pass
#3	1.7	Pass
#4	6.1	Fail
#5	3.5	Pass
#6	1.3	Pass
#7	1.4	Pass
#8	2.7	Pass
#9	3.7	Pass
#10	3.2	Pass
#11	4.9	Pass
#12	3.3	Pass

Sample	ΔE^*_{ab}	Conformance
#13	2.4	Pass
#14	2.9	Pass
#15	6.7	Fail
#16	2.1	Pass
#17	1.9	Pass
#18	3.8	Pass
#19	7.3	Fail
#20	10.3	Fail
#21	7.0	Fail
#22	6.2	Fail
#23	4.0	Pass
#24	2.6	Pass

Sample	ΔE^*_{ab}	Conformance
#25	4.9	Pass
#26	3.4	Pass
#27	5.2	Fail
#28	3.0	Pass
#29	3.1	Pass
#30	1.9	Pass
#31	5.2	Fail
#32	4.8	Pass
#33	4.5	Pass
#34	5.2	Fail
#35	3.1	Pass

Step-by-Step Optimization

2) Data are sorted into two groups:

- Pass ($= < 5 \Delta E^*_{ab}$)
- Fail ($> 5 \Delta E^*_{ab}$)

3) ΔE_{00} of 35 samples are calculated based on the measurements & ISO aim.

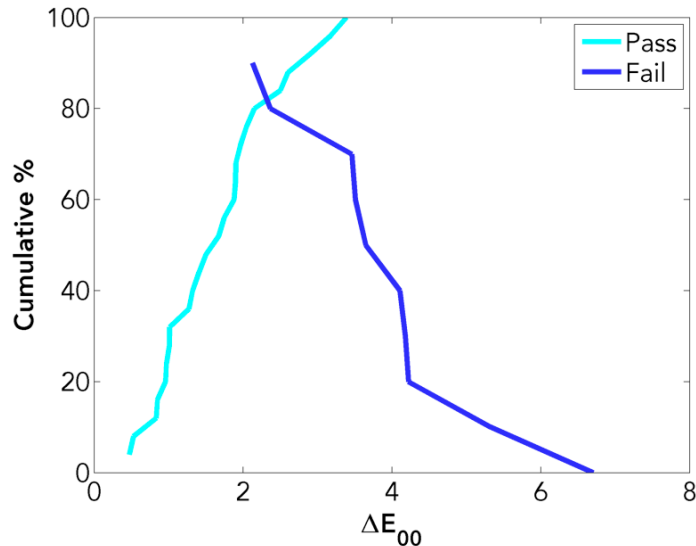
- Pass and fail data are listed with corresponding CIEDE2000 values in ascending order.

Pass	CIED2000
1	0.5
2	0.5
3	0.8
4	0.9
5	1.0
6	1.0
7	1.0
8	1.0
9	1.3
10	1.3
11	1.4
12	1.5
13	1.7
14	1.7
15	1.9
16	1.9
17	1.9
18	2.0
19	2.0
20	2.2
21	2.5
22	2.6
23	2.9
24	3.2
25	3.4

Fail	CIEDE2000
1	2.1
2	2.4
3	3.5
4	3.5
5	3.6
6	4.1
7	4.2
8	4.2
9	5.3
10	6.7

Step-by-Step Optimization

- 4) Cumulative percentages (%CRF) for pass and fail groups are calculated.
- 5) CRFs were plotted as a function of CIEDE2000.



Pass Cumulative %	CIEDE2000
4	0.5
8	0.5
12	0.8
16	0.9
20	1.0
24	1.0
28	1.0
32	1.0
36	1.3
40	1.3
44	1.4
48	1.5
52	1.7
56	1.7
60	1.9
64	1.9
68	1.9
72	2.0
76	2.0
80	2.2
84	2.5
88	2.6
92	2.9
96	3.2
100	3.4

