CGATS RECOMMENDED INDUSTRY PRACTICE

Color characterization data set development — Analysis and reporting

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Introduction

The objective of this CGATS Recommended Industry Practice is to define the key steps necessary to create color characterization data from press sheets collected from a press run associated with a specific defined printing condition. It includes recommendations for preliminary evaluation and sheet selection, data collection, data analysis and data reporting. It is intended as a reference for persons/organizations responsible for preparing color characterization data.

The key steps necessary to conduct press runs with the purpose of deriving color characterization data are covered in another CGATS Recommended Industry Practice: *Developing a color characterization data set — Press run guidelines*[8]. That document is useful as a reference and checklist for standards and industry groups developing reference color characterization data, as well as by individual printing organizations as they develop their own internal procedures. This document incorporates the knowledge gained from early work by CGATS in this area. Over the last several years both the standards community and various industries trade groups have developed process control aims for various printing conditions. These groups have also been conducting press tests to produce sample material as close to the selected aims as possible. Such tests usually contain a multi patch CMYK target such as ANSI IT8.7/3 or ANSI IT8.7/4 which provides the source data to develop the relationship between the CMYK input data and printed color defined in CIELAB which we refer to as color characterization data.

A second document, CGATS Recommended Industry Practice, *Color Characterization Data Set Development – Procedures for color measurement system process control and inter-lab coordination*[9] defines the key steps necessary to measurement systems process control and may be a valuable resource for making the measurements and recording data for further analysis. It is intended as a reference for persons/organizations responsible for preparing color characterization data, and therefore has a strong relationship to the content covered in the document.

CGATS RECOMMENDED INDUSTRY PRACTICE

Color characterization data set development — Analysis and reporting

1 Scope

The objective of this CGATS Recommended Industry Practice is to define the key steps necessary to create color characterization data from press sheets collected from a press run associated with a specific defined printing condition. It includes recommendations for preliminary evaluation and sheet selection, data collection, data analysis, data consolidation and data reporting.

2 Applicability

The procedures described in this recommended practice have been used by CGATS as it develops Technical Reports for color characterization data. This procedure is recommended by CGATS for use by groups developing color characterization data sets for use by an industry segment and is equally applicable to a single company or organization.

This document forms a part of a series of documents addressing the generation and use of color characterization data sets. These include the following CGATS Recommended Industry Practices:

Color Characterization Data Set Development — Press run Guidelines;

Color Characterization Data Set Development — Procedures for color measurement, system process control and inter-lab coordination;

Color Characterization Data Set Development — Analysis and reporting.

It also provides a bibliography of other relevant documents.

3 Preliminary evaluation

This document assumes that press sheets have been prepared in accordance with CGATS Recommended Industry Practice: *Color characterization data set development – Press run guidelines*[8]. That document assumes that process aim points have been established and validated, that printed results have been demonstrated to be repeatable and reproducible within agreed-upon or specified tolerances, and that good manufacturing procedures are being followed.

Sample sheets from the press run should be evaluated to be sure that the portion of the press run from which samples are to be selected are within the aims and tolerances specified (e.g. solid area densities, tone value increase at 50%, uniformity and print contrast, etc.) defined.

The purpose of this validation is to determine whether or not the press run represents the intended condition. The result of this validation is to pass or fail the press run.

4 Sheet selection

4.1 General

CGATS recommends that a minimum of five sheets be selected as close to the aims as possible. There is no theoretical upper limit to the number of samples used in creating a color characterization data set. However, there is a trade off between measurement capability (time and cost) and data refinement that should be recognized. This requires that a larger number of samples be collected initially to insure an adequate selection is available for further evaluation.

Three primary sheet selection strategies are described. The sheets selected by these methods may then be subjected to an additional selection refinement (sub-selection) process depending on the objective of the characterization data set.

It is important that regardless of the sampling strategy used, all sheets selected should be evaluated for printing artifacts (e.g. hickeys, scratches, voids, doubling, etc.) prior to being accepted for inclusion in the selected sample.

The sheet selection strategy should be developed and agreed upon prior to the commencement of the press run from which reference color characterization data is to be obtained. More information is available in CGATS Recommended Industry Practice: *Color characterization data set development – Press run guidelines*[8], 3.5.1.

