PROCESS CONTROL IN COLOUR REPRODUCTION

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Abstract: The evolution of process control in colour reproduction has recently reached a new milestone with the publication of internationally agreed standards for the control of various printing processes. This paper reviews the methods for process control in colour reproduction and discusses the significance of these standards for both traditional colour separation techniques and a colour management approach. It is suggested that the requirements for Graphic Arts workflow mean that these standards are applicable to the colour management environment, albeit with some modifications in certain circumstances. Suggestions for future standards activity are made, including test images for control of colour management, better image setter calibration methods, print control bar production in a computer to plate situation and printing specifications for gravure packaging and flexography.

Introduction

During the past 25 years we have seen the Graphic Arts industry begin a transition that many believe will take colour reproduction from an entirely craft based process to a manufacturing process based on fully quantifiable data. From a personal perspective I have seen two quite different approaches evolve in that time, each of these being a response to a specific workflow procedure and industry structure. The first of these evolved from the requirement in the industry for advertisers to provide copies of a set of separations to a number of printers. This led to the development of 'standard' conditions for printing and/or proofing so that the results obtained from such separations would be consistent between the various printing sites. Little attempt was made in this workflow environment to specify the relationship between the colour of the original and the print in any objective way. It was assumed that the creator of the separations would interpret the original as required by the customer and provide a proof of this interpretation for his approval. So long as each of the printers could then match the approved proof consistency between them was assured. All that was then remaining was that each printer maintain this result during the course of the production run. During the past 20 years these standards have evolved, for various processes, around the world.

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and recently a number of these have been consolidated into a series of International Standards; the status of these will be reviewed later in this paper.

More recently, however, the industry has progressed towards the transportation of electronic images, rather than images being provided on film. This progression is far from complete but is growing, and in such a workflow other possible scenarios arise. Initially, image exchange has largely been based based on the assumption that the files moved between users were in CMYK format, prepared for a specific printing process; such as one of those standardised as described above. The files could be thought of simply as electronic separations although generally in continuous tone form; without the imposition of the halftone screen. Thus, all the constraints placed on controlling the process are the same as for the exchange of film separations. It is obviously essential for the final user to ensure that the output device is properly calibrated, and that the correct screen is selected, but otherwise there is little difference to the workflow based on separations.

For such a situation to be fully effective it is necessary to ensure that proofing systems are predictable and provide a good simulation of the print. Much research and development effort was put into the problems of matching flat bed proofing presses to the running press and vendors of 'traditional' off-press proofing systems sold their product as a good match to the press. However, since these proofing systems were simply reproducing the separations it was essential that the colour of the pigments (or dyes) matched those of the inks and that the tone reproduction of the proof simulated that obtained by platemaking and printing. However, with electronic files it is possible to transform the data in a way that is not possible with traditional proofing systems and this permits the use of colorants for the proof that are dissimilar to those of the print. Whilst such a process can be effective, if the colour transformation is well defined and controlled, it does add a degree of uncertainty to the process insofar that the printer using the proof to set up the press cannot be completely certain that the proof has been made in a predictable and consistent way. The colour bars used for process control in the film separation environment are no longer the independent indicator that they generally were in the past.

This ability to process electronic files with a colour transformation can be implemented at any stage in the process; not just proofing. This leads to a control procedure usually known as colour management. In such an environment it can be argued that it is far less important that the process characterisation be consistent between printing presses because, as described for proofing above, a colour transformation can easily be applied to the electronic data file when it is output; a situation which is not possible when film separations are supplied. Each individual press can be 'fingerprinted' with its own characterisation data, such that a colour transformation may be applied which matches the proof, and yet is unique to that press, when the image is produced. The reference is no longer the halftone dots themselves but the colour that they will produce.

My main objectives in this paper are to review the process control standards that have evolved, discuss the process control procedures implicit in them and consider their significance in both traditional and colour managed workflows.

The Development of Standards for Process Control

There were various relevant standards and specifications developed prior to the late 1970s which quantified certain aspects of the Graphic Arts colour reproduction process; for example, various British and other national Standards pertaining to such matters as the colour of inks and viewing conditions led to similar international standards. In addition, trade organisations such as SWOP specified certain requirements for the separations provided to printers for magazine production and, later, approved specific inks and densities to which the **proofer** should print them. However, no attempts were made to produce a **complete** system of colour reproduction control until FOGRA proposed a procedure which pulled together a number of activities in the late 1970s.

It may seem surprising that such activities are so relatively recent, but the limited use of colour prior to this time, coupled with the widespread use of letterpress printing, really required little else. However, as colour and lithographic printing both became increasingly popular, with somewhat greater potential for variability between presses (both production and proofing), the situation became far more difficult. In particular, proofs of separations made on proofing presses were generally not capable of being matched in production.

One of the major causes of variability became known as 'dot gain' (although the term tone value increase is now preferred and will be used throughout the remainder of this paper). This term reflected the fact that halftone dots could change in size and density, according to conditions of printing, to a far greater extent than was usual with letterpress. Research showed that a significant number of variables would affect this although ink properties were the most significant. As a general rule proofing presses, with their shorter roller trains and using more concentrated and/or viscous inks, produced far lower levels of tone value increase than production presses, even when printing on the same substrate. This led to a significant problem in that printers could frequently not match the proofs already approved by the customer and would attempt to modify the print characteristics in an effort to do so. This generally required a different characteristic for each job printed as the proofs and separations often came from a variety of trade separators each working to their own specification. Thus, when images from different suppliers were mixed in the same sheet all that could be obtained was a compromise which frequently led to a certain amount of dissatisfaction.

In an attempt to overcome this problem the concept evolved that the printing characteristics of a press should be specified to the pre-press operator. He would then be expected to produce the same levels of ink density and tone value increase on his proofing press, thereby ensuring that separations were made with this printing characteristic in mind. By characterising the press in this way, and matching the proofs to this print characteristic, the problem could be significantly eased.

Clearly for this procedure to work satisfactorily it was important that printing presses were controlled across the whole range of jobs produced on them in order that consistent results be obtained and at this time various organisations around the world (e.g. Felix Brunner, UGRA, GATF and RIT) had been developing process control aids such as colour bars containing halftone patches, control patches for assessment of slur and doubling, plate and film contacting control wedges and test formes for establishing the printing characteristics of printing presses (particularly grey balance). Procedures were also published by these organisations explaining how individual users could make use of these in order to control the consistency of various facets of the process in a single plant environment. However, this inevitably led to a situation in which a variety of printing conditions were encountered around the industry, which made the production of images in multiple publications liable to significant variation between the images. To some extent this was minimised by the provision of proofs from the advertiser but only insofar that the printer was able to compromise between all the different proofing conditions used to produce them.

The SWOP approach to this problem was to specify the conditions for proofing. The logic of this is that if the printer has to match the proof then it constrains the variability he can print to. If all proofs are made to a common specification it is anticipated that they can all be matched together on the press and that there will similar results obtained between different presses printing the same advertisement. Such a situation allows some flexibility on the part of the printer to compensate for proofing differences, since it is not possible to specify the proofing and measuring systems so stringently that all are produced to an identical specification. But, it is this flexibility that leads to the limitation of this approach. Unless the match obtained on the press is specified numerically it must be subjective, and it is easy to see how one printer can print to a condition that he finds acceptable and another with a different condition that is also acceptable on its own, but lies at the other extreme of density or tone value increase to the first printer. The advertiser could thereby still find big differences between the same page in a range of magazines.

However, at about the same time that SWOP were developing the standard proofing concept, and as the methods of control of the printing process became better understood, Rech et al (1977) proposed the concept of 'standardised' printing. This proposal was that numerical values should be specified for colour and tonal reproduction, and that **all printers and proofers** were expected to adhere to them. It was a logical extension of the procedure whereby a printer produced his own 'numbers' and used the process control aids to maintain consistency within his own environment. The proposal thereby attempted to overcome the problem of variability between printers.

In this context the FOGRA/BVD specifications which were subsequently produced by Rech et al (1981) specified tone value increases for each of the inks as well as providing targets for solid colour. In conjunction with this a substantial body of work was brought together (from FOGRA and elsewhere) which demonstrated how the various parameters of the print characteristic specification could be influenced and controlled. Better understanding of the effects of ink rheological properties and film thickness on ink transfer, combined with an improved understanding of the control of platemaking, enabled the printer to determine how the control of these parameters could be managed.

