CGATS/Idealliance TR 015-2022
Revision of
CGATS/Idealliance TR 015-2013

A Technical Report

Prepared by

Committee for Graphic Arts Technologies Standards (CGATS)

Graphic technology — Methodology for Establishing Printing Aims Based on a Shared Near-neutral Gray-scale

SECRETARIAT
APTech THE ASSOCIATION FOR PRINT TECHNOLOGIES

APPROVED FEBRUARY 11, 2022
AMERICAN NATIONAL STANDARDS INSTITUTE, INC.

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A CGATS TECHNICAL REPORT

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This Technical Report was developed in cooperation with Print Properties and Colorimetric Working Group of Idealliance.

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Foreword

This CGATS Technical Report was prepared by the members of CGATS Subcommittee 3, Metrology & Process Control, in cooperation with the members of the GRACoL Working Group and the Idealliance Print Properties Committee. At the time of its approval, the following were the Participating Members and Observers of CGATS SC3.

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Introduction

In 1979, Don Hutcheson discovered that calibrating offset presses and proofing systems to common gray balance and neutral tonality aims simplified the production and exchange of CMYK images. In 2004, a group of New York ad agencies and printers called the “Manhattan Project”[1] confirmed that Hutcheson’s calibration method, known as Proof2Press, produced more consistent visual similarity between different CMYK imaging systems than standard TVI calibration. The Manhattan Project merged with the Idealliance GRACoL® committee, which used the P2P method, re-named G7®[2], to develop three CRPCs, GRACoL2006, SWOP3 and SWOP5, that shared common neutral appearance characteristics. Since then, all CRPCs developed by the Idealliance Print Properties and Colorimetric Council have been G7-based.

Idealliance has freely shared the specifications and algorithms for G7, otherwise known as the “near-neutral calibration method” with ANSI CGATS and the International Standards Organization (ISO).

This document represents a shared effort between ANSI CGATS and the Print Properties Colorimetric Council to document the fundamental principles behind the shared near-neutral gray-scale approach to press calibration and characterization data set development. It is not the intent of this document to provide how-to instructions or applications but rather to provide a common reference for such materials.

The expectation of the print buyer is that the image should look the same regardless of what type of printing press or paper is being used. The reality of the printer is that this expectation is difficult to meet.

Content is being shared across various types of printing. An image may be printed in a newspaper ad, in a magazine ad, and also on a cereal box. In other situations, the print buyer might be looking for the best price from the printer, and may not care what type of press is used. Or, an individual printer may have the capability and latitude to decide, based on workload at the time, what type of press the job will run on. Changes in the paper to be used can also introduce modifications of the result.

A colorimetric match is not, in general, possible simply because different types of printing and different types of stock may have different gamuts. A color that is specified and printed on one type of press may just not be attainable on another. On the other hand, it is generally possible to find a reasonable compromise where the overall impression generated by two images is the same. This is something that has not been scientifically quantified. There is currently not an algorithm that can measure the extent to which two images with slightly different color are perceived to match. It may be that, for the purposes of retail advertising, this problem is not solvable. The colors that are important in an image of a woman’s face depend a lot on whether the ad is for make-up, hair coloring, or lipstick.

There are two important principals for process color printing. First, reproduction of tone scale and color for grays and near neutrals is a primary factor in assessing color quality. Second, for many images, an overall scaling of the gamut (called perceptual intent in ICC profiles) is preferable to clipping of the gamut at the edge (called relative colorimetric rendering intent). This is not necessarily true for product colors.

This technical report describes a near-neutral scale tone reproduction and gray balance aim that has been adopted by the Idealliance Print Properties Colorimetric Council as a common feature of its characterization data sets. This aim was used to develop the characterization data associated with a family of Reference Printing Conditions representing a wide range of commercial print in North America and other parts of the world. It can also be used for the calibration of any 3- or 4-color printing system or device to the same near-neutral scale aim.

