HOW TO TEST A COLOUR MANAGEMENT SYSTEM

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Abstract: One of the problems preventing a widespread adoption of colour management systems (CMS) is the fact that the user is unable to judge a system and to know which system fits best the purpose.

To overcome this problem, two assessment tools have been developed: The first is a checklist allowing the user to identify the basic requirements for a given application environment. The second tool enables an assessment of the quality of a CMS for a given rendering intent. For this purpose, a method has been developed to objectively compare the colour values of the output with aimpoint values calculated by a special programme. Results obtained with this method are shown for an example of a commercially available CMS.

What is colour management?

In the days of proprietary colour electronic prepress systems (CEPS) colour management was no issue, because all input, display and output devices were calibrated in a close-loop fashion, ascertaining in this way the desired colour match between original and reproduction.

With the advent of open systems based on desktop components an automatic compensation of the differences occurring between input and output was no longer guaranteed. A theoretical way to overcome this problem was to individually calibrate all input and output devices with respect to a device-independent standard. Due to the nature of open systems, however, such a task is beyond the qualification of most device users.

The practical solution of the problem is therefore to provide a software being able to compensate for the different colour characteristics of the input and output devices in an automatic manner. Such a software is called a *colour management system (CMS).*

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An integral function of a colour management software is to store and handle all data describing the colour characteristics of the input and output devices. Such a device description is called a *colour profile.*

Colour profiles may be either delivered from the device manufacturer or be created by the device user who may utilize standard tools specially designed for this task. A profile delivered by the manufacturer simplifies the job for the user, but it usually describes a factory calibration, while user-made profiles characterize the device in its production condition. However, the user has to make sure that the device is always operated under the condition for which the profile has once be created.

A further task of a colour management software is to map the colours recorded with an input device optimally into the gamut of the output device. This function is called *colour gamut mapping.*

Soon after the idea of colour management systems was born, it became obvious that its realization could not be left to the initiative of the vendors of input and output devices. Rather, it was necessary to develop a common platform comprising a definition of the basic functions and a data format for colour profiles. For this purpose, the International Color Consortium (ICC) was established by a number of leading suppliers and software companies. The work done by ICC is published in a document with the title «International Color Profile Format».

An ICC profile, however, is not able by itself to translate the colour data from an input device to an output device. To do this, a further function of a CMS is required, i.e. a colour space transformation which, in the terminology of ICC, is called a *colour matching method (CMM).* A CMM must be specific for the type of colour space being used by the input or output device.

Colour spaces may be divided into two basic families (see figure 1):

- device-dependent spaces

- device-independent spaces.

Device-dependent means that the colour co-ordinates defining the space are different from device to device, although the names of the co-ordinates are the same. An example for this is the CMYK space used for colour printing with process inks. Though the process inks are always named CMYK, a Magenta ink may be on one device more yellowish and on another device more bluish. The same is true for RGB primaries of monitors where phosphors with differing hues and saturations are used. As a consequence, identical CMYK or RGB values may lead to a different colour appearance on different devices.

