AN OBJECTIVE ANALYSIS OF ICC DEVICE PROFILES AND THEIR PERFORMANCE IN A PRODUCTION ENVIRONMENT

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Abstract: The ability to assess the accuracy of a colour management system is dependent on the test methodology in use. This report aims to develop a method by which ICC device profile generators can be objectively assessed and to show how the colour management transformations perform in a production environment. The performance of device profiles can be attributed to their ability to convert from a device-dependent space (RGB or CMYK) to CIELAB. This paper suggests a method of comparing two profile generators to determine the accuracy of each. The ability of a device profile to convert from CIELAB to a device-dependent gamut is tested in a production environment, with consideration given to the factors involved in gamut compression techniques.

Introduction

Colour management means many things to different people. Recent developments within the industry have revolved around the work of the International Colour Consortium to standardize a cross-platform, device-independent profile format. (International Colour Consortium, 1995)

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There has been a lot of discussion within the industry over the last four years about the implications of colour management, how it works and what systems are available, but little work has been done to evaluate the ability of a device profile to perform its task.

Many factors must be taken into consideration when dealing with the transformation of colour gamuts. Uncontrolled conditions will very quickly lead to irrelevant unrepresentative results. In a recent publication (Johnson A, 1996) Johnson discusses the underlying principles and shortfalls of colour management architecture. He also notes that the ICC profile specification is still evolving. This evolution is set to continue. With the general market acceptance of low-end flatbed scanners continuing to grow, the acceptance of open systems colour management is a natural progression.

It is desirable to have an understanding of the basic principles of colour management to be able to choose which system will suit the requirements of a specific workflow. Care and consideration taken at the evaluation stage could potentially save unnecessary problems later on.

The ability to assess the accuracy of such systems is very much dependent on the test methodology in use. It is the aim of this paper to develop a method by which colour management system profile generators can be objectively assessed and to show how the colour management transformations fare when put to the test in a production environment.

Affecting Factors

There are a number of factors that will affect the ability of a colour management system to perform reliably. Reference to such factors must be made to minimize experimental error when performing the evaluation. The main factors that must be considered are:

- Illuminant
- Rendering intent
- Gamut transformation
- Spectral and geometric conditions
- Input reference target

Illuminant

The distribution of energy across the wavelengths of the electromagnetic spectrum has a definite effect on the appearance of colour. In order to specify the appearance of a colour it is not only necessary to know how a surface reflects or transmits light, but also the spectral characteristics of the illuminant.

In 1931 the CIE specified three standard illuminants A, B and C (CIE, 1986), to which were later added a series of D illuminants, a hypothetical E illuminant and a series of fluorescents F. These standard illuminants all have their own spectral characteristics and are specified as tungsten light sources reproducing certain colour temperatures. When a colour is viewed its appearance can be dramatically influenced by these spectral characteristics. This phenomenon, known as metamerism, can result in the same object appearing to be a different colour under different light sources.

The CIE standard illuminants are relied upon when defining a colour using the tristimulus colour equations. Tristimulus data is concerned with describing how the colour of an object appears to a viewer or how it could be reproduced on an output device such as a printer or monitor. Therefore in order to specify a colour using tristimulus data that is dependent on viewing conditions, it is crucial that the type of lighting under which the colour is to be viewed is also stated.

The two illuminants most commonly used for colour matching evaluation are D50 and D65. The 50 and the 65 refer to the colour temperatures of the light source in degrees Kelvin, which are 5000K and 6500K for these two illuminants. For colour management the ICC recommends using D50.

Rendering intent

The ICC device profile specification lays down the specification for three standard intents; absolute colorimetric, relative colorimetric and saturation rendering. A fourth 'perceptual rendering' intent is devised on a vendor to vendor basis, allowing third party companies to promote specifically optimized gamut transformation techniques for specific processes. (Johnson A, 1996)

Both absolute and relative colorimetric rendering define colours in the Profile Connection Space (PCS) in relation to white points, irrespective of the rendering capabilities of the output device. Absolute colorimetric specifies colours in relation to the white point of the illuminant (D50, D65, etc.) whereas relative colorimetric is defined in relation to the white point of the substrate. Any colours that are beyond the output device's gamut are 'clipped' without any gamut expansion or compression taking place.