4.2 Primary sampling strategies

4.2.1 Random sampling

Random sampling is suggested in cases where the printing conditions are believed to be consistent and stable within the press run and no particular efforts are (were) made to tune a specific portion of the press run. The use of random samples also allows other statistics about printing variability within the specific press test to be developed. Random samples are selected by generating scaled random numbers from random number generators (such as those found in common office suite software, or from tables of random numbers found in the appendices of most statistics textbooks). If a random sampling strategy is chosen, CGATS recommends collecting a larger number of sheets than when sheets are pulled from a specific portion of the press run.

4.2.2 Uniform sampling

Uniform sampling addresses long term drift in printing conditions within a press run. It is typically taken from a press run at uniform intervals. The uniform sampling method is suggested in cases where the long term variation of the press is deemed unacceptably large. For example, in a press run of 5,000 sheets, samples might be taken at intervals of 100 impressions. Alternatively, samples might be taken in uniform measures of time (such as every 30 seconds).

4.2.3 Sequential sampling

Sequential sampling addresses sheet-to-sheet variation in printing conditions within a press run. For example, selecting sheets 101, 102, 103…n would provide the ability to determine press performance at certain points in the press run. Sequential sampling is suggested in cases where it is felt to be important to apply specific controls or adjustment of printing conditions, within a press run, to ensure a close match to the specified aims and tolerances.

4.3 Selection refinement strategies

4.3.1 General

The objective of the color characterization data is to use press sheets that match as closely as possible a set of predefined printing criteria, therefore an additional selection refinement step is often appropriate. This can be used to further refine a larger data set, selected using either the random or sequential sampling techniques.

Sub-sampling requires that specific criteria associated with a particular printing specification (such as solid ink density (SID), grey balance, color, tone value increase (TVI), etc.) have been selected as the factors to be used for evaluation. A set of weighting factors can then be established against these criteria. Evaluating individual printed sheets using these criteria results in a subset of the overall sample population.

4.3.2 Demerit method

The demerit method is based on ranking sample sheets based on the sum of the demerits assigned to each individual sample and selecting the desired number of sheets based on the lowest demerit sum. A demerit is based on the deviation between the measured value of a sheet and the aim point for that value. Density-based demerits may include, but are not limited to, solid ink density of CMYK, midtone spread, etc. The total demerits are the sum of all demerits combined. Suggested density-based demerits are shown in Table 1 and colorimetry-based demerits in Table 2. Normally the choice of density-based or colorimetric-based demerits depends on the form in which the process aims are specified.

Table 1 — Suggested density-based demerits

Process Variable	Sample	Aim point	Deviation	Demerit
Solid ink density, (C, M, Y, K)	C,M,Y,K	C_0,M_0,Y_0,K_0	$\lvert C-C_0\rvert$ $\lvert M-M_0\rvert$ $\lvert Y-Y_0\rvert$ $\lvert K-K_0\rvert$	0, if $\Delta<0.05$; 1, if $\Delta<0.10$, 2, if $\Delta<0.15$; 4, if $\Delta\geq0.15$
Tone Value Increase* (C, M, Y, K)	C,M,Y,K	C_0,M_0,Y_0,K_0	$\lvert C-C_0\rvert$ $\lvert M-M_0\rvert$ $\lvert Y-Y_0\rvert$ $\lvert K-K_0\rvert$	0, if $\Delta<3$; 1, if $\Delta<5$; 2, if $\Delta<7$; 4, if $\Delta\geq7$
Mid-tone spread**	C,M,Y,K	C_0,M_0,Y_0,K_0	**	0, if $\Delta<2$; 2, if $\Delta<4$; 4, if $\Delta<6$; 8, if $\Delta\geq6$

* Tone value is expressed as a percentage (i.e. 22%); Tone value increase is expressed as Δ %.

** Midtone spread is defined by the following relationship:

S
quantity defined by the equation

$$S = \max[(A_c-A_{c0}),(A_m-A_{m0}),(A_y-A_{y0})] - \min[(A_c-A_{c0}),(A_m-A_{m0}),(A_y-A_{y0})] \quad (1)$$

where

A_c is the measured tone value of the cyan process color image;
A_{c0} is the specified tone value of the cyan process color image;
A_m is the measured tone value of the magenta process color image;
A_{m0} is the specified tone value of the magenta process color image;
A_y is the measured tone value of the yellow process color image;
A_{y0} is the specified tone value of the yellow process color image.

