

An Analysis of M0 and M1 Measurement Conditions

Bruce Leigh Myers and Rachel Silvestrini

Keywords: colorimetry, measurement condition, spectrophotometer, ISO13655:2009, inter-instrument agreement

The increased use of optical brightening agents (OBAs) in substrates for printing is well documented, as are the complications surrounding spectrophotometric color measurement when OBAs are present. In an effort to better address measurement of OBAs, the International Standards Organization (ISO) has published ISO 13566:2009, where the illuminations utilized in spectrophotometric instrumentation is more clearly defined than in previous standards. It is recognized that moving ahead the illuminant utilized in spectrophotometers should be able to better correlate to standardized viewing conditions, including the amount of ultra-violet (UV) present in the illuminant, as the effect of the OBAs is dependent on the amount of UV.

Of particular note, ISO 13655:2009 recognizes measurement condition M0 as a 'legacy' condition, representative of the wide range of spectrophotometers utilized in the field. Condition M0 instruments illuminants correspond to illuminant "A," while measurement condition "M1" specifies that the instrument illumination corresponds to D50, which is better correlated to standardized viewing conditions and has a more clearly defined UV component. One goal of M1 is to achieve better agreement between various manufacturers and models of instrumentation.

While M1 instruments are being utilized more and more frequently in the field, there is a large population of legacy M0 instruments also in use. For those interested in understanding the variation that can be expected in the comparison of various instruments, the question of how much variation can be eliminated through the exclusive adoption of M1 instruments is especially germane.

RIT School of Media Sciences, Rochester, NY 14623

Methods

The present study examines difference readings of both M0 and M1 instruments. As instruments capable of reading M1 include the ability to read the M0 condition, three measurement conditions were examined, as follows:

1. M0 Legacy: M0 readings from instruments not capable of reading the M1 measurement condition
2. M0: M0 readings from instruments capable of reading the M1 measurement condition
3. M1: M1 readings from instruments capable instruments.

Forty different spectrophotometers were utilized: twenty M0 Legacy instruments and twenty instruments capable of reading both M1 and M0.

In selecting samples with which to measure color differences, criterion included sample pairs with small color differences that would remain stable over the time needed to record the measurements. To meet these criteria, two LAB-REF's™ were purchased from IDEAlliance. Each IDEAlliance LAB-REF™ includes the following colors:

White	Black	Cyan
Magenta	Yellow	Gray
Red	Green	Blue
Brown	Purple	Pastel

Table 1: Colors Represented by IDEAlliance LAB-REF™

As the LAB-REF™ does not include OBAs, two paper samples were also selected to be measured: one with OBAs and the other with no OBAs.

It is important to note that for the present study there is no presumption of a standard reference of known colorimetric values for the purpose of the comparison; the study is limited to examining the variance in the difference of each measurement condition between the 12 color pairs represented by the two LAB-REF's™ and the two papers.

The study addresses the following research question: Is there a difference in the colorimetric variance between M0, M1 and M0 legacy instruments for the selected sample pairs?

Spectral data were collected over a seven month period beginning in September, 2014. Instruments utilized included various models of instruments commonly used

in the graphic arts from Konica Minolta, Techkon and X-Rite. All instruments were directional geometry (0/45 and 45/0). Spectral readings were taken with each sample pair, and difference information was calculated and reported as Delta-E CIE2000 (ΔE_{00})

Metrics:

To examine the equality of variances among M0 Legacy, M0 and M1, Levene's Test was utilized. Commonly used as a post-hoc test to meet the conditions of Analysis of Variance (ANOVA) and other statistical tests, Levene's tests for homogeneity of variance. An examination of boxplots and histograms of the raw ΔE_{00} values indicated that they data for many of the samples included outliers, and were non-normally distributed. Therefore, a non-parametric Levene's Test as advanced by Nordstokke and Zumbo (2010) was utilized.

