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Reference Printing Conditions: Where Can it Lead Us?

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Abstract: In the traditional world of printing, the approach used to define the relationship between CMYK and printed color has been to define the ink color, screen ruling, substrate, and printing process to be used, along with its associated process control parameters (such as density of the solids, tone value increase at several points, ink trap, etc.). In the days before we had the ability to create, distribute, and manipulate electronic data, this was the logical approach. However, electronic data distribution and color management allow us new freedoms to simplify, optimize, and achieve the definition of the desired relationship between CMYK data and printed color, and at the same time give more freedom to both the preparers and printers of graphic arts data.

Printing characterization data is the term that is currently used to define the relationship between CMYK electronic data and printed color. The concept of reference printing conditions is simply the organization of such characterization data sets into a minimum logical family that covers the full range of printable color gamut. ANSI CGATS TR 001 is one example of a characterization data set that is a logical candidate for such a family of reference printing conditions. Two recent events, that facilitate the use of both printing characterization data and reference printing conditions, are the establishment of the ICC Characterization Data Registry and the introduction of the OutputIntents array in the PDF/X file structure.

Introduction

In the current world of printing, the media that is exchanged among the various participants is electronic data. We have developed file formats to efficiently exchange that data, and communication bandwidth and cost are no longer a real problem. However, the key issue that we have not properly addressed is the meaning of the data that we are exchanging. We must find ways to better define the meaning of our data (the color that is expected on the printed page) and ways to simplify and consolidate the resultant definitions into a manageable set of industry wide options.

Historically, the approach used to define the relationship between CMYK and printed color has been to define materials and process control aims to be used for various application areas. This includes the ink, substrate (often but not necessarily the paper type), printing process, screen ruling, density of the solids, tone value increase at several points, ink trap, etc. When film was the media used to exchange print-ready information, this was a logical approach. Segment-specific industry-wide aims were used for all stages of the process – prepress, proofing, and printing. Because the same "data" (halftone film separations) went to everyone, the only way that consistent results could be obtained from multiple printers, was for everyone to use the same basic materials, printing process, and process control aims. Within any one type of printing (offset, gravure, flexo, etc.) these industry process control aims were generally tied to the particular grades or types of paper used. In the United States, the SWOP and SNAP specifications are examples of this approach in the publication and newspaper advertising segments of the industry. As the work of ISO/TC130 was started, the ISO 12647 family of printing definition standards also followed this approach. The only use we made of colorimetry was to define the color of the inks and/or the printed solids and their two-color overprints.

A New Opportunity

However, the recent advances in electronic data distribution, color measurement, color management, and modern computer capabilities, combine to allow us the freedom to take a new look at the ways in which we define and control the meaning of CMYK printing data. This was not possible even a few years ago.

A key concept is that regardless of the printing process or equipment used, if the printable color gamut (defined colorimetrically) of two or more processes is the same, then within each process there will always be combinations of CMYK values that will produce a color match to the other process. The identification of such pairs of CMYK values that produce colorimetric matches is one of the basic capabilities of a color management system. Further, the computational speed and capabilities of modern computer systems allow the data transforms associated with such matches to be applied efficiently and economically, and at the speed needed to be done on-line to a modern film or plate setter.

This leads us to the proposal that various classes of printing (or even specific printing setups) can be defined in terms of the outer gamut that is achieved and a reference tabulation of the CMYK to printed-color relationship of within-gamut data. Color management systems refer to this type of information as characterization data. Where such characterization data is related to a specific class of printing, I have chosen to refer to it as a reference printing condition.

How does this help?

First, we must make some assumptions that we will verify later:

1. The basic color gamut available is primarily dependent on the pigments in the ink and the substrate used, and is largely process (offset, gravure, flexo, etc.) independent. Therefore, separate definitions are not required for different printing processes.
2. The logical size of the steps between individually identified gamuts should be about equal to the tolerances that we currently place on the color of inks and/or the color of solids in process color printing specifications; that is, about 4 to 5 delta-E units.
3. Approximately 5 to 7 reference printing conditions would span the range of color gamut normally seen in process color printing from newsprint to commercial, annual report grade, printing (one step larger in color gamut than publication printing).