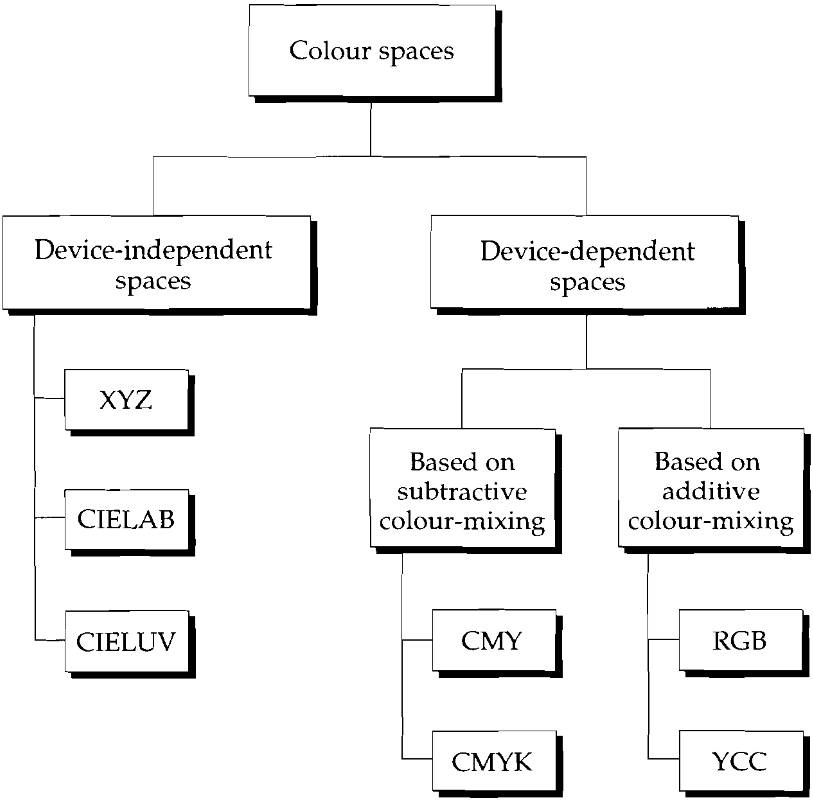

Figure 1 **Classification of colour spaces**

In contrast to this, device-independent colour spaces define colours in a unambiguous way, meaning that a given combination of values always produce the same colour appearance, irrespective of the device being used.

The most important group of device-independent colour spaces are based on the definition of the CIE Standard Observer (1931 and 1964). The basic CIE colour space was established 1931 by defining the eye sensitivity curves XYZ of the standard observer. From there a number of spaces based on perceptive criteria such as hue, chroma and lightness have been derived, the most popular being CIELAB and CIELUV.

An important characteristic of ICC profiles is that they are based on a device-independent colour space. Like an adapter plug, a profile links the device-dependent colour space with the device-independent reference space, which is called in the terminology of ICC the *profile connection space (PCS)*.

According to ICC, three types of colour transformations (CMMs) have to be distinguished, i.e.

RGB (scanner values) ←——→ XYZ

RGB (monitor values) ←——→ XYZ

CMYK ←——→ XYZ

ICC has described standard CMMs which may be used as default transformations, if a CMS does not offer a third-party CMM.

A further important concept of colour management is that the user may define the type of match to be obtained between original and reproduction. In the language of ICC this is called the *rendering intent.* According to ICC, four different rendering intents are defined:

- *absolute colorimetric:* In this case the output colours are rendered identically with the input colours. If the output gamut is smaller than the input gamut, the input gamut will be cropped.

- *relative colorimetric:* This is achieved by making the white points of the input and output device identical. Otherwise, no gamut mapping takes place.

- *perceptual:* This kind of reproduction includes gamut mapping and gradation optimizing. Although this might be regarded as the preferred rendering intent for most originals, ICC has not given a mathematical definition for this kind of reproduction. Other terms being used for this rendering style are *appearance match* or *photographic match.*

- *saturation preserving:* This reproduction style combines lightness mapping with maintaining the saturation of the original. This may be desirable, if an original consists of highly saturated colours as critical elements.

To summarize, a CMS is a software being able to translate the colour data recorded with an input device into device-dependent output data with the aim to achieve a user-defined match between original and reproduction.

Requirements for a colour management system

One fundamental drawback of the first colour management systems was that they used all a different architecture. As a consequence, there was no compatibility between profiles and no consistency among the results. Each system was proprietary and users could not exchange profiles with users of different systems.

To overcome this problem, Apple Computer introduced ColorSync 1.0 in 1993. The goal of ColorSync was to provide a common architecture for colour management systems. ColorSync 1.0 was a first step toward a solution, but it did not completely meet customer needs in certain key areas. Based on input from end-users and developers, Apple redesigned ColorSync by developing Version 2.0.