Saturation rendering relies on the theory of reproducing colours at maximum saturation, irrespective of any degradation of hue or lightness. This is mainly used when reproducing images like bar charts, pie charts or graphs from vector applications (such as Microsoft Excel or Macromedia Freehand), where image contrast is more important than colorimetric accuracy.

For the system evaluation testing in this paper, colour transformations have been made using the perceptual rendering intent, thus allowing each colour management system rendering algorithm to be assessed.

It is also useful to note that the ICC profile specification does not specify the inclusion of colorimetric data within a device profile, but does make room for it should the vendor decide it necessary. (Johnson A, 1996) Inclusion would be useful, because it would allow the Colour Management Module (CMM) to interrogate the device characterization and decide on its quality. If the quality were not sufficient the colorimetric data would enable the CMM to optimize the conversion on the fly—although this would require more processing power and possibly slow down colour transformations.

Gamut transformations

Gamut transformations are a means of transforming colours described in one space into the gamut of another space. Input and output devices work in different colour spaces, and each has its own unique gamut. For example, monitors operate in RGB but have different RGB gamuts, just as printing presses that work in CMYK have varying gamuts.

It is commonly found that the gamut of an original is much larger than that achievable by the output device. It is for this reason that good gamut transformations are required to perform the function of converting and matching these original colours appropriately to achieve the best possible similarity from the gamut of one colour space to that of another.

Within colour management systems a CMM uses profiles to perform the transformations and matching, using an intermediary, device-independent colour space. When an image is created a profile is associated with the image that describes the characteristics of the input device used, known as the source profile. If the original is then converted into another colour space, the CMM uses the profile information to identify the original colours and match them to colours in the new colour space. When the image is subsequently printed the CMM uses the printer's profile to transform and match the image's colours to the gamut of the printer, known as the destination profile.

Where the gamut of the source profile is different to the gamut of the destination profile, the CMM is relied upon to take the stored information in both profiles and to map the colours from the source to the destination. The CMM uses the algorithms and transformation matrices defined in the device profile for colour matching. It compares the colour gamut of one device against another and checks to see which colours can and cannot be reproduced. Each profile contains a header that includes the preferred CMM to be used for performing the transformation and matching to be used for the specific profile. The method used when a CMM maps or translates the colours of an original to the gamut of an output device is known as the rendering intent.

Spectral and geometric conditions

A requirement when implementing a Colour Management System is the ability of instruments to accurately and consistently measure colour. The components within the instrument used can substantially effect the results obtained. Instrumental conditions of measurement include the measurement geometry, spectral illuminant and light receptor. It is important to understand the significance of geometric and spectral properties so that the correct conditions for certain measurements can be known.

Wavelength (or spectral) variability is primarily responsible for colour, while geometric (or directional) selectivity is primarily responsible for gloss, luster and translucency. However, geometric conditions do not just affect variables such as gloss and transparency, but also colour, diffuse reflectance and transmittance. Similarly spectral conditions can affect the measurement of geometric attributes of appearance. It is for this reason that both spectral and geometric conditions for measurement must be identified when describing the colour of an object or surface.

Geometric conditions of measurement include variables such as the direction of the incident and viewing beams. The CIE recommendation for the geometry of measuring diffuse reflectance are illumination at 45° with normal viewing, or normal illumination with viewing at 45° (CIE, 1986)

The spectral response of the instrument depends on the power distribution on the specimen and the spectral sensitivity of the light receiving sensor mechanism (detector). The sensitivity of a detector is the ratio of the signal in to the signal out. The spectral characteristics of the instrument will be influenced by the spectral transmittance of filters or other wavelength selective devices in either the source or the viewing beams. The spectral bandwidth of the instrument can determine the accuracy of measurements. A true spectrophotometer can measure the whole of the visible spectrum in increments of one nanometer and will therefore give a full description of the colour. In many cases however abridged spectrophotometers are used which commonly measure the spectrum in increments of 10 nanometers (32 measurements) and will not give as good a description, although some people would differ in opinion. Although these instruments are sufficient for most applications it is important to realize that notable differences could occur when certain colours are measured leading to further inaccuracies within the colour management system as a whole.

