Impact of Light Exposure on Measurements of Print Images

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Abstract

Observations of print sample measurements have shown that some inks are more prone to noisy measurements than other inks. After investigation it was found that these inks exhibited behavior that may be described as luminescent. More precisely, the measured density of these inks is higher when the samples are stored in the dark and lower when the samples have been exposed to light—either from recent testing or from ambient office light. For example, a sample that is tested in a Xenon light chamber then removed for measurement, will measure lower density if measured immediately after removal compared to a measurement several hours or a day later. This study identified which inks were sensitive to light exposure, the magnitude of their response to ambient light, and their recovery in the dark.

Introduction

During routine testing of inkjet print samples and replicates over the past few years it has been possible to identify patterns in measurement noise. One of these patterns was a step shaped decrease in sample patch optical density observed in measurements from the Xenon light test. Usually two 3-day test cycles are run each week. If a test starts on Monday, it finishes on Thursday, and if another test is started on Thursday it will finish on Sunday. The test chamber is programmable, so an actively controlled dark cycle will maintain the chamber environment until Monday when the samples are measured.

However, some samples showed less fading per cycle on measurements made on Monday than those made on Thursday. And if the test cycle was started on Friday, then the same amount of fading was observed on Monday as on Thursday. The practical difference between these tests was in the length of time that had passed from the end of the active light portion of the test cycle and when the sample was measured.

To confirm this behavior, a series of experiments were devised to systematically investigate whether light could affect the optical density of the sample, and if so, do samples recover over time in the dark after the end of a light exposure test.

Experiment Results and Discussion

Samples are not only exposed to light during the light stability test, but they also receive incidental light from the ambient office conditions while being removed from the test chamber and in preparation for measurement. Moreover, samples are exposed to light from the measurement device itself. The Gretag Spectrolino Spectroscan table used to measure test targets utilizes reflected light from a tungsten halogen bulb. The light is on for a fraction of a second, but it is in close proximity to the sample patch during that time. In contrast to the standard method of measuring a sample patch once then moving on to the next one, the spectrophotometer was programmed to measure specific color patches repeatedly at the same location before moving on to the next patch. Most colorants will consistently yield the same measurement value each time they are measured. However, colorants which are sensitive to light exposure show a decrease in measured density with each successive measurement, as shown in Figure 1.

As will be demonstrated later, light sensitive colorants which are not being actively exposed to light will begin to recover. The spectrophotometer used in this study was configured to check a white calibration reference block every 50 measurements, which in this sample occurred at measurement 20, hence there is a slight 'bump' in density between measurement 19 and 20 since the duration between light exposures had increased.

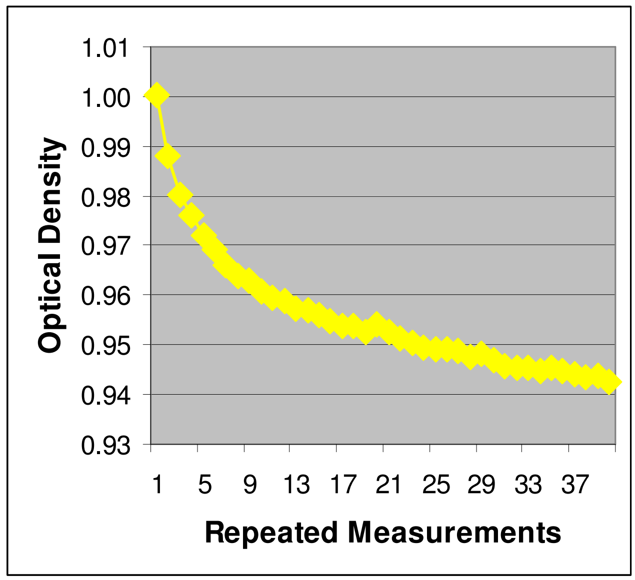

Figure 1. Repeated measurements of a yellow color patch using a spectrophotometer with tungsten halogen bulb.

Measurements such as the one shown in Figure 1 were collected on a wide range of print systems. To simplify the data presentation, only the percent difference in density between the first and fortieth measurement are shown in Tables 1 and 2. Also, it was observed that light and dark patches had similar percent change in density, and that each component of a neutral color patch behaved similarly to that of the pure color. Hence the data was consolidated without much loss of information.