ColorSync 2.0 is a software at the operating system level, not requiring any special hardware. However, ColorSync does require certain baseline hardware and software configurations to perform properly. ColorSync 2.0 supports both the 68000-family and PowerPC processors.

ColorSync is not a colour management system by itself, but it provides some elements in form of default functions such as colour space transformation algorithms for RGB ÷ XYZ and CMYK ÷ XYZ and a limited number of device profiles (mainly for Apple monitors and printers). However, these functions are only intended to be used, if they are not provided by a third-party developer. The main purpose of ColorSync remains to provide a platform and an architecture that ICC colour profiles and tailor-made colour space transformation methods can be incorporated by CMS developers or end-users.

A basic requirement for a CMS is therefore that it be compatible with ColorSync 2.0.

While ColorSync is a specific solution for Macintosh, a similar solution for PCs became only recently available. Microsoft has announced a system-level software called Image Color Matching 1.0 (ICM) to be used with Windows 95. Comparable system-level products are also announced for Windows NT and Unix.

If the compatibility of a CMS with ColorSync is ascertained, the CMS also permits to use ICC profiles.

An important question is then whether a CMS must necessarily provide a colour transformation software (CMM) or whether the system-level CMM is sufficient for an exact colour space transformation. Until recently, a number of proprietary CMMs were offered by commercial CMSs as alternative to the default CMM offered by ColorSync.

In the meantime, the new ColorSync CMM, developed by Linotype-Hell and using a look-up table based on 32 x 32 x 32 values, has found a wide acceptance. As a consequence, it is no longer a must for a CMS to offer a proprietary CMM. This, however, is only true for ColorSync, and not for other system-level softwares.

Another very basic criterion of a CMS is whether colour profiles can be created by the user. Although creating a profile requires a certain competence of the user, the advantage is a better reproduction quality compared with the application of vendor-made profiles. Profiles provided by a vendor represent an average device description which fails to give an optimum result in case of a particular device or process. A CMS should therefore not be judged by the number of generic profiles being delivered by the vendor but by the criterion of how easy profiles can be created by the users.

As to this, three cases are to be distinguished:

- *Creating input profiles:* This is now a standardized procedure for all commercial CMSs. The tool is the IT8.7 Colour Target (according to ISO 12641) for which the calibration values are incorporated in the CMS software. After the target has been scanned with the device to be profiled, the automatic calculation of the colour profile takes only one minute. The IT8.7 Target has to be provided by the CMS vendor as both a transparency film and a reflection copy on photographic paper. Although the device profile depends on the colour dye set used to manufacture the target, input profiles are usually made only for one dye set.

- *Creating output profiles:* This procedure includes the following steps:
  - printing a colour chart on the device to be profiled
  - measuring the colour chart
  - entering the values into the CMS software
  - calculation of the profiles.

  A CMS must provide a data set for printing the colour chart, and an algorithm to calculate the profile. The most important criterion, however, is that the procedure of measuring and entering the colour values is fast and simple. The minimum solution to fulfil this requirement is that the CMS offers an interface to automatically enter the colour values which is compatible with the most widely used colorimeters in the graphic arts industry.

Some CMS vendors have even initiated special measuring tools for colour profiling together with the manufacturers of colorimeters. Examples for this are the Gretag Spectrolino/Spectroscan and the X-Rite DTP 51.

Another characteristic of a CMS for creating output profiles is the number of colour values necessary to calculate the profile. The current number varies between 200 and 800 values. Clearly, the higher the number of input values is, the more important is a fast and simple measuring procedure. The accuracy of the profile, however, is not strongly dependent on the number of input values as long as this number is at least 200. When calculating an ICC profile, the measured values are anyway interpolated to a much higher number of look-up table values, i.e. to 32 x 32 x 32 = 32,768 colours.