EXAMPLE:

For measured values $A_c = 22$, $A_m 17$ and $A_y = 20$ and specified values $A_{c0} = 20$, $A_{m0} = 20$ and $A_{y0} = 18$:

$S = \max[(22-20),(17-20),(20-18)] - \min[(22-20),(17-20),(20-18)] = 2-(-3) = 5$

Table 2 – Suggested colorimetry-based demerits

Process variable	Sample	Aim point	Deviation	Demerit
CIELAB of solid ink, (C, M, Y, K)	CIELAB	$CIELAB_0$	ΔE	0, if Δ<2; 1, if Δ<4, 2, if Δ<6; 4, if Δ≥6
CIELAB overprint, (R, G, B)	CIELAB	$CIELAB_0$	ΔE	0, if Δ<2; 1, if Δ<4; 2, if Δ<8; 4, if Δ≥8
C* of 3-C midtone grey	C*	C_0*	$\lvert C-C_0^* \rvert$	0, if Δ<2; 2, if Δ<4; 4, if Δ<6 8, if Δ≥6;

4.3.3 CGATS density method

The CGATS density method is based on ranking sample sheets based on the sum of the absolute values of the weighted density differences between the measured value of a sheet and the aim point for that value. The two density criteria that CGATS uses are the solid ink density (SID) and the mid-tone tone value increase (expressed as a density difference) of the individual colors. Because mid-tone deviations have a much more significant effect on visual appearance of halftone images than deviations in SID these are weighted by a factor of 2 compared to SID deviations.

Mathematically this becomes:

$$R = \Delta D_{CS} + \Delta D_{MS} + \Delta D_{YS} + \Delta D_{KS} + 2 \times \left(\Delta D_{CM} + \Delta D_{MM} + \Delta D_{YM} + \Delta D_{KM}\right) \quad (2)$$

where

- R = rank
- ΔD_{CS} = absolute value of density difference between aim and measured cyan solid
- ΔD_{MS} = absolute value of density difference between aim and measured magenta solid
- ΔD_{YS} = absolute value of density difference between aim and measured yellow solid
- ΔD_{KS} = absolute value of density difference between aim and measured black solid
- ΔD_{CM} = absolute value of density difference between aim and measured cyan midtone
- ΔD_{MM} = absolute value of density difference between aim and measured magenta midtone
- ΔD_{YM} = absolute value of density difference between aim and measured yellow midtone
- ΔD_{KM} = absolute value of density difference between aim and measured black midtone

NOTE Tone values can be converted to density for use in the creation of the weighted rank using the following equation:

$$D_t = D_0 - \log\left[1 - \left(\frac{TV}{100}\right) \times \left(1 - 10^{-(D_s - D_0)}\right)\right] \quad (3)$$

where:

- TV is the tone value
- D_t is the density of the corresponding input tone value area in the image
- D_o is the density of the paper substrate
- D_s is the density of the solid colorant in the image area

The data should also be examined to be sure that no one specific data point, within the components of the computation of the weighted ranking, overly contributes to the ranking and thus could represent a color shift. If such a condition is found that sample should be either discarded or lowered in rank.

5 Data collection

During the data collection step, color characterization target(s) from selected sheets are measured. The actual number of targets and the specific data recorded will depend on the application.

Where multiple laboratories are participating in the development of data sets CGATS recommends that one or more samples be measured by a coordinating lab and that those measured samples, along with additional samples, be supplied to each of the other participating laboratories to provide measurement system crossover data.

NOTE When multiple measurement laboratories are being used it is very important they establish measurement system agreement and control prior to making measurements to be used in generating the color characterization data. See the CGATS Recommended Industry Practice: *Color characterization data set development — Procedures for color measurement system process control and inter-lab coordination*[9] for further information.

Press sheets and proofs may degrade relatively quickly. It is important to complete all measurements before discoloration has occurred. However, press sheets must be allowed to thoroughly dry before being measured to ensure that any effects of ink dry-back are excluded.

It is highly recommended that spectral data be collected. If only colorimetric data is available, CIEXYZ data is preferred. If CIEXYZ or CIELAB data is collected directly from measurement instrumentation the user should consult with the instrument manufacturer to ensure that the data is computed according to the applicable standards. The data files corresponding to each target measured should be separately identifiable.

Calculation of the CIE tristimulus values, XYZ, and any subsequent CIELAB values should use the weighting functions and equations of ANSI CGATS.5[2], which are based on the 1931 CIE 2^{o} observer and the D50 illuminant.