If these assumptions hold, we could use these reference printing conditions as the aims for prepress and for proofing, and to identify the intended color of CMYK data exchanged within the industry. Proofing vendors and users would love to be able to live with a limited number of standard setups. Prepress and separation software would be easier to use and getting color correct would be easier to describe and accomplish.

Further, it would allow us to change the way that printing equipment is set up and controlled. The primary goal would be to match the intended color gamut - the color of the solids and overprints - and find the most stable operating condition for that press when matching the defined gamut. Based on characterization data for the press at that operating condition, coupled with the reference printing condition characterization data, color management transforms would then be used to compensate for any within-gamut differences in tone value increase, trapping, etc.

If presses really have a sweet spot (and although I have no personal experience, I believe they do, or we would not be having a TAGA session to talk about it) this approach would allow us to take advantage of any natural stability that is available without having to drive a press to an arbitrary printing condition. The primary goal would be to archive the correct color gamut and, using locally defined process control aims, maintain consistent printing.

Some Background and Validation

While this approach may appear to be "off the wall" there is some experience that points to its potential. The following are several snapshots of independent activities that all point to the need for, and are in support of, the concept of reference printing conditions.

CGATS TR 001

Several years ago, in a collaboration between the SWOP (Specifications for Web Offset Publications) Committee and CGATS (Committee for Graphic Arts Technologies Standards), a set of characterization data, known as TR 001, was prepared and published in an ANSI Technical Report. Its proper title is ANSI/CGATS TR 001:1995, Graphic Technology — Color Characterization Data for Type 1 Printing.

SWOP currently states: "ANSI/CGATS TR 001 documents the colorimetric characterization of the CMYK-to-CIELAB relationship for print conditions that are used to produce SWOP certified press proofs. SWOP specifies the use of ANSI/CGATS TR 001 characterization for any color-managed applications (e.g., SWOP certified off-press proofing, remote proofing, etc.)." As with the basic SWOP Specification itself, this reference is used for both offset and gravure printing.

In a recent evaluation of publication gravure printing for input to an ISO/TC130 standard, the Gravure Association of America (GAA) concluded that: "...using today's inks, the largest practical publication gravure printing gamut is not significantly different than the color gamut associated with CGATS TR 001."

Digital Color Proofing

Virtually every graphic arts digital color proofing device on the market today uses some form of color management to modify standard CMYK data so that the results will match the appearance of the intended printing. These are virtually all four-color (i.e., four-dimensional transforms) within-gamut modifications. Yet, the same technology is seldom applied to plate setters or image setters.

Newsprint Advertising Input

Recent work by CGATS and SNAP (Specifications for Newsprint Advertising Production) suggests that essentially the same color gamut is achieved on newsprint using letterpress, offset, and flexographic printing. One possibility being studied is the use of a single characterization data set to define proofing and data input for all input materials, regardless of the printing process to be used. Appropriate data transforms would be used to adjust the data as necessary for the particular process and/or printing equipment to be used.

In a parallel activity, Ifra has recently published a set of color characterization data for newspaper printing based on the work of a group of German newspapers in a project on the implementation of ISO 12647-3 called "Quality Initiative Newspaper Printing". ISO 12647-3 specifies printing conditions for newspaper single- or four-color printing and proofing. It is Ifra's intent that this be the reference characterization data for newspaper printing for their members and the advertisers that supply material to them. (Ifra's name originates from "INCA-FIEJ Research Association", whereby "INCA" stands for "International Newspaper Colour Association" and "FIEJ" stands for "Fédération

Internationale des Editeurs de Journaux". Today the name "Ifra" stands by itself.)

<u>Electronic Data Exchange</u>
The recently approved ISO PDF/X-1 standard and the ISO PDF/X-3 standard, which is in the final approval stage, state that all printing data in the file must be prepared for the same printing condition. In addition, both standards make use of the PDF OutputIntents array to either point to a printing condition included in the registry of characterizations maintained by the ICC, or to carry an ICC output profile describing the printing conditions to be used.