The only difference between the data sets of Tables 1 and 2 is the manner of preparation of the samples prior to the repeated measurement of the spectrophotometer. The Table 1 data set is from samples which were kept in the dark prior to measurement, while the Table 2 data set is from the same set of samples which were placed in office light prior to measurement. By comparing these data sets, it was inferred that the samples' optical density had already shifted in the office light and therefore had less room to move when subjected to the repeated measurements of the spectrophotometer.

While it was found that media can have an influence on an ink's sensitivity to light, the media itself was not affected by this small amount of light exposure, having less than a 0.01 density shift. Moreover, this test was of new and previously untested media samples, not those that had been subjected to any kind of accelerated aging and could therefore be susceptible to 'bleaching'. Unless explicitly listed, the media used in each printer corresponded to each manufacturer's brand: Lexmark Perfectfinish, HP Advanced Photo, Brother Glossy, Canon Plus II, Kodak Ultra, and Epson Ultra. The default ink cartridge set was also used in each test case, and printers with pigment inks are denoted by gray shading.

Table 1. Percent optical density change of cyan, magenta, and yellow patches of inkjet print samples between 1st and 40th repeated measurements on spectrophotometer. Test sample kept in dark prior to measurement.

Printer	%ΔdC(R)	%ΔdM(G)	%ΔdY(B)
Lexmark X5650	0.0%	0.1%	-4.2%
Lexmark X9575	-0.1%	-0.1%	-0.2%
Lexmark S305	0.1%	-0.1%	-2.5%
HP B9180	0.0%	0.0%	-0.1%
HP L7580	0.3%	0.0%	-1.2%
HP 6500	0.1%	0.0%	-1.0%
HP 8500	0.0%	-0.1%	0.0%
Brother MFC-5890cn	0.0%	0.0%	-0.1%
Canon MX300	0.1%	-0.1%	-6.0%
Canon MP620	0.0%	0.0%	-0.8%
Canon MX7600	0.0%	0.0%	-0.2%
Kodak ESP7	-0.1%	0.0%	0.0%
Epson Artisan 700	0.1%	0.0%	-0.2%
Epson WF500	0.1%	-0.1%	-0.1%

Table 2. Percent optical density change of cyan, magenta, and yellow patches of inkjet print samples between 1st and 40th repeated measurements on spectrophotometer. Test sample placed in office light prior to measurement.

Printer	%ΔdC(R)	%ΔdM(G)	%ΔdY(B)
Lexmark X5650	-0.1%	0.1%	-2.0%
Lexmark X9575	-0.2%	-0.1%	0.0%
Lexmark S305	0.2%	-0.3%	-1.4%
HP B9180	0.1%	-0.1%	-0.1%
HP L7580	0.2%	0.0%	-0.5%
HP 6500	0.1%	0.1%	-0.6%
HP 8500	-0.2%	0.0%	-0.1%
Brother MFC-5890cn	0.0%	0.0%	0.0%
Canon MX300	0.0%	-0.2%	-2.0%
Canon MP620	0.0%	0.0%	-0.2%
Canon MX7600	0.0%	0.0%	0.0%
Kodak ESP7	-0.1%	0.0%	0.0%
Epson Artisan 700	0.0%	-0.1%	-0.2%
Epson WF500	0.1%	-0.1%	0.0%

Another observation from the data in Tables 1 and 2 is that yellow is the most light sensitive colorant—specifically yellow dye inks. Newer generation yellow inks from Lexmark and Canon were less sensitive than previous generations, but still showed some light sensitivity.

The response of inks to repeated measurements was a contrived experiment to simply identify which inks may be sensitive to light exposure. From this point forward, all measurement data from the spectrophotometer will be single measurements. Moreover, for conciseness the remaining data analysis presented in this paper will focus solely on yellow inks, although full data sets were tested.

The next round of experiments focused on the influence of fluorescent office light in the lab where samples are printed and measured. A new set of samples were allowed to dry for 2 weeks in the dark and then measured in the dark. These samples were then placed out on a table illuminated at 500 lux +/- 50 lux. After 1 hour, the samples were measured again and placed back on the table. After 4 hours, 24 hours and 72 hours the process was repeated except after the last measurement the samples were then placed in the dark. Once the samples had been in the dark for 4 hours they were measured again (in the dark) and kept in the dark for additional measurements. Then another measurement was made after further exposure to office light, and a final measurement after the samples were kept in the dark once more. The timing of the light and dark storage of the samples and their corresponding measurement data are shown in Table 3.