Traditionally, one seeks to maintain standardized CIELAB values for the solids and overprints through overall process control and by final adjustment of the ink film thickness or pigment concentration on press. Tone value

[1] http://www.hutchcolor.com/PDF/ManhattanProject.pdf

[2] G7® and GRACoL® are registered trademarks of Idealliance

increase is measured on the printed sheet and accounted for through plate curves. Press maintenance helps to keep the tone value increase of the press constant. Thus, the overall goal of traditional process control is to control the solids and the single ink tone scales. This has been shown to produce acceptable results in many situations. Under these conditions, the shared near-neutral gray-scale method and the traditional process control approach produce very similar results.

The aim points developed over the years for various types of printing (both process and substrate) are the result of optimization of that particular process and substrate and are not the result of a deliberate attempt to harmonize the results from all the different processes. The basis of the "shared near-neutral gray-scale" method is the premise that since gray balance is generally perceived as being very important in image perception, the appropriate place to put aim points is in the near-neutral gray area.

Another shortcoming of the traditional printing aim points is that all are based on a specified paper color. Unfortunately, paper color varies between paper types and even batch-to-batch within a given paper type. The color of the paper is important for several reasons. Clearly, the color of a tint is very dependent on the color of the paper, since much of the paper is visible. Second, since inks have some transparency, the measured CIELAB values of a solid depend on the color of the paper. Third, it is perhaps not well appreciated that the perceived color of fixed CIELAB values depends on the color of the paper, since when no other white reference is available, the brain uses the paper as a white reference to compare other colors against. The "shared near-neutral gray-scale" method is based on a paper relative approach.

Simply put, the shared near-neutral gray-scale method is a set of definitions and equations that allow one to set aim points for printing. These definitions and equations are shared across printing platforms and substrates so that disparate printing methods can achieve some amount of similarity of the near-neutral tone scale. The method defines a relationship between the magenta (M) and yellow (Y) tone values and the cyan (C) tone values that is defined to be a substrate relative near-neutral tone scale. This set is identical across all print platforms and substrates. A computation is also provided that defines the absolute (measurable) color of this "neutral gray" as a function of the substrate color and the cyan tone value.

The shared near-neutral gray-scale method also includes an equation for the aim near-neutral tone reproduction curve based on the CIELAB L* of the three-color overprint solid and separately for the black tone reproduction curve based on the black solid. This defines the "neutral print density" of any particular point on the near-neutral tone scale. This neutral print density can be directly converted into CIELAB L*. The goal of the aim near-neutral tone reproduction curve computation is to have (irrespective of printing process and substrate) the target neutral print densities reasonably close from the highlight end up to about 30% of the tonal range. At the shadow end of the tonal range the target neutral print density diverges depending on the CIELAB L* of the three-color overprint solid.

Graphic technology — Methodology for Establishing Printing Aims Based on Shared Near-neutral Gray-scale Appearance

1 Scope

This Technical Report defines a methodology for establishing individual printing tone reproduction and near-neutral gray-scale aims, and families thereof, based on a shared near-neutral gray-scale definition.

This methodology can be used to establish such aims for any CMYK printing system regardless of the printing process used or gamut involved.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 13655:2009, *Graphic technology — Spectral measurement and colorimetric computation for graphic arts images*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply

3.1
apparent neutral gray-scale
a range of tones from full coverage to unprinted substrate in which the appearance of each tone is that of a paper relative achromatic or gray stimulus

3.1
tone value (TV)
(data〉 proportional printing value encoded in a data file and interpreted as defined in the file format specification, usually indicating the fraction of a picture element covered by ink

NOTE Tone value is expressed in units of percent of the solid or fully covered picture element.

3.2
tone value increase (TVI)
difference between the apparent tone value on the print and the tone value in the digital data file

3.3
near-neutral gray-scale
a range of tones from full coverage to unprinted substrate in which the measured value of each tone is that of an achromatic or gray stimulus.

