Digitization and Metric Conversion for Image Quality Test Targets

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Abstract

A common need of the INCITS W1.1[1,2] Macro Uniformity, Color Rendition and Micro Uniformity *ad hoc* teams is to digitize image quality test targets and derive parameters that correlate with image quality assessments. The digitized data should be in a colorimetric color space such as CIELAB and have no spatial artifacts that reduce image quality parameter accuracy.

Input digitizers come in many forms including inexpensive scanners used in the home, a range of sophisticated scanners used for graphic arts and scanners used for scientific and industrial measurements (e.g., micro-densitometers). Some of these are capable of digitizing hard copy output for image quality objective metrics, and this report focuses on assessment of high quality flatbed scanners for that role.

Digitization using flatbed scanners is desired because they are relatively inexpensive, easy to use, and most are available with ADF permitting analysis of a stack of documents with little user interaction. Other authors have addressed using scanners for image quality measurements.[3,4] This paper focuses on color transformations from RGB to CIELAB and demonstrates that flatbed scanners can have a high level of accuracy for generating accurate, stable images in the CIELAB metric.

Flatbed Scanners as Input Digitizers for Image Quality Work

The scanners considered herein have been designed for the graphic arts industry. Their accuracy in the role of image quality digitizers is dependent upon a number of factors, including:

1. **Scanner Spatial Uniformity.** Two types of uniformity were assessed:
   a. Overall top-bottom, side-to-side uniformity. This can be assessed with uniform input targets, such as a sheet of Munsell neutral. For a good quality scanner, variation within a letter-size page should be a fraction of one RGB code value. Very high-resolution scans that increase scan times significantly, can reduce uniformity because of lamp and electronics changes.
   b. Pattern noise from sensor and/or motion noise. These was assessed both visually and using Fourier analysis to detect patterns within the image. For good quality scanners spatial uniformity was not an issue.
2. **Scanner Repeatability.** Including samples of Munsell material along the edge of each scan can monitor scan-to-scan variability. Warming up the scanner before each image capture can reduce variability and typically, scan-to-scan differences have been a fraction of one RGB code value.
3. **Scanner Resolution.** Low scan resolution can cause aliasing with output device halftones. For micro-uniformity work, scanner internal down-sampling methodology may generate problematic data because of data elimination instead of averaging. For critical micro evaluations, highest optical-resolution scans and averaging down in linear space may produce the best results. For this study, most materials were continuous tone and all reported results were from scans done at 300 dpi. Very similar results were obtained for 600 and 1200 dpi scans. Scanner MTF was characterized using *Sine Patterns* test targets and was found to be more than sufficient.
4. **Automatic Exposure Adjustment.** Some scanners automatically adjust factors such as exposure, color balance and contrast to reduce user effort in obtaining high quality images. This can both increase variability and eliminate signal (e.g., cause saturation) in image quality measurements. Automatic color settings and use of color conversions should be turned off or disabled and previews watched for automatic changes in density and balance. The use of uniform samples of Munsell materials such as RGBCMY primaries and neutrals can monitor any automatic adjustments. These can be placed (e.g., taped) outside the normal scan area and included in all scan data.
5. **Scanner Dynamic Range.** Lower cost scanners may lack the dynamic range required for accurate digitization of test targets. Relating target progressions in neutrals and colors to measurements with GretagMacbeth or X-Rite spectrophotometers can test dynamic range.
6. **Uniformity of the Hard Copy Output Being Characterized.** Poor uniformity from irregular media (e.g., textured), the marking process (e.g., ghosting, holes, adjacency, halftoning, granularity) and/or dust/dirt on the print can introduce variability in both colorimetric and scanner measurements.

7. **Integrating Cavity Effects, or ICE.** Flatbed scanners can have considerable adjacency effects introduced by target reflections back into the illumination system and then directed back onto the document. The reflectance measured by the sensors is not only a function of the document reflectance at that point but of surrounding reflectance. Scanner design, target design and scanner processing can influence the degree of ICE effects in a scan. ICE is discussed in the next section.
8. Bit-depth. It is important to retain accuracy throughout the image quality assessment procedure and 16-bit capture is recommended. All analysis performed herein has been done with 16-bit RGB capture converted to 16-bit CIELAB values.
9. **Color Accuracy.** Calculations of metrics correlated with appearance require that RGB scanner data be converted to a color space such as CIELAB. Because scanners are not colorimetric, accurate conversion of RGB scans to the CIELAB metric requires a target made from the particular hard copy device (colorants and media) being assessed. The conversion should not generate spatial artifacts.