- *Creating display profiles:* The number of colours necessary for calculating a display profile is significantly smaller than for making a CMYK profile. Theoretically, only the three primaries RGB used for the display device have to be measured. Independent of the number of colours being measured, a special colorimeter designed for a self-luminous surface has to be used. Until recently, only very few instruments were available for this purpose meaning that profiling display devices was very uncommon. Therefore most CMSs were limited to the possibility of creating input and output profiles. Nowadays, however, topical colorimeters offer the measurement of both self-luminous and surface colours. As a consequence, a modern CMS should also support the profiling of display devices.

Another important function of a CMS is to create device link profiles. They allow to simulate the colour rendering properties of one device when using another device. The practical significance of device link profiles is in the proofing application. When, for instance, the profile of the newspaper printing process is connected with a digital printer, this device allows to simulate the newspaper printing conditions. The same simulation is possible, if a colour monitor is linked with the profile of the production output device.

Last but not least, a CMS should offer the choice of a rendering intent. Theoretically this could also be a function of a system-level software such as ColorSync. But the current definitions of the rendering style as published in the ICC document are not fully satisfactory. Therefore any proprietary rendering definition incorporated in a CMS could be an improvement over the present situation.

To summarize, a system-level CMS software should provide the following functions:

- colour space transformation algorithms for XYZ ↔ scanner RGB, XYZ ↔ CMYK and XYZ ↔ monitor RGB.
- the choice of different rendering intents, including a gamut mapping algorithm.

A proprietary CMS software should provide:

- compatibility to the system-level CMS software being used
- instructions and a software to create user-defined device profiles in the ICC format: This should include profiles for input, display and output devices.
- compatibility to colorimeters offered for colour management purposes.
- calibrated IT8.7 targets in transmissive and reflective form for creating input profiles.
- a data set to produce a colour chart for output profiles providing a sufficient number of colour patches.
- a function to link two output profiles in order to produce hard-copy proofs or soft proofs.

Generic profiles may either be provided with the system-level CMS or with a proprietary CMS or even from a device manufacturer.

Testing the colour rendering quality of a CMS

To test the colour rendering quality of a CMS, a programme has been developed which transforms the colour values of an original into those of the reproduction by making allowance for the colour gamut of both, the original and the output device. The transformation is aimed at giving an optimized gradation for so-called normal-key images. If the reproduction made with a CMS matches the colour values calculated according to this programme, the CMS may be considered to yield an optimal appearance match. In this way the programme tests all functions of a CMS being shown in figure 2.