<u>ISO 12647-7</u>
Within ISO/TC130 a work item has been established to develop ISO 12647-7 *Graphic technology - Process control for the manufacture of half-tone colour separations, proof and production prints- Part 7: Processes using digital printing or reproductions made on various traditional printing processes from digital files*. The scope of this standard is stated as follows:

"This part of ISO 12647 specifies procedures for ensuring colour matching when the same digital colour image file is printed by a variety of processes. It defines a restricted number of colour gamuts that may be achieved by a variety of combinations of substrates and printing processes (including digital printing) in order to ensure gamut compatibility between the processes. It also provides reference characterization data for each gamut specified. Seven printing categories, identified primarily by the paper type used but also by the colorant set and rendering method, are included.
This part of ISO 12647 is:

- directly applicable to all situations in which colour images are reproduced by different processes and in which a colour match is required;
- directly applicable to all printing processes regardless of whether they are halftone or continuous tone"

Work is progressing slowly because of a lack of practical test data and experimental verification of the conceptual approach. There are too few graphic arts practitioners that have collected these types of data and experimented with printing based on standard gamuts and reference data encoding and transforms based on local press optimization.

These initiatives indicate that the concept of reference printing conditions is real and gaining momentum. However, it is fragmented, and as yet there is no overall model into which all of the various printing conditions fit. This is particularly true in the area of commercial printing.

Some Technical Observations

One of the factors contributing to the slow adoption of these concepts is the fact that few of us have looked at printing from a colorimetric point of view. The CIELAB color space seems to be the generally accepted coordinate system used to look at the color of printed material. In the three-dimensional CIELAB system the vertical axis is L*, which is a lightness-darkness scale. An L* value of 100 is a perfect white and a value of 0 is black. The a* axis is a reddish-greenish scale and the b* axis is a yellow-blue scale. Positive values of a* are reddish, while positive values of b* are yellow.

Ideally, we should look at color gamuts in a three-dimensional view. That is difficult to accomplish and we usually resort to looking at projections onto the a*b* plane and plots of L* vs C* for selected hue angles. (In a polar coordinate system, hue angle is measured counter-clockwise from the plus a* axis and C* is the radial distance out from the neutral axis; i.e., C* equals the square root of the sum of the squares of a* and b*). Although not precisely correct, we usually judge gamut by the a*b* projection.

Figure 1 shows such an a*-b* projection of the TR 001 data and the Ifra data

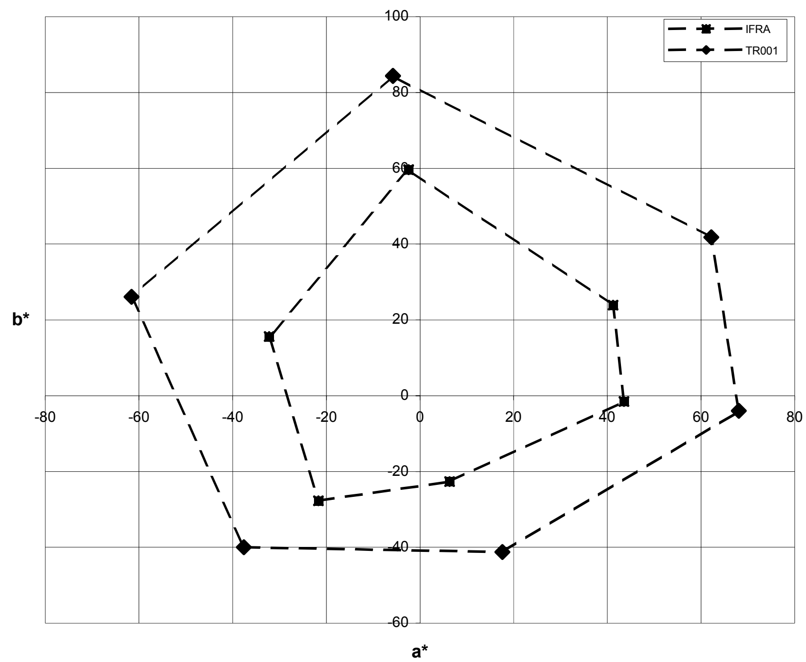

Figure 1 - Typical a*b* Gamut Plots for Publication and Newsprint Printing

The Ifra gamut represents the smallest gamut generally encountered in widespread use, and the TR 001 gamut represents one of the larger gamuts in widespread use. As can be seen, the difference between these gamuts is about 20 to 25 units in chroma (radial difference from the neutral axis where a* and b* equal 0).