Inevitably there were many practitioners at the time who said it couldn't work; that the process variability was too great, the measurement inconsistencies were too significant, that independent control of tone value increase and density was not feasible, etc. Whilst there is some validity in such claims experience has shown, in practice, that the process can be constrained within reasonable limits, and since the first proposals for such a procedure were published a limited number of specifications have subsequently evolved which are increasingly accepted world-wide. Various national standards, or industry specifications, have been produced during the past 20 years and these have now been brought together in a series of International Standards. In fact, the concept is now being extended into processes such as screen printing and gravure which, with isolated exceptions, have seen little of such standardisation in the past.

The development of these printing specifications has made the calibration of pre-press systems much easier since it is no longer necessary to characterise individual presses. Unless otherwise specified the assumption is now generally made that printing will be undertaken in accordance with these specifications. Pre-press calibration is thereby restricted to a limited number of possibilities which makes the workflow relatively simple to control.

Process control procedures

In this section I will start by outlining the overall process control procedure which needs to be implemented in order to maintain consistent, high quality, colour reproduction. I will then briefly summarise how the individual components are established before turning to the details of the specifications which have been derived for this process. My discussion will be largely focused on offset lithography but can be extended by analogy to all other processes.

Ensuring good quality colour reproductions requires regular calibration of all components in the system. However, this is not sufficient without initially ensuring proper characterisation and control of the printing press. It is a fundamental tenet of pre-press calibration that colour transformations are defined by the press characterisation, and that sufficient control be implemented throughout the process to maintain consistent output using these transformations. Defining the overall calibration may, therefore, be thought of as a sequential 6 stage calibration process:

a) Stabilise and control the platemaking and printing processes.
b) Characterise the press by printing and measuring suitable test images made to the procedures defined in a).
c) Match the proofing system to the press (for both soft and hard copy proofs).
d) Linearise input scanners and imagesetters to a specific calibration.
e) Using the scanner and imagesetter calibration specified by d) define the colour transformation required to produce high quality reproductions when proofed.
f) Control scanning, imagesetting and/or platesetting to maintain the transform.

Note: The term press characterisation is used here in its general form; that is simply to define certain parameters of the press by some means of measurement. In colour management the term characterisation is often used in a more restrictive way in which the measurement procedure is colorimetry and the characterisation therefore refers to the tristimulus values produced by combinations of inks.

Stabilising and controlling platemaking and printing: It is absolutely essential to an effective workflow that the platemaking and printing procedures produce a consistent result day in and day out. To this end it is necessary for a printer to define a printing condition that he can maintain consistently with the minimum of trouble. This means that a platemaking procedure (principally vacuum level as well as processing and exposure conditions) is defined which satisfactorily removes dust spots and edge lines (without excessive loss of fine lines or halftone dots) for positive working plates, or produces satisfactory hardening of the image area (without excessive growth of fine lines or halftone dots) for negative working plates. Having determined this condition a suitable control target consisting of variable thickness micro-lines or fine halftone dots is exposed in the non-printing area of a plate to ensure consistency is maintained.

For the printing press it is not quite so easy to define the 'optimum' printing condition at which the press should be stabilised. In general it will be when printing at an ink film thickness which best permits the following conditions; tone value increase can be held at a reasonably stable level, a good colour gamut is produced, ink drying is acceptable and high speed printing with few press stops is permitted. However, these conditions are the result of a quite complex interaction between press, materials and ambient conditions and this is why different printers may well end up with quite different characteristics from their stable printing condition, without any external reference. Once the press is stable the characteristic should be controlled by means of a well-defined process control target containing fields discussed in the next section.

The development of 'standardised' offset printing was an attempt to reduce this variability by explicitly defining the characteristic of a stabilised press. The printer was expected to select his materials and set up the press to ensure that the specific conditions defined in the standard were achieved. It is not my intent in this paper to discuss in detail the techniques for 'standardising' offset printing. For those who require more information there is now a substantial body of literature. Early examples are given in Mill et al (1980), Rech et al (1981) and Johnson et al (1982) but much of this work has been brought together in various publications; see, for example, Tritton (1993).

Press characterisation: Once a stable printing process has been defined and achieved it is necessary to characterise it. This can be done in two quite different ways depending upon whether the system is considered to be device dependent or independent. Current practice is still dominated by the former and much of the early part of this paper will be devoted to this. However, device independent characterisation, and the implications of this, will be discussed later.

The way in which the process is characterised has implications for the way it is controlled, or vice versa, since it is essential that the characterisation process permits definition of the parameters which are to be subsequently used for control. Many test formes have been designed for characterisation but to be satisfactory they must include the following fields as an absolute minimum.

- Areas of full ink coverage in each colour
- Steps of increasing dot area in each colour
- Grey balance determination
- Black over trichromatic grey at varying levels

Other fields which are optional but prove useful for most applications include:

- Two and three colour combinations of full ink coverage
- Two and three colour combinations of step wedges (in which all colours have the same value in any step printed)
- Two and three colour combinations of varying halftone values (in which all colours have different values in any step printed)

Note: The test forme must also contain fields which indicate the absence of directional effects (slur and doubling), and should also contain fields to indicate any lack of uniformity over the printed sheet. However, these are not used for the characterisation and are not considered in this context. As a general rule the variability of the printing process is such that it is inadequate to rely on only one set of measurements. Multiple copies of the test forme should be printed on a sheet (space permitting) and a number of prints selected at random. Statistical analysis of these should be undertaken to define the characterisation accurately.

The various fields described above are used in different ways. Some of them (particularly single colour full ink coverage and certain halftone areas, as well as some optional secondary and tertiary combinations) are primarily designed to be measured for control purposes and to enable the criteria to be specified by which any halftone proofing system can be matched to the press. Once this has been achieved the proof can then be taken as the definition of the characterisation to enable the colour transformation between scanner 'tristimulus' values and colorant amounts (generally defined as halftone dot area) to be determined. However, the fields on the press test forme which are used for defining the colour transformation (the grey balance, black over grey and other secondary and tertiary combinations) also act as a useful visual check that some of the second order effects such as ink trap or gloss are not causing significant differences between proof and print.

For reasons I find difficult to comprehend it is often debated whether densitometry or spectrophotometry is more appropriate for press control. The answer seems clear to me: colorimetry is more approriate for defining the match between different media (proof and print, for example) because of the possibility of metamerism. However, densitometry, preferably narrow-band, is more appropriate to control of a press run because of the increased sensitivity provided.

Proof matching: As already stated, only two of the fields described above are required to match a proofing system to a press when <u>both have similar gloss, a similar substrate and use colorants which match</u>. The full coverage fields and halftone step wedges, which are the same as those used for press control, enable densitometry or spectrophotometry to be used to ensure the proofing process simulates the press. However, specification of additional fields such as secondary and tertiary colours permits a slightly more stringent control to be applied which ensures better balance between the colours.

For proofing systems which use different colorants the situation is somewhat more complex. As discussed by Johnson (1986) an approximate match can be obtained using simple single dimensional corrections based on the data obtained from the grey balance field if the differences are relatively small. However, with the computation power now available a full, three or four dimensional, colour transformation is now quite straightforward and can generally be obtained by simple modelling techniques, even if the differences between the colorants are large. For more details of these procedures see, for example, Johnson (1996).

Soft proofing, using colour monitors, represents the extreme case of differing colorants. Various techniques are employed to obtain colour accuracy but most rely on some form of modelling. Many attempts have been made to do this objectively but these are rarely completely successful because of viewing condition influences. Empirical adjustments which rely on visual assessment are usually required to optimise the match.

For high quality proofing many users have traditionally been suspicious of systems which do not use the same colorants as the print. If such a proof is to be used as the criterion of acceptance of the separations (a so-called contract proof) the customer is totally dependent upon the colour transformation that is used to define the press simulation being accurate and well maintained. He has no simple way of checking the accuracy of the match, except over time, and consistency of proofing poses another problem. Even if traditional colour control bars are shown on the proof the user cannot verify consistency of the colour transformation simply by measuring these. Differences in media colour from batch to batch, for example, may well have been compensated for in the transformation itself. For these reasons, proofing systems of choice, at least at present, are still those in which colorants are the same as the printing process. However, since this situation is now changing quite rapidly suggestions to resolve this problem will be discussed later.