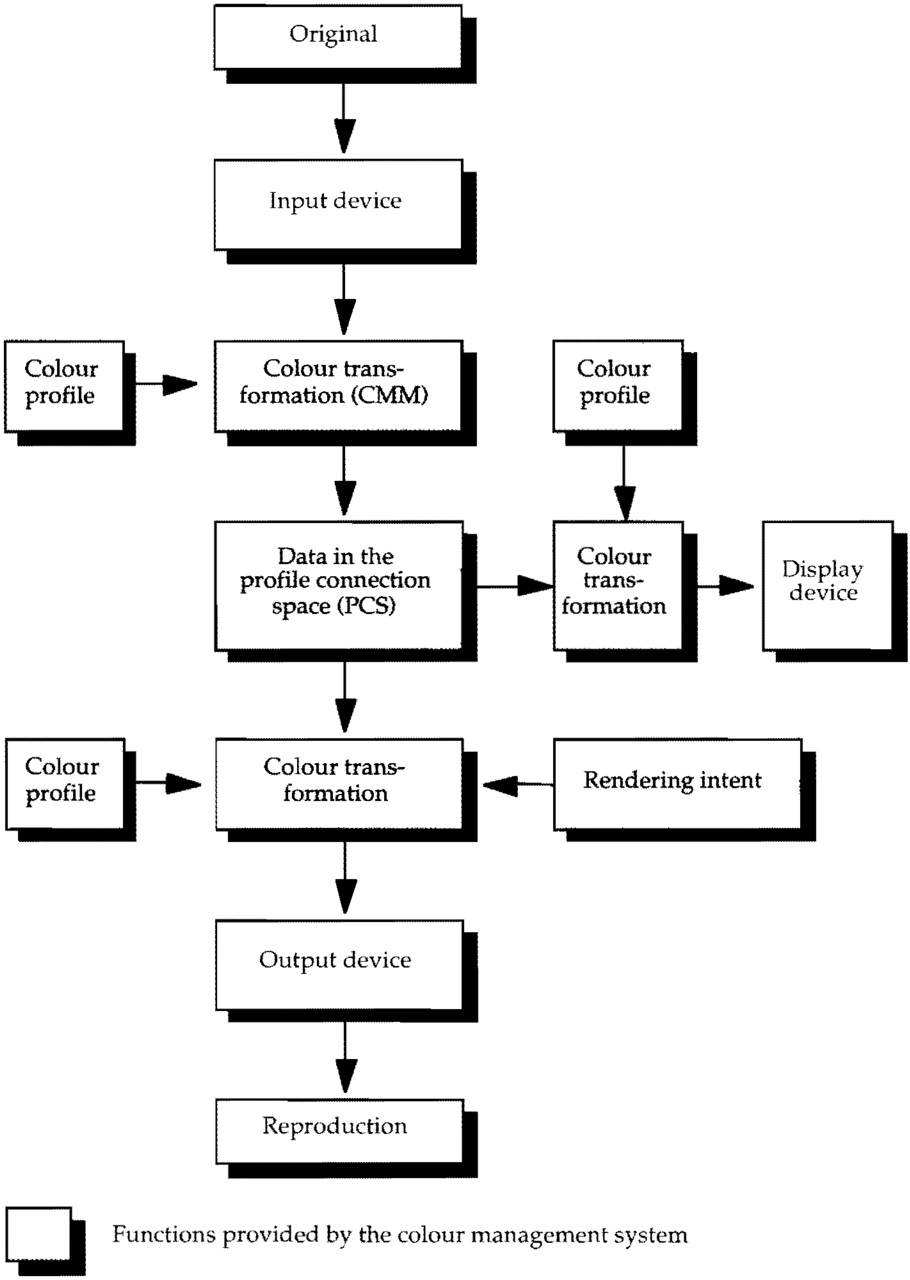

Figure 2 **Workflow of the reproduction process with colour management**

The workflow of the test programme is described in figure 3.