As previously indicated, a major motivating factor underlying the development of the M1 measurement condition is the prevalence of OBAs, the present study provides a detailed analysis of the results of the paper samples measured, namely the paper with OBAs compared to the paper sample without OBAs. Summary data is presented for the comparison of the two IDEAlliance LAB-REF's™.

Measurement of OBA and Non-OBA Paper with M0 Legacy, M0 and M1

As a reminder, the present analysis does not presume standard values to judge instrument accuracy, but rather examines the variance in instrument measurement condition when measuring the same sample pairs. Hence, the means of the instrument readings is not analyzed in favor of examining the variances represented. When examining the difference readings between the OBA and non-OBA paper samples, the null and alternative hypotheses are as follows:

$$H_0: \text{var}(M0 \text{ Legacy}) = \text{var}(M0) = \text{var}(M1)$$

$$H_1: \text{var}(M0 \text{ Legacy}) \neq \text{var}(M0) \neq \text{var}(M1)$$

The ΔE_{00} values were normally distributed, as assessed by Shapiro-Wilk's test ($p > 0.05$). An assessment of a boxplot, however, did indicate outliers greater than 1.5 box-lengths from the edge of the box in the instance of M0 Legacy, as shown in Figure 1. The decision was therefore made to utilize the non-parametric Levene's test (Nordstokke and Zumbo, 2010), which has demonstrated to be robust in instances where outliers are present and the data are not normally distributed.

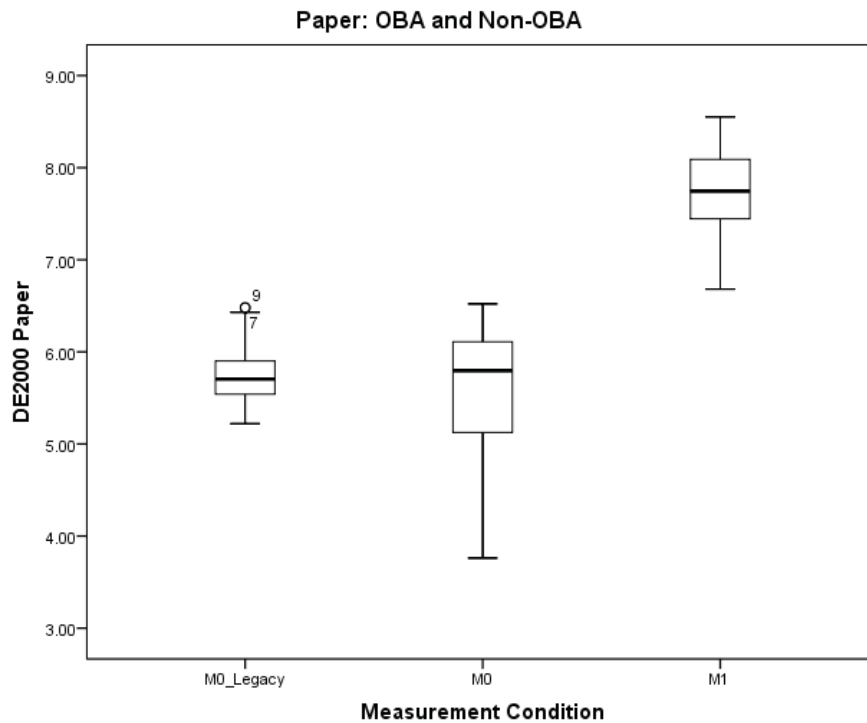


Figure 1. Boxplots of ΔE_{00} readings for OBA and non-OBA paper samples by measurement condition.

The non-parametric Levene's test dictates pooling the data from the groups, ranking the scores, placing the rank values back into their original groups, and conducting the Levene's test on the ranks (see Nordstokke, Zumbo, Cairns and Saklofske, 2011).

The ranked ΔE_{00} values for each measurement condition were examined for normality and outliers prior to attempting the Levene's test for homogeneity of variance.

The ranked ΔE_{00} values were normally distributed, as assessed by Shapiro-Wilk's test ($p > 0.05$). An assessment of a boxplot, did not indicate outliers greater than 1.5 box-lengths from the edge of the box as shown in Figure 2.