4 Background

Prior to the early 1980's the definition of printing aims was largely the prevue of industry trade associations and was based on using agreed-upon inks at specified values of density and tone value increase (TVI), then called dot gain. In the early1980's ISO TC130 was created and one of its early standards was ISO 12647, *Graphic technology - Process control for the manufacture of half-tone colour separations, proof and production prints*. This was a multi-part standard that defined printing aims for various printing technologies. It built upon the earlier industry work but substituted colorimetric aims for the primary color solids and two-color overprints. It also substituted the terms tone value and tone value increase for dot value and dot gain.

In these early printing definitions the TVI that was specified was based on averages of typical good printing on the reference stock with the correct ink at the specified density or color for a specified set of screening parameters. This was important because once color separations were made and exchanged using halftone film the only control of TVI was to vary the ink film thickness by changes to the solids. This led to a proliferation of characterization data sets because different substrate types required different aims for the solids and different TVI aims.

About this same time it was realized that a more robust definition was needed of the relationship between CMYK and the color printed in accordance with these printing specifications. This lead to the ANSI IT8.7/3 and IT8.7/4 color characterization targets and the development of color characterization data. The initial color characterization data sets were created by printing the IT8 targets as close to the specified conditions as possible and then measuring the color of the patches in the printed image. (The existence of such characterization data sets is one of the factors that enabled the development of color management systems

Today, digital data has replaced film as the medium of image exchange, and printing formes (e.g offset plates) are being made directly from that digital data. Computer capabilities have also increased to the point that data can be manipulated in real time during plate-making. These changes mean that characterization data no longer needs to be tied to the natural behavior of a specific printing processes, (including screening parameters etc.), but can be based instead on models of ideal printing on virtual presses. These virtual presses can share characteristics that improve the movement of data between processes and paper types.

5. Shared near-neutral gray-scale technical description

5.1 General

The lightness aims for the 3-color near-neutral tone scale are based on the assumption that the substrate relative highlight lightness values should follow a common curve to the extent possible commensurate with variations in the three color minimum near-neutral lightness. To maintain optimum shared near-neutral tonality across printing conditions with different dynamic ranges a common near-neutral tone reproduction is maintained through the lightest approximate 30% of the tonal range while a controlled compression or expansion function is applied in the darker approximate 70%.

The color aim for the 3-color near-neutral tone scale (a.k.a. gray balance) is defined as a function of substrate CIELAB a* and b* values, reduced in proportion to the relative darkness of the scale.

5.2 Defined 3-color near-neutral tone-scale

The 3-color near-neutral tone-scale is composed of C, M, and Y tone-value triplets that have the relationship defined by equation 1.

$$M = Y = 0.7470C - 4.100\times10^{-4}C^2 + 2.940\times10^{-5}C^3 \quad (1)$$

The values computed can be rounded to the nearest integer 8-bit tone values or maintained at a higher resolution depending on the capability of the imaging system being used.

Note: Equation 1 preserves the traditional 10% cyan bias at 50% that is traditionally expected to produce a balanced gray in offset lithography. It should be noted that this bias evolved out of historical habit and no longer has any good scientific basis, however it is preserved here in order to maintain compatibility with legacy printing methods, datasets and CMYK files.

5.3 3-color near-neutral tone scale color

Where the printing substrate is neutral (i.e., CIELAB a* = CIELAB b* = 0) the triplets of the 3-color near neutral tone-scale are defined to be neutral. Where the substrate values of CIELAB a* and/or b* are not 0, equations 2 and 3 provide a smooth transition for CIELAB a* and CIELAB b* values between the color of the paper and the target color for the CMY solid. This is accomplished by linear scaling of the CIELAB a* and/or b* values as a function of the tone value of the cyan component of the 3-color near-neutral (TV_C).