NOTE When CGATS is developing its characterization data set technical reports, a full target is measured on three of nine sheets by a coordinating location or laboratory. One of these pre-measured sheets, acting as a crossover reference sheet, along with two additional sheets, is then sent to each of the other locations. Each of the locations measures the full target on the three sheets provided. The data for each target should be separately identifiable. CGATS recommends that spectral reflectance data be collected and returned to the coordinator along with any other data that may be of interest in an application. CGATS acknowledges that not all instruments will report spectral data; in this situation the data being reported should be agreed upon in advance. This procedure results in a minimum of nine sets of measurements across seven sheets, yielding many data points. This also provides duplicate measurements between the coordinating location or laboratory and each measuring location on a single sheet per site basis.

6 Data evaluation

6.1 General

After the selected press sheets have been measured, the resulting pool of data must be evaluated to look for outlier data points and/or extreme (suspect) data. This ensures that the final data set is as statistically sound as possible and that sufficient information is included with the data set to allow user evaluation.

6.2 Patch specific evaluation

Before multiple measurements of individual patch samples (either repeat readings of the same sample or readings from different samples) can be combined they must be evaluated to determine consistency of the data. The method currently used by CGATS is to compute CIELAB data for each sample, and the CIELAB ΔE between each sample and the average CIELAB for that patch. The statistics of the CIELAB ΔE population can then be used to identify potentially bad data. Samples with significantly larger CIELAB ΔE values can indicate either measurement errors or printing anomalies that were missed in earlier evaluations.

Suspect patch measurements should be identified and removed from the data before further evaluation.

NOTE See *CGATS Recommended Industry Practice: Color characterization data set development — Procedures for color measurement system process control and inter-lab coordination*[9] for further information on this topic.

6.3 Composite data set evaluation

Once outlier points have been removed, new average values and CIELAB ΔE values can be computed. The total population of CIELAB ΔE values can then be pooled and histograms and cumulative probability plots prepared. Histograms and cumulative probability plot can be easily prepared using any of the typical spreadsheet tools.

A simplified way to create a cumulative probability plot is as follows:

1. Sort all the CIELAB ΔE values from smallest to largest and number the resulting list from 1 to N (where N is the number of samples).

2. Plot the resulting data (rank number vs. CIELAB ΔE values) using CIELAB ΔE values as the abscissa and the sample number divided by N as the ordinate.

Comparing the shape and values of the resultant histogram and cumulative probability plots with those of other data sets can help evaluate the consistency of the composite data set. Figures 1 and 2 show the histogram and cumulative probability plots of the ΔE statistics of two sets of press characterization test data. While the two types of plots show similar characteristics of the data, each has advantages and disadvantages. The histogram shows the distribution of the ΔE values and can be useful in understanding what realistic variations are.

The shape of the cumulative probability plot helps provide an insight into how tightly grouped the data is. For example the 50^{th} percentile point for the data set of the tightly distributed data set correlates well with the peak of the histogram. On the other hand the wider distribution has a peak that occurs before the 50^{th} percentile point. In general, the steeper the cumulative probability curve, the tighter the data distribution. However, any evaluation of the distribution of the ΔE values of a data set must also take into account the size of the data set.