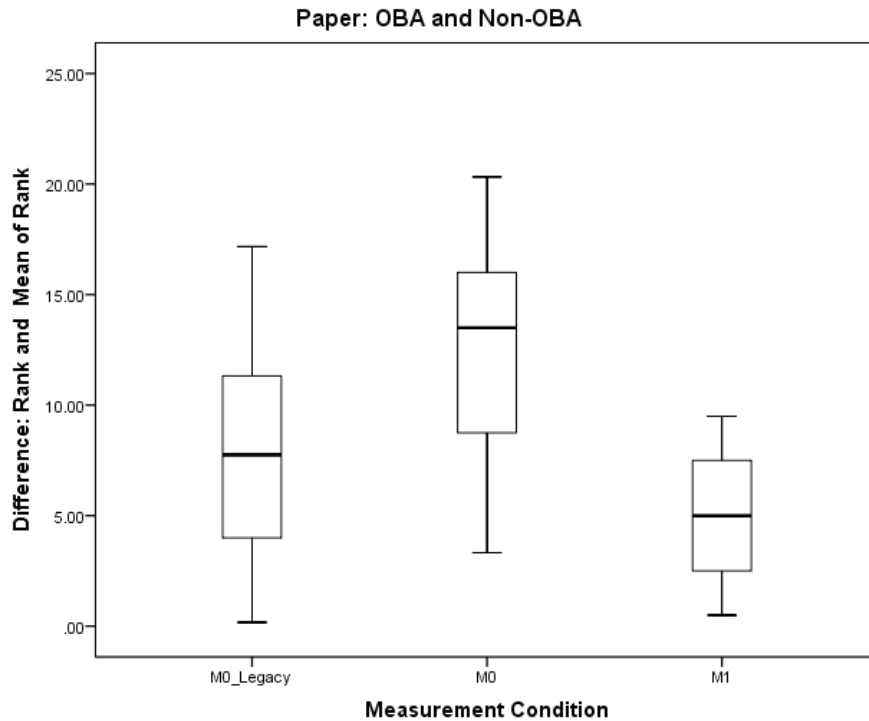


Figure 2. Boxplots of ΔE_{00} readings for ranked OBA and non-OBA paper samples by measurement condition.

For the ranked ΔE_{00} data, homogeneity of variances was violated, as assessed by Levene’s test ($p = 0.04$). If we examine the standard deviation of each measurement condition as shown in Table 2 and the boxplots of the ranked data as shown in Figure 2, it is suggested that when measuring the difference between the utilized OBA and non-OBA papers and ranking the resultant data the M1 measurement condition results in less variance than either the M0 Legacy or the M0 measurement conditions.

	M0 Legacy	M0	M1	Levene’s Test p
Variance	29.02	25.51	8.68	0.04

Table 2: Paper: OBA and Non-OBA Ranked ΔE_{00}

Measurement of OBA and Non-OBA Paper with M0 Legacy, M0 and M1

Results of the ranked color difference for each of the colors samples included with the IDEAlliance LAB-REF™ is demonstrated in boxplot form in Figure 3 and Table 3. For each color pair, the Levene’s test for homogeneity of variances resulted in p values > 0.05 , indicating that there was no statistically significant difference in the variances among the measurement conditions tested.