This paper demonstrates that flatbed scanners can satisfy all these conditions and are capable image quality digitizers.

Integrating Cavity Effects, ICE

The adjacency effects of ICE were large enough in the initial experiments using inexpensive flatbed scanners to warrant additional investigation. Experiments with wedge ("V") targets and different reference density levels, and black masks over parts of the document demonstrated that (1) the ICE influence can extend a number of millimeters, (2) the influence may not be symmetrical in the horizontal and vertical scan direction, (3) high density strips between patches appear to reduce these effects, (4) the effects are different than flare, an overall veiling glare affecting mainly darker areas of the document, and (5) if the scanner has ICE compensation, it may not be perfect. The conclusion was that high quality scanners and neutral separations between the patches can reduce, but not eliminate, ICE.

The removal of ICE from scanned data has been mentioned in the literature[3,7] but this would be scanner specific and the techniques may be difficult to specify in a standard. Generally, ICE effects unavoidable but small for high quality flatbed scanners. The characterization (ICC profile) has ICE influences in the data and the amount and nature depend upon the scanner and the layout and the orientation of the test target. It should be noted that there are caveats to be considered with the addition of neutral patch borders:

1. The border reduces the target area and might cause artifacts in the marking process (e.g., ghosting and adjacency)
2. All characterization requires RGB averages in the center of the scanned target and the size of borders should be small enough so not to influence this average.

Procedure for this Analysis

An image quality assessment includes a printing of all image quality test targets at the same time, the same printer settings and using the same media. The targets are scanned, RGB data is converted to CIELAB and image quality metrics are calculated. Figure 1 shows a flow chart of the characterization and analysis procedures used for this study.

Figure 2 shows the two test targets proposed by a W1.1 *ad hoc* working group for characterizing CMYK and RGB printers.

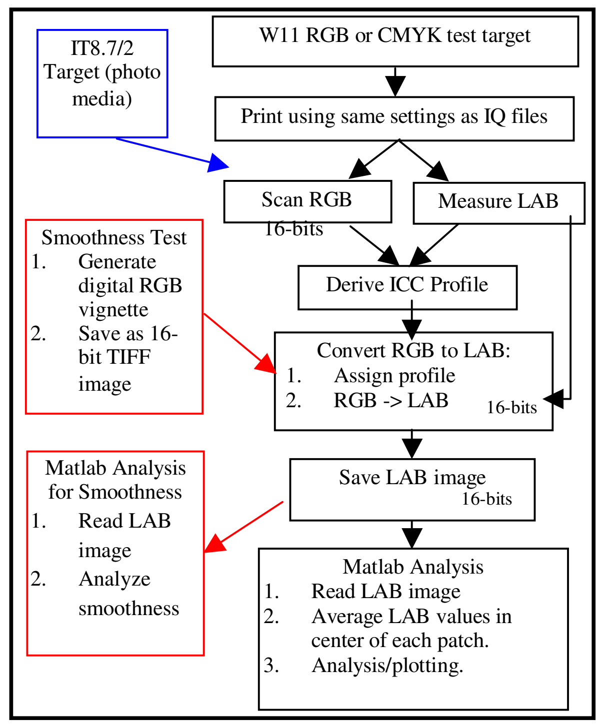

Figure 1. Procedure used in evaluating color profiling and transformations.

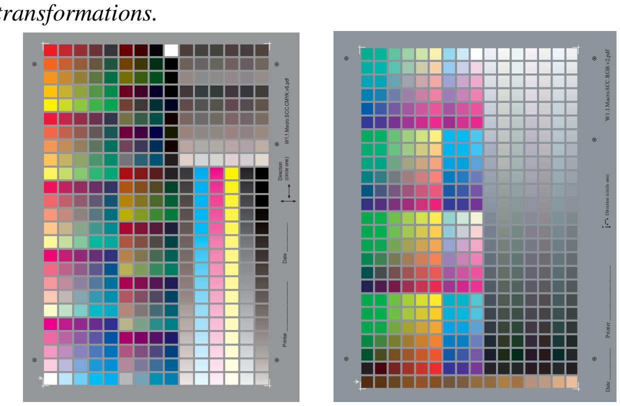

Figure 2. CMYK (left) and RGB (right) test targets used for scanner characterization. These targets will be available in PDF format with Adobe Illustrator editing enabled.