There is a widely held belief that printing to higher densities produces a larger printing gamut and better printing results for those who can afford the extra ink. Two factors come into play when we look at this option. First, the change in chroma, that is to say gamut, varies slowly as a function of density. Figure 2 shows a plot of the chroma of the reference SWOP cyan, magenta, and yellow inks as a function of density. (These data are from the tests that were conducted to verify that the SWOP inks met the ISO 2846 criteria.). Yellow is the only color that has any significant slope, but pushing yellow by itself doesn't buy us anything if we wish to maintain an ink set in reasonable gray balance.

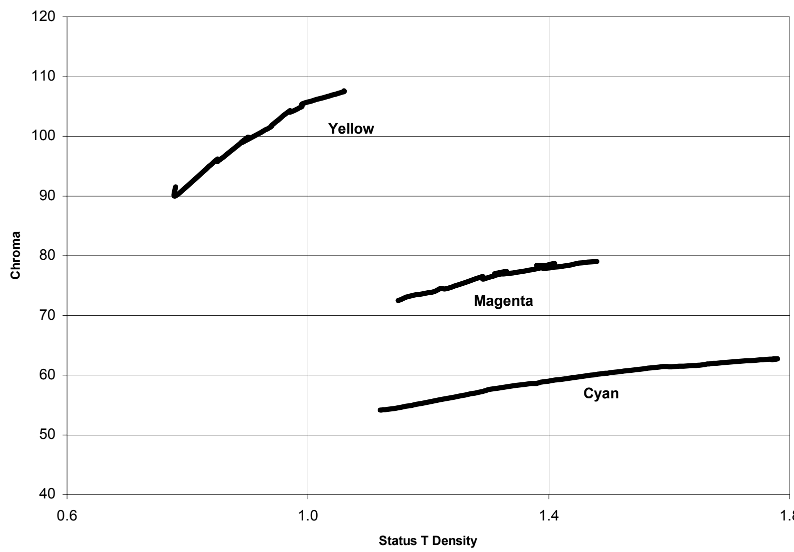

Figure 2 - Plot of Chroma vs Density for SWOP Inks Over a Range of Ink Film Thicknesses

The other issue is the relationship between hue and ink amount, particularly for magenta and cyan. Figure 3 shows an a* b* plot of the same reference SWOP cyan, magenta, and yellow inks over the same range of ink film thickness (and densities) shown in Figure 2. (The heavy lines represent actual data. The dotted lines are extrapolations based on typical data to show the overall relationship) Although these tests were done using the reference coated paper specified for ink testing - Phoenix Imperial APCO II/II - similar results are found with typical printing papers. Both cyan and especially magenta "hook" appreciably just beyond the point corresponding to the SWOP aims. Printing in a region where variations in ink lay down result primarily in a color (hue) change is probably not a good place to set aims.

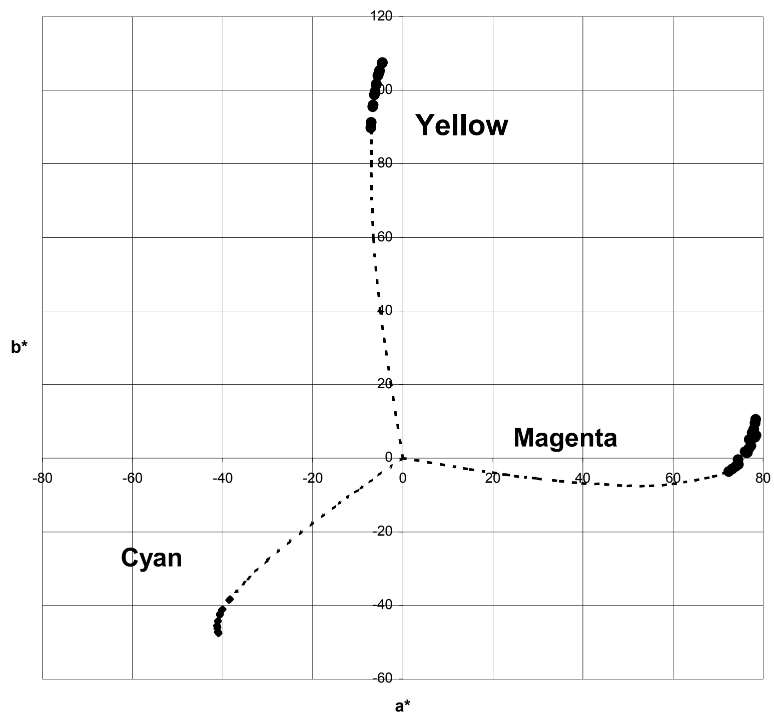

Figure 3 - Plot of a*b* Values for SWOP Inks Over a Range of Ink Film Thicknesses