Input reference target

A fundamental tool when using scanner profile generators is the ANSI IT8.7/1 or 7/2 target, developed by the ANSI Accredited Standards Committee IT8 Working Group II to study the colour definition requirements of the graphic arts industry. (McDowell D, 1991)

The target was designed to contain colour patches of relatively uniform mapping in visual terms, containing three principle elements—dye scales, neutral dye scales and a colour gamut area. With each photographic target, a digital file is supplied, containing reference CIEXYZ and CIELAB values for each patch in absolute colorimetric form.

The main problem with the reference targets is the variance of the reference values when compared with the actual measured values. The IT8 specification knows of this problem and attempts to compensate by specifying manufacturing tolerance factors. A target needs to be within 10 ΔE of the aim value to comply. Further, for each batch of production, the batch must be within 5 ΔE of the aim value. (McDowell D, 1991)

i. To assess the effects of this batch variance, in a separate work by Shaw (Shaw M, 1997), an analysis was performed in which the reference data values supplied with the target were compared with the actual values of the target. The IT8.7/2 target was measured using a Gretag SPM100-II spectrophotometer with D50/2° absolute reference and the results were used to build a reference file. The measured reference file was then compared against the supplied reference file, calculating the mean ΔE and standard deviation across the whole target.

ii. Both the measured reference file and supplied reference file were used to generate scanner profiles using the same source RGB image. The image was then separated using an output device profile, and an Imation Matchprint proof generated.

The results in (i) showed that the mean colour difference between the measured values and the supplied reference file was 1.35 ΔE, with a standard deviation of 0.38. Visually, the difference in (ii) was very small with the highlight area being affected mainly. The image separated using the supplied reference data file had a very light green cast in the highlights over the whole image, while the image separated using the measured reference file did not. This green cast can be attributed to a white point colour difference of 2.03 ΔE between the measured and supplied reference data files, in the green direction.

Evaluation Methodology

The ability of colour management systems to accurately render the original image on the output device is mainly based on two types of device profile; input and output.

In the context of this paper, it is the responsibility of the device profile to render the input gamut as accurately as possible on the output gamut, whilst taking into account factors such as gamut compression.

When converting colour data from one colour space to another, the ICC profile specification determines the transformation method by the nature of the transform. If converting from a device dependent gamut to CIELAB, then a direct colorimetric AtoBTag transformation is used. When converting from CIELAB to a device dependent gamut, a BtoATag is used whereby the user can select the rendering intent.

This paper has been split into three main sections, determining an evaluation methodology at each stage;

- Input AtoBTag characterization evaluation
- Output AtoBTag characterization evaluation
- System evaluation with specific application to the newspaper industry

As well as performing objective colorimetric measurement using a spectrophotometer, the system evaluation uses visual perception to assess the quality of gamut reproductions.

Input AtoBTag characterization evaluation

The default conversion process used in an input device profile is the AtoBTag. The direct colorimetric transformation yields data that can be compared with the measured values of the original photographic target for evaluation purposes.

When evaluating a scanner device profile the AtoBTag can be assessed using the following procedure, summarized in Figure 1.

i. Measure and record the CIEXYZ values of each patch on the IT8.7/2 target, D50/2° ensuring white point absolute measurement.

ii. Scan the IT8.7/2 target as an uncalibrated RGB high resolution image.

iii. Downsample the high resolution image using Adobe Photoshop for use in scanner characterization software. Create device profile from low resolution image.