The RGB targets were used for characterizing the ink jet printers with RGB addressability, and the CMYK targets were used for the 4-color color electrophotographic printers. The IT8.7/2 target was used for characterizations of photographic media.

A neutral background and 1.5 mm neutral borders have been added for each patch. The targets were scanned on a high quality Epson scanner with automatic controls off, a bit depth of 48, and 300 dpi resolution. The scanner had neutral and color reference patches attached to the edges of the platen for verification of its stability. All CIELAB measurements were made using a GretagMacbeth Spectrolino Spectroscan (absolute reference, D50, 2 degree observer) with the GretagMacbeth MeasureTool 4.1 utility. ICC profiles were made with two profiling products:

1. GretagMacbeth ProfileMaker 4.1 resulting in 33x33x33, 16-bit profiles.
2. MonacoPROFILER 4.5[1] resulting in 25x25x25, 16-bit profiles.

The scanned RGB data was converted to CIELAB using the PC version of Photoshop 7.0 (Adobe ACE, Absolute Colorimetric) by assigning the appropriate profile and converting to LAB. The 16-bit CIELAB data was read into Matlab and for each patch, L* a* b* values averaged from a 40% square in the center of the patch. The average CIELAB was then compared with the measured CIELAB data. CIEDE2000 was calculated using a Matlab program provided by a W11 working group member and checked with data in a CR&A publication.[5]

The results are shown for three marking technologies, color electrophotographic, ink jet and photographic.

Summary of Characterization Results

Table 1 (at the end of this report) summarizes the characterization results from three marking technologies for the two profiling products. The same scanner and characterization data was used for evaluating both GretagMacbeth and Monaco characterization programs. The first number shows the RMS delta E error and the second shows DE2000. The photographic results had the lowest delta E error and the color electrophotographic the highest, but all were small and acceptable. The Monaco results were slightly better than the GretagMacbeth for average errors, but occasionally the maximum error was larger. Sharma[6] described similar results.

Table 1 also shows the results of a cross rendering study where the ICC profile from the photographic media was used to convert RGB values to LAB values for other media. The results for individual technologies and cross rendering will be described in the next sections.

It is interesting to note the difference between RMS (Euclidean) Delta E calculations and DE2000 calculations. For all technologies analyzed, the DE2000 mean and maximum were always smaller than the RMS values. However, as the Figure 3 illustrates, the near neutral RMS values can become higher for DE2000 while the larger saturation values become smaller.

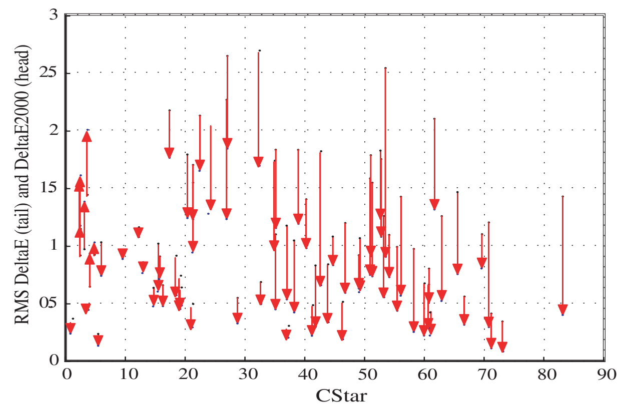

Figure 3. The difference between RMS Delta E (arrow tail) and DE2000 (arrow head) are shown for a sampling of the 375 patches of the CMYK target for the color electrophotographic characterization described in the next Section.

Results for Color Electrophotographic Printer

Figures 4 and 5 show the results of the color electrophotographic printer. Figure 5 illustrates the coverage using the CMYK target of Figure 2. The Delta E averages (see Table 1) were slightly larger than for other technology because of slightly unsmooth paper media (Hammermill Copy Print Photo Bright 96), slight non-uniformities in the patches due to marking and slight dithering effects from multi-bit halftoning.

