So You Think You Want a 2 ΔE?

David Hunter
Audience Roles

What is your Primary Role

- Brand Manager
- Creative
- Print Buyer
- Prepress
- Printer Operator
- Manufacturer
- Other?
3 Questions- Heard of it, Understand it, Teach it
Raise Hand for each definition, and keep raised
- Delta E 2000
- Different Delta E formulas
- CIE Lab color space
- Spectral color space
- Traditional Score Card App (ColorCert/PressSign)
- G7 Methodology
- Understand Standards only take us so far…
Agenda

**Chain of Tolerances**

- What reference? Aim point: $\Delta$?
- Delta What? $\Delta$?
- Print Device capabilities
- Reference disagreements
- Substrate disagreements
- Measurement disagreements
- Light booth disagreements
- Rules of Engagement
Print Manufacturing Road Map

Maturity of Print Service Providers
Covering Eight Device Tolerances

Four levels Color Control Maturity

- Don’t have the time to Cover the first three level
- They are in PDF of this presentation

- We are covering the most mature color control option
- Only way to hope to achieve a 2 $\Delta E$ tolerance

- Reference hand outs to provide road map to 2 $\Delta E$
Defining Color Salability (Acceptability):

**Depends on:**

- Print buyer’s *expectations*
  - *Spot/brand color match*
  - *Image/page color match*
- Print device’s *production capability*

- Important related variables (instrument/lighting/substrate)
- All of which affect print devices production capabilities
Requirements to Define Color Match

Requires:

- Defining **Reference** to Match:
  - *Spot/brand color match*
  - *Image/page color match*

- Allowable **Tolerance** ($\Delta$):
  - Dependent on variables
  - *Printing process, device, consumables, measurement, light booth,*
How Different is Too Different?

Which one is Correct? Which is the Reference?
Options for defining reference

- Physical Print
- Industry References (7 CRPCs)
- SCCA Adjusted to CRPC
- Actual Print Condition
  - Create custom ICC Profile
Limitations of Print Sample to Match to ...

No idea how it was printed

- Is it reproducible?
- Standard colorants, and densities for CMYK primaries?
- Dot gain, gray balance and overprints?
- Will require a lot of trial and error, and may never match
Characterized Reference Printing Conditions

Representing 7 different conditions/substrates

- 4 Coated stocks, 3 Uncoated stocks
SCCA Adjusted CRPC to accommodate paper

*Works well if substrate is Lab=95,1,-4 (M1)*

- But not many substrates match this value which requires:
  - Suppliers to apply SCCA to their process to match
  - Suppliers use M1 measurement devices
- If substrate is close (within 5 ΔE) than use SCCA
Limitations of Reference Print Conditions match

**Works well if substrate is within 2ΔE (00)**

- But not many substrates match this value which requires:
  - Suppliers to apply SCCA to their process to match
  - Suppliers use M1 measurement devices
- If substrate is close (within 5 ΔE) than use SCCA to define a new Reference Print Condition
- If substrate is greater than 5ΔE, suggest creating Custom Profile (Actual print condition)
Actual Print Condition

Need to run on multiple printer runs

- Provides most accurate rendition of Print Condition
- Requires fairly small target (no dedicated press runs)
  - Spectral prediction software
  - Ready for ICC Max (next generation profiling)
- Use one master instrument that can be adjusted for
- Takes extra time and money, but much more accurate
Reference Options for Process Color

Road Map to Analytic Based Print Manufacturing

- **Physical Print Sample**
- **CRPC (Lab)**
- **CRPC (SCCA)**
- **Actual Print Condition**
1b. Defining Brand/Spot References

Options for defining reference

- Master Library and palettes for different substrates
- PMS book (coated/uncoated/other)
  - Age of book, batch number
  - Physical sample
- Numeric value based on CIE-Lab (illuminant dependent)
- Numeric value based on Spectral (illuminant independent)
Options for Defining Brand Color References