Even after only 1 hour in the light, there is a dramatic shift in density for some of the more light sensitive samples. With continued light exposure, the density continued to decrease but at a slower rate. When samples were placed back in the dark, the samples began to recover and the density increased. This cycling of density to light exposure could be repeated over and over again. However, this testing also showed that although samples did recover from the light exposure, the recovery was not complete to the original state.

A second office light experiment used a smaller sample set by eliminating some samples that were found not to be sensitive to light exposure in the first test. Moreover, several different photo media were printed with the Canon MX300 to better understand the influence of media. While the test was similar to the previous one, the measurements spanned a greater duration of time as shown in Table 4. The change in optical density was found to exhibit a logarithmic response—most of the change occurred when first placing a sample in the light or the dark.

By plotting the data from this experiment it was found that the measurements at 24 hours in the light did not align with the other measurements. It was discovered that while this test was in progress there was a failure in the humidification system and the relative humidity in the lab was not stable—varying between the normal control point of 50%RH down to 30%RH. Subsequent testing confirmed that this difference in humidity altered the density measurements by up to 1.1% for many of the samples. This event served to confirm the importance of humidity control in the sample holding and measurement environments.

The test case of using several media with the Canon MX300 showed that while media did affect the magnitude of the ink response to light, the trends remained the same.

Table 3. Percent change in optical density of yellow patches with respect to initial dark measurement. Placed in fluorescent office light for indicated time, then in dark for indicated time, then back in light, then back in dark.

	Office Light at 500 lux				Dark			Light	Dark
Printer	1 Hour	4 Hours	24 Hours	72 hours	4 Hours	24 Hours	1 Week	24 Hours	24 Hours
Lexmark X5650	-4.8%	-5.6%	-5.5%	-6.0%	-5.4%	-2.8%	-3.3%	-5.8%	-3.2%
Lexmark X9575	0.0%	-0.2%	0.0%	-0.2%	-0.5%	-0.2%	0.3%	0.0%	-0.3%
Lexmark S305	-2.2%	-2.9%	-2.9%	-3.2%	-3.0%	-1.0%	-1.6%	-3.3%	-1.5%
HP B9180	-0.1%	-0.2%	0.0%	-0.2%	-0.3%	-0.1%	-0.1%	-0.3%	-0.2%
HP L7580	-1.5%	-2.1%	-2.2%	-2.6%	-2.4%	-1.2%	-2.0%	-2.8%	-1.6%
HP 6500	-1.1%	-1.7%	-1.7%	-2.3%	-2.1%	-0.9%	-2.1%	-2.1%	-1.3%
HP 8500	-0.3%	-0.3%	-0.3%	-0.3%	-0.4%	-0.2%	-0.3%	-0.2%	-0.3%
Brother MFC-5890cn	-0.2%	-0.2%	-0.4%	-0.3%	-0.4%	-0.3%	-0.8%	-0.4%	-0.6%
Canon MX300	-6.5%	-7.9%	-8.5%	-9.3%	-7.3%	-4.6%	-4.8%	-9.5%	-5.2%
Canon MP620	-1.4%	-1.6%	-1.6%	-1.9%	-1.5%	-1.0%	-1.2%	-1.9%	-1.3%
Canon MX7600	-0.2%	-0.2%	-0.1%	-0.2%	-0.2%	0.0%	0.1%	0.1%	0.3%
Kodak ESP7	-0.2%	-0.4%	0.0%	0.0%	-0.5%	0.1%	0.0%	-0.1%	-0.1%
Epson Artisan 700	0.0%	-0.1%	-0.5%	-0.4%	-0.2%	-0.3%	-0.5%	-0.5%	-0.4%
Epson WF500	0.0%	-0.2%	-0.7%	-0.7%	0.0%	-0.5%	-0.1%	-0.3%	-0.3%

Table 4. Percent change in optical density of yellow patches with respect to initial dark measurement. Placed in fluorescent office light for indicated time, then in dark for indicated time.