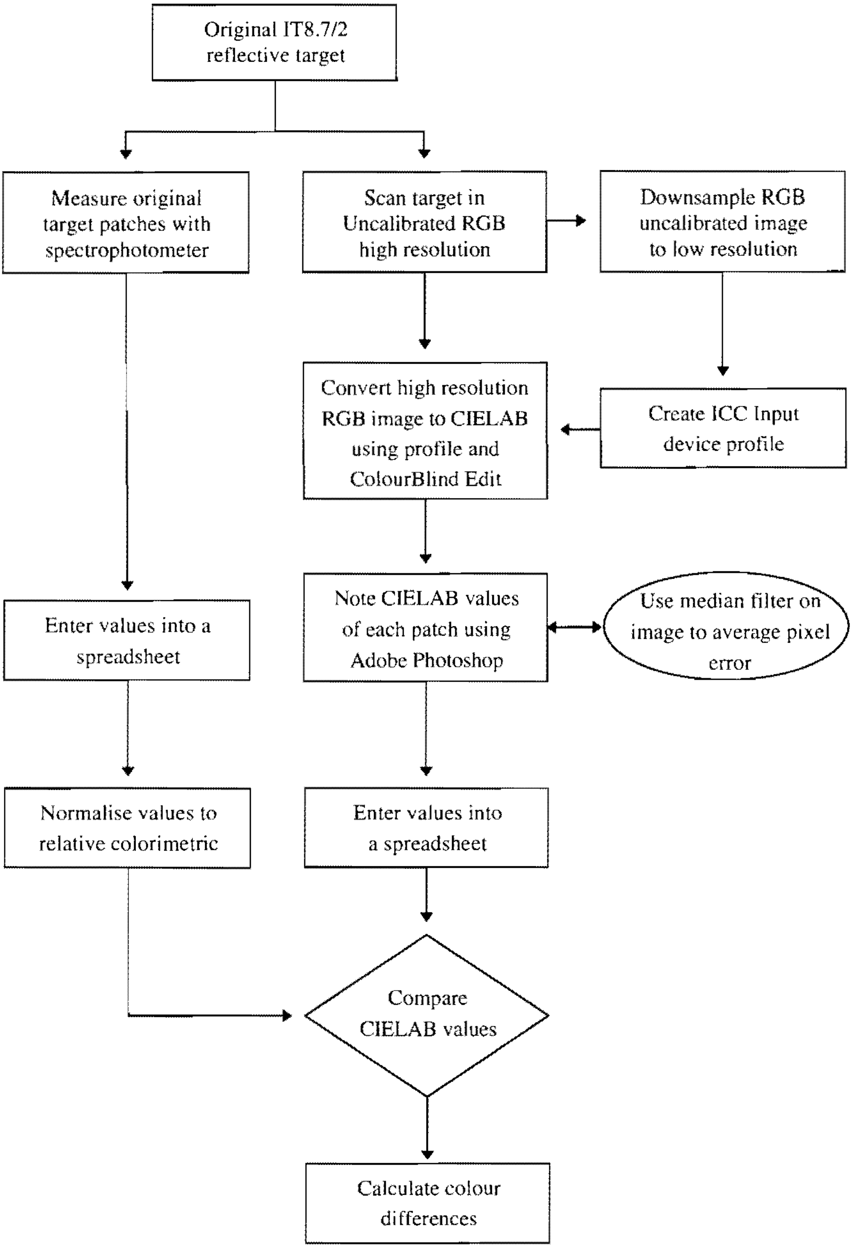

Figure 1. Input device profile AtoBTag evaluation

iv. Using ColourBlind Edit, convert the uncalibrated RGB high resolution image to CIELAB using the generated device profile.

v. Load the CIELAB image into Adobe Photoshop, apply median filter over the whole image to average out sampling error of the scanner's optics. Record the CIELAB values of each patch into a spreadsheet.

vi. Normalize the values measured with the spectrophotometer in (i) to relative colorimetric using the measured white point of the paper.

vii. Compare the CIELAB values obtained in (v) and (vi); calculate the ΔE, ΔL, Δa, Δb of every patch. Then compare the mean ΔE and standard deviation about the mean over all patches on the target.

By performing this procedure it is possible to assess the device profile's ability to characterize the input gamut of the scanner. Theoretically, a perfect device characterization would yield 0 ΔE over all patches on the target. In reality this is very seldom possible, the inherent inaccuracies of the digital reference file introduce error on top of the noise generated whilst scanning.

Quantization artifacts also need to be considered when dealing with 8 bit per pixel images due to the rounding error introduced. Although small, the build-up of rounding errors will affect the results' accuracy and should be taken into consideration. When loading the image into Adobe Photoshop, a median filter was applied. This enabled the assessment of the average colour value of the patch under inspection. The digital CIELAB values were measured using the colour picker and manually inserted into a spreadsheet.

The ICC device profile specification defines that colorimetric data is handled internally in a relative colour space. For this reason the measured CIEXYZ absolute values of the IT8 target were normalized in relation to the white point of the paper before comparison. The results are displayed in Table 1.

Application	**ΔL**	**Δa**	**Δb**	**Mean ΔE**	**Standard Deviation of Mean**	**Highest ΔE**
Input profile generator	0.47	0.88	2.28	3.03	1.31	7.90

Table 1 : Input device profile AtoBTag analysis

Only one application was analyzed, with the aim of developing a method that could be applied to multiple systems for comparative analysis.