Small changes in density, as have been proposed for some of the GRACoL work, are reported to change the physical appearance of the images. This often has been claimed to be an increase in gamut. Many things could alter appearance – a change in the tone value increase and thus tone reproduction; a change in the ink coverage resulting in an improvement in the gloss or smoothness of the image; the effect of the paper substrate itself; or some other phenomena. However, from what we see in Figure 2 the appearance change is probably not due to a change in gamut. Part of our challenge is to understand what is changing, and to harness that change in a controlled manner. Figure 4 shows very preliminary results from GRACoL tests on Grade 1 and on Grade 3 papers along with the TR 001 data.

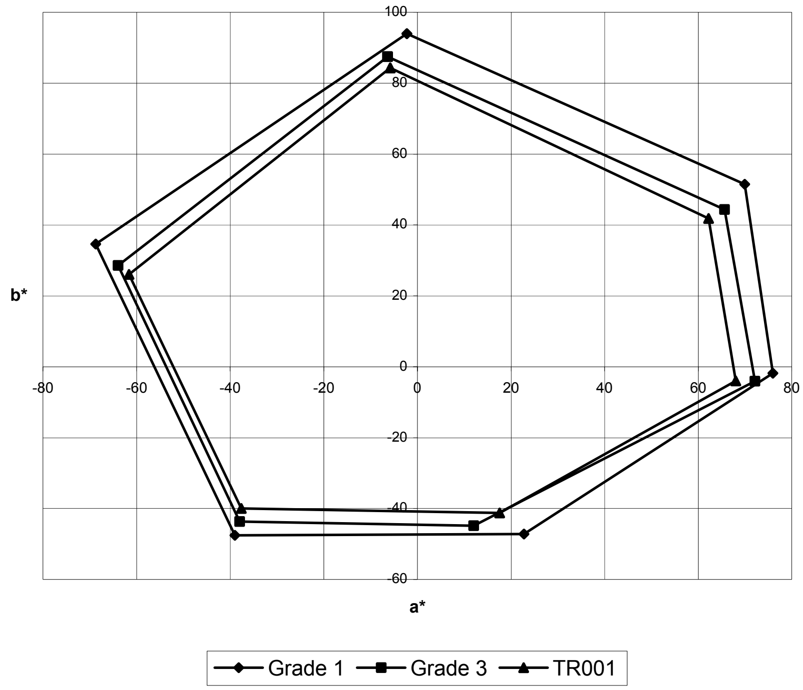

Figure 4 - Sample a*-b* Plots for GRACoL Grade 1 and Grade 3 Paper - Absolute Referenced Colorimetry

All of the above colorimetric data has been relative to the perfect white diffuser. We usually refer to it as “absolute” even though that term is incorrect according to the CIE definitions. As we have looked at these data, it has become obvious that differences in the reflectance of the various papers is part of the difference we are seeing. We compute the apparent size of halftone dots from reflectance measured with respect to the substrate. Color management usually uses substrate-relative colorimetry to insure that the image starts with respect to the paper and we do not get scum dots to unnecessarily darken the background, or that there are no "no-dot" areas because the substrate is darker than expected.

Building on these examples, if we look at color gamut using substrate related colorimetry, we find that apparent differences in gamut data between papers are brought even closer together. Figure 5 is based on the same data as Figure 4, except that the computations are done with respect to each individual paper substrate rather than with respect to the perfect white diffuser. This plot suggests that the gamuts are much closer together and that the largest differences are in the yellow. Based on the data shown in Figure 2, small density changes in yellow solid ink density may bring these conditions very close together.