		Office Light at 500 lux						Dark		
Printer	Media	15 Min.	1 Hour	4 Hours	24 Hours	72 hours	1 Week	24 Hours	1 Week	3 Weeks
Lexmark X5650	Perfectfinish	-3.0%	-4.3%	-5.0%	-5.0%	-6.5%	-7.0%	-4.3%	-3.5%	-2.5%
Lexmark X9575	Perfectfinish	0.1%	0.0%	0.3%	0.0%	-0.1%	0.0%	-0.2%	-0.3%	-0.2%
Lexmark S305	Perfectfinish	-1.7%	-2.6%	-3.4%	-4.1%	-5.9%	-6.3%	-4.8%	-4.1%	-3.2%
HP 6500	HP Adv	-0.7%	-1.1%	-1.5%	-1.6%	-2.8%	-3.2%	-2.1%	-2.1%	-1.6%
Canon MX300	Perfectfinish	-3.4%	-4.3%	-5.1%	-5.4%	-6.9%	-7.6%	-5.1%	-4.5%	-3.1%
Canon MX300	HP Adv	-3.8%	-4.7%	-5.6%	-6.1%	-8.2%	-9.1%	-6.0%	-4.9%	-3.4%
Canon MX300	Canon Plus II	-3.8%	-5.0%	-6.2%	-7.1%	-9.6%	-10.9%	-7.9%	-7.0%	-5.5%
Canon MP620	Canon Plus II	-0.8%	-1.0%	-1.2%	-1.5%	-2.0%	-2.4%	-1.4%	-1.2%	-0.9%
Epson Artisan 700	Epson Ultra	-0.3%	-0.3%	-0.4%	-0.1%	-0.6%	-0.9%	-0.7%	-0.4%	-0.5%

Table 5. Percent change in optical density of yellow patches with respect to initial dark measurement. Placed in Xenon light for 1 hour, then in dark for indicated time.

	Xenon 80klux for 1 hour then dark						
Printer	Xenon	1 Hour	4 Hours	24 Hours	72 hours	1 Week	2 Weeks
Lexmark X5650	-8.2%	-7.2%	-6.3%	-3.2%	-1.8%	-2.6%	-1.4%
Lexmark X9575	0.4%	-0.1%	0.0%	0.0%	0.2%	0.1%	0.0%
Lexmark S305	-7.1%	-5.9%	-4.9%	-2.8%	-1.6%	-2.5%	-1.3%
HP B9180	-0.1%	-0.2%	-0.2%	-0.3%	-0.1%	-0.2%	0.0%
HP L7580	-3.7%	-2.8%	-2.5%	-1.0%	-0.4%	-1.5%	-0.3%
HP 6500	-4.2%	-3.1%	-2.7%	-1.8%	-0.9%	-2.0%	-0.8%
HP 8500	-0.2%	0.1%	-0.1%	-0.1%	0.0%	-0.1%	-0.1%
Brother MFC-5890cn	-0.7%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.2%
Canon MX300	-13.4%	-12.0%	-10.0%	-6.8%	-4.1%	-4.4%	-3.1%
Canon MP620	-2.1%	-1.8%	-1.6%	-1.0%	-0.4%	-0.8%	-0.5%
Canon MX7600	-0.4%	-0.5%	-0.6%	-0.4%	-0.4%	-0.5%	-0.2%
Kodak ESP7	0.3%	0.4%	0.2%	0.2%	0.3%	0.3%	0.2%
Epson Artisan 700	-0.5%	-0.7%	-0.7%	-0.5%	-0.3%	-0.5%	-0.2%
Epson WF500	-0.1%	-0.3%	-0.1%	-0.2%	-0.1%	-0.2%	0.3%

Table 5 shows data from a separate test where samples were placed in the Xenon test chamber for 1 hour at a light intensity of 80 klux. After removing the samples, they were immediately measured then stored in the dark for additional measurements. The initial density shift of these samples was larger than in the office light experiments, despite nearly equivalent cumulative light exposure to the office light test after 1 week. This may have been a result of either the higher light intensity or the different spectral power distribution of the light source. Even with the large initial density shift, these samples showed excellent recovery back to their original condition.

The final experiment was to run the standard Xenon light stability test, except with additional measurement protocols. The first adjustment was ensuring that samples were allowed to dry in the dark and measured in the dark. These samples were then placed in office light for 4 hours and measured again prior to placement in the Xenon chamber. The next modification was in the timing of the test cycles, which were started such that samples could immediately be measured after the light cycle concluded. These samples were then put in dark storage for a day and measured again before resuming the Xenon test.