Linearising scanners and image/platesetters: Linearisation refers to the procedure of ensuring that the devices produce a specified result over the full range of the device. For input scanners this means that a specific electrical signal is obtained for a particular light level. With well designed photomultiplier scanners linearity should be achieved over a substantial range of density; typically 4 decades in transmission mode. The signal obtained should be proportional to the transmittance measured by the detector. Flare is generally the limiting factor (assuming good optical alignment) and this is invariably more difficult to minimise in reflection mode. However, for CCD scanners it is even more difficult, and 3 decades of linear response is rather more typical, although devices are undoubtedly improving.

To ensure consistent results from the scanner it is necessary to scan a step wedge which has reasonably well-defined transmittance or reflectance values (such as the IT8 target discussed later) and ensure that the signal obtained is predictable. If the dynamic range is too limited, or the signal not reasonably proportional to transmittance or reflectance over much of the range, the scanner should be investigated to establish the cause of this. However, the latter effect can be corrected in the colour transformation if not too severe.

For imagesetters linearisation means ensuring that the halftones dots produced on film are those defined by the RIP. Linearisation simply consists of outputting a test image of a full range of defined halftone dot percentages and ensuring the values achieved on film or plate are those specified. In general a look up table is modified as necessary to achieve this although if the deviation from the anticipated result is too severe the device should be investigated to find the cause.

Colour transformation definition: Colour transformation techniques for most existing device dependent systems rely on filters being chosen in the scanners which provide minimal crosstalk between the primary absorption bands of the photographic dyes being scanned. The signal obtained through each filter can therefore be considered to be a measure of the complementary dye present in the original. By replacing this dye amount with an ink quantity of equivalent light absorption, whilst taking account of any difference between the colour of the dye and ink colorants, a colour match will be obtained. This simplistic view does not take account of a number of problems which require additional computation but these will not be explored in depth in this paper. They have been discussed at length by Johnson (1992) and will only be summarised here.

The controls provided for most device dependent colour transformations largely adjust the following parameters, which are usually considered to be fundamental to high quality reproduction:

- Tone reproduction
- Grey balance
- Colour rendition
- Calculation of the black printer.

Essentially the first two parameters can be thought of as defining lightness reproduction and colour balance; the third defines the hue and chroma. It is because all of these parameters are affected by the conditions of printing that the data for setting the controls of a scanner must be derived from the characterisation data described above. Tone reproduction for any particular original is a direct function of both the density and halftone dot reproduction characteristics of the process as well as the white and black point of the original. As the maximum ink density and tone value increase parameters vary so the tone reproduction needs to be adjusted to compensate and thereby maintain the required lightness relationship between the original being scanned and it's reproduction. Grey balance data simply defines the balance between the chromatic inks by quantifying how neutral colours should be rendered. It is clearly affected by the colour of the ink and substrate, tone value increase of each ink and the ink film thickness printed. Thus it is an important part of the press characterisation in practice.

Colour rendition parameters are required in the colour transformation to correct for a variety of problems. Since all dyes and inks used have some unwanted absorption, when compared to the 'ideal' colorants defined by Hardy and Wurzburg (1937), it follows that any single dye in the original will generate some crosstalk (i.e. produce a signal in other than the channel defined by the complementary filter). By measuring the unwanted absorption of the chromatic inks printed on a specific substrate, and correcting for these, perfect colour rendition can be obtained. Unfortunately, this correction is not simple. The colorants are not a set of stable primaries and so the ratio of wanted to unwanted absorption is not constant as concentration or dot area varies. (This is known as proportionality failure). Furthermore, there is no simple unit of measurement of light absorption which provides a simple linear system for correction and additional complexities are caused by gamut mapping, measurement difficulties on different media and the effects of viewing conditions. Because of all these issues empirical techniques are generally employed to optimise corrections for colour rendition. Typically these divide the colour space up into a number of regions, somewhat arbitrarily, and enable independent modification in each of these, Johnson (1992). By this method the colours are generally modified empirically until an acceptable reproduction is achieved, although objective derivation based on measurement of the optional colour fields used for characterisation is possible.

Controlling scanners and imagesetters: Input and output devices should have facilities for ensuring that they produce predictable output despite changes occurring in such factors as temperature, film batches and/or developer, lamp output, etc. Both analogue and digital corrections are used in practice although digital routines can introduce quantisation errors if precision is limited. Input scanners should be treated as any optical measuring instrument and calibrated fairly regularly to set the offset and gain of the amplifier circuitry and, in the case of a CCD scanner, to balance the individual sensor elements. Transmission scanners are generally set relative to air for setting the white point and a neutral filter of known transmittance for setting the black. White and black reference reflecting samples are necessary for reflection scanners. Less frequently it is necessary to verify linearity as stated earlier.

Output recorders require that light levels be adjustable to take account of variation in speed of materials but by itself this is generally inadequate. Factors such as developer edge effects mean that dot areas do not change linearly from one material batch to another and when halftone dot generation is achieved by varying exposure profile across a dot the deviations can be even more significant. For this reason some non-linear correction is generally required.

Clearly, any scanner or recorder variation can be compensated by direct modification of the colour transformation. Calibration samples can be measured on the scanner and the transformation modified according to the differences obtained from previous measurements. If variations occur frequently this is not generally a very efficient procedure but it can be very effective. However, it may mask serious problems in the device if care is not taken to understand the cause of any changes.

Process control standards

In graphic arts much of the important current standards activity is being undertaken by ISO TC 130, the International Standards group concerned with Graphic Technology. A significant part of this work is related to the process control of colour reproduction; both in terms of specifications for printing and proofing as well as methods of measurement and visual assessment.

It was pointed out earlier that a skilled scanner operator, in a device dependent system, can only provide high quality reproductions if he has default colour transformations defined for his scanner that provide satisfactory reproductions for the printing processes he is reproducing the images for. It follows that these default transformations are only useful if the printing process is itself well defined and controlled. Without adequate process control each device would need to be calibrated individually, and possibly on a fairly frequent basis. By providing specifications for particular printing conditions generic transformations can be provided which are optimised for that process; it is also possible to ensure that proofing and printing systems match one another; and that pages produced on various presses are themselves consistent.

In the following paragraphs I will briefly review some of the main specifications of the standards that have been developed in recent years, and attempt to indicate how they provide part of the total process control specification defined earlier.

Process ink specifications: Over 30 years ago a number of European organisations, under the auspices of the European Ink Commission of that time, developed a proposal for the standardisation of the colour and strength of inks for Lithographic and Letterpress printing. Although this work was widely accepted in Europe, resulting in a number of European national standards, and was also developed into ISO standards ISO 2845 and ISO 2846 in 1975, it never received broad acceptance in the USA or Japan. By the mid 1980s it had become clear that the standard was now out of date, even in Europe, and so in 1989, under the auspices of CEPE, the Europeans produced a proposal for revision. Following the 'resuscitation' of TC 130 in that same year the proposal was passed to them in order to revise ISO 2846. (It was felt that the Letterpress standard was not worth revising due to the limited application it now has).

The CEPE proposal was investigated in some detail by experts in the USA and Japan and significant differences between the colour of the inks used in those countries and those specified in the proposal were noted. In particular, there seemed to be a significant between the CEPE proposal for cyan and the measured values from elsewhere. After much discussion it transpired that this was, in reality unlikely, and after re-evaluation of a number of German inks it was agreed that the original proposal should be modified and a new specification agreed that would be acceptable to the experts from the USA, Europe and Japan. The resultant standard, ISO 2846-1 (1996), specifies the colour (with tolerances) that lithographic inks for sheet-fed, heatset web and radiation cured production must attain at some ink film thickness within a specified range. It also specifies the lower limits for transparency of the inks, to ensure that reasonably good secondary colours are obtained. The transparency value is obtained by measuring the colour differences between a black substrate and the test ink printed on it at a range of film thickness; see Bassemir and Zawacki (1994) for details. By measuring the slope of the resultant plot it can be established whether it is within the limit specified in the standard.

The values given in the standard are specified in table 1. It should be noted that the standard specifies the colour of the inks when printed on a specific substrate (APCO II/II - selected because it exhibits no fluorescence) within a specified range of ink film thickness, **not** the colour on other substrates. Obviously, the resultant colour will vary from the standard when a conforming ink is printed on different substrates. Other standards to be discussed later in this section cover this, but without this basic standard the others would not be possible.