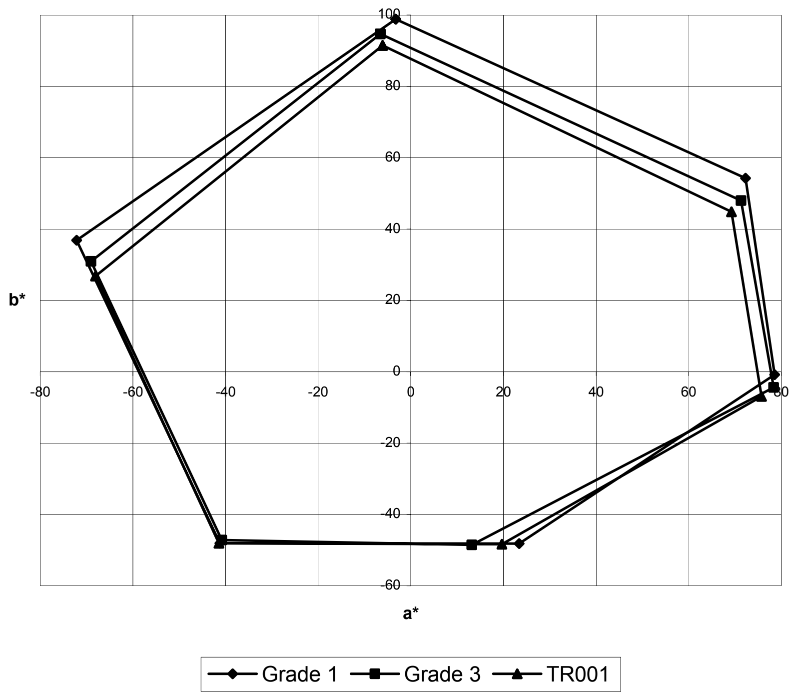

Figure 5 - Sample a*-b* Plots for GRACoL Grade 1 and Grade 3 Paper - Substrate Referenced Colorimetry

Admittedly, we are still trying to learn how to handle this way of looking at data, but it may help to point to new ways of comparing and/or standardizing printing gamuts

ISO 12647-2, *Graphic technology — Process control for the manufacture of half-tone colour separations, proof and production prints — Part 2: Offset lithographic processes*, defines offset printing aims for five typical paper types. These are:

1 gloss-coated, wood-free;
2 matt-coated, wood-free;
3 gloss-coated, web;
4 uncoated, white; and
5 uncoated, yellowish.

Both the German Graphic Technology Research Association FOGRA and the Japanese TC130 standards group have developed characterization data for paper types 1 through 4. These are shown on a substrate-relative basis in Figures 6 and 7.

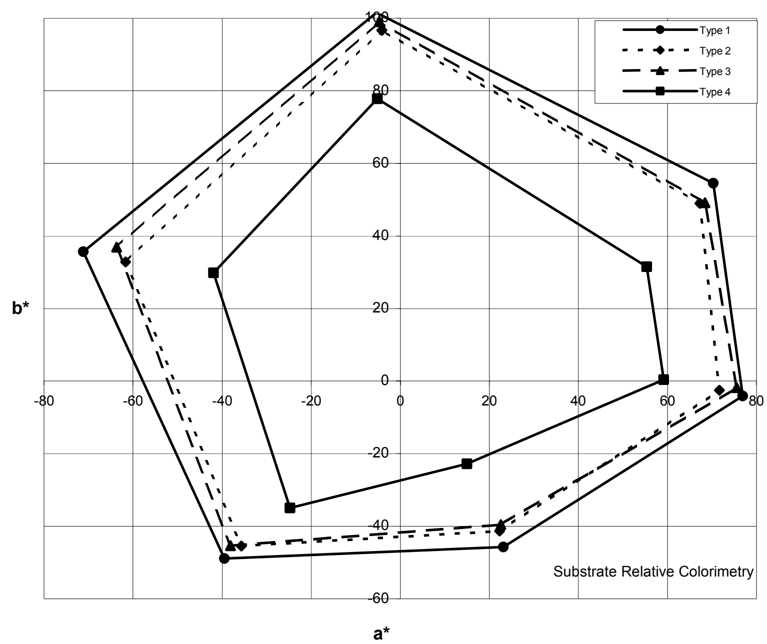

Figure 6 - Gamut of types 1 - 4 of ISO 12647-2, Fogra data

As might be expected, these data are not exactly the same even though the same aims were used by both organizations. One might suggest that the differences between the data for equivalent paper types offers a measure of the uncertainty of a particular set of aims. However, both sets of data show that the gamut difference between the aims for types 1, 2, and 3 is small when viewed in terms of substrate-relative colorimetry. If TR 001 data, shown in Figure 1, were added to Figures 6 and 7, that data would fall in the middle of the type 1-3 grouping.