Output AtoBTag characterization evaluation

The conversion of CIELAB to a device-dependent colour space uses the BtoATag definition contained within the ICC device profile specification. This, by its nature is a more complex operation. The transformation used to render the device-independent colour space on the device-dependent gamut depends on which rendering intent the user specifies.

When evaluating the system's ability to map existing colours onto the new gamut, and scale those that are beyond the gamut boundary it is important to remember that the two factors are both variables in their own right, working toward providing a common goal. Therefore, assessing an image separated using the perceptual intent will also contain colours compressed and scaled from their original out-of-gamut values.

This methodology assumes that the scaling techniques used in the gamut mapping algorithms of BtoATag conversions are not used. It is the AtoBTag that is under evaluation using direct colorimetric transformations. The evaluation procedure described below is summarized in Figure 2.

i. Output CMYK test chart on Matchprint proof using linearized film separations and standard exposures.

ii. Using the output profile generator application, measure the CMYK characterization target with the spectrophotometer and create an ICC output device profile.

iii. Separate the CIELAB IT8.7/2 digital image created in the previous test into CMYK using the generated output profile.

iv. Output CMYK image on imagesetter and make Matchprint proof from films using standard exposures.

v. Measure the printed IT8.7/2 target values with spectrophotometer using D50/2°, ensuring absolute white point measurement. Transfer the CIEXYZ values to a spreadsheet and normalize in relation to the substrates white point.

vi. Using ColourBlind Edit, convert the CMYK IT8.7/2 image (iii) to CIELAB using the AtoBTag from the profile of the output device.

vii. Load the CIELAB image created in (vi) into Adobe Photoshop, apply median filter over the whole image to average out sampling error. Record the CIELAB values of each patch into a spreadsheet.

viii. Compare the CIELAB values obtained in (v) and (vii), calculate the ΔE, ΔL, Δa, Δb of every patch. Then compare the mean ΔE and standard deviation about the mean over all patches on the target.

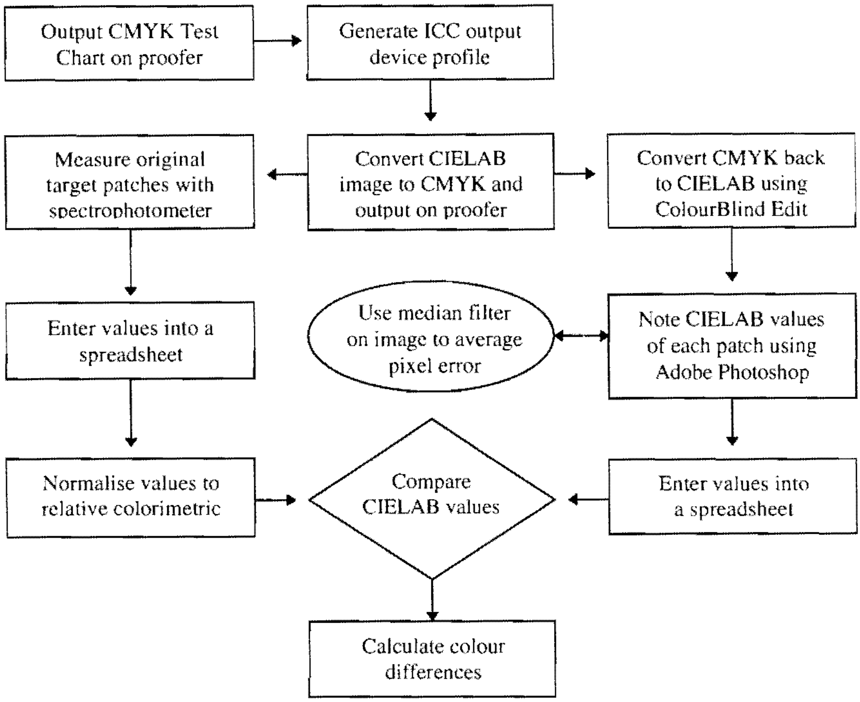

Figure 2 : Output device profile AtoBTag evaluation

By performing this procedure it is possible to assess the device profile's ability to predict the required CIELAB values to give a CMYK colour with reference to the media's white point.

For a device profile to perfectly characterize the output medium, the ΔE on each patch would yield 0. Like the previous test method, this is seldom possible and the lowest mean ΔE is preferred. The results are displayed in Table 1.