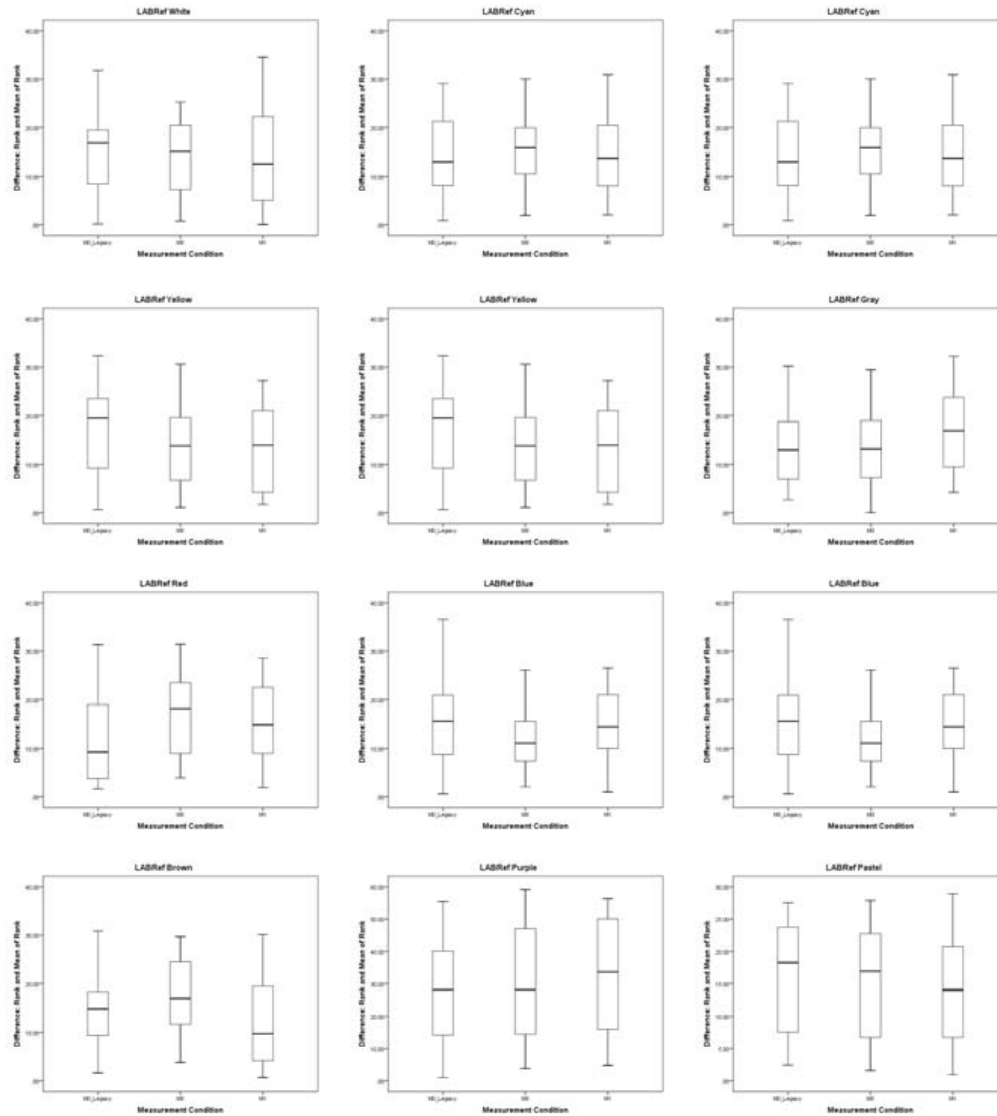


Figure 3. Boxplots of ΔE_{00} readings for ranked LAB-REF™ samples by measurement condition.

	M0 Legacy	M0	M1	Levene's Test p
White Variance	65.68	56.64	87.15	0.64
Black Variance	70.21	55.07	79.15	0.29
Cyan Variance	65.15	55.72	67.9	0.85
Magenta Variance	49.04	85.21	106.75	0.08
Yellow Variance	87.4	66.16	79.69	0.63
Gray Variance	69.03	72.07	79.73	0.79
Red Variance	81.63	74.52	67.69	0.80
Green Variance	54.87	72.87	56.69	0.74
Blue Variance	107.2	38.36	46.11	0.21
Brown Variance	71.29	67.3	85.13	0.54
Purple Variance	269.52	342.06	302.46	0.33
Pastel Variance	75.05	79.08	69.05	0.62

Table 3: IDEAlliance LAB-REF™ Ranked ΔE_{00}

Discussion

Inter-instrument agreement is an ongoing concern, and one of the primary challenges that researchers face in the examination of the variance that can be expected here are the characteristics of the sample. Relevant concerns here include the presence of OBAs, the surface characteristics of the samples, and even the lightfastness of the samples over time.