Work is now under way to produce comparable standards for News, Gravure and Screen ink. At the present time only the Coldset Offset (News) Ink standard is nearing agreement. The values which seem likely to be defined, on a specified Newsprint substrate, are given in table 2.

Specifications for proof and print production: Once the basic ink colour is specified it is possible to produce specifications for the production and proofing of printed images by any process on any substrate. In this way, if a number of printers all meet the specification, it is possible to provide them with the same images and ensure that consistent results are achieved without the need for individual calibrations. Furthermore, the producer of separations may develop colour transformations for these standardised processes without needing to develop them separately for individual printing conditions.

A number of standards, each specifying different processes, are in different stages of production as ISO 12647 parts 1 to 5 (199_). The first part specifies the parameters, definitions and measurement procedures whilst the second part specifies the characteristics to be achieved by offset lithography on various substrates. Parts 3, 4 and 5 specify the characteristics for Newspaper production and the Gravure and Screen printing processes respectively.

The standards specify a variety of parameters including characteristics of the separation films used to make the printing surface, such as dot hardness, D_{max} and D_{min}, preferred screen ruling and angles, UCR (by defining the maximum tone value sum), fit and grey balance, as well as print parameters. The print parameters specified include the colour, gloss, brightness and mass per area of the substrate; the resultant ink colours when printed on the substrate; tone value increase; highlight and shadow separation halftone values that are expected to reproduce smoothly and registration tolerances.

Part 2 of the standard specifies offset lithographic printing on 5 substrates; gloss coated woodfree, matt coated woodfree, gloss coated web, uncoated (white) and uncoated (yellowish). These represent the range of paper substrates typically printed by lithography and the user is expected to select the specification which best approximates his production substrate. It is not my intention in this paper to list values for all of the parameters in the standard; they can be obtained from the standard itself. However, as an example of the sort of parameters defined (and hence a definition of the process control procedure required) I will provide a summary of the separation specifications and main parameters of the standard for the print produced on the gloss coated woodfree paper, which are given in table 3.

Measurement procedures: It is clear from the above specifications that measurement plays a fundamental role in these specifications. To this end a number of standards have been produced dealing with measurement issues. These are important in ensuring that consistency is obtained between instruments used by the various production sites, without recourse to cross-calibration between them. In general these standards are specific to the requirements of Graphic Arts, and supplement those already in existence. However, it does seem likely that they may be useful in other industries also.

a) Colorimetry: Despite the long-standing existence of the CIE system there are still a variety of areas where ambiguity exists because of the existence of alternative specifications which allow users to select the one most appropriate to their purpose. In order to minimise the variations which occur from such a situation ANSI developed a computation procedure and specified the particular parameters most appropriate to our industry. Thus it was agreed we would use the 2° standard colorimetric observer, D50 illumination, a triangular band-pass when calculating tristimulus data from spectral data obtained from measurements carried out with a 0°/45° or 45°/0° instrument geometry and a black backing to the print. Since CIE does not provide observer weighting functions for the 10nm and 20nm bandpass spectrophotometers widely used in the graphic arts industry (only 1nm and 5nm are recommended and provided by CIE), suitable weighting functions have also been specified based on those proposed in the US standard test method ASTM E-308 (1985). The same standard has now been approved as an International Standard, ISO 13655 (1996).

b) Densitometry: The standardisation of basic densitometry characteristics, such as spectral response, instrument geometry, diffuser characteristics, etc. are the responsibility of the Photography Standards Group, TC 42. They are specified in a series of 4 standards, ISO 5-1 to 5-4. However, the graphic arts industry obviously has a significant interest in these and liaises with TC 42 on this. Where the specifications produced by TC 42 do not meet graphic arts needs TC 130 produces any supplementary specification necessary and one particularly important area is the calibration of transmission densitometers for the measurement of dot area on film. Whilst there is little dispute that dot area should be calculated using the well-known Murray-Davies equation, there is no agreed method for validating the calibration of a densitometer used in this way. This is particularly important since various sources of error may arise (in particular slope and non-linearity errors) when an opal-glass type of transmission densitometer is used for the measurement of halftones. ISO 12645 (199_) provides a specification for a half-tone calibration device for transmission densitometry. It specifies two types of devices; one a glass substrate coated with chromium and the other a film device. Fairly stringent conditions are specified concerning the thickness of the device, the quality of the image on the device (in terms of dot core density and accuracy of each step), screen ruling range ($50 cm^{-1}$ to $70 cm^{-1}$), dot shape (circular) and the following dot area percentages are specified; 2%, 20% or 25%, 50%, 75% or 80% and 98%.

Two other TC 130 specifications are concerned with reflection densitometry. One deals with optical and geometric properties for graphic arts use, the other with applications of the measured results. The former - ISO 14981 (199_) - deals with detailed reflectance instrument issues that may be peculiar to graphic arts as they are either excluded from, or not specified, in the ISO 5-4 (1995) specifications for geometric conditions for reflection density. In summary, the main additions are the inclusion of polarisation, a small tolerance around the angles of incident illumination and detection, linearity requirements, spectral requirements and test objects for validating densitometers with polarisation. It is felt that such additions will improve inter-instrument agreement to the extent necessary for exchange of data between sites.

Agreed measurement procedures for graphic arts applications are clearly important to achieve the consistent output required both within and between sites. To this end ISO 13656 (199_) has been produced which specifies various process control requirements including the deviation between the coloration of solids on an OK print and a proof; the measurement of density of a solid and tone value (tone value increase) on a print or lithographic plate; measurement of ink trap, doubling and slur and variation of coloration on a single print and over the production run in measurement. The most appropriate measurement (density or colour) is specified for each of these, the calculation method where appropriate and how the data needs to be reported. Good communication and site to site consistency will be assured if users ensure that instruments and the calculation procedures derived from the measured data conform to the specifications given in ISO 13655, 13656 and 14981. It would also be helpful if the tolerances on instrument geometry defined in 14981 were also applied to spectrophotometers of the 0°/45° geometry specified in ISO 13655.

Viewing Conditions: ISO 3664, the International Standard for viewing prints and transparencies, dates back to 1974 and is badly in need of revision. This is being done jointly between the Photography Standards Group TC 42 and TC 130, also taking advice from the Pulp and Paper Standards group, TC 6. Whilst it is not anticipated that there will be a significant shift from a 5000 Kelvin reference illuminant there was, initially, some pressure to move from D50 to a more practical spectral power distribution because of the difficulty of getting fluorescent simulators of Daylight. However, studies undertaken by members of the standards group indicate that this brings little advantage and may retard the introduction of alternative sources of illumination with improved properties such as better colour rendering or higher ultra-violet emission. For this reason, and to ensure reasonable backwards compatibility the standard is still likely to be based on D50 as the reference illuminant. However, the method for defining the tolerances that a lamp may achieve is likely to change in order to recognise a problem which is becoming increasingly acute. As proofing systems are being widely used which are NOT based on the colorants used for printing inks, metamerism between proof and print is becoming increasingly severe. For this reason a metameric index specification has been added to the colour rendering index previously specified. In addition, the chromaticity tolerance from D50 has been halved for this revision.

The other main areas of concern addressed during this revision have been the high level of illumination currently specified in ISO 3664 and the surround conditions which are defined for the viewing of transparencies. It is anticipated that two illumination levels will be specified; one for critical appraisal (such as when comparing transparencies to proofs and proofs to prints) and one for practical evaluation of the reproduction quality of prints under more practical assessment conditions which have a profound effect on appearance. It is also likely that the standard surround for transparencies will change from white to black, but with some veiling flare included. An additional section has been added which specifies the viewing conditions to be used for colour monitor displays. At the time of writing a draft revision of the standard will shortly be going out for circulation to all national standardising bodies as a Draft International Standard.

Platemaking Procedures: As stated earlier, in order to ensure that consistency is achieved between print runs it is important that all aspects of the process remain under control. Platemaking is a critical part of this. Standardising this is relatively easy for positive working offset plates but far more difficult for negative working plates because of the link between exposure level and plate wear. However, a procedure has now been agreed and a standard exists as ISO 12218 (1996). The standard requires that a halftone control wedge, with circular dots of a specified frequency (50 - 70 cm^{-1}), core density and fringe width and accurate to within one percent of the nominal value, be exposed with the work. A 40% or 50% dot must be included amongst the tone values on the wedge and for positive plates the dot loss on the plate is specified (between 2.5 and 4.5% for a 40% dot, and between 3 and 6% for a 50% dot, depending on the screen frequency selected for the test image). For negative working plates no such specification is given, the over-riding specification is that the plate should be sufficiently exposed to harden the image area according to the manufacturer's specification. This must be evaluated by a continuous tone step wedge with density increments no more than 0.15 apart. Dot increase values are given for information, being the same as the loss values for positive working plates.