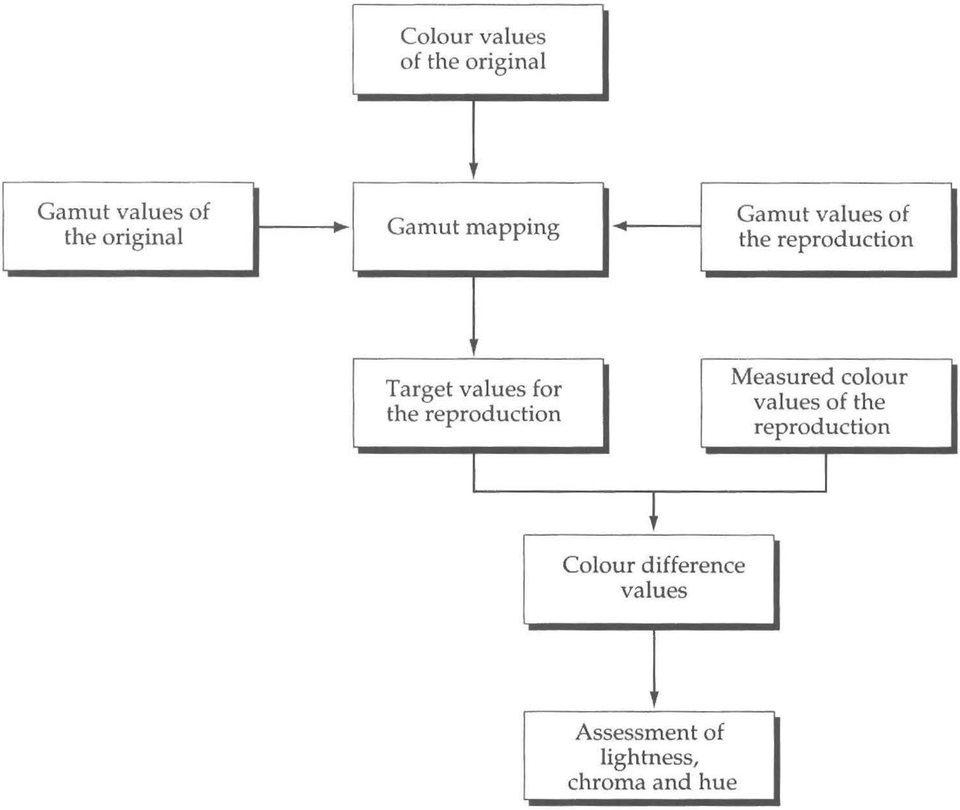

Figure 3 **Workflow of the programme to calculate the colour rendering quality of a CMS**

As original for testing a CMS the IT8.7 Test Chart is being used. This is, because the IT8.7 is the only standardized element allowing to determine the colour gamut of the original (which is indispensable for a correct gamut mapping).

The gamut mapping algorithm is described in figure 4. The programme starts from the CIELAB values for lightness, hue and chroma (L^*, C^*_{ab}, h_{ab}).

The lightness values are mapped linearly after the lightest and the darkest tones of the original have been shifted to match the lightness gamut of the output device.