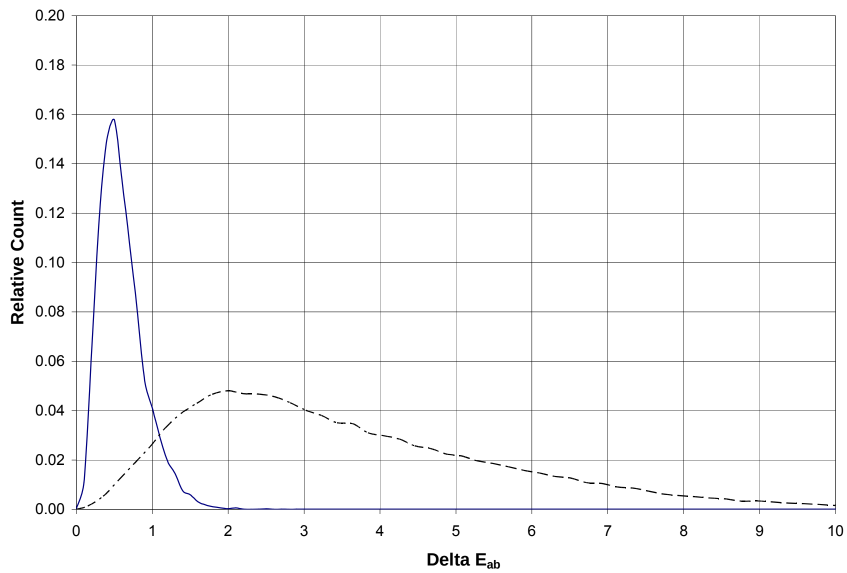

Figure 1 — Typical histograms

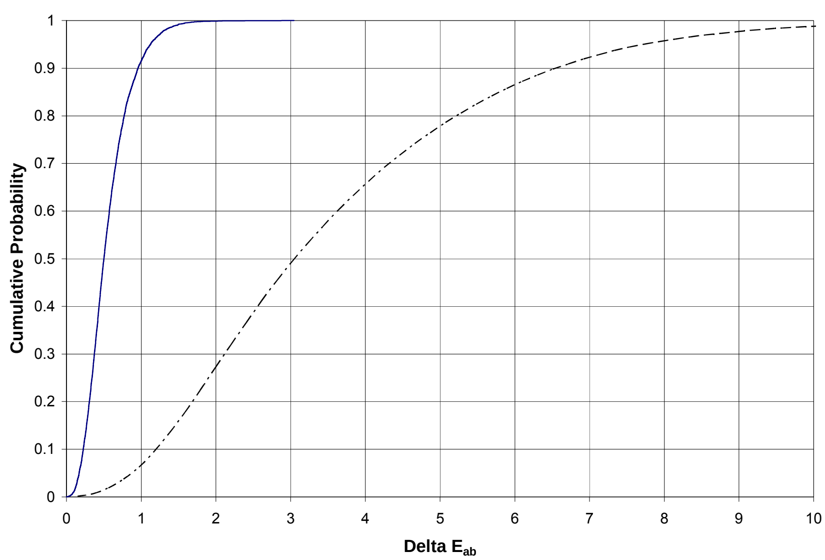

Figure 2 — Typical cumulative probability plots

Where plotting tools are available, additional visual representations of the data set can assist experienced practitioners in evaluating the smoothness of the data set, particularly by comparison to data sets of known quality. Typical plots used for such evaluation are 3-dimensional plots of CIELAB data, 2-dimensional plots of CIELAB data projected on the a*b* plane, L* C* plots of selected data (e.g. single color scales and single color solids with varying black, and L* and/or C* vs. input tone value). See Annex A for examples of these plots.

7 Data set preparation

The data set spectral data, from which outliers have been removed, is averaged on a patch-by-patch basis. Both CIEXYZ and CIELAB data is computed from the averaged spectral data. These averaged CIEXYZ and

CIELAB data are the color characterization data to be reported. Where spectral data has not been maintained, the CIEXYZ data is averaged and the reported CIELAB data is computed from these averaged data.

8 Data reporting

CGATS Technical Reports for characterization data typically report average CIEXYZ and CIELAB data as a function of patch ID and a cumulative distribution function of pooled CIELAB ΔE. It is also recommended that the average spectral data be reported in a similar fashion. A third tabulation that may be useful is the standard deviation of CIEXYZ and CIELAB as well as the number of measurements for each patch (the number of measurements for each patch may not be the same after rejecting outliers).

The relationship between patch ID and CMYK tone values is contained in the appropriate target standard (e.g. ANSI IT8.7/3, ANSI IT8.7/4, etc.) and is copyrighted information. It is not a necessary part of a characterization data set.

The data files should conform to one of the data reporting formats defined in ANSI CGATS.17[3].

Annex A

Example charts for data analysis

The following are examples of plots that may be useful for evaluation of the smoothness and uniformity of data intended for use in color characterization data sets. The data used in all examples is that of CGATS TR 001[4]. Although dynamic modeling in three dimensions using a variety of commercial programs is also useful, examples cannot be easily shown on the two dimensional page.