Clearly, this means that negative working systems are not so well defined as positive systems. However, the implications are clear. Any printer should evaluate the dot increase obtained at the exposure level required for full hardening and control to that. If it is not within the informative range of dot increases this must be compensated for in pre-press, on the press, or a different manufacturer's plates selected.

Colour proofing using video colour monitors: As colour monitors become an increasingly important part of the colour approval process it is important that procedures for calibration and matching to hard copy production systems are developed. Again, to ensure consistency it is important that procedures are agreed for these. Work on this is only just starting as ISO 12646 (199_). This is an extension of the viewing conditions for monitors specified as part of the new revision of ISO 3664 discussed earlier, and defines the conditions when comparing hard copy and soft copy. The 'soft' proofing standard will be based on ISO 3664, but the likely outcome is that the wide tolerances specified in that will be tightened. In particular, D50 will be specified as the chromaticity of the white point, the minimum monitor luminance will be higher and the level of ambient illumination will be lower.

Process Control procedures

The process control procedures to be implemented in any pre-press and printing works should be clear from the discussion above. The 6 stage control process specified earlier needs to be implemented. However, if the values specified in the various standards are employed this becomes considerably simplified to:

a) Stabilise and control the platemaking, proofing and printing processes to the values specified in the appropriate parts of ISO 12218 and 12647.
b) Linearise input scanners and imagesetters to a specific calibration.
c) Using the scanner and imagesetter calibration specified by b) define the colour transformation required to produce high quality reproductions when proofed.
d) Control scanning, imagesetting and/or platesetting to maintain the transform.

If the measuring procedures specified in ISO 13655 and 13656 are used, according to calibration methods specified in ISO 12645, and made with equipment conforming to ISO 14981, the consistency obtained between proofs and prints - as well as between printers - will be generally acceptable for most distributed applications, so long as they viewed according to ISO 3664. Inevitably the tolerances are too large for some critical applications but it is to be hoped that future revisions of the standards will address this.

Inevitably there are still areas of process control which need addressing in the standards activity, apart from continuing work on the standards still under development (such as specifications for gravure and screen printing). In my view we need to address the problems of calibrating platesetters, and the associated problem of producing print control bars, because there is no longer the independent control provided by separate film based plate control wedges and colour control bars. We also need to improve the specifications for the linearisation and calibration of imagesetters and produce specifications for gravure packaging and flexography. The problem with the specification of imagesetter quality is that the current definition of fringe width on halftone dots is actually very difficult to measure. In that context an interesting proposal has been produced by Yeadon (1997) which is worthy of further consideration.

I would also like to see much better specifications around the whole area of proofing; control procedures based on control of the colorants (colour of the solids and tone value increase) cannot be satisfactory with proofing systems based on other colorants. As will be discussed in the next section this has not even been addressed by colour management and leaves a major area for concern. It is necessary to define a procedure in which a number of colours are specified and tolerances placed around them. As we shall such a procedure would be quite simple to specify. There are problems when the substrate and/or gloss of the proof is different to that of the print and that needs further consideration, but it is not difficult to see how this might be achieved. If this procedure were extended it would also provide a method for defining matching between printing specifications for colour management; although gamut mapping would complicate this and need to be addressed. This will be returned to in the next section.

The role of standards in colour management

As we have seen, the colour specification which is currently more commonly used in the graphic arts is that whereby the amount of ink which needs to be printed is defined directly, so-called device dependent data. Such data will therefore produce different colour reproductions if the printing characteristic is changed and no compensation is made. Device independence, when referring to colour definitions for image data to be used for publishing, is generally taken to mean that the colour of a pixel is specified with reference to the CIE system of colorimetry. Since device independent data must be transformed before it is printed the user has the opportunity to match the colour specified by the tristimulus values (or their derivative). The process of defining the tristimulus values at the time of generating the digital image, and ensuring the optimum approximation of these is achieved when the image is rendered, is known as colour management.

There are clearly advantages and disadvantages in both approaches. Device dependent data is generally an efficient way of describing an image for a specific process since no transformation is required at output. Furthermore, where more than three colorants are used and no unique solution exists for achieving a specific colour such encoding will ensure that user requirements are maintained with minimal encoding. The most important advantage, however, is that quality is likely to be optimised for that specific process both in terms of colour accuracy and quantisation artefacts.

Device independent data is really more appropriate to multi-media environments providing that the data has sufficient precision for the colour space chosen. If the colour is defined in an unambiguous way it follows that for each device on which the image is rendered the same colour will be achieved providing that each device is properly calibrated and the colour gamuts permit. However, as printing simply becomes one amongst many other media colour management will inevitably become a requirement for printing as well. For other reasons, such as ease of use, many people in Graphic Arts consider it to be desirable for printing, even in a single media environment and so we are already seeing a growth in its use for colour reproduction by printing, despite certain problems. The requirement that colour be defined in an unambiguous way is normally met by defining the data with reference to the CIE system of colorimetry, CIE (1986). However, it should be noted that the problems of colour appearance modelling, differing media and gamut compression discussed in Johnson (1992), for example, mean that any colorimetric definition is not generally unambiguous. This creates a difficulty for device independent working which has yet to be fully resolved.

For effective colour reproduction in an open environment standards are absolutely essential. Whether these are de-jure standards from accredited standards bodies or de-facto standards from industry groups recognising a particular need does not matter; some source of agreement is essential. One of the problems with the official standards process is the relatively slow pace of development. This is becoming more significant given the rate of change of the technology and so the ISO process is attempting to speed up. Nevertheless, because it is usually a 'spare time' job for most people working on them, in between their salary earning activities, and because of the need to consult all industry groups, nationally for national standards and internationally for ISO standards, it is true that the process can often be too slow to really meet the immediate needs of the industry. This is why the development of de-facto standards, such as the ICC profile specification discussed below, is so important since they can (sometimes) be much faster. Later ratification of them by ISO can then be a procedure whereby some of the major problems get removed and the process becomes much tighter. Now that the ICC profile specification is being moved to become an international standard this process can be anticipated for that specification.

In the ensuing sections I will discuss a number of standards which are necessary to ensure colour management works effectively and review the role of the process control standards defined above in this environment.

ICC specification: In an open environment it is important that images moved from one system to another have an unambiguous definition. A major issue is the file format but for the purposes of this discussion this will be ignored. What is critical to this discussion is the need to unambiguously decode the colour of each pixel in order to reproduce the image properly.

Some of the early attempts at this, such as that in TIFF 6.0, provided descriptions in the file header which gave some indication of the colour 'meaning' of the pixels. If an image were encoded in CIELAB, or XYZ, a tag was inserted in the file header which enabled the user to specify this so that the receiver of the image knew what values to render on the output device. However, although this information is quite adequate for defining a high quality colour reproduction (providing that certain, fairly limited, information about the conditions of measurement and viewing are provided also, or are standardised among users) it does have certain limitations. To overcome these objections, and because many people in industry felt that such a definition did not sufficiently define an architecture and workflow, it was felt that a more precise and less ambiguous definition was required so that users could expect to obtain more predictable results regardless of the colour management system used. To this end a number of vendors came together, to form a consortium known as ICC, with the express intent of resolving this. The initials have remained constant, although they have meant various things, over the 4 years since it was first formed.

Among the founding members of ICC were Agfa-Gevaert, Eastman Kodak, Apple, Silicon Graphics, Sun and Microsoft. The former represented the main colour management vendors at the time of formation; the others speak for themselves as the key platform and operating system suppliers. It is not my intention in this paper to discuss the details of the ICC profile specification (1995); it is quite an extensive document. However, a brief summary is appropriate.