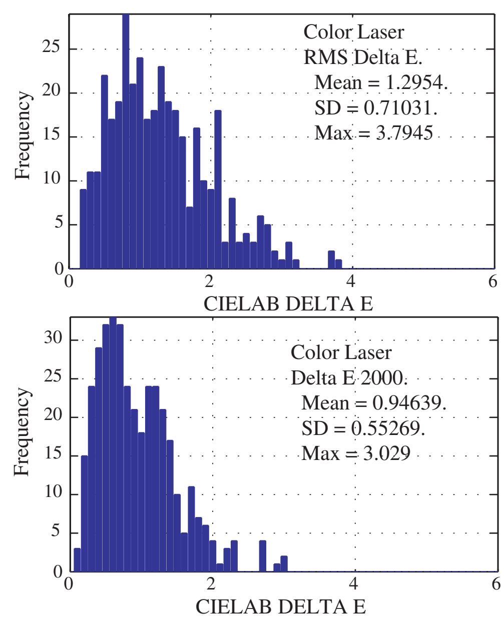

Figure 4. Histogram of the RMS Delta E and DE2000 errors from color electrophotographic characterization.

[1] Monaco Systems provided an early version of Monaco PROFILER that handles general scanner targets.

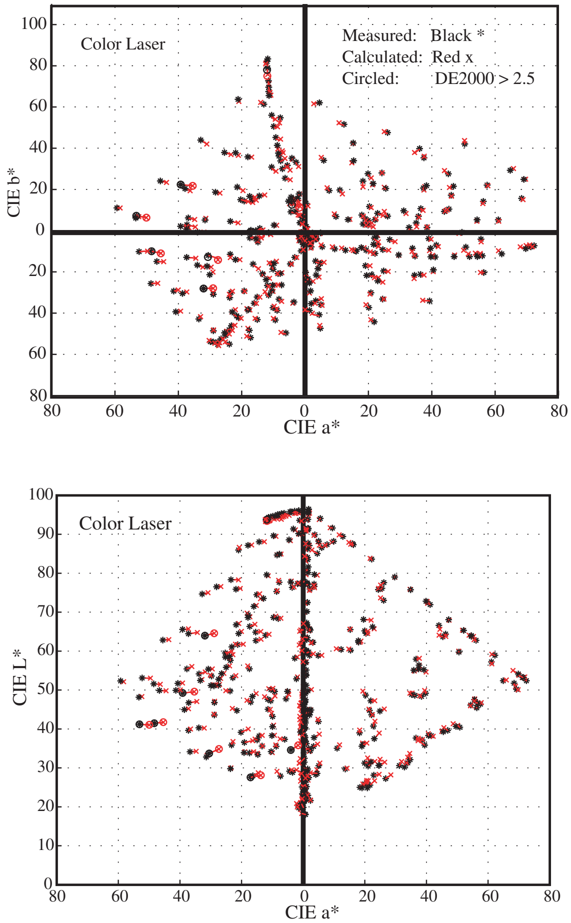

Figure 5. CIELAB plots showing measured versus calculated for a color electrophotographic. These Figures show the color space coverage using the CMYK test target shown in Figure 2.

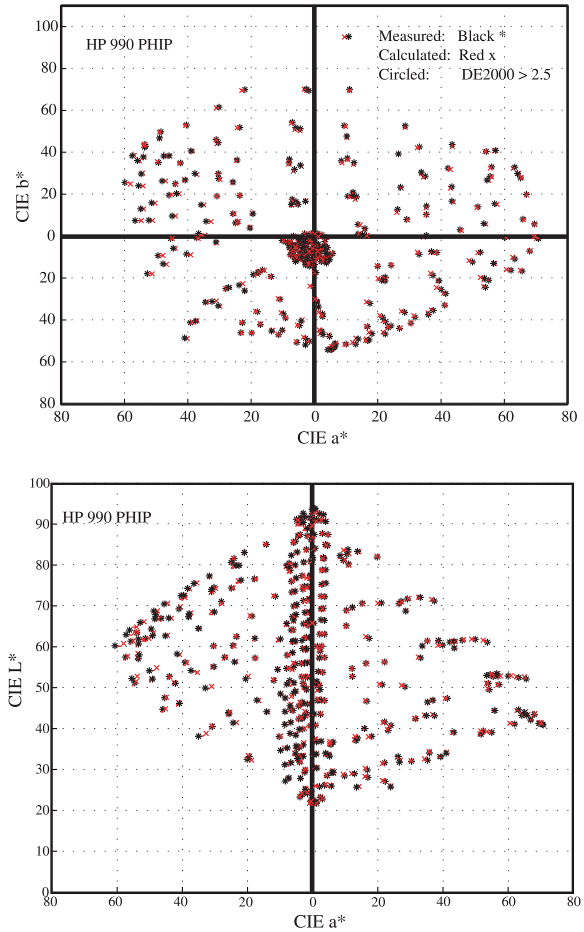

Figure 6. CIELAB plots showing measured versus calculated for the HP DeskJet 990 Cxi ink jet printer using Premium Heavyweight Inkjet Paper. These Figures show the color space coverage using the RGB test target shown in Figure 2.