The Xenon test was in an Atlas Ci4000 Weather-Ometer, set to 80 klux and 70-hour light cycles. An ink was selected for testing that had shown sensitivity to light. Multiple sample replicates were run together and the results averaged.

Figure 2 shows all the measurement data for a 1.0 optical density (OD) yellow patch. Before the test started, placing the sample in office light resulted in a -2% OD shift. Immediately after the first test cycle the patch measured a -12.3% OD shift, but storing the sample in the dark for 1 day resulted in a new measurement showing only a -9.4% OD shift, a recovery of 3% just based on the timing of the measurement after the Xenon test light cycle had ended.

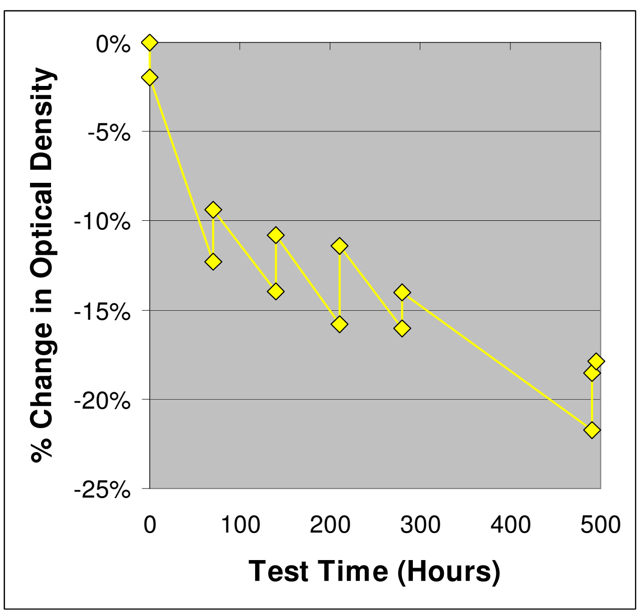

Figure 2. Sequential measurements of 1.0 OD yellow patch during Xenon test with 70 hour light cycles. Measurement at time zero first in dark, then in office light. Measurements after each light cycle done immediately, then after 1 day in the dark. Final measurement was 1 week in dark.

If all these measurements had not been carefully timed and recorded, then the test data could have looked like Figure 3.

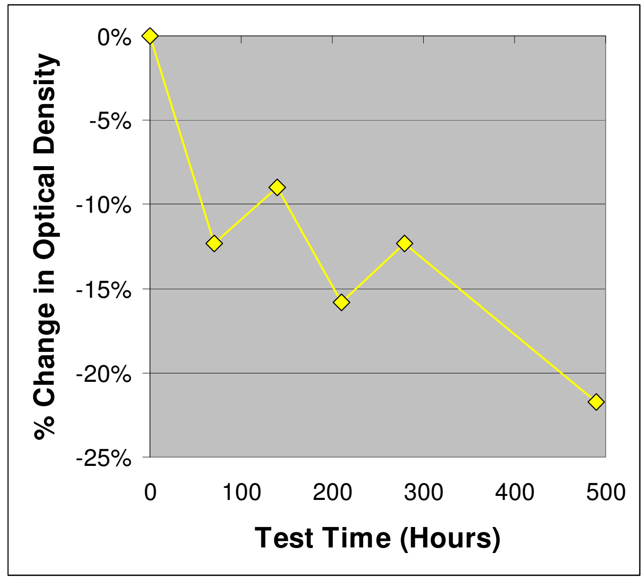

Figure 3. Random timing in measurements of Xenon test of light sensitive ink.

By consistently measuring samples the same way, such as storing samples in the dark for 1 day prior to each measurement, the result would look like Figure 4. The data from Figures 3 and 4 are just subsets of the data collected and shown in Figure 2.