The basic architecture is really quite simple. At the centre is a reference colour space known as the Profile Connection Space (PCS). It is defined such that images are specified by their CIE tristimulus values in relation to the typical graphic arts viewing and measuring conditions, for reflection copy, specified in ISO 3664 (1974) and ISO 13655 (1996). This means that the image can be encoded directly as tristimulus values specified for the conditions; D50 illuminant, 0°/45° measurement geometry and 2° standard colorimetric observer, but without gamut compression, or as device dependent data from the scanner, but with provision of a look-up table, which defines how this data may be converted into such tristimulus values, as is the more common practice. (This transformation definition is often known as the characterisation). For optimum quality it is best to keep the number of colour transformations applied to image data to a minimum. For this reason it is usually deemed preferable to keep the 'raw' scanned data unmodified and provide a 'profile' (or 'tag') which specifies how the device dependent data should be transformed to CIE data such that it may be interpreted by any other colour management system.

The profile specification describes how an input characterisation is defined as a matrix or look up table in the profile to enable the colour management system to know how to convert the device dependent data into colorimetric data. So, if the image is rendered such that these values are achieved it will reproduce the measured values of the original image exactly. However, it may not look correct because of the appearance, gamut and measurement issues mentioned above. To, overcome this the specification states that if the image is to be editorially corrected (e.g. a cast removed or a tonal adjustment made), or compensation made for media and viewing condition differences, this should be incorporated into the profile accompanying the image so that the PCS defines the tristimulus values necessary to provide the desired **appearance** of the image to be reproduced on a print media with no gamut limitations. Thus, the highly objective colorimetric definition is replaced by a more subjective characterisation, which corrects for appearance and measurement effects.

Scanner characterisation (ANSI IT8.7/1 and 7/2 input targets): A range of tools have been developed by a group working under the auspices of an ANSI Graphic Arts group, consisting of a series of photographic prints and transparencies, which are used for defining the colour transformation to be applied to data obtained from an input scanner. The specifications have now been approved by ISO as ISO 12641 (1996). A colour test image has been designed, based on the Kodak Q60 test transparency described by Maier and Rinehart (1988), and this image has been made on a range of materials from each of the major film suppliers. Kodak supply the image on both Kodachrome and Ektachrome transparency material and Fuji and Agfa supply it on Fujichrome and Agfachrome respectively. Each of the vendors also supply the same image on their print materials.

The design of the original Q60 target was produced with the empirical requirements of device dependent scanning in mind and it is still intended that it can be used in this mode where required. This may be particularly relevant given the earlier suggestion that such empiricism may still play a part in colour management. For this reason the design underwent few changes from the original Q60. It consists of a series of 12 steps of each of the single dye scales (cyan, magenta and yellow) with approximately equal intervals of analytical density between white and full chroma. In addition there are equivalent two and three dye combinations with the same colorant concentration as the single dyes. These scales are particularly useful in setting up colour transformations on traditional scanners since the resultant colours are similar to the regions of colour space in which such scanners permit independent correction.

The remaining colours consist of 12 samples at each of 12 hues. The samples are selected to be at 4 chroma levels at each of three lightness levels. Each of the lightness and chroma intervals are approximately equally spaced and for each material the colours of maximum chroma which can be achieved are produced at each of the three lightness levels. A 22 step grey scale is also included which, together with the D_{min}, D_{max} and 36 vendor selected colours, provides a total of 288 colours. Thus, the calibrated colour target provides known tristimulus values which cover, more or less uniformly, the full colour gamut of the specific material on which the target has been imaged, as an input to the colour scanner characterisation.

It was originally intended that each target provided could be calibrated by the vendor so that the user knows the tristimulus values of each patch. This would be necessary for those who require device independent calibrations and have no appropriate colour measuring facilities themselves. However, early experiences suggest that, for some vendors at least, the sample variation within a batch is sufficiently small that use of a batch calibration data set is adequate for all but the most critical users. For this reason at least one of the vendors (Kodak) only plans to provide batch calibration data at present.

The reason that the image needs to be reproduced on each of the film materials is that few scanners are designed as colorimeters. Filters are often chosen to minimise crosstalk and are therefore relatively narrow-band when compared to colour matching functions. This is to optimise signal-to-noise ratio. Since the dyes used in the various materials are generally metameric to each other it is necessary, for some scanners, to have separate transformations for each material. However, for many scanners the degree of metamerism is sufficiently low, and the filters sufficiently broad, such that a calibration made with one film (or paper) type is adequate for all other film (or paper) types, with the possible exception of Kodachrome.

The definition of input profiles in the ICC profile specification can be conveniently achieved by use of these targets. The data obtained by scanning the target and the tristimulus values obtained by measuring it can be used by the colour management system to define the profile by suitable modelling. If necessary, and the colour management system permits, the profile can be defined from modifications of the colorimetric data to take account of the desired appearance. This is the recommended working practice.

Output device characterisation (ANSI IT8.7/3): This method was defined to allow images encoded in CMYK to be transformed into any other colour encoding scheme which has been referenced to the CIE system. A data file was defined, as ISO 12642 (1996), which could be transmitted with any image and specifies the tristimulus values of a number of pre-defined ink combinations. This data would enable the user to transform the image into any colour definition required for different media by producing an input profile. Since the standard defines the values of a series of CMYK colour patches for which tristimulus values must be determined in order to generate the device characterisation it effectively defines a colour target which can be rendered to enable the measurement of the tristimulus values. As such it provides a useful definition of a range of colours which are reasonably well spaced in CMYK and by simple, single dimensional modification, would also provide a useful guide for other devices.

The data is divided into two parts. One section consists of 182 combinations of the 4 colours; the second part expands on this and contains 928 combinations. It is anticipated that the smaller data set would be adequate for most applications and is deemed to be the default data set. Where greater accuracy is required the larger set may be used. There is also provision for a user to define his own set although in this situation both dot area and tristimulus values would need to be specified.

There are 2 different methods of characterising a printing press in terms of tristimulus values or L*a*b*; modelling or interpolation between a reasonable number of measured points. Modelling techniques generally involve either solving Neugebauer equations, or polynomial fitting. These can be achieved by measuring a limited number of colours with a colorimeter or spectrophotometer and using these values to define the appropriate coefficients in the equations. For higher accuracy a far larger number of colours may be measured and used to define a look-up-table which specifies the ink amount required for each of the colours measured. Interpolation is then used for any intermediate points. The default data set would be used for modelling; the extended data set for interpolation.

It was originally intended that data to fill the file, which would be transmitted with the image, would be obtained by printing the ink combinations specified and measuring the tristimulus values of the resultant colours. The transformation from device dependent data to that required could then be carried out by the recipient using his preferred method. It was anticipated that modelling techniques would be used with the default data and interpolation techniques with the larger data set.

This standard does not fit well with the requirement by ICC that profiles define the transformation (rather than the data to enable it). This means that a look up table directly defining the transformation must be provided rather than the colorimetric data. Of course, the values derived from this data file could be used as part of the definition for the 3-dimensional LUT for an ICC output profile specification. However, further information would need to be added to take account of gamut compression and thereby cover the perceptual and saturation rendering intents specified in that document.

ISO 13655 and ISO 3664: Such standards are important to colour management: without them the accuracy of communication required to achieve predictable colour will not be achieved. They have been defined as the default measurement procedure and viewing condition in the ICC profile specification.

Three stimulus colour specification (ANSI IT8.7/4): For situations where the primary objective is to view an image on a colour monitor a device dependent colour space based on 'typical' phosphors represents a very efficient encoding method for the image, requiring no colour transformation to be calculated and applied when the image is displayed. Such a specification is being prepared by ANSI as IT8.7/4 (199_), and may become an ISO standard, for the preferred colour space in which data should be represented when not appended by an ICC profile. The encoding scheme being favoured is based on HDTV phosphors and the draft ITU recommendation (ITU-R BT.[11A/AW]) for colorimetry and related characteristics of future television and imaging systems (1997). However, the transformation from this encoding scheme into any CIE specification is quite simple and is defined explicitly. A simple procedure, as defined in the ICC profile specification, will thereby enable users to convert the data into any device independent specification.

It is also intended that two CIE colour spaces be defined in the IT8 standard for direct encoding of images. One of these is for 16 bit data and is likely to be simple XYZ tristimulus values. The other is for 8 bit CIELAB data and this is more difficult. To avoid quantisation artefacts it is desirable to ensure that as many of the encoded values as possible represent colours within the image. To achieve this limits have been put on the a^* and b^* values which were derived from the maximum value obtained during the work to assess the gamut of colours of transparency materials.