Results for the HP DeskJet 990 Ink Jet Printer

A W1.1 *ad hoc* group member provided print samples on two media for the HP DeskJet 990 ink jet printer, the glossy Premium Photo Paper, and the matte Premium Heavyweight Ink Jet Paper. Figure 6 shows the results for the HP matte media and illustrate the color space using the RGB target shown in Figure 2. Similar results were obtained for the glossy media that had a much larger color gamut.

Results for IT8 Photographic Target

The IT8.7/2 target was measured and scanned as described above (the provided reference data was not used). As indicated in Table 1, the average error for all 288 patches of this target was very small. It was this ICC profile that was used in the cross media study described below. In one experiment, the IT8 target was scanned in both horizontal and vertical directions and characterized in each direction. Cross rendering demonstrated some errors, suggesting that ICE is not symmetric.

Cross Media Rendering

A question that had been asked was why not just use the ICC profile for current IT8.7/2 (photographic) target and convert all scanner measurements from RGB to LAB using that profile regardless of the media. Of course, this can be done, but because of scanner metamerism, the errors could be large and will depend upon the relative spectral characteristics of the different media.

To illustrate the magnitude of the errors, the scanner RGB values from the three media, color electrophotographic, HP DeskJet 990 (PHIP media), and Epson 2000P were transformed to CIELAB using the ICC profile derived from the IT8 photographic target. Table 1 shows that the average errors can be quite large and the maximum errors not acceptable. Note that the worst maximum errors were from the Epson 2000P media. These colorants exhibited serious illuminant metamerism because of deficiencies in the yellow and magenta colorants (Kress, ColorSync forum 01-2001) and inadequate black colorant utilization.

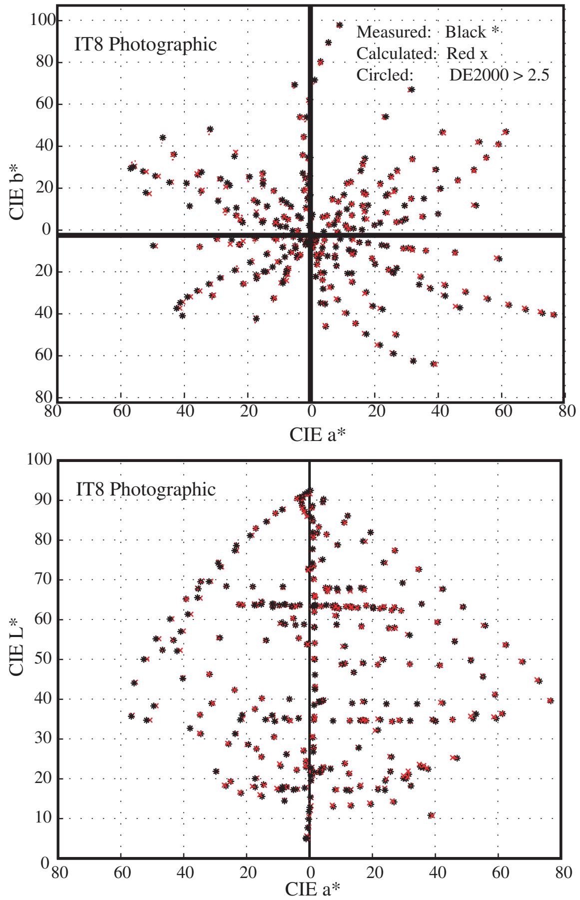

Figure 7. CIELAB plots showing measured versus calculated for photographic media (IT8)