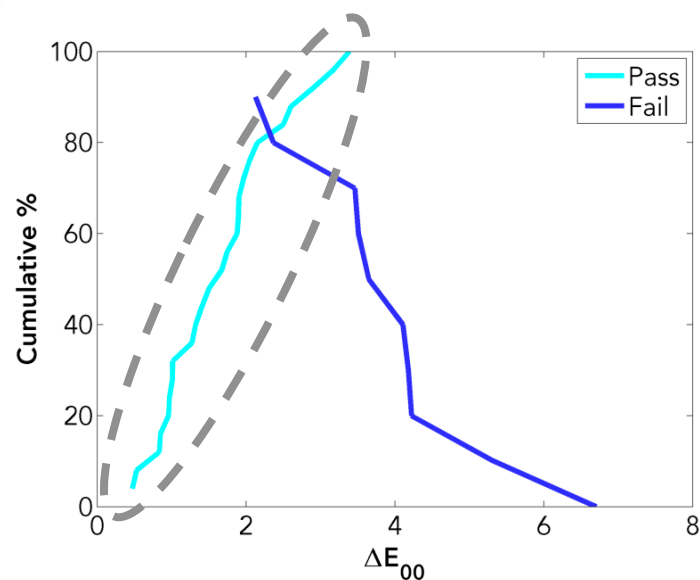
Fail Cumulative %	CIEDE2000
90	2.1
80	2.4
70	3.5
60	3.5
50	3.6
40	4.1
30	4.2
20	4.2
10	5.3
0	6.7

$$Cumulative_{pass,i} = 100(i/n_p)$$

$$Cumulative_{fail,i} = 100 - 100(i/n_f)$$

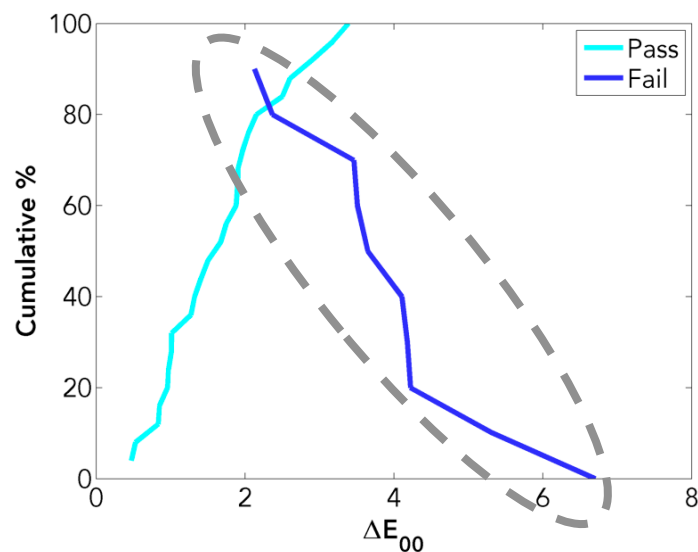
Step-by-Step Optimization

- 6) If only the CRF of passed samples is plotted (colored in cyan), one might conclude that the equivalent tolerance is the maximum ΔE_{00} .
- Kraushaar's case



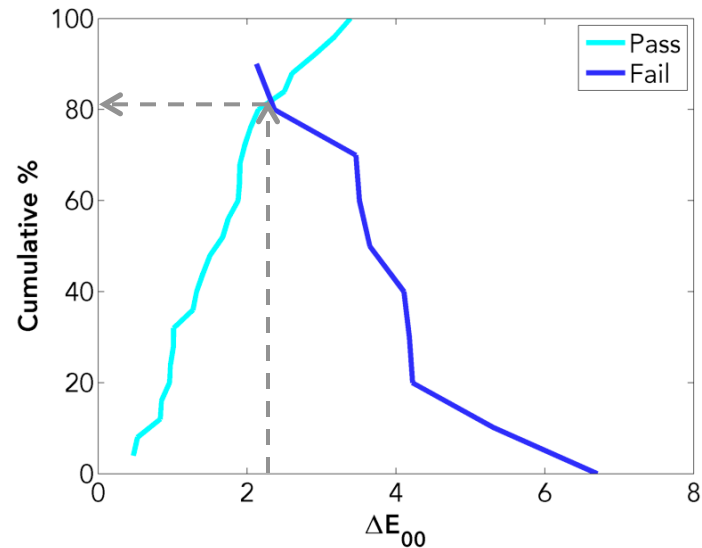
Step-by-Step Optimization

- 7) If only the CRF of failed samples is plotted (colored in blue), one might conclude that the equivalent tolerance is the minimum ΔE_{00} .