**Pros and Cons**

- PMS Number (PMS 185) and the chip book
  - Visual only, every chip book is different
- Printed Color with CIE Lab values (GMI)
  - Every print is slightly different and ages differently
  - Lab values are not Illuminant independent, No tints
- PMS Number and digital value in CxF format
  - Which PMS Library? M0, M1, RIPs have M2 but you want M0, easy 5 ΔE difference accidental substitutions
## Reference Disagreements - PMS Guides

### ΔE =

PMS Books compared over 30 years (perfect condition)
Limitations of PMS/Printed Samples-30 year

PMS Books compared over 30 years (perfect condition)
Limitations of PMS/Printed Samples - Same Yr

Actual Comparison:
- Printer: Formulation Guide
- Customers: PMS Bridge
- Differences w/in <1 $\Delta E$
- Between 1-5 $\Delta E$???
Limitation with Library in CIE Lab Space

Effect of Illumination Not Quantifiable

- Color Inconstancy: Lighting illuminates colors differently

- Assess affect of suppliers light booth on brand colors
Benefits of Library in CxF X4 Complete

Accurate Simulation:
- Visual and numeric value for all tints
- Visual and numeric value for all spot overprints
- Visual and numeric value for effect of lighting on color
How to Make CxF/X4 Brand Library

Use CxF/X4 Template with your Suppliers

- Spectral solid value using CxF format
  - No ability define tints or overprinting with another color
- Spectral solid and tints values using CxF/X4 format
  - Accurate definition of solids, tint, and overprint value with another spot or process color
- This is the optimum format for Brand Color Definitions
Options for Spot/Brand Color Reference

Road Map to Analytic Based Print Manufacturing

PMS Chip
Print Sample

PMS Name
(Lab/CxF)

Custom Name
(Lab/CxF)

Custom Name
Spectral/Tints CxF/X4
2. Delta What?? (Δ)

*How to Define Color Difference*

- Know the Reference- How close is close enough?
- 2 Rings, 4 Rings, 6 Rings?
- More Rings, bigger difference

- How to Quantify with Numbers?
What Type of Color Match?

- Match specific colors: Spot, brand colors

- Match between pages and or images: Process Color
How Close is Close Enough- to Sell Print?

*How different is too different for Customer?*

- Actual printed sample from multiple suppliers…
How to Quantify Color Differences

What Type of Color Match?

- Match for individual colors: Brand/Spot Color
  - $\Delta E$ (delta E) quantifies single color differences
  - Bigger the number, bigger the difference

- Match between pages or images: Many Colors, Pages
  - E-Factor (EF)- quantifies process color differences
  - Type of $\Delta E$ (CRF at 95th percentile)
  - Think $\Delta E$ for process colors, same relative difference
Quantify Color Differences

**What Type of Color Match?**

- Match specific colors: Process Control (C,M,Y,K), Spot
  - Digital (uncalibrated)
  - Ink Jet (uncalibrated)
  - Offset (uncalibrated)
  - Digital (G7)
  - Ink Jet (G7)
  - Offset (G7)

\[ \Delta E = 4 \quad 3 \quad 2 \quad 2 \]

- Match between pages and or images: Process Color

\[ \Delta E = 3 \quad 4 \]

\[ =3 \quad =6 \]
What is E-Factor: $\Delta E_{00}$ CRF at 95th Percentile

Compare Measurements from 2 Prints

- Example with Idealliance Control Wedge ISO12647-7 (2013)

Color Aim/Reference: GRACoL2013

Actual Printing Condition: “Large Format”
What is E-Factor

Many software programs support today...