Today, instrument accuracy in terms of inter-instrument agreement are published for readings on BCRA Series II Tiles, which are more stable than colorant-on-paper samples but are not especially well suited for replicating the surface characteristics of the products produced by the graphics industry. Ambiguity here is furthered by instrument manufacturers' lack of publishing inter-model agreement among their particular models, and more importantly a lack of consistency in the methodology which underscores their published accuracy information.

The results here underscore the recommendations that, in workflows involving multiple instruments, the measurement condition utilized to create the standard needs to be specified together with other colorimetric variables (e.g.: illuminant, observer, tolerancing method). Further, when OBAs are present, instruments utilizing measurement condition M1 may result in less variance than measurement condition M0. The present study does not support this contention with samples that do not include OBAs, as is the case with the IDEAlliance LAB-REF™.

Future Research

Future researchers are encouraged to build on the results presented: a larger set of samples which include OBAs would be welcome to support the data presented here. To overcome the inherent challenges for this type of study, it is suggested that collecting data at one point in time would result in greater internal validity. One way to accomplish this would be to do so at a summit wherein the manufacturers are invited to send representatives with certified instruments to measure colorant-on-paper samples representative of the type of work commonly produced by printers. Such summits, sponsored by institutions, were successful in comparing proofing technologies in the past: the nature of color measurement has reached the point where such a summit would be welcomed.

References:

- Nordstokke, Zumbo, Cairns and Saklofske (2011). The operating characteristics of the nonparametric Levene test for equal variances with assessment and evaluation data. *Practical Assessment, Research & Evaluation*, 19(5), 1-8.
- Nordstokke, D.W. & Zumbo, B.d. (2010). A new nonparametric test for equal variances. *Psicologica*, 31, 401-430.

67th

Annual Technical Conference Handbook

March 22–25, 2015

Hotel Albuquerque

Albuquerque, NM

tagaatc.printing.org



TECHNICAL ASSOCIATION OF THE GRAPHIC ARTS

Printing Industries of America



**CENTER FOR
TECHNOLOGY
AND RESEARCH**

67th Annual Technical Conference

Albuquerque, NM, USA

Development of a Unique Indicator Label

Martin Habekost, Jason Lisi, and Krishan Rampersad

Bringing 2D Inkjet into 3D Forming Applications Using Monofunctional, Low-crosslinking and Heat-stable UV Inks

Don Sloan and Mike Plier

Digital Flexible Packaging

Raia Slivniak-Zozin

10:30 a.m.–11:00 a.m.

Refreshment Break

Alvarado FGH

11:00 a.m.–12:00 p.m.

Session 2A: Workflow

Alvarado A

Moderator: Clarence Penge

Theory of Global Optimization - The Science Behind a Theory Global Optimization in the Printing Industry

Udi Arieli

JDF After More than a Decade - Success Stories, Issues, New Developments

Rainer Prosi

11:00 a.m.–12:00 p.m.

Session 2B: Instrument

Alvarado C

Moderator: William Li

Inter-Model Agreement Under M1 Conditions and the Implications for Graphic Reproduction

Veronika Lovell, Robert Marcus, and Danny C. Rich

An Analysis of Instrument Measurement Conditions on Various Substrates

Bruce Leigh Myers

12:00 p.m.–1:30 p.m.

Lunch & Annual TAGA Business Meeting

Alvarado DE

1:30 p.m.–3:00 p.m.