Step-by-Step Optimization

8) When both CRF curves are plotted, the intersection of the pass and the fail groups provide the “optimized ΔE_{00} tolerance” that maximizes the agreement between two metrics.

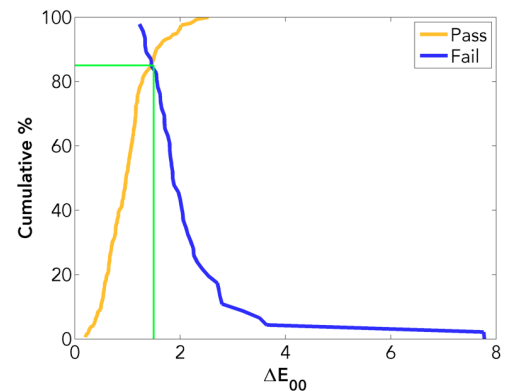
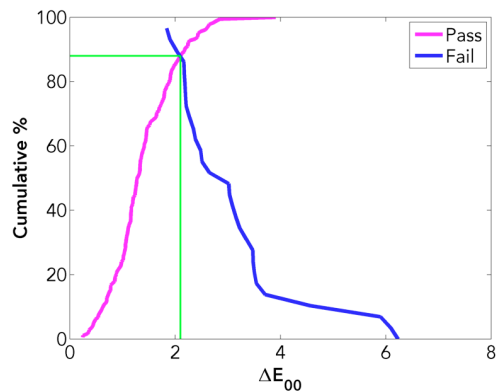
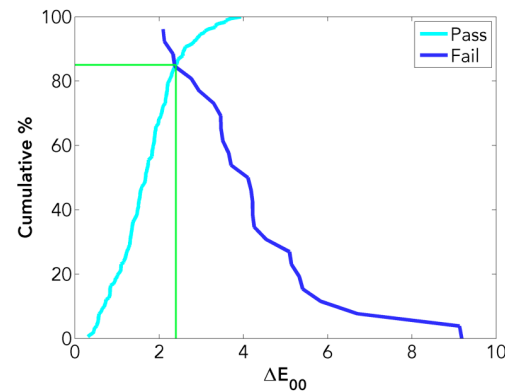
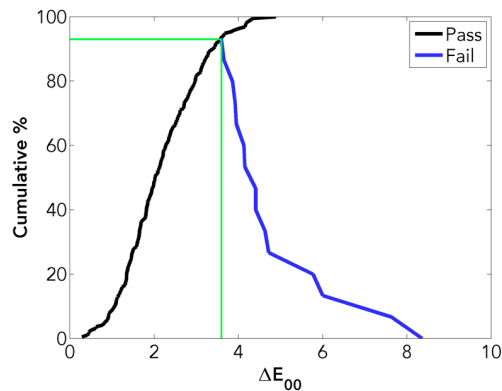


Optimization Plus Database

- A total of 208 jobs from three databases were used in the optimization.
 - Unfiltered PSA database (n = 35)
 - Samples collected during PSA survey
 - Filtered PSO database (n = 88)
 - Courtesy of bvdM/Fogra
 - Filtered G7 database (n = 85)
 - Courtesy of IDEAlliance

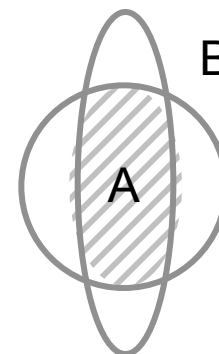
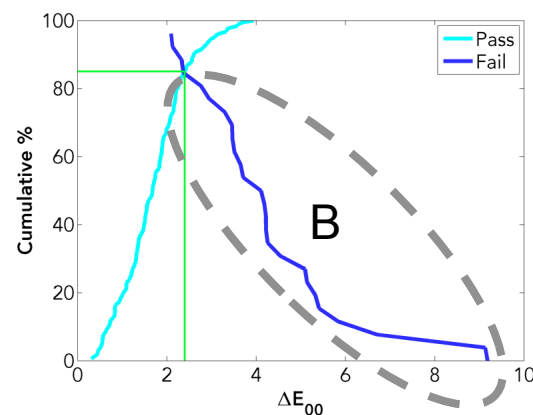
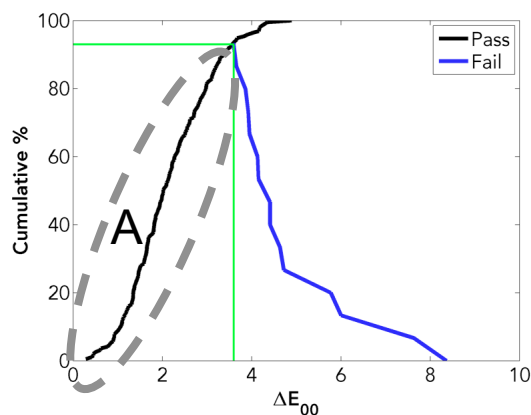
Results