1. Calculate $\Delta E_{00}$ difference for each patch

   GRACoL2013 vs “Large Format”

2. Reorder patches from the smallest to largest $\Delta E$

   Smallest (1.17$\Delta E_{00}$)
   
   Largest (16.12$\Delta E_{00}$)
Metric required for G7 Color Space

95% Chance of Colors being within Expectations

3. Calculate 95th percentile (95% worst match of patches)

95% of reordered patches are below the $\Delta E$ value (12.5$\Delta E_{00}$)

GRACoL2013 vs “Large Format”
($\Delta E$ reordered)

Last 5% of reordered patches have larger $\Delta E$ values (12.5$\Delta E_{00}$) - outliers
Defining Color Salability (Acceptability):

*Research Shows*

- $\Delta E$ and E-Factor 2-3 almost universally **accepted**
  - *Spot/brand color match*
  - *Image/page color match*
- $\Delta E$ and E-Factor 8+ almost universally **unacceptable**
- $\Delta E$ and E-Factor between 4-7- **depends on person**
Enter Actual Lab values for your Colors

**Preview actual differences**

- 3M Red- Entered Lab values
- Spot Color Exercise
- Choose Different delta E formulas
- Compare across hue angles
- Use to determine Acceptability
- Show numbers show the Δa and Δb and ΔE
Visualize All $\Delta E$ variations: Seeing Believing

*Use Visualizer to See the Result for each Color*

- Shows all variations of any $\Delta E$ in every direction
Customize Tolerance add additional metrics

**Customize Tolerance**

- Use $\Delta E$ and add $\Delta h$ maximum
- Every color can have different metrics
Customize Tolerance Visually, Define digitally

\( \Delta E (00) \) differences are non uniform

- Different colors render differently in different hue angles
- Visually use \( \Delta L \), \( \Delta a \) and \( \Delta b \) to change relative difference
- Document the delta differences
- Addresses the non linearity of \( \Delta E \) as tolerance metric
Customize Tolerances based Visual Acceptance

**Blindly determine Acceptable Tolerances**

- Four corners, center are reference, 4 sides are different
Specification for Brand/Spot Tolerancing

Road Map to Analytic Based Print Manufacturing

Visual Review

Delta E (00)  Delta E (00)  \pm L, \pm a, \pm b

\Delta h, or additional
Page (Process) Color Differences…

*Which one is the Most Correct- Closest?*

- Actual printed sample from multiple suppliers…
Which GRACoL2006 or 2013?

*Visual Difference Between the Two...*

- They are Different...

GRACoL2006  GRACoL2013

\[ EF = 2 \]
How Close is Close Enough- to Sell Print?

*How different is too different for Customer?*

- How different from the Reference (GRACoL)?

GRACoL

\[ EF = 6 \]

GRACoL

\[ EF = 3 \]

GRACoL

\[ EF = 12 \]
How Close is Close Enough- to Sell Print?

*How different is too different for Customer?*

- How different from the Reference (GRACoL)?

![Diagram showing EF values for different GRACoL samples](image-url)
How Close is Close Enough- to Sell Print?

How different is too different for Customer?

- Actual printed sample from multiple suppliers…

= 10

EF

= 5
How Close is Close Enough- to Sell Print?

*How different is too different for Customer?*

- Score Cards do not communicate Visual Difference well

55%

82%
What about Score Carding Programs

**Purpose of Score:**
- Assess print is within customer expectations
- Assess how close printer is to reference
- Assess how close printer is to itself over time
- Assess how close two different printers are to one another
What about Score Carding Programs

**Purpose of Score:**
- Assess print is within customer expectations
- Assess how close printer is to reference
- Assess how close printer is to itself over time
- Assess how close two different printers are to one another

**Process Control Score Cards- Old Way-**
- Score doesn’t relate to Customer Expectations
- 85% Score doesn’t relate to Expectations…
- Score doesn’t relate to how close two prints are to one another
- Week to week from same vendor, or between two vendors
Specification for Image/Page Tolerancing

Road Map to Analytic Based Print Manufacturing

Visual Review

Score Card
ColorCert/ Bodoni

G7
ColorSpace

CRF 95th Percentile
Understand... Tighter the Tolerance - Harder

Exponentially Harder to Achieve - More $$$

ΔE = 8
ΔE = 7
ΔE = 6
ΔE = 5
ΔE = 4
ΔE = 3
ΔE = 2

Spot Tolerances

Process Tolerances
3. Output Device Capabilities?