Specifically:

$$a^*(TV_C) = a^*_S \times \left(1 - \frac{TV_C}{100}\right) \tag{2}$$

$$b^*(TV_C) = b^*_S \times \left(1 - \frac{TV_C}{100}\right) \tag{3}$$

Where:

$a^*(TV_C)$ = modified a*

a^*_S = the a* value of the substrate

$b^*(TV_C)$ = modified b*

b^*_S = the b* value of the substrate

TV_C = the cyan tone value of the 3-color near-neutral scale

Where the three-color solid (100C, 100M, 100Y, 0K) cannot be made neutral (a* ≈ b* ≈ 0), equations 4 and 5 should be used for TVc values between 50 and 100. Equations 4 and 5 blend the a* and b* values of the device's three-color solid with the nominal target a* and b* values produced by equations 1 and 2, in proportion to $(TV_C - 50)/(100 - 50)^4$. A gray scale meeting these new target values will exhibit normal gray balance from substrate to TV_C 50, with a progressive shift toward the device's native gray balance on a three-color solid. The exponent (4) in equations 4 and 5 ensures that the deviation from normal gray balance should only be visually significant (if at all) in gray triplets whose TV_C values are approximately 75 or higher.

$$a^*(TV_C) = a^*_s \times \left(1 - \frac{TV_C}{100}\right) + a^*_{3c} \times \left(\frac{TV_C - 50}{50}\right)^4 \tag{4}$$

$$b^*(TV_C) = b^*_s \times \left(1 - \frac{TV_C}{100}\right) + b^*_{3c} \times \left(\frac{TV_C - 50}{50}\right)^4 \tag{5}$$

Where:

a^*_{3c} = the a* value of the three-color solid (100C, 100M, 100Y, 0K)
b^*_{3c} = the b* value of the three-color solid (100C, 100M, 100Y, 0K)

5.4 3-color near-neutral scale tone value aims

The lightness metric adopted for the 3-color near-neutral tone scale is called Neutral Print Density (NPDC). It is simply the substrate relative colorimetric Y density (This is approximately equal to the ISO 5 visual status density).

The relationship between the cyan tone value (TV) of the CMY triplets defined by equation 1 and the NPDC of the three color scale is defined by the following:

For all values of TV between 0 and 100,

If Y_R (TV)> Y_C

Then

$$\text{NPDC(TV)} = -\log_{10}(Y_R(\text{TV})) \quad (6)$$

Else

$$NPD(TV) = -\log_{10}\left(Y_R(TV) - \left(R_A - R_R\right) \times \left(\frac{Y_C - Y_R(TV)}{Y_C - 1 + R_R} \right)^{((\frac{R_A}{2})+1)} \right) \quad (7)$$

Where

$$Y_R(TV) = 1 - R_R \times \left(\frac{TV + TVI}{100} \right) \quad (8)$$

$$Y_C = \left(0.7 + 0.3 \times \left(\frac{Y_D}{Y_L} \right)^{1/3} \right)^3 \quad (9)$$

$$R_A = 1 - \frac{Y_D}{Y_L} \quad (10)$$

$$R_R = 0.956649 \quad (11)$$

$$TVI(TV) = 1.31587TV - 2.21633 \times 10^{-2} TV^2 + 1.32926 \times 10^{-4} TV^3 - 4.288 \times 10^{-7} TV^4 \quad (12)$$

And

Y_D = luminous reflectance factor of the dark end of the three color scale in the range of 0 to 1

Y_L = luminous reflectance factor of the substrate in the range of 0 to 1

Y_R (TV) is the luminous reflectance factor corresponding to the reference NPDC curve

Y_C is a control point along the NPDC curve at which the scaling of Y_R is initiated.

R_A is the actual reflectance range based on the light and dark ends of the tone scale

R_R is a defined reflectance ratio which is used to adjust the subsequent scaling of the data.

NOTE 1 An estimate of Y_D can be derived from the visual density of the dark end of the 3-color near-neutral scale using the relationship that $Y_D = 10^{-D}$.