- Optimized ΔE_{00} tolerances of CMYK solids
 - Equal pass/fail outcome is above 80% for CMYK.



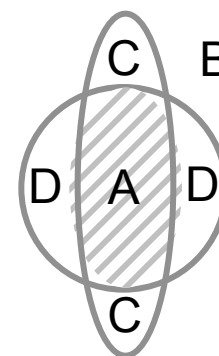
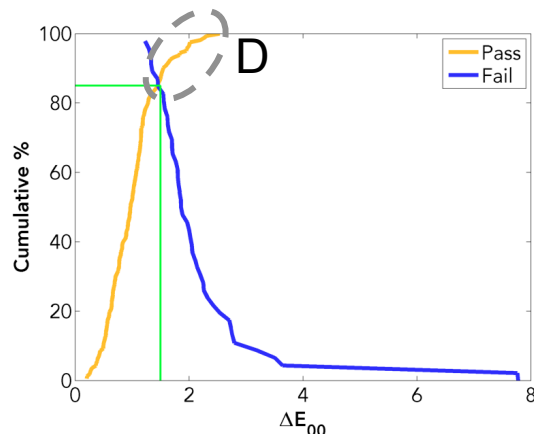
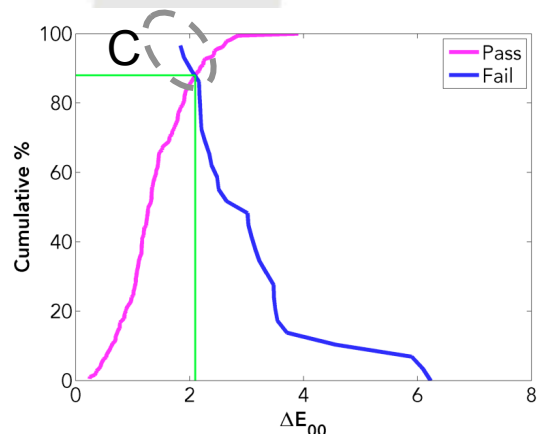
Discussion

- The lower left of the 'X' represents samples that pass 5 ΔE^*_{ab} and the optimum ΔE_{00} (region A).
- The lower right of the 'X' represents samples that fail 5 ΔE^*_{ab} and the optimum ΔE_{00} (region B).



Discussion

- The upper left of 'X' represents samples that fail ΔE_{ab}^* metric, but pass at its optimum ΔE_{00} metric (region C).
- The upper right of 'X' represents samples that fail optimum ΔE_{00} metric, but pass at 5 ΔE_{ab}^* metric (region D).



Recommendation

- There is no single ratio between ΔE_{ab}^* to ΔE_{00} . There is an optimized ΔE_{00} that maximizes the same pass/fail outcome as ΔE_{ab}^* .

	ΔE_{00}			
	K	C	M	Y
ΔE_{00} Tolerances	3.6	2.4	2.2	1.5

- The results provides the best compromise between the two metrics.
 - It also reflects the lack of equal visual difference in current 5 ΔE_{ab}^* tolerance in CMYK.

Recommendation to ISO TC130

- Consider the same tolerance in DE2000 metric for all primary solids.
 - This study offers a good starting point.
- Option 1 – Single tolerance for CMYK
 $(3.6+2.4+2.2+1.5) / 4 = 2.4$ for CMYK
- Option 2 – One tolerance for CMY & the other for K
 $2.4 \Delta E_{00}$ for CMY;
 $3.6 \Delta E_{00}$ for K

Thanks for Listening

Robert Chung
Professor
School of Print Media
RIT
Rochester, NY, USA
Phone: 585-475-2722
email: rycppr@rit.edu