Work on this standard has not progressed very fast since to a large extent it was overtaken by the ICC profile specification which seemed to make such direct encoding redundant. However, as discussed earlier there is still some feeling that defining a colour with the independent PCS is rather unnecessary for simple transformations and it may therefore be reactivated.

Recently workers at Hewlett-Packard and Microsoft have proposed an encoding method (known as sRGB) which is quite similar to the first of the proposals above. It was originally presented by Stokes and Motta (1996) but has since been updated and retitled. This updated proposal, from Stokes et al (1996), is primarily aimed at the Internet but certainly has applications elsewhere as the authors recognise in their paper. It is available from the same web site as the ICC specification and can therefore be downloaded from http://www.hpl.hp.com/personal/Michael_Stokes. It is also based on HDTV phosphors and may also be progressed as an international standard.

Other standards required for colour management

As discussed earlier, the ability to process electronic files with a colour transformation that can be implemented at any stage in the process means that it can be argued that it is not important that the process characterisation be consistent between presses. This is because each individual press can be 'fingerprinted' with its own characterisation data (in this case the data relating the tristimulus values produced by mixtures of any specific ink printed on any specific substrate), such that a colour transformation may be applied which matches the proof, and yet is unique to that press, when the image is produced. The reference is no longer the halftone dots themselves but the colour that they will produce. The control procedure would then be the 6 stage calibration process specified at the outset of this paper but modified slightly as follows:

a) Stabilise the imagesetting, platemaking and printing processes.
b) Characterise the press and proofing system (for both soft and hard copy proofs) by rendering and measuring suitable test images, such as that defined in ISO 12642 for proofing and printing, made to the procedures defined in a).
c) Characterise the input scanner by scanning a test image such as that defined in ISO 12641 (the IT8 target), and append the profile to any scanned image.
d) Combine the characterisations to process the image when it is output.
e) Control scanning, imagesetting and/or platesetting, proofing, platemaking and printing to maintain the characterisations.

Clearly, the nub of this system is the need to stabilise and control the various process steps, followed by measurement of the colours produced at the output stages of the process using tristimulus colorimetry. In order to make this system effective it is absolutely essential that the conditions for colour measurement and viewing are both well-defined. To this end ISO 13655, the Graphic Arts standard for the use of CIE colorimetry, and, to a large extent, ISO 3664 are the standards defined for this application. The other important area for agreement is the way in which the colorimetric data associated with an image is transmitted. This could either be by defining the image encoding to be directly in a colour space which has a well defined colorimetric derivation (such as the standard RGB defined above) or by appending a definition of the transformation from image data to CIE data in a well-defined format that can be interpreted by any other user of the file. The ICC specification would seem to achieve that and should be the preferred method for Graphic Arts applications.

However, because the process control procedures in such an environment are very 'press specific', standardisation of proofing and printing conditions, as defined in ISO 12647, would seem to be far less important. The situation would seem to be a return to that pertaining in the 1970s when printers were encouraged to define their own stable printing condition and then use the variety of process control aids available to maintain this. Because the use of colour management implies that colour separation is carried out right at the time the printing surface is produced it would seem that it can be specific to that press without introducing any workflow difficulties. It should be possible to match the results obtained from various presses, each printing with quite different characterisations, by use of the appropriate colour transformation for that press. Undoubtedly the use of the process control standards which define the 'best' procedures, instruments and methods for instrument calibration are beneficial in this, but not essential.

However, I will strongly argue that this is not the case. Even in a colour management environment the process control standards discussed earlier in this paper are equally important, although certain aspects which currently have great significance may become less important. The reasons for this are really twofold but centre around the importance of the proof in any sensible workflow.

Proofing is an essential element to Graphic Arts colour reproduction as was recognised in the core role it played in the early specifications for SWOP. It should show the buyer of the reproduction how the image supplied for reproduction will actually look when taking account of edits required on the original (such as cast removal, local colour changes and contrast enhancements) and the limited gamut which is likely to be used for rendering. Except for the simplest of situations it is largely impossible for the user to define all these changes in a simple numerical way and some degree of subjective interpretation is essential. The only way that the print buyer can actually see this, even if he scans and edits the image himself, is to view a proof of that image to determine whether the result is pleasing for the purpose. It is this requirement that places certain, quite restrictive, conditions on the whole process.

At face value it might appear that the use of colorimetry as a reference would deal with this situation. The proofing system would show the effect of any edits required on the image and the printing system would then show the best approximation to this proof that could be produced on it. However, unless the colour gamut of the proof is constrained to be within that of the print the printer is placed in a very difficult position. Does he try and extend the gamut for that press run, and if he cannot what is the best approximation? Bearing in mind that he is likely to be mixing images from various sources on the press forme it can be seen that it quickly becomes impossible to properly predict the final result in such a situation. I believe it is really quite important that the buyer of the print sees a proof that is limited in gamut such that it provides a reasonable approximation of the final print product. To this end the gamut of colours which can be produced must be standardised for much the same reason as discussed in the earlier part of this paper.

This issue is complicated by some of the less well-defined parts of the colour management process. In particular, the gamut compression and appearance matching issues mean that colour management systems are likely to provide the highest quality only when profiles are 'hand-tuned' empirically. This may be done by the supplier of the colour management system, or by the user himself. The profile editing packages now coming onto the market are providing any producer of profiles with the functionality previously provided to scanner operators. That is the ability to optimise the colour transformation in a subjective manner. These are essential to high quality requirements because of the difficulty of specifying a perfect colour transformation numerically. However, the result of such editing is that a variety of output characteristics are likely to be obtained when different users output the same file.

As stated earlier, there are two implications of this discussion. The first is that the various printing gamuts needs to be defined in order that proofing systems can match them. The second is that the proof profile **must** be transmitted to the printer in order that he can achieve any specific characteristics of that.

The definition of the printing gamut follows directly from the standard ink and printing definitions provided in the various parts of ISO 2846 and 12647. Although the tone value increase parameters which play a large role in that standard are of lesser importance in the colour management environment, since they can be defined within the proof profile which should be transmitted with the image, the paper and ink colour attributes are clearly very significant in the definition of the gamut limits. However, I would argue that even the tone value increase tolerances should be considered because of the role of digital halftone proofing systems still deemed important by many users. By definition a halftone proofing system must have colorants similar to those of the print and specifying tone value increase is a very convenient way of quantifying the way in which the halftone elements are transferred in the process.

The issue of the transmission of a proof profile is a slightly complicated one. As already stated the fact that a proof profile is likely to have been 'hand tuned' by the user, or supplier of his particular colour management system, means that the information about this profile must be communicated to the printer. It would have been helpful to Graphic Arts if the ICC architecture had consisted of 4 profiles:

- the input characterisation
- an 'edit profile' for edits to the image (this could be achieved by direct editing of the image data but to maximise precision a profile is preferable, and should also include appearance and measurement effects associated with the scanned media)
- a gamut mapping profile (which also includes various other effects such as appearance and measurement effects associated with the rendered media), and
- an output characterisation

The advantage of this approach is that it would enable any user who has rendered an image on one device to provide the editing and gamut mapping information necessary to ensure it is matched by another that has quite different characteristics (even if it has the same gamut). The combining of gamut mapping with the output characterisation, as is currently done in the ICC profile, means that a far more complex procedure is needed to ensure proofs and prints will match. Incidentally, the approach above also has the potential to be extended to overcome a limitation of the ICC architecture. That is that it is really only possible to define a gamut mapping when both the input and output gamut are known. By combining it with the output profile it is clearly not possible to do this. It will be fixed regardless of the input gamut. The way around this is to define a procedure rather than a specific mapping.

If the industry adopts a colour management approach base on ICC profiles, without any other restrictions, every image will need to have associated with it the input profile and output profile used for proofing (with both its perceptual and colorimetric renderings). At the time it is output for printing the input profile, forward proof output profile (with perceptual rendering to provide the gamut mapping), inverse proof output profile (with colorimetric rendering to generate tristimulus values) and print output profile (with colorimetric rendering) would need to be combined to ensure print and proof match. Although such combinations are anticipated in the ICC architecture I am not sure that they have been suitably evaluated by our industry.

An alternative approach, when the output gamut is known at the time of scanning as it largely is for Graphic Arts, is to define a gamut mapping at input and simply require that the output uses a colorimetric rendering. For multi-media production this approach cannot be any more effective than the current ICC architecture but for Graphic Arts it is more practical. This is why defining the gamut mapping separately would be more effective; it provides a far more general solution. The issue is complicated by the fact that, in my view, gamut mapping is an issue of both media and image but space excludes more discussion of that. For more details see Johnson (1996).