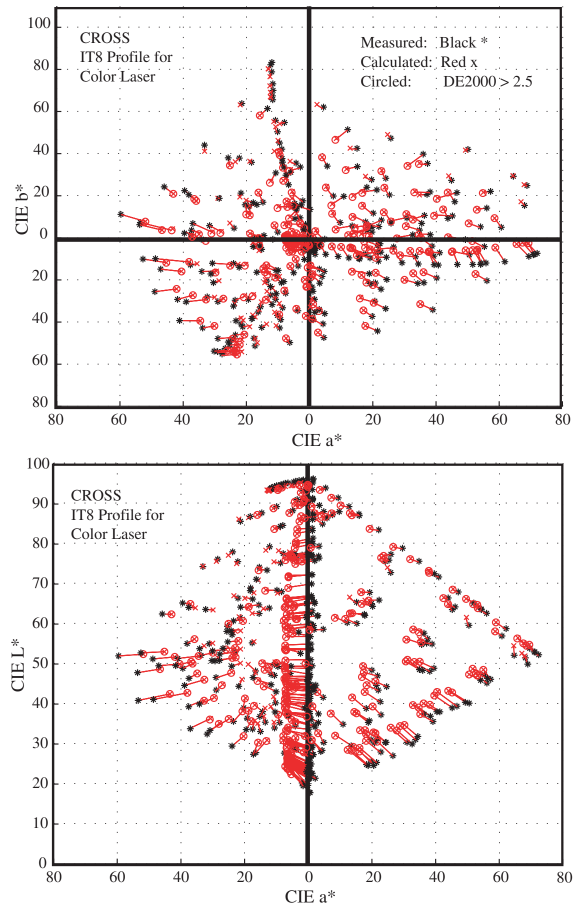

Figure 8. CIELAB plots showing measured versus calculated for the case of cross rendering. The IT8 ICC profile was used to transform the color electrophotographic RGB scan to CIELAB.

Figure 8 shows the cross-rendering results for color electrophotographic printer RGB values converted by IT8 characterization.

Smoothness and Verification Tests

While the accuracy of metric conversion is important, it is critical that the RGB to LAB transformation not introduce noise in the measurements. Input color tables (combinations of LUTs and CLUT) generated by recent characterization software such as the two evaluated in this report, are quite smooth within the gamut of the device. Similarly, color engines that use the ICC profile data have been refined and are well behaved. A test of the combination of these factors was conducted by making digital 16-bit RGB vignettes within the RGB gamut using Matlab. These were saved as a TIFF image and converted to LAB using the above techniques. Analysis of these CIELAB vignettes confirmed that there was no noise introduced by the metric conversion.

In this report, the ICC profiles were derived using either the test targets shown in Figure 2 or the IT8 target, and the errors were calculated using those same targets. Verification can be done using another test target having different starting RGB or CMYK values. All tests using a separate verification target demonstrated a slightly higher average and maximum Delta E. This small increase was due to a combination of scanner ICE, scanner stability and color table generation. Verification target definition, design and testing will be a future INCITS activity.

Conclusions

Because scanners are not colorimetric, accurate conversions from scanner RGB to CIELAB require color characterizations for the particular media (colorant and substrate) and marking technologies being assessed. The proposed CMYK and RGB targets shown in Figure 2 are adequate for scanner characterizations. Procedures for digitizing images and converting their metric to CIELAB have demonstrated results that were accurate and without spatial artifacts. Although scanner variability and flatbed scanner ICE are in the characterization data, these effects are small. The two characterization programs handle custom targets (square or rectangular) very well, are easy to use and have demonstrated very accurate results.

A worthwhile utility would be the ability to perform ICC transformations within a Matlab environment.

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Biography

William Kress received his BS and MS in electrical engineering and has spent the last 30 years working in the fields of analog and digital imaging. His vocational interests include digital image capture systems, image processing algorithms, color optimization, and development and use of preference-, attribute- and metric-based image quality assessment techniques. His e-mail address is wckress@worldnet.att.net

Table 1. Summary of Characterization Results Showing RMS / DE2000 Values for the Three Marking Technologies and Two Profiling Packages.

	GM ProfileMaker		MonacoPROFILER	
Technology	**Average**	**Maximum**	**Average**	**Maximum**
IT8.7/2 Photographic	0.47 / 0.30	1.60 / 0.93	-	-
Ink Jet-HP 990 (PPP)	0.64 / 0.36	3.11 / 1.56	0.61 / 0.39	6.58 / 3.90
Ink Jet-HP 990 (PHIP)	0.55 / 0.34	2.18 / 1.42	0.47 / 0.32	2.03 / 1.39
Ink Jet-Epson 2000P	1.12 / 0.70	3.72 / 3.57	0.67 / 0.47	4.38 / 3.06
Color electrophotographic	1.30 / 0.95	3.79 / 3.03	0.94 / 0.68	4.56 / 3.36
Cross-render IT8 -> Color electrophotographic	5.18 / 4.49	10.88 / 10.36	-	-
Cross-render IT8 -> HP990 PPP	2.73 / 1.60	7.35 / 4.99	-	-
Cross-render IT8 -> Epson 2000P	5.76 / 4.31	19.98 / 9.99	-	-