Session 3A: Printed Electronics

Alvarado A

Moderator: Brian Lawler

Capacitors Out of Recycled Printed Electronics Paper Substrates

Veronika Husovska, Jan Pekarovic, Alexandra Pekarovicova and Paul D. Fleming III

Printing Transparent Grid Patterns with Conductive Silver Ink with Flexography

Colleen Twomey, Dr. Xiaoying Rong, Dr. Charles Tonkin, Dr. Liam O'Hara, Malcolm Keif

The Use of Electron Microscopy and the Optical Profilometer for Quality

Joseph Tissera, Thomas E. Schildgen, and Howard Nelson

67th Annual Technical Conference

Albuquerque, NM, USA



Marc Levine
Schawk



William Li
Eastman Kodak Company



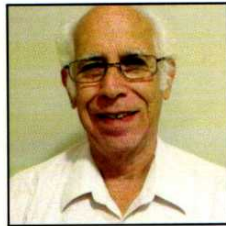
Jason Lisi
Ryerson University



Mei-Chun Lo
Shih Hsin University



Veronika Lovell
Sun Chemical Color
Research Laboratory



Robert Marcus
Sun Chemical Color
Research Laboratory



Dr. Bruce Leigh Myers
Rochester Institute of
Technology



Liam O'Hara
Clemson University



Shreyas Pathak
Western Michigan University



Jan Pekarovic
Western Michigan University



Alexandra Pekarovicova
Western Michigan University



Clarence Penge
Heidelberg



Stephen Pollard
HP Labs



Rainer Prosi
Heidelberg



Krishan Rampers
Ryerson University



Im Rangwalla
Energy Sciences Inc.



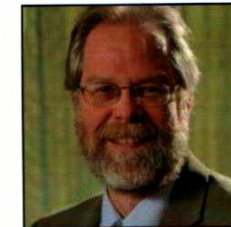
Danny C. Rich
Sun Chemical Color
Research Laboratory



Xiaoying Rong
California Polytechnic State
University



Juergen Seitz
GMG Color



John Seymour
QuadTech

An Analysis of M0 and M1 Measurement Conditions

- Bruce Leigh Myers, Ph.D.
- Rochester Institute of Technology

RIT



Inherent Variation

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

RIT



Special Case of Color Measurement

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

RIT



Manufacturers' Perspective

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

RIT



Making a Flawed Situation Even More Confusing

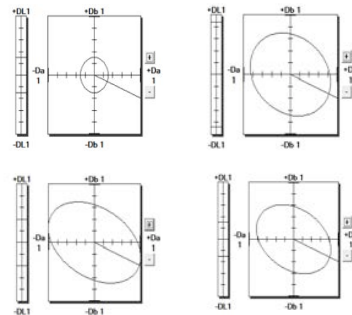
- No Consistency on HOW Specifications are Published
 - *Average of 12 BCRA's, Max. on Single BCRA, or Both?*
 - *Tolerancing Method?*

Published Inter-Instrument Agreement Specifications for Graphic Arts Spectrophotometric Instruments	
0.4 ΔE_{cmc} MAX	0.4 ΔE_{94} Average, 1.0 ΔE_{94} MAX
0.3 ΔE^* MAX, 0.15 Average	0.3 ΔE^*
0.3 ΔE_{ab} Average	0.25 ΔE^* Average, MAX 0.45 ΔE^*
< 1 ΔE MAX, < 0.5 ΔE Average	0.3 ΔE_{00} Average
0.3 ΔE^* , 0.15 ΔE_{cmc} Average	

RIT



Green BCRA with Same Tolerance Number Using ΔE^* , ΔE_{cmc} , ΔE_{94} and ΔE_{00}

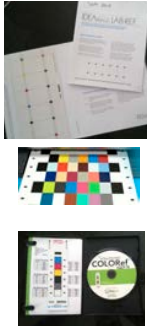


RIT



Efforts to Drive Variance

- Internal SOPs
 - BCRAs
 - IDEAlliance LabREF
- Round Robin
- Third Party, e.g.
 - ChromaChecker
 - Vogelsong Color Ref



RIT

Motivation

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

RIT

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?