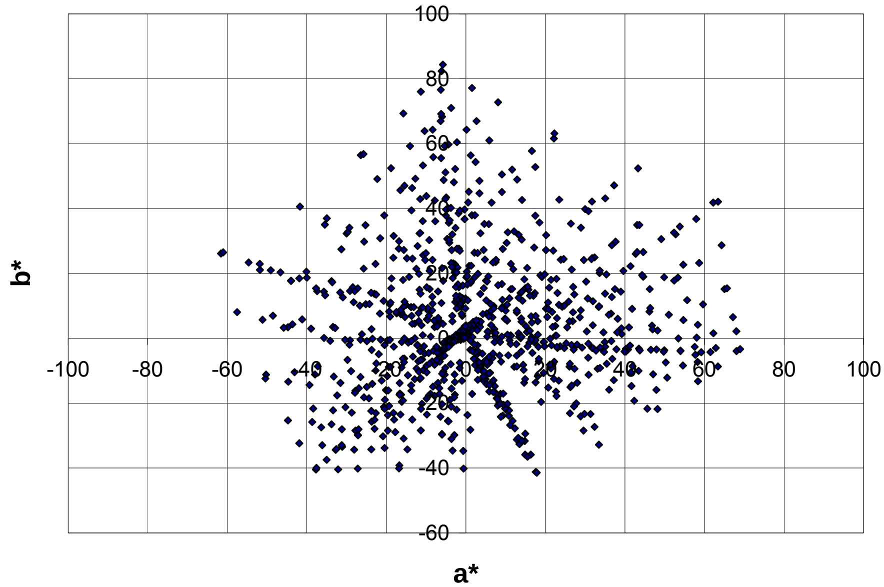

Figure A.1 — a* - b* projection for all data

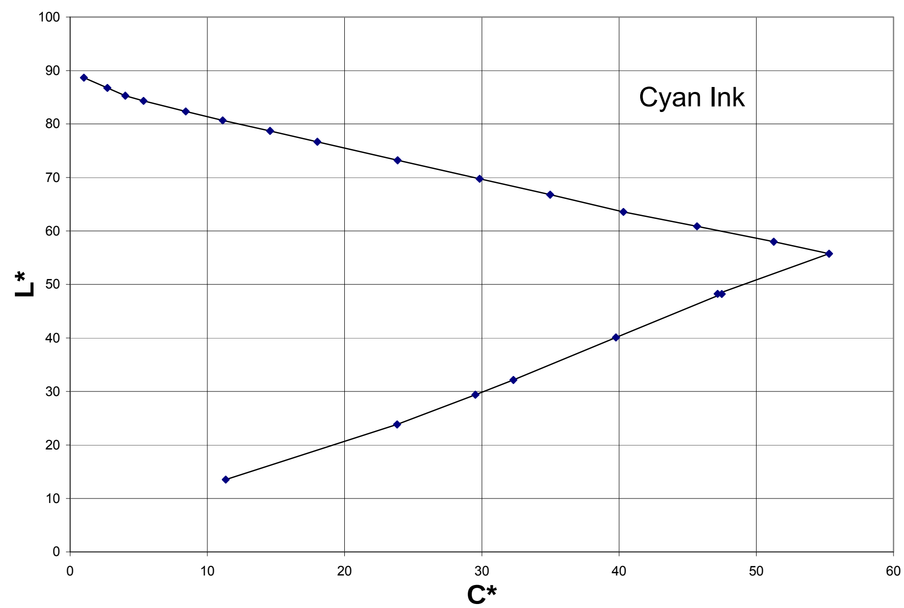

Figure A.2 — L* - C* projection for cyan alone and cyan plus black

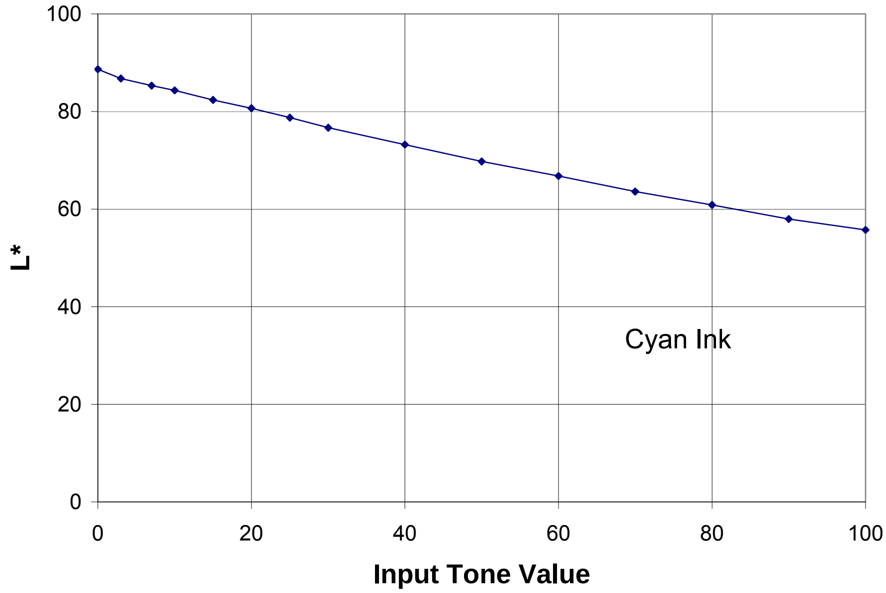

Figure A.3 — L* vs. input tone value for cyan scale

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