*Print Device Production Capabilities*

- Not just process control (ensuring CMYK and G7 gray is OK)
- Sum of all variables: print device, consumables, operator
- Manufacturer’s don’t publish this number (mileage varies)
Defining Method to Characterize Output

*Depending upon Process, and Reference*

- Create Tone Curve to accommodate device condition
  - E-Factor = 5-6
- Create an ICC Profile to accommodate device condition
  - E-Factor = 3-5
- ICC Device links with ink savings
  - E-Factor = 2-4
Then Determine if Tolerance is Possible…

**Depending upon process, may not maintain**

- True spot color with custom ink formulation for substrate
- Spot color simulation on digital device
  - Using CMYK builds to simulate the desired color

![Color Inspector Chart](image)
Benchmarking Printing Devices

**Over 1 Million measurements - published report**

- Benchmark procedures to audit your devices - free software
- Digital press, large format, flexo, offset
- Gamut Size, Consistency, Accuracy, Resolution

### Benchmark #1 Gamut Size: Results

<table>
<thead>
<tr>
<th>Printer</th>
<th>Gamut Size</th>
<th>Consistency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuji J-Press*</td>
<td>558,700</td>
<td>75%</td>
</tr>
<tr>
<td>Kodak Prosper</td>
<td>513,900</td>
<td>76%</td>
</tr>
<tr>
<td>KM1 Press*</td>
<td>512,900</td>
<td>76%</td>
</tr>
<tr>
<td>Konica Minolta KM1</td>
<td>504,100</td>
<td>71%</td>
</tr>
<tr>
<td>Digital Press NEE</td>
<td>459,400</td>
<td>70%</td>
</tr>
<tr>
<td>Digital Press N</td>
<td>451,100</td>
<td>68%</td>
</tr>
<tr>
<td>Indigo 10000*</td>
<td>450,500</td>
<td>66%</td>
</tr>
<tr>
<td>Indigo 12000*</td>
<td>443,300</td>
<td>68%</td>
</tr>
<tr>
<td>Indigo WS6500*</td>
<td>420,900</td>
<td>63%</td>
</tr>
<tr>
<td>Igen 6 Press*</td>
<td>401,300</td>
<td>65%</td>
</tr>
<tr>
<td>Digital Press N</td>
<td>351,900</td>
<td>57%</td>
</tr>
<tr>
<td>Kodak Nexpress*</td>
<td>350,700</td>
<td>57%</td>
</tr>
</tbody>
</table>

### Benchmark #2 Variation: Results

<table>
<thead>
<tr>
<th>Printer</th>
<th>Within</th>
<th>Between</th>
<th>E-Factor M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indigo 12000*</td>
<td>1.0</td>
<td>P</td>
<td>1.0</td>
</tr>
<tr>
<td>Domino press</td>
<td>1.0</td>
<td>P</td>
<td>1.0</td>
</tr>
<tr>
<td>Fuji J-Press*</td>
<td>1.2</td>
<td>P</td>
<td>1.1</td>
</tr>
<tr>
<td>KM1 Press*</td>
<td>1.3</td>
<td>P</td>
<td>2.0</td>
</tr>
<tr>
<td>Kodak Nexpress*</td>
<td>1.2</td>
<td>P</td>
<td>1.8</td>
</tr>
<tr>
<td>Konica Minolta KM1</td>
<td>1.4</td>
<td>P</td>
<td>1.2</td>
</tr>
<tr>
<td>Digital Press O</td>
<td>2.3</td>
<td>F</td>
<td>3.2</td>
</tr>
<tr>
<td>Igen 6 Press*</td>
<td>2.5</td>
<td>P</td>
<td>2.2</td>
</tr>
<tr>
<td>Kodak Prosper</td>
<td>3.0</td>
<td>F</td>
<td>1.4</td>
</tr>
<tr>
<td>Digital Press N</td>
<td>5.1</td>
<td>F</td>
<td>5.5</td>
</tr>
<tr>
<td>Indigo 6500*</td>
<td>9.0</td>
<td>P</td>
<td>Incomplete</td>
</tr>
<tr>
<td>Indigo 6000*</td>
<td>1.5</td>
<td>F</td>
<td></td>
</tr>
</tbody>
</table>
Is Color Close Enough?