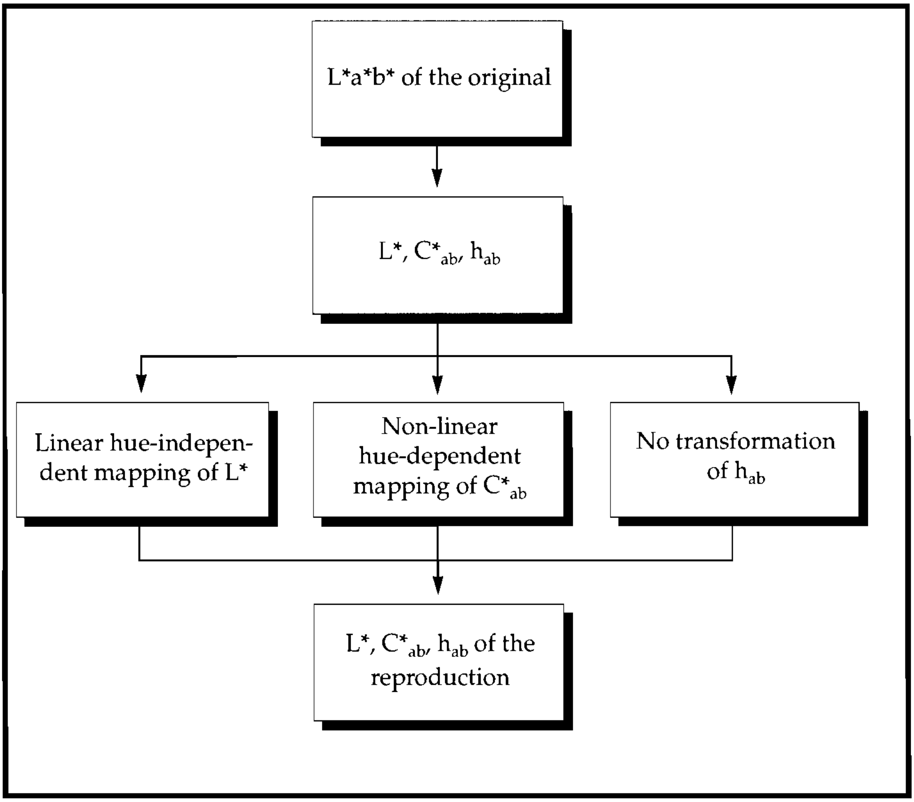

Figure 4 **Principle of colour gamut mapping**

The chroma values undergo a non-linear transformation such that the higher saturated colours are less affected than the lower saturated colours. To do the chroma mapping, the maximum chroma values for different hue angles must be known for both, the original and the output device.

In contrast to lightness and chroma, the hue values undergo no transformation. The underlying idea is here that the hue values of the original must be maintained irrespective of the gamut of the output system.

The programme described in figure 3 ends up with the colour difference values obtained between calculated and measured colours. These differences allow to assess the colour rendering quality of the CMS with respect to lightness, chroma and hue. Moreover the grey balance can be judged.

Table 1 shows an example of the results obtained with ColorBlind 2.1 and compared with a reproduction without CMS. The reproduction made with ColorBlind 2.1 required beforehand to create an input and an output profile for the devices to be used. The reproduction without CMS was made by observing some standard parameters such as dot gain compensation and grey balance setting.

To obtain the values of table 1, the IT8.7 target was scanned on a DTP scanner and printed on a Fuji proofing system (calibrated for standard offset printing). The colorimetric assessment comprised 77 patches of the IT8.7 target. The measured values for each criterion were compared with the values calculated according to figure 3. Table 1 shows the difference of the 77 patches from the precalculated values, expressed as the deviation of a single patch. As can be seen from table 1, the tested CMS leads to a clearly better colour rendering quality than the reproduction without CMS.

Assessment criteria for the colour rendering quality	**Average deviation of the reproduction from the precalculated colour values**	
	Reproduction with ColorBlind 2.1	**Reproduction without CMS**
Lightness deviation ΔL^*	-1.14	+2.53
Chroma deviation ΔC^*_{ab}	-3.82	-4.86
Hue angle deviation Δh_{ab}	+10.9	+11.6
Grey balance deviation* ΔC^*_{ab}	+1.59	+3.62

* Difference between measured and calculated values of the grey scale

Table 1 Assessment of a colour management system with respect to its colour rendering quality

However, the purpose of these figures is only to exemplify the assessment procedure and the order of magnitude of the outcoming results and not to illustrate the difference between a CMS and a non-CMS reproduction. For the interpretation of the results, the tolerances given in table 2 may be used.

Criterion	**Tolerance for a**	
	good match	**acceptable match**
Lightness deviation ΔL^*	<4	<8
Chroma deviation ΔC^*_{ab}	<2	<4
Hue angle deviation Δh_{ab}	<10	<20
Grey balance deviation ΔC^*_{ab}	<2	<4

Table 2 Tolerances for assessing the colour rendering quality

Appendix: Evaluation criteria for a colour management system

The evaluation of a colour management system (CMS) has to answer the following questions:

1. Is the CMS compatible with ColorSync?

2. Can profiles for input devices be created by the user?
   - Are the input profiles based on the IT8.7 Input Target?
   - How many versions of IT8.7 are provided (reflective, transmissive, different dye sets)?

3. Can output profiles be created by the user?
   - How many colours have to be measured?
   - With which colorimeters is the CMS compatible?
   - How much time is needed to measure the colours?

4. Can display profiles be created by the user?
   - How many colours have to be measured?
   - With which colorimeters is the CMS compatible?

5. Which rendering intents are offered:
   - perceptual
   - saturation-preserving
   - absolute colorimetric
   - relative colorimetric
   - others?

6. Does the CMS support proofing on
   - monitors
   - output devices?

7. Price of CMS?

8. Installation time for the CMS?

9. Does the CMS price include training?