RIT

Methods

- Read and Record ΔE_{00} 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)

RIT

Data Collection

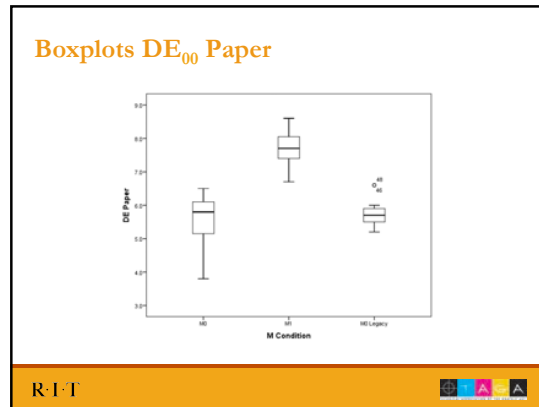
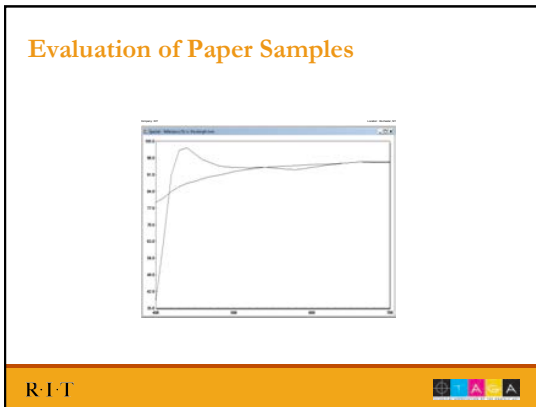
- Goal to Measure with as Many Instruments as Possible
 - Began at GraphExpo in Fall
 - Instruments at RIT
 - Customers and Vendors

RIT

Descriptive Data: Ranges

	M0	M1	M0 Legacy
ΔE_{00} Paper	2.7	1.9	1.4
ΔE_{00} White	.38	.42	.5
ΔE_{00} Black	.74	.44	1.39
ΔE_{00} Cyan	.47	.48	.52
ΔE_{00} Magenta	.34	.37	.28
ΔE_{00} Yellow	.18	.19	.26
ΔE_{00} Gray	.82	.82	.58
ΔE_{00} Red	.33	.39	.37
ΔE_{00} Green	.6	.31	.63
ΔE_{00} Blue	.39	.21	.53
ΔE_{00} Brown	.61	.29	.49
ΔE_{00} Purple	.27	.21	.32
ΔE_{00} Pastel	.29	.22	.42

RIT



Evaluation of Paper Samples M1 vs. M0

- M1 Delta-E₀₀: ($M = 7.7$, $SD = 0.47$)
- M0 Delta-E₀₀: ($M = 5.6$, $SD = 0.67$)
- $M = -2.05$, 95% CI[-2.44 – 1.68], $t(36) = -10.97$
- $p < 0.01$.

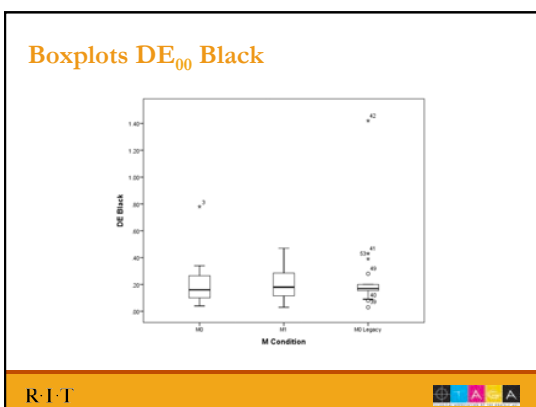
• There were 19 M0 and 19 M1 Instruments analyzed. An independent-samples t-test was run to determine if there were differences in Delta-E in reading an OBA paper and a non-OBA paper by measurement condition. There were no outliers in the data, as assessed by a visual inspection of the boxplot. There was homogeneity of variances for Delta-E₀₀ Paper, as assessed by Levene's test for equality of variances ($p = 0.13$). Delta-E₀₀ Paper for each level of Measurement Condition (M0/M1) were normally distributed, as assessed by Shapiro-Wilk's test ($p > 0.05$).