- Define Production Capability of all Devices
- Define if devices are within Customer Expectations

![Diagram showing the relationship between Buyer Expectation, Production Capabilities, Satisfaction, and Profit](diagram.png)
Assessing all Output Devices

- Centralized, Accountable Color Control
- Allows Each Operator to be Responsible
- Notifications sent if Device not maintained

System Overview
4. What Variables affect assessment

All variables have a cumulative affect

- Difference in paper manufacturing
- Difference between measurement backing
- Differences between measurement devices
- Differences between lighting
Paper Manufacturing

Many Variables, OBA, Water, Fiber

- Paper variation in manufacturing - Oregon vs. Wisconsin
- Proofing Paper tolerances - Max 1\( \Delta \) in L\(^*\) or a\(^*\) or b\(^*\)
- Photo Paper tolerances - Max 2\( \Delta \) in L\(^*\) or a\(^*\) or b\(^*\)
- Track Paper independent of Ink
Measurement Backing Differences

**Actual Data - Changing backing behind measure**

- Measuring same target with same accurate instrument
- Measure on ISO White, ISO Black, and actual paper
- Differences are greater than 2 E-Factor…

ISO 13655

\[ L^* = 95 \]
\[ a^* = .9 \]
\[ b^* = 1.3 \]

Press Side
Measurement = Black

Proofing
Measurement = White
Instrument Gauge Factor

- Every Manufacturing Industry using this metric, except
- Defines what percentage of Production tolerance can be used up due to instrument disagreement (20%-33%)
- Means, if tolerance is $2\Delta E$, need to give up $0.4-.66\Delta E$ to within instrument variation
- Delta E stacks on top, two or more instruments total difference be within $0.4\Delta E$ (stay within 20% of $2\Delta E$)
How Measurement Device Influences Result

No two measurement devices measure same...
How Measurement Device Influences Result

No two measurement devices measure same...

$59

$6000
Instrument Needs to be Considered!

**Different Instruments Measuring Same Colors:**

- Same Brand Color bar measured with i1, Exact, SpectroDens

<table>
<thead>
<tr>
<th>ΔE Values- only difference is the instrument...</th>
<th>Primaries and Spots</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Understand Supplier Differences

Different Printers attempting to Print desired colors

- Each Printer could be within $2\Delta E$ of Reference
- But be up to $4\Delta E$ to each other - different inks/toners
- Realistic Tolerances
Same Color bar measured with 3 instruments

- Comparison between 3 measurement devices
- X-Rite Exact vs i1; Peak $\Delta E = 6.4$: White
- Tolerance is $2\Delta E$?
- Fails due to Instrument Differences
Two Instrument Strategies: Process vs Spot

**Process Color Instrument Strategy**

- Harmonize Instruments to one another- Compensate on fly
- Build profiles for each instrument, compensate measurements

- Without Harmonization- Mix instruments require E-Factor= 6
- With Harmonization- Mix instruments enables E-Factor= 1.8
Two Instrument Strategies: Process vs Spot

**Spot/Brand Color Instrument Strategy**

- Resign that every instrument is different
- Track same color product with different instruments/conditions

- Accommodates mixing Spherical measurements and 45/0
- Communicate references to supply chain
Instrument Tracking and Compensation

