An Analysis of M0 and M1 Measurement Conditions

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- Rochester Institute of Technology

Inherent Variation

- The Hallmark of a Seasoned Professional
- New Metrics = New Challenges

Special Case of Color Measurement

- Terminology Confusion
  - Inter-Instrument Agreement
  - Inter-Instrument Disagreement
  - Inter-Model Agreement
  - Instrument Uncertainty

Manufacturers’ Perspective

- Instruments Certified Using BCRA Series II Tiles
  - Stability
  - Traceable
  - Widely Adopted
- Recertification Services
  - Recommended for ‘Normal Use’

Making a Flawed Situation Even More Confusing

- No Consistency on HOW Specifications are Published
  - Average of 12 BCRAs, Max. on Single BCRA, or Both?
  - Tolerancing Method?

<table>
<thead>
<tr>
<th>Published Inter-Instrument Agreement Specifications for Graphic Arts Spectrophotometric Instruments</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4 ΔEcmc MAX</td>
</tr>
<tr>
<td>0.4 ΔE94 Average, 1.0 ΔE94 MAX</td>
</tr>
<tr>
<td>0.3 ΔE* MAX, 0.15 Average</td>
</tr>
<tr>
<td>0.3 ΔE* Average</td>
</tr>
<tr>
<td>0.3 ΔEab Average</td>
</tr>
<tr>
<td>0.25 ΔE* Average, MAX 0.45 ΔE*</td>
</tr>
<tr>
<td>&lt; 1.0 MAX, &lt;0.5 ΔE Average</td>
</tr>
<tr>
<td>0.3 ΔE00 Average</td>
</tr>
<tr>
<td>0.3 ΔE*, 0.15 ΔEcmc Average</td>
</tr>
</tbody>
</table>

Green BCRA with Same Tolerance Number Using ΔE*, ΔEcmc, ΔE94 and ΔE00
Efforts to Drive Variance
- Internal SOPs
  - BCRAs
  - IDEAlliance LabREF
- Round Robin
- Third Party, e.g.
  - ChromaChecker
  - Vogelsong Color Ref

Motivation
- Climate Comprised of Factors Surrounding Color Measurement Accuracy
- Introduction of M1

Research Questions
- Are There Differences in Variance in M1 and M0 Readings With Instruments Capable of Measuring Both?
- Are There Differences in Variance Among M1 Instruments and M0 Legacy Instruments?

Methods
- Read and Record ΔE00 in Color Pairs with M1, M0 and Legacy (M0) Instruments
- Evaluate White Points of M1, M0 and M0 Legacy Instruments
- Color Pairs
  - Twelve Color Samples in IDEAlliance LabREF
  - Two Paper Samples (One OBA, One No OBA)

Data Collection
- Goal to Measure with as Many Instruments as Possible
  - Began at GraphExpo in Fall
  - Instruments at RIT
  - Customers and Vendors

Descriptive Data: Ranges

<table>
<thead>
<tr>
<th></th>
<th>M0</th>
<th>M1</th>
<th>M1 Legacy</th>
</tr>
</thead>
<tbody>
<tr>
<td>DE00 Papers</td>
<td>2.7</td>
<td>1.9</td>
<td>1.8</td>
</tr>
<tr>
<td>DE00 White</td>
<td>.98</td>
<td>.90</td>
<td>.75</td>
</tr>
<tr>
<td>DE00 Black</td>
<td>.72</td>
<td>.71</td>
<td>.59</td>
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<tr>
<td>DE00 Cyan</td>
<td>.07</td>
<td>.08</td>
<td>.02</td>
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<tr>
<td>DE00 Magenta</td>
<td>.31</td>
<td>.37</td>
<td>.26</td>
</tr>
<tr>
<td>DE00 Yellow</td>
<td>.38</td>
<td>.39</td>
<td>.26</td>
</tr>
<tr>
<td>DE00 Green</td>
<td>.35</td>
<td>.38</td>
<td>.25</td>
</tr>
<tr>
<td>DE00 Blue</td>
<td>.27</td>
<td>.22</td>
<td>.18</td>
</tr>
<tr>
<td>DE00 Brown</td>
<td>.26</td>
<td>.21</td>
<td>.21</td>
</tr>
<tr>
<td>DE00 Purple</td>
<td>.24</td>
<td>.20</td>
<td>.19</td>
</tr>
<tr>
<td>DE00 Pastel</td>
<td>.29</td>
<td>.22</td>
<td>.17</td>
</tr>
</tbody>
</table>
Evaluation of Paper Samples