NOTE 2 An estimate of Y_L .can be derived from the visual density of the light end of the 3-color near-neutral scale, which is typically the substrate, using the relationship that $Y_L = 10^{-D}$.

NOTE 3 Y_D and Y_L are the only user requirements that are required to compute NPDC(TV).

NOTE 4 The TVI equation used is based on the mathematics shown in Annex A with the following coefficients: a = 24.321, b = 2.246, and c = 0.670

NOTE 5 The values of Y_R, Y_C, Y_D, and Y_L fall in the range of 0 to 1

Annex B provides an explanation of the physical significance of the constants and variables used and their interaction.

5.5 Black tone scale aims

The relationship of the NPDC of the black tone and its input tone value is defined by computations similar to those of 5.3 as follows.

If Y_R (TV) > Y_C

Then

$$NPDC(TV) = -\log_{10}(Y_R(tv)) \tag{13}$$

Else

$$NPD(TV) = -\log_{10}\left(Y_R(TV) - (R_A - R_R) \times \left(\frac{Y_C - Y_R(TV)}{Y_C - 1 + R_R} \right)^{((\frac{R_A}{2})+1)} \right) \tag{14}$$

Where

$$Y_R(TV) = 1 - R_R \times \left(\frac{TV + TVI}{100} \right) \tag{15}$$

$$Y_C = \left(0.7 + 0.3 \times \left(\frac{Y_D}{Y_L} \right)^{1/3} \right)^3 \tag{16}$$

$$R_A = 1 - \frac{Y_D}{Y_L} \tag{17}$$

$$R_R = 0.978223$$

$$TVI(TV) = 0.967175TV - 1.525445\times10^{-2}TV^2 + 9.1347\times10^{-5}TV^3 - 3.552\times10^{-7}TV^4 \tag{18}$$

And

Y_D = luminous reflectance factor of the dark end of the black scale in the range of 0 to 1

Y_L = luminous reflectance factor of the substrate in the range of 0 to 1

Y_R (TV) is the luminous reflectance factor corresponding to the reference NPDC curve

Y_C is a control point along the NPDC curve at which the scaling of Y_R is initiated.

R_A is the actual reflectance range based on the light and dark ends of the tone scale

R_R is a defined reflectance ratio which is used to adjust the subsequent scaling of the data.

NOTE 1 An estimate of Y_D can be derived from the visual density of the dark end of the black scale using the relationship $Y = 10^{-D}$.

NOTE 2 An estimate of Y_L .can be derived from the visual density of the light end of the black scale, which is typically the substrate, using the relationship $Y = 10^{-D}$.

NOTE 3 Y_D and Y_L are the only user requirements that are required to compute NPDC(TV).

NOTE 4 The TVI equation used is based on the mathematics shown in Annex A with the following coefficients: a = 19.421, b = 0.967, and c = 0.555.

NOTE 5 The values of Y_R, Y_C, Y_D, and Y_L fall in the range of 0 to 1

Annex A
(informative)

Formulae for TVI curves used in defining NPDC curves

Although it is not necessary to understand or measure TVI in order to use the near-neutral method, the NPDC curves and formulae described above are based in part on to two fixed TVI curves described in this annex.

A fourth order polynomial can usually be used to describe the relationship of TVI to TV. However, the fourth order polynomial can be reformulated to provide a better understanding of the characteristics that contribute to the shape of the curve and allow an intuitive selection of coefficients for the equations.