Application	**ΔL**	**Δa**	**Δb**	**Mean ΔE**	**Standard Deviation of Mean**	**Highest ΔE**
Output profile generator	2.06	4.57	6.45	5.40	3.17	18.37

Table 2 : Output device profile AtoBTag analysis

System evaluation with specific application to the newspaper industry

When using a colour management system, both the input device profile and output device profile are used. Even if they are able to convert from a device dependent colour space to CIELAB perfectly, it is still up to the CMM to determine the quality of the BtoATag transformation. 'ICC compatible applications read ICC profiles for source and destination in association with images and then direct the operating system to process the image data using the indicated profiles. The actual processing of the image data via the profile information is done by the installed CMM in the operating system.' (Edge C, Hujanen A, Meek S and Fagley H, 1996)

It is therefore important to also look at a colour management system as a whole unit. An investigation into the requirements of a Newspaper were assessed in a separate work by Henley (Henley S, 1997). It was found that one method of assessing the accuracy of reproduction is to look at way in which a large input gamut is compressed into a smaller output gamut, such as is achievable on a printing press. For this reason the input and output device profiles were kept constant and the CMM changed, enabling an evaluation of each colour management system.

Input characterization

The first stage of the process was to characterize the Agfa scanner and create an ICC profile. Using Agfa's FotoTune software, an IT8.7/2 reflection target was scanned in and compared with the supplied reference data file to create an ICC profile. The scanner was also used to scan in two images to be used later for visual analysis.

Output characterization

DuPont's Digital Cromalin was used to generate the output device profile and print the test images, the profile and prints were printed on news-stock. This was used because it was already being used as a reliable rendition of the printing press and because it was not feasible to perform actual press tests at the time.

Passing the images through a number of colour management applications

Four different colour management systems were loaded onto an Apple Macintosh (Agfa FotoTune 3, ColorSolutions ColorBlind Pro, Linotype LinoColor 3 and Logo) Then the IT8.7/2 target and two other images were passed through each colour management system and printed using the Digital Cromalin with the previously generated device profile. The images were printed for each colour management system and then again using no colour management system at all.

Comparing the Colour Management Systems

To assess the results both mathematical and visual evaluations were performed. The main assessment is concerned with the rendering capabilities of the colour management system. It is this quality alone that can determine the colour management system's suitability within a newspaper environment. The mathematical evaluation was carried out in a number of stages:

i. The IT8.7/2 reflection target was measured using a spectrophotometer to determine their original CIELAB values. A measurement was taken for each patch on the target, and recorded on a spreadsheet.

ii. The five sets of IT8.7/2 targets printed on the Digital Cromalin were measured using the same spectrophotometer. Again the CIELAB readings were taken for each patch and recorded in a spreadsheet.

iii. A formula for optimum gamut compression in newspapers, as defined by IFRA's gamut compression model, (Ruokosuo N, 1995) was used as a method of determining the quality of the reproductions. The formula compresses any original CIELAB value to an optimum newsprint value. The formula was applied to the patches on the IT8.7/2 targets and the optimum CIELAB values were recorded.

iv. The optimum CIELAB values for each of the targets were compared with the five sets of printed CIELAB values. The comparisons were made using the colour difference ΔE equation.

v. The ΔE of each patch, on each target, for all five sets was recorded in a spreadsheet. Once these figures had been computed, the average ΔE along with its standard deviation was taken for each target.

The average ΔE for each of the five sets of targets was then compared. Each of the targets was ranked as to how well the gamut compression of each colour management system had achieved. The results can be found in Table 3 below.

Differences between the IFRA optimum values (using the IFRA colour gamut compression model) and the measured values through the following systems					
	Linotype LinoColour	ColourBlind Pro	Logo	Agfa FotoTune	No CMS
Lightness	Acceptable	Acceptable	Acceptable	A little dark	Very dark
Chroma	Acceptable	A little low	Acceptable	Very low	Very low
Hue	Acceptable deviation	Acceptable deviation	Small deviation	Unacceptable deviation	Large deviation
Mean ΔE	6.7	7.8	8.1	9.4	13.7
Ranking	1st	2nd	3rd	4th	5th

Table 3 : Reproduction analysis of IT8.7/2

The visual evaluation

For the visual evaluation a panel of 15 people were asked to comment on the general reproduction qualities of the IT8.7/2 targets and the two demo images. They were asked to comment on hue, lightness and saturation under D65 viewing conditions as well as to make any personal remarks. The results were collated and a summary of the findings can be found in Tables 4 and 5.