Based on the experience with TR 001 and its applicability to offset and gravure printing, along with the CGATS/SNAP work, there seems to be reasonable confirmation that gamut data is largely printing process independent. Looking at the color gamut spread in Figure 1, and using roughly a 5 delta-E step criteria, it would appear that 5 to 7 steps would cover the expected gamut range based on projections on the a*b* plane.

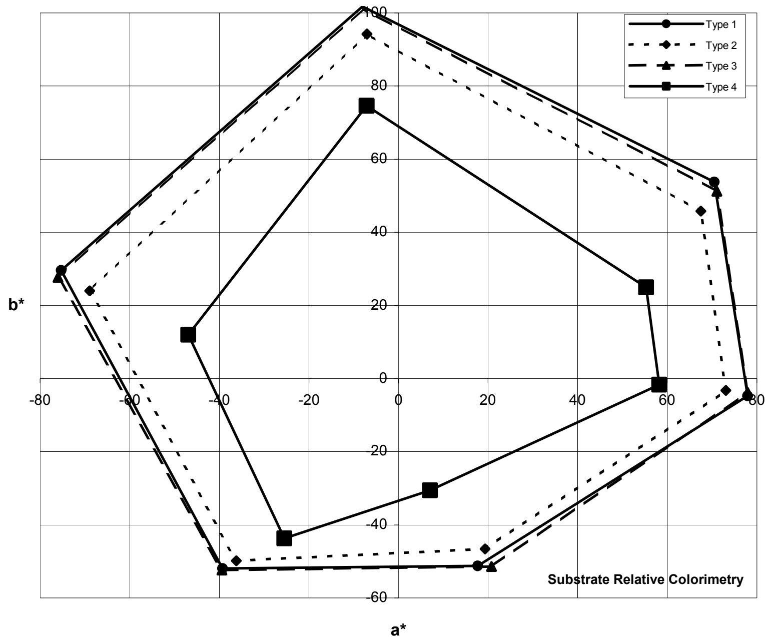

Figure 7 - Gamut of types 1 - 4 of ISO 12647-2, Japanese data

Summary and Conclusions

Substrate-referenced colorimetry seems to minimize differences in apparent gamut between printing on papers of different reflectance (brightness). However, a lot more work appears to be needed to understand the mechanisms involved and their impact on the process of establishing density aims for process control. Further, these types of data need to be analyzed using three-dimensional models rather than multiple two-dimensional projections.

Differences between various types of printing, such as the GRACoL work on Grade 1 and Grade 3 paper, although historically explained as color gamut differences, cannot be attributed to differences in color gamut. However, because these differences exist, they need to be studied and explained if they are to be used to advantage.

An uncoordinated family of reference printing conditions is being developed within the industry on an ad hoc basis that lacks any real technical analysis or coordination. While the effect of each individual reference is beneficial to that industry segment, it is not moving the industry toward a cohesive family of references. Further, these individual references seldom are developed with the intention of using color management to adapt standard data to specific printing equipment to make printing simpler or more cost effective. They are rather aimed at enabling limited use of color management to support single application traditional process control based printing definition.

As an industry we have a limited window of opportunity to create a family of coordinated, technically sound, uniformly spaced, process independent, reference printing conditions that can become the basic reference for commercial and publication printing. Whether these are based on absolute or substrate relative colorimetry will require additional study. Such a family of reference printing conditions would simplify the task of prepress preparation, proofing, and data exchange. They would also give the printer more freedom in the choice of operating conditions and would increase the importance of process control and printing consistency. However, to take advantage of this opportunity we must accomplish the necessary research and study of both the required data manipulation (CMYK to CMYK transforms) and the printing process control (gamut aims, local process control aims, etc.) to provide reasonable workflow models for the broad base of the industry to follow. The standards community can help but what is needed is a commitment on the part of the various industry trade groups and research communities.

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