The basic equation for TVI as a function of TV is given as follows:

$$TVI(x) = a \times p_1(x) + b \times p_2(x) + c \times p_3(x) \quad \text{(A.1)}$$

where

TVI is the tone value increase as a percentage value;
p_1, p_2, and p_3 are fundamental TVI curves, described below;
a, b, c are the coefficients of p_1, p_2, and p_3, representing TVI, lean, and bulge, respectively.
TV is the tone value in % ranging from 0 to 100; and

$$p_1(TV) = -4 \times \frac{TV}{100} \times (\frac{TV}{100} - 1) \quad \text{(A.2)}$$

$$p_2(TV) = 21 \times \frac{TV}{100} \times (\frac{TV}{100} - 1) \times (\frac{TV}{100} - 0.5) \quad \text{(A.3)}$$

$$p_3(TV) = -64 \times \frac{TV}{100} \times (\frac{TV}{100} - 1) \times (\frac{TV}{100} - 0.5)^2 \quad \text{(A.4)}$$

NOTE Curves p_1, p_2, and p_3 are referred to as basis or fundamental curves because the final TVI curve is the proportional sum of these individual curves.

Figure A.1 shows the three fundamental TVI curves, p_1(TV), p_2(TV) and p_3(TV). The first thing to note is that all three of the polynomials are zero at both TV=0, and TV=100. This assures that the TVI curve will be zero at these points regardless of the choice of coefficients.

As can be seen, the first curve, p_1(TV), has the general overall parabolic shape of a TVI curve. Since the other two curves are designed to be zero at TV = 50, the coefficient of this curve is identical to the TVI at 50%. The second fundamental TVI curve, p_2(TV), defines the lean of the curve. If the value of this coefficient is positive, then the TVI curve will lean to the left. A left-leaning TVI curve will reach a maximum TVI below a tone value of 50%. A negative value will cause the maximum to occur above 50%. The larger the second coefficient (in magnitude) the farther the maximum will move from 50%. This second coefficient is analogous (but not equivalent) to the statistical term “skewness”.

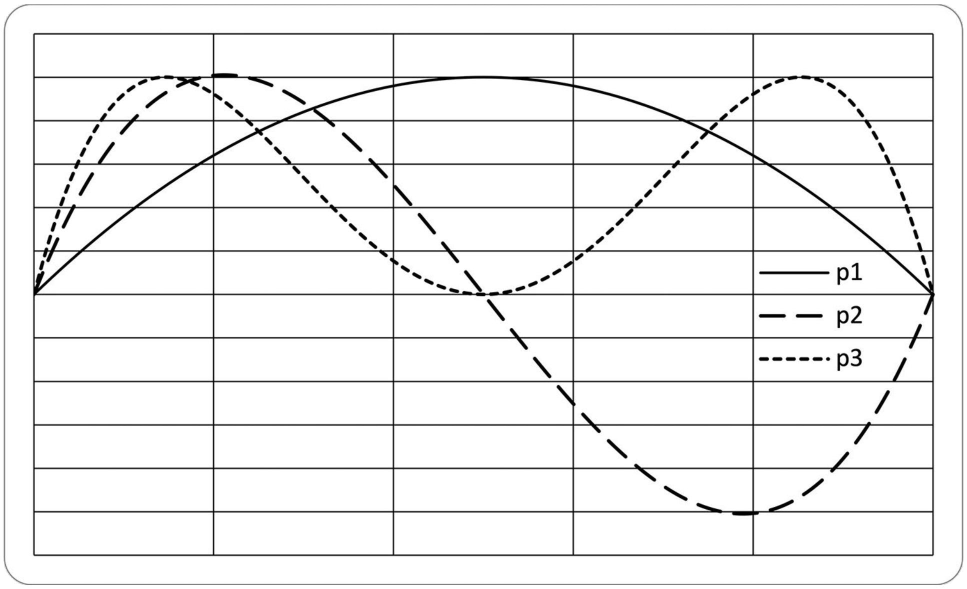

Figure A.1 – The three fundamental TVI curves

Figure A.2 is an example of the effect of adding lean to the TVI. The curve t1 is the TVI curve generated with a TVI of 15 with no lean parameter. The curve t2 is the TVI curve with a lean parameter of 2.0. That is to say,