R-I-T

Evaluation of Paper Samples M0 vs. M0 Legacy

- M0 Delta-E₀₀: ($M = 5.6$, $SD = 0.67$)
- M0 Legacy Delta-E₀₀ ($M = 5.7$, $SD = 0.38$)
- $p > 0.05$

R-I-T



Evaluation of LabREF Black M0 vs. M1 and M0 vs. M0 Legacy

- M1 Delta-E₀₀: ($M = 0.20$, $SD = 0.13$)
- M0 Delta-E₀₀: ($M = 0.21$, $SD = 0.17$)
- $p > 0.05$

- M0 Delta-E₀₀: ($M = 0.21$, $SD = 0.17$)
- M0 Legacy Delta-E₀₀: ($M = 0.25$, $SD = 0.30$)
- $p > 0.05$

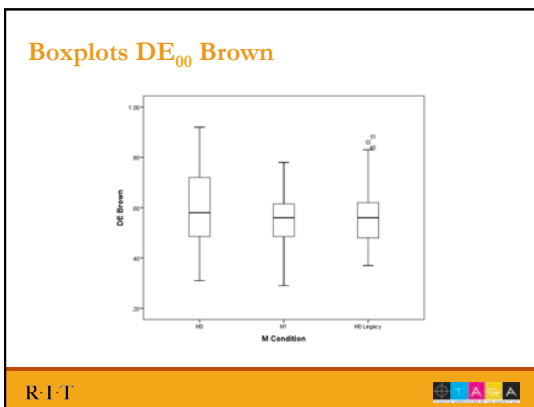
R-I-T



Evaluation of LabREF Gray

- M1 Delta- E_{00} : ($M = 0.54$, $SD = 0.21$)
- M0 Delta- E_{00} : ($M = 0.52$, $SD = 0.18$)
- $p > 0.05$
- M0 Delta- E_{00} : ($M = 0.52$, $SD = 0.18$)
- M0 Legacy Delta- E_{00} : ($M = 0.53$, $SD = 0.19$)
- $p > 0.05$

R-I-T



Evaluation of LabREF Brown

- M1 Delta- E_{00} : ($M = 0.56$, $SD = 0.19$)
- M0 Delta- E_{00} : ($M = 0.59$, $SD = 0.12$)
- $p > 0.05$
- M0 Delta- E_{00} : ($M = 0.59$, $SD = 0.16$)
- M0 Legacy Delta- E_{00} : ($M = 0.58$, $SD = 0.14$)
- $p > 0.05$

R-I-T



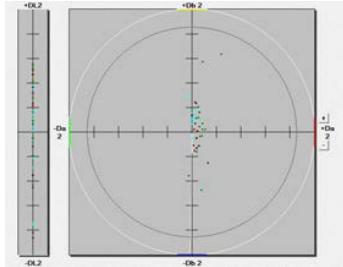
Evaluation of LabREF White

M1 vs. M0 and M0 vs. M0 Legacy

- M1 Delta- E_{00} : ($M = 0.23$, $SD = 0.12$)
- M0 Delta- E_{00} : ($M = 0.27$, $SD = 0.13$)
- $p > 0.05$
- M0 Delta- E_{00} : ($M = 0.27$, $SD = 0.13$)
- M0 Legacy Delta- E_{00} : ($M = 0.40$, $SD = 0.15$)
- $p > 0.05$

R-I-T

White Points, M0, M1 and M0 Legacy



M0 = Brown, M1 = Cyan, M0 Legacy = Green

RIT



Conclusions: Instrument Accuracy in Workflow

- Support for Widely Recognized Realizations
 - *Difference Information is Best Method*
 - *Careful Specification of Measurement Parameters Necessary*

RIT



Implications

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

RIT



Future Research

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

RIT



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*

RIT