Road Map to Analytics Based Print Manufacturing

**Visual Review**
- Personal perception-based comparison to physical standard
  - no knowledge required
  - expensive and time-consuming
  - personal supervision
  - dependent on the person
  - lighting conditions related
  - uncontrolled metamericism

**Send to Factory**
- Instrument-based comparison to physical standard
  - numerically expressed color differences
  - expensive and time-consuming
  - personal supervision
  - uncontrolled metamericism
  - initial swatch-book Inaccuracy

**Vendor tools**
- Instrument-based comparison to colorimetric standard
  - numerically expressed color differences
  - stable color definition
  - exchangeable color definition
  - the possibility of remote control

**Harmonize to Master**
- Instrument-based comparison to spectral standard
  - numerically expressed color differences
  - spot colors, SCTV, CxF/X compliant
  - exchangeable color definition
  - lighting condition
Light Booth Differences

**Two most used light booths on market**
- Press has one, Prepress has other - Mismatches

Vendor J

Vendor G

Brand Colors React differently to different lighting (LED)…
Quantify How Close to One Another

- Multiple Light Booths, normal variations
Light Booths

Quantify How Close to D50, and to One Another

- Two light booths that pass ISO doesn’t guarantee match
- Never mind two different vendors- same vendor!!!
  - T8 Bulbs versus T12 bulbs- and different ages > 2
- Trying to match E-9900/Gracol06 with 9000/Gracol2013
- Color server, manual corrections: very close- customer rejected- Due to Light booth!!!
- Changed ballast to support same tube, bought same batch, set schedule for change out
Light Booth Tracking and Compensation

Road Map to Analytics Based Print Manufacturing

**Visual Review**
- Once year audit
- Same Batch, Manufacturer

**Measure Monthly**
- Monthly measurement
Rules For Engagement

*Understand the Ramification of Every Variable*

- Need to be Advanced in Every Category
  - Defining References
  - Defining Tolerances
  - Defining Backing
  - Defining Instrumentation- and Harmonization
  - Defining Lighting
Cumulative Process:

• Each Workflow Component is tracked using $\Delta E$ or E-Factor

• They all stack on each other

Each Variable Stacks on Top of Each Other
Print Manufacturing Salable Number

Road Map to Analytics Based Print Manufacturing

VISUAL
- Personal perception-based comparison to physical standard
- No knowledge required
- Expensive and time-consuming
- Dependent on the person
- Lighting conditions related
- Uncontrolled metamerism

BASIC INSTRUMENTAL
- Instrument-based comparison to physical standard
- Numerically expressed color differences
- Expensive and time-consuming
- Personal supervision
- Uncontrolled metamerism
- Initial swatch-book Inaccuracy

COLORIMETRIC AIM
- Instrument-based comparison to colorimetric standard
- Numerically expressed color differences
- Stable color definition
- Exchangeable color definition
- The possibility of remote control

SPECTRAL AIM
- Instrument-based comparison to spectral standard
- Numerically expressed color differences
- Spot colors, SCTY, CxF/X compliant
- Exchangeable color definition
- Lighting conditions

\[ \text{EF} = 9^+ \quad \text{EF} = 6-8 \quad \text{EF} = 4-5 \quad \text{EF} = 2-3 \]
Color Conformance vs. Process Control

**Defined tolerances in $\Delta E$, E-Factor will determine:**

- What type of process control for given manufacturing
- How often process control is performed
- How tight the process control metrics are
- How tight raw materials have to accountable to
- Proactively assessing all variables, all time
  - Not sending instrument back to factory once/year
- Communicating to Operators, Management, Sales etc.
If You Want any Chance for 2 $\Delta E/E$-Factor

Need to be maximum maturity for every category

- Defining and Communicating Digital References
- Defining and Communicating Intelligent Tolerances
- Defining Print Manufacturing Capability (E-Factor)
- Defining Substrates, and allowing SCCA
- Harmonizing Instruments (Compensate for differences)
- Using same light booth/bulbs, tracking bulb age
- Real time tracking and assessment
Thank you for attending!