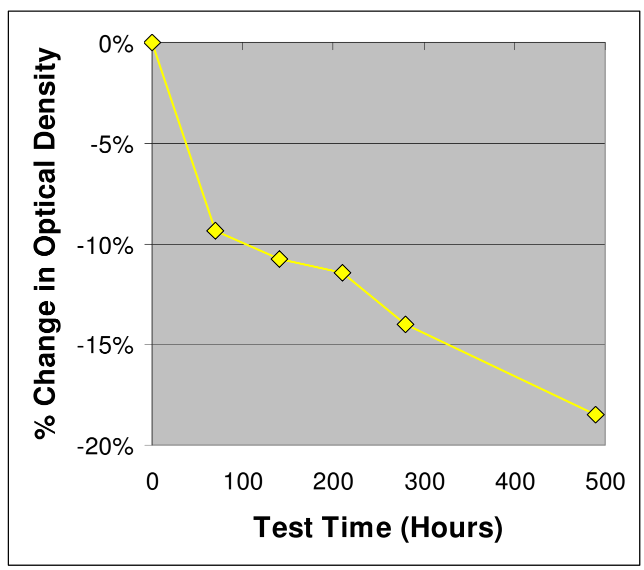

Figure 4. Consistent timing in measurements of Xenon test of light sensitive ink with samples stored in dark for 1 day prior to measurement.

Conclusion

After extensive investigation it has been found that inkjet samples can be influenced by incidental office light exposure during preparation and handling. Moreover, the length of time that passes after samples are removed from a light stability test can also affect measurements.

This response to light is different than the permanent fading typically associated with light exposure, and can more accurately be described as luminescent behavior. Samples placed in light experience decreasing density, but when stored in the dark the lost density is recovered. This process is repeatable and the density change rate appears to have a logarithmic response.

Several light sources have been identified which can induce this behavior: incandescent, fluorescent, and Xenon. Initial screening measurements of different ink systems found that none of the pigment inks exhibited this kind of light sensitivity. And among dye inks, it was primarily the yellow ink which showed sensitivity. Nevertheless, other ink colorants and pigment inks not evaluated in this study may display the type of light sensitivity demonstrated through these experiments. It is the responsibility of the investigator to check for this type of response and make adjustments to the testing procedure to accommodate such samples.

Samples which demonstrate this kind of sensitivity to light exposure should be handled and measured consistently to minimize errors in the data analysis. For example, an ozone test is conducted with samples in the dark, so it is best to minimize any incidental exposure to office light before and after testing the samples in ozone. The same goes for thermal and humidity tests.

Consistency is more problematic for light stability testing. There are two options for light stability testing. The first is to expose samples to a small dose of light just before the initial control measurement and then measure samples immediately after removal from the light at each step in the test. The second is to keep samples in the dark prior to measurement and allow samples to be stored in the dark for at least a day prior to measurement after each test segment in light.

Both choices have their own unique problems. For example, how much light is sufficient to excite the sample without causing permanent fading? What if a different light source is used to excite the sample than the one used for the light stability test? And samples must consistently be measured immediately after removal from the light stability test chamber. Many Xenon chambers hold dozens of samples, and if samples are not removed one at a time while the light is on, then a large gap of time can occur between the first and last sample measured at the conclusion of a Xenon test cycle.

Conversely, samples measured in the dark require a recovery time, which slows down the test. Moreover, it is inconvenient to keep the lab dark during sample measurements, so other precautions must be made to keep the samples out of bright office light while waiting to be measured. Careful consideration should be given to avoid handling samples differently, such as having a stack of samples out in the open waiting to be measured with the sample on top being exposed to more light than the ones underneath.

In addition to light, ambient lab humidity was also found to have a small influence on density measurements. This detectable influence on measurement data further demonstrates the importance of controlling the sample measurement and handling environment.

Author Biographies

Matthew Comstock received his B.S and M.S. degrees from Purdue University in Mechanical Engineering specializing in heat transfer and thermodynamics. He joined Lexmark International, Inc. in 1999 as a development engineer for color laser products. Since 2005 he has been responsible for the Lexmark Image Permanence Lab in Lexington, KY. His work is primarily focused on image permanence test method development and image permanence testing.

Ann McCarthy is an Imaging Systems Architect with Lexmark International, Inc., in Lexington, KY. She received her BS (1982) in Computer Engineering and MS (1997) in Imaging Science from the Rochester Institute of Technology. Ms. McCarthy has been active in the imaging and printing industry for over 25 years, including seventeen years with Eastman Kodak Co., five years with Xerox Corporation, and over five years with Lexmark International, Inc., with contributions in color image and print path development, color data encoding, imaging interoperability across distributed workflows, and work on related international standards, including IEC ISO JTC1 SC28, CIE Div 8, ISO TC 42, ECMA TC46, and the International Color Consortium (ICC). Her publications include IS&T tutorials on color management, ICC white papers, and ISCC, SPIE and IS&T conference presentations.