Visual analysis of demo image No. 1					
	ColourBlind Pro	Linotype LinoColour	Logo	Agfa FotoTune	No CMS
Lightness	Acceptable	Acceptable	A little dark	A little dark	Too dark
Chroma	A little low	A little low	A little low	Too low	Too low
Hue	Acceptable	Small deviation	Acceptable	Small deviation	Large deviation
Remarks	• Good contrast • Vivid colours • Good reproduction	• Fair contrast • Good colours • Acceptable reproduction	• Medium contrast • Acceptable reproduction	• Too saturated • Poor contrast • Poor reproduction	• Too saturated • Poor overall reproduction
Ranking	1st	2nd	3rd	4th	5th

Table 4 : Reproduction analysis of demo image No. 1

Visual analysis of demo image No. 2					
	Linotype LinoColour	ColourBlind Pro	Logo	Agfa FotoTune	No CMS
Lightness	Acceptable	A little dark	A little dark	Too dark	Far too dark
Chroma	Acceptable	A little low	Acceptable	A little low	Far too low
Hue	Acceptable	Small deviation	Acceptable	Small deviation	Large deviation
Remarks	• Good contrast • Good colours • Good reproduction	• Fair contrast • Vivid colours • Good reproduction	• Contrasts • Too saturated • Limited acceptability	• Too saturated • Poor colours • Poor reproduction	• Too saturated • Too dark • Poor reproduction
Ranking	1st	2nd	3rd	4th	5th

Table 5 : Reproduction analysis of demo image No. 2

Conclusion

When analyzing the Input and Output device profile's AtoBTag, only one colour management application was analyzed. The aim was to develop methods that could be applied to multiple systems for comparative analysis. The documented methods proved to be sufficient in accurately comparing gamut characterization. It is evident from the results of the system evaluation that the colour rendering quality of the images separated using colour management systems were superior to those produced without colour management. However, not all of the systems produced optimum reproductions and it was apparent that an amount of differentiation existed between the systems.

To further qualify the results of all three evaluations one should also consider the noise of each device, determining the magnitude of noise and its implications on the results obtained.

When looking at the ΔE results of the five IT8.7/2 images in Table 3, taking the tolerance of a good newspaper match to be less than 5.3 ΔE and an acceptable match to be less than 10.6 ΔE (Schläpfer K, 1996), all reproductions made through colour management provided a match within the tolerance boundaries of good and acceptable. The match without colour management fell beyond the range, thus indicating an unacceptable match.

The ColourBlind Pro and LinoColour systems produced remarkably good visual quality results on both the IT8.7/2 target and images 1 and 2. It was clear that exceptional contrast and ideal colour saturation had been achieved. The Logo system, although not quite as good still managed to produce satisfactory results far better than those without colour management. The lowest ranked colour management system was FotoTune, the colours were found to have too high a saturation and poor tonal gradation.

This research has shown that through the use of colour management systems the reproduction quality and consistency was enhanced.

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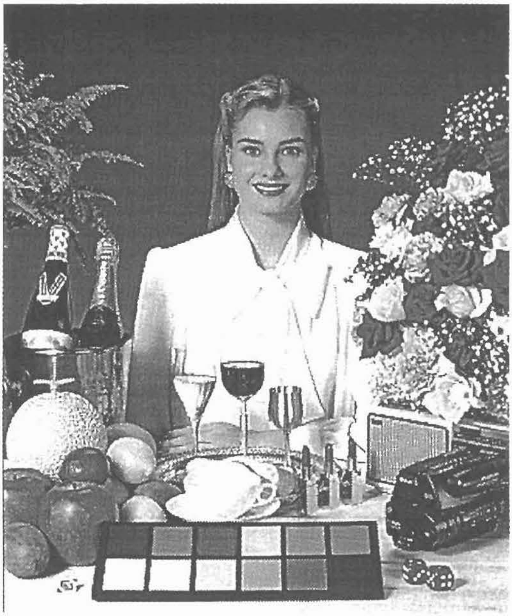

Demo Image 1 (Source : IFRA)

Demo Image 2

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