M1 vs. M0

- M1 Delta-E_{00}: (M = 7.7, SD = 0.47)
- M0 Delta-E_{00}: (M = 5.6, SD = 0.67)
- $M = -2.05$, 95% CI[-2.44--1.68], $t(36) = -10.97$
- $p < 0.01$.

- There were 19 M0 and 19 M1 Instruments analyzed. An independent-samples t-test was run to determine if there were differences in Delta E in reading an OBA paper and a non-OBA paper by measurement condition. There were no outliers in the data, as assessed by a visual inspection of the boxplot. There was homogeneity of variances for Delta-E_{00} Paper, as assessed by Levene’s test for equality of variances ($p = 0.13$). Delta-E_{00} Paper for each level of Measurement Condition (M0/M1) were normally distributed, as assessed by Shapiro-Wilk’s test ($p > 0.05$).

Evaluation of Paper Samples

M0 vs. M0 Legacy

- M0 Delta-E_{00}: (M = 5.6, SD = 0.67)
- M0 Legacy Delta-E_{00}: (M = 5.7, SD = 0.38)
- $p > 0.05$

Boxplots DE_{00} Black

- M1 Delta-E_{00}: (M = 0.20, SD = 0.13)
- M0 Delta-E_{00}: (M = 0.21, SD = 0.17)
- $p > 0.05$

- M0 Delta-E_{00}: (M = 0.21, SD = 0.17)
- M0 Legacy Delta-E_{00}: (M = 0.25, SD = 0.30)
- $p > 0.05$
Boxplots DE₀₀ Gray

Evaluation of LabREF Gray

- M₁ Delta-E₀₀: \( M = 0.54, SD = 0.21 \)
- M₀ Delta-E₀₀: \( M = 0.52, SD = 0.18 \)
- \( p > 0.05 \)
- M₀ Legacy Delta-E₀₀: \( M = 0.53, SD = 0.19 \)
- \( p > 0.05 \)

Boxplots DE₀₀ Brown

Evaluation of LabREF Brown

- M₁ Delta-E₀₀: \( M = 0.56, SD = 0.19 \)
- M₀ Delta-E₀₀: \( M = 0.59, SD = 0.12 \)
- \( p > 0.05 \)
- M₀ Legacy Delta-E₀₀: \( M = 0.59, SD = 0.16 \)
- \( p > 0.05 \)

Boxplots DE₀₀ White

Evaluation of LabREF White

M₁ vs. M₀ and M₀ vs. M₀ Legacy

- M₁ Delta-E₀₀: \( M = 0.23, SD = 0.12 \)
- M₀ Delta-E₀₀: \( M = 0.27, SD = 0.13 \)
- \( p > 0.05 \)
- M₀ Legacy Delta-E₀₀: \( M = 0.27, SD = 0.13 \)
- \( p > 0.05 \)
White Points, M0, M1 and M0 Legacy

Conclusions: Instrument Accuracy in Workflow
- Support for Widely Recognized Realizations
  - Difference Information is Best Method
  - Careful Specification of Measurement Parameters Necessary

Implications
- Instrument Manufacturers:
  - Provide Common Inter-Instrument Agreement Specifications for Real Comparison
  - Implement Black Trap Calibration

Future Research
- Continue Data Collection with Additional Instruments
- Measurement Systems Analysis
  - Fixed Effects (Measurement Condition)
  - Random Effects (Various Instruments)
  - Restricted Maximum Likelihood (REML)

Thank You!
- In addition to my colleagues at RIT including the Printing Applications Lab, I would like to thank the following companies for their support with this project:
  - Konica Minolta Sensing
  - Techkon USA
  - X-Rite