Yet another approach, which would not be very different from traditional work practices, would be to consider workflows with a fixed output profile for each printing condition. The implication of this is that all users, printers and proofers, would use the same profile for output which could even be standardised. The generator of the input image would then edit the input profile to overcome any shortcomings they perceive with this output profile, and edit the image (or profile) for any image specific corrections. I find this an attractive solution and believe there have been proposals for such an approach in certain sectors of the European industry.

Whichever of the above approaches is adopted by the industry it is clear that the standardised printing conditions are important to ensuring satisfactory reproduction in a colour management environment; either simply to define the gamut limits or, as in the latter case, to define the whole profile. In this context work has been undertaken to define the colours obtained when the 928 ink combinations defined in the ISO 12642 (ANSI IT8.7/3) data file specification are printed to the various conditions specified in ISO 12647-part 2 (Offset Lithography). The first of these was undertaken for the American CGATS Type 1 printing specification, published as ANSI CGATS.6 (1995). This is similar to SWOP (a US specification for Web Offset Publications) which, in turn, is very similar to one of the specifications in ISO 12647 part 2. The colour data obtained by printing this file is available as ANSI CGATS TR 001-1995 which provides full spectral and colorimetric data for the file, when printed close to the aim points of the specification. Similar work has been undertaken in Europe and Japan and the tristimulus values are now available for all parts of ISO 12647. It is anticipated that similar data will be produced for all of the parts of 12647 as they are agreed and published as ISO Technical Reports.

Thus, depending on the approach selected, all or some of the various process control standards discussed earlier are of great significance to colour management in Graphic Arts. The 'standard' profile approach is essentially the same as the traditional approach and all the process control standards are important as they stand. If an approach whereby the proof profile is transmitted with the image is adopted, the gamut definition parts of the printing specifications are important but the tone value increase parts of it, together with the plate control standards, decline in importance; they become user defined parameters which are controlled in order to maintain the characterisation.

The only exception to the last part of the previous paragraph is for the case of halftone digital proofing. By definition these must match all the characteristics of the printing process. In this sense the full standards defined earlier are important. It is only for proofing systems based on different colorants that the latter considerations apply.

So, does colour management require any new standards? The main ones I would like to see are much better specifications for control of proofing and digital printing; procedures based only on control of the colorants (colour of the solids and tone value increase) cannot be satisfactory with proofing and printing systems based on various colorants. As stated earlier it seems necessary to also define a procedure in which a number of colours are specified and tolerances placed around them. By outputting these colours on the various devices, with every image output, it will be possible to define the quality of the output profile in matching the various prints.

The approach I recommend is to define a selection of tristimulus values from the colours defined in ISO 12641, which would then be used to generate a test image on the proof and print to ensure that they match to within some tolerance, such as an average ΔE of 2. If not it would be simple to define algorithms, based on Neugebauer or masking equations for example, that define how the press settings should be altered to minimise the error, or the profile modified to eliminate it. There are problems when the substrate and/or gloss of the proof is different to that of the print and this needs further consideration, but it is not difficult to see how this might be achieved. Algorithms could be devised quite easily, based on colour and/or gloss measurements of the media, which could provide a correction routine.

Summary

Techniques for process control have been discussed and the evolution of standards for achieving satisfactory control across a range of printing conditions in a traditional workflow. This includes procedures for control of proofing and printing, platemaking and imagesetting or platesetting. How these come together to provide a complete process control system has also been reviewed.

The requirements for process control in a colour management environment have been discussed and the differences between this and the requirements for traditional procedures reviewed. It is suggested that the requirements for Graphic Arts workflow mean that these standards are applicable to this environment, albeit with some modifications in certain circumstances. Other standards which are largely applicable to colour management have also been discussed.

Suggestions for future standards activity have been made, including test images for control of colour management, better imagesetter calibration methods, print control bar production in a computer to plate situation and printing specifications for gravure packaging and flexography.

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Table 1 - Specifications for Standard Lithographic inks

Ink Colour	Range of ink film thick. (μm)**	Tristimulus values and tolerances							Lower limit for transp-arency
		X	Y	Z	L*	a*	b*	ΔE_{ab}*	
Yellow	0.7-1.1	73.21	78.49	7.40	91.00	- 5.08	94.97	4.0	0.08
Magenta	0.7-1.1	36.11	18.40	16.42	49.98	76.02	- 3.01	5.0	0.12
Cyan	0.7-1.1	16.12	24.91	52.33	56.99	-39.22	-45.99	3.0	0.20
Black	0.9-1.3	2.47	2.52	2.13	18.01	0.80	- 0.56	***	

** Note: These values are for oxidation drying inks. For radiation cured and heatset inks the upper limit is increased to 1.3 microns for all colours.

*** Note: Tolerances for Black are given as upper limits for Δa* and Δb* of 1.5 and 3 respectively and an upper limit for L* of 18.01.

Table 2 - Specifications for Coldset Offset Lithographic inks

Ink Colour	Range of ink film thick. (μ)	Tristimulus values and tolerances							Lower limit for transpa r-ency
		X	Y	Z	L*	a*	b*	ΔE_{ab}*	
Yellow	0.8-1.2	55.07	58.29	12.04	80.90	- 2.85	61.79	4.0	0.20
Magenta	0.8-1.2	34.30	22.55	18.43	54.60	49.95	0.39	5.0	0.50
Cyan	0.8-1.2	20.46	27.03	39.71	59.00	-25.07	-27.41	3.0	0.40
Black	0.8-1.2	10.64	10.81	7.51	39.27	1.60	5.34	***	

*** Note: Tolerances for Black are not yet agreed though an upper limit for L* of 40 seems likely.

Table 3 - Specification for separations and print production on a gloss coated woodfree substrate which has a gloss of 65, Brightness of 85 and mass of 115 g/m^2 (from ISO 12647-2)

The separation films should have the following characteristics:

1. Density of clear film: less than 0.15.
2. Core density of halftone dots: greater than 2.5.
3. Dot fringe width: less than one fortieth of the screen width.
4. Rulings: 45-80 cm^{-1}. The lower end of the range is for periodical printing and the upper end for commercial printing.
5. Fit: images on the separations shall not differ by more than 0.02% in length when measured on the diagonals.
6. Tone value sum: less than 350% for sheet-fed and less than 300% for web-fed printing.
7. Grey balance: 25, 19, 19; 50, 40, 40 and 75, 64, 64 for cyan magenta and yellow respectively.

Colour

	L*	a*	b*	Tolerance
Substrate	93	0	-3	L*±3, a*±2, b*±2
Black	18	0	-1	Deviation = 4ΔE_{ab}, Variation = 2ΔE_{ab}
Cyan	54	-37	-50	Deviation = 5ΔE_{ab}, Variation = 2.5ΔE_{ab}
Magenta	47	75	-6	Deviation = 8ΔE_{ab}, Variation = 4ΔE_{ab}
Yellow	88	-6	95	Deviation = 6ΔE_{ab}, Variation = 3ΔE_{ab}
Red	48	65	45	
Green	49	-65	30	
Blue	26	22	-45	

Tone value increase between film and print (for a 50% tone value on a control strip film with a screen ruling of 60 cm^{-1}) when both are computed with the Murray-Davies equation (in percent dot).

Plate type	Chromatic Inks	Black Ink	Deviation tolerance Proof print	Deviation tolerance OK print	Variation tolerance Production print
Positive plates	17	19-20	3	4	4
Negative plates	25	27-28	3	4	4

Note 1: All colour measurements are for illuminant D50, 2° observer, 0/45 measurement geometry and a black backing.

Note 2: Deviation refers to the difference between the specified value and any single sheet (usually proof or OK sheet). Variation refers to the tolerance within a production run from the OK print. It is defined such that the average of the run is less than or equal to the OK print deviation and that the standard deviation should not exceed half of the variation tolerance.

Note 3: Tone value increases are for ISO status E response density with polarisation. For ISO status T density without polarisation the values for yellow are about 2% lower.

Note 4: To ensure reasonable balance between the colours the maximum spread of tone value increase between chromatic colours is an added restriction. For the proof print it is 4%; for the OK print and production print tolerance it is 5%.