$$t_1(TV) = 15 \times p_1(TV) \tag{A.5}$$

$$t_2(TV) = 15 \times p_1(TV) + 2 \times p_2(TV) \tag{A.6}$$

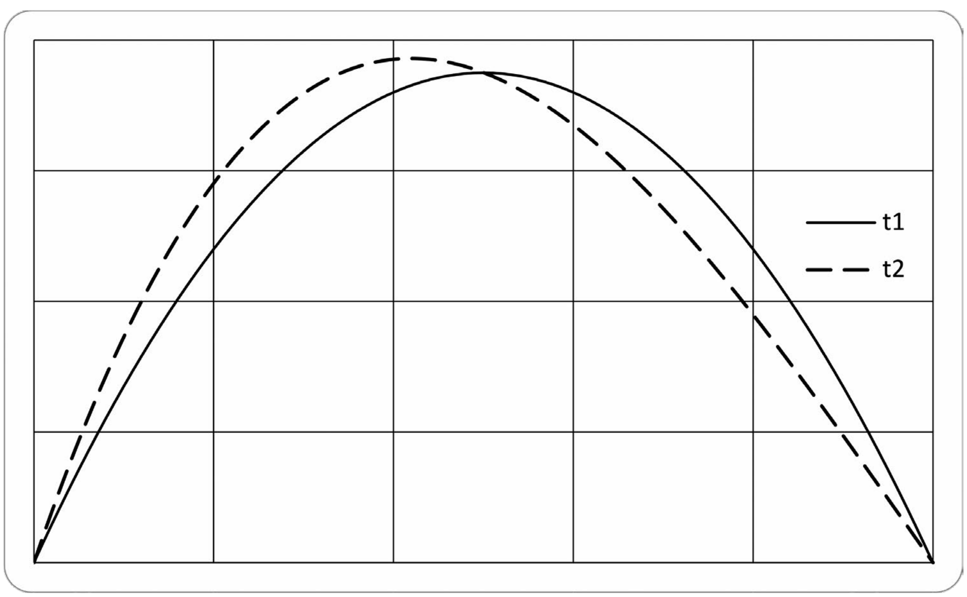

Figure A.2 – The affect of the lean parameter

Note that adding in lean will change the maximum TVI. In this example, the maximum TVI is 15.42 with the lean parameter added in, as opposed to 15 without this parameter. The amount of TVI at 50%, however, remains constant.

The third fundamental TVI curve, $p_3(TV)$, defines the bulge of the TVI curve. If the bulge coefficient is positive, the resulting TVI curve will bulge out more than a parabola. A negative bulge coefficient will not bulge out quite as much as a parabola. The bulge coefficient is analogous (but not equivalent) to the statistical term "kurtosis".

Figure A.3 is an example of the affect of adding bulge to a TVI curve. The curve t1 is, as in the previous example, a 15% TVI curve with no lean or bulge. The curve t3 shows the affect of adding a bulge of 2.

$$t_1(TV) = 15 \times p_1(TV) \tag{A.7}$$

$$t_3(TV) = 15 \times p_1(TV) + 2 \times p_3(TV) \tag{A.8}$$

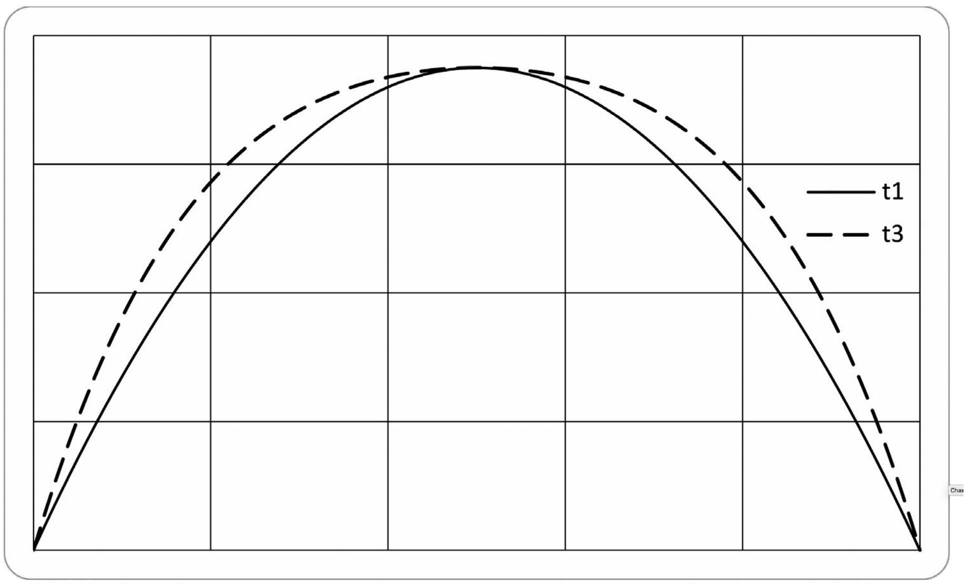

Figure A.3 – The affect of the bulge parameter

The fundamental TVI curves are designed to have a maximum of very close to 1. This is reflected in the choice of -4, 21, and -64 as coefficients buried in the formulas. (The curve $p_2(TV)$ has a maximum of roughly 1.01. The benefit of having this be exactly 1.00 was weighed against the cleanliness of having the number 21 in the formula instead of 20.7846.)

Since the maximum of the curves is 1.00, it is easy to look at the coefficients of $p_1(TV)$, $p_2(TV)$ and $p_3(TV)$ to determine the magnitude of the affect of each.

NOTE This analysis and Annex was provided by John Seymour of QuadTech

Annex B
(Informative)

Description of the constants and variables used in 5.3

The relationship between NPDC and TV defined by the equations in clauses 5.4 and 5.5 acts aggressively in darker tones while maintaining nearly constant slope, or ND contrast, in the lighter part of the tonal scale. This ensures imaging processes with widely differing Dynamic Ranges share the same relative image lightness and contrast in visually-important highlight tones.

Clauses 5.3 and 5.5 define the relationship between aim NPDC and the tone value of the cyan component of the near-neutral scale and/or the tone value of the black scale. The equations used and their associated constants and variables are in many cases arbitrarily chosen and or defined. A brief explanation and discussion of their interaction follows. It is important to note that the only user inputs required for a new printing condition are the Y value (or visual density) of the substrate and the Y value (or visual density) of the dark end of the three–color near-neutral scale and the Y value (or visual density) of the dark end of the black ink scale.

TV is the tone value of the Cyan in a three color near-neutral scale or the Black in a black scale. It is in the range of 0 to 100.

TVI(TV) is the tone value increase which is computed as a function of the tone value and is a reference input.

Y_R (TV) is the luminous reflectance factor corresponding to the reference NPDC curve which is a function of tone value (including tone value increase) and forms the reference for the remainder of the calculations.

R_R is a defined reflectance ratio which is used to adjust the subsequent scaling of the data for various tone scale ranges.

R_A is the actual reflectance range based on the light and dark ends of the tone scale and is computed from the visual densities and/or the CIE Y values of the 3-color near-neutral scale or the black scale as appropriate.

Y_C is a control point along the NPDC curve at which the scaling of Y_R is initiated. This occurs at approximately 30% of the L* range of the intended printing condition.

Y_D is the luminous reflectance factor of the dark end of the three color or black scale in the range of 0 to 1. An estimate of Y_D can be derived from the visual density of this same point.

Y_L is the luminous reflectance factor of the substrate in the range of 0 to 1. This is equal to the light end of the 3-color and black scales. An estimate of Y_L can be derived from the visual density of this same point and is the same as the Y value of the substrate divided by 100.

As Y_R is computed for each tone value, its magnitude is compared to the value of Y_C. If Y_R is less than Y_C then the computed value of Y_R is used. If Y_R is greater than Y_C then a new value is computed based on Y_R, Y_C, R_A and R_R.