# A Comparative Study on Analog and Digital Printing Systems Performances

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## Abstract

Our work consists in a comparison of various printing systems: offset lithography, analog Matchprint proofing, Rainbow sublimation proofing, Epson 5000 inkjet printing, Docucolor 2045 digital printing.

Several paper grades were used (mainly matt and glossy coated papers). With the offset process as a reference, the goal was to characterize print rendering for each printing technique by means of colorimetric and densitometric quality parameters. In the first class, we find:

- color gamut volumes, in order to decide whether (and to which extent) the standard quadrichromic offset process reproducible colors are included within the borders of the other gamuts or not,
- color L*a*b* coordinates associated to primaries and to their combinations and corresponding to the same CMYK set of values in the original computer file.

The densitometric measurements were : solid density, dot gain, and relative contrast index.

With the help of a novel method, we can exploit the whole necessary set of informations to automatically calculate all the above figures from experimental data using an IT8-7.3 test chart. This leads to a possibility to classify printing systems at least qualitatively: the results show the offset paper has the smallest performance of all the tested systems.

## Introduction

This report is involved in a global study about print quality. It is well known that technical quality corresponds to an estimate of the fulfillment of a customer's requirements in terms of page layout, text organization and image color rendering. It is largely admitted that the approval of a proof or of a OK-sheet by the customer implies a kind of contract according to which the printer has to deliver the requested number of copies in conformity with the proof.

With the development of the digital printing processes like electrophotography or inkjet in the field of short runs, new proofing techniques become available. We undertook a study to determine whether it is possible to qualitatively classify printing techniques or not. We studied the following processes:

- two analog techniques: offset lithography (which remains the most important traditional printing process), and Matchprint proofing (largely used in the pre-press area),
- three digital techniques: Rainbow sublimation printing, Epson 5000 inkjet printing and Docucolor 2045 electro-photographic printing.

The experiments were carried out on various paper grades in order to characterize the technical performance of each paper/printing device pair in terms of print rendering. Table A shows some characteristics of all the papers (O stands for Offset, D for Docucolor, E for Epson with two papers P and K, MP for Matchprint and R for Rainbow).

**Table A. Various paper (with the corresponding device)**

| | Grammage | Bekk Index | PPS Rough | Whiteness |
|---|---|---|---|---|
| | g/m2 | seconds | µm | 457nm, % |
| O A | 80 | 22.6 | 6 | 105 |
| O B | 174 | 682 | 1.1 | 93 |
| O C | 170 | 208 | 2.5 | 95 |
| D A | 168 | 674 | 1.4 | 91 |
| D B | 112 | 1128 | 1.1 | 92 |
| D C | 78 | 22.9 | 6.1 | 107 |
| D D | 135 | 172 | 2.1 | 91 |
| E P | 190 | 56.7 | 1.7 | 101 |
| E K | 165 | 40 | 3.8 | 111 |
| MP | 318 | 3000 | 1.3 | 98 |
| R | 184 | > 10000 | 0.9 | 101 |

## Quality Criteria

With the offset process using the paper C as a reference, one main goal was to characterize color rendering for each printing technique by means of both colorimetric and densitometric quality parameters. The test form consisted in a standard IT8-7.3 target comprising 928 color patches. In the category of colorimetric criteria, we find:

- color gamut volumes, in order to decide, for instance, whether (and to which extent) the standard quadrichromic offset process reproducible colors are included within the borders of the other gamuts or not,

- mean color deviations associated to each paper/printing device pair according to the appreciation of the position of the geometrical center of their respective gamuts under the assumption that the color points are regularly distributed in the L*a*b* color space.

The experimental data acquisition was made with a spectrophotometer (X_Rite "Spectrofiler") automatically scanning the patches and connected to a microcomputer.

The densitometric determinations were classical:
- solid densities of CMYK primaries,
- dot gain according to the Murray-Davies formula,
- relative contrast index (by the well known FOGRA formula).

## Handling the Data

At the beginning of the work, we thought it was convenient to use a Gretag Macbeth D19-C densitometer (equipped with a Status E set of color filters, polarization filters and using illuminant A) as the measuring device for optical densities. But, it rapidly turned out that, due to the great number of handled data, it was preferable to write a specific program (named Color Tool) to calculate all the necessary figures for exploiting the experiments. Basically, the spectrophotometer reads a series of reflectances in the range 400nm to 700nm, step 10nm. Colorimetric coordinates are calculated according to a simulated D65 illuminant with a view angle of 10°. Taking these specifications into account, it is easy to determine L*a*b* values and to compare the results to those directly provided by another colorimeter (X-Rite D968). The correlation was very good as can be seen in Figure 1.

We have applied the same principle for the densitometric determinations: the knowledge of the filters spectra corresponding to a Status E and of to a simulated illuminant A provide a way to determine the optical densities delivered by a D-19C densitometer.

The results may be compared to direct measurements in order to validate the calculation method: on the example of the cyan color, figure 2 shows that a linear behavior is obtained. The resulting slope differs from 1 because of the real properties of the densitometer light source and of the differences between the configurations (e.g. filters). If we notice that, globally, all the slopes turned out to be similar, we are led to validate our method for making reliable comparisons. Thus, it became possible to classify all the paper/device pairs and to verify, for instance, which pair was the most suitable to predict the rendering of an offset printed paper (a goal which is of great importance in the case of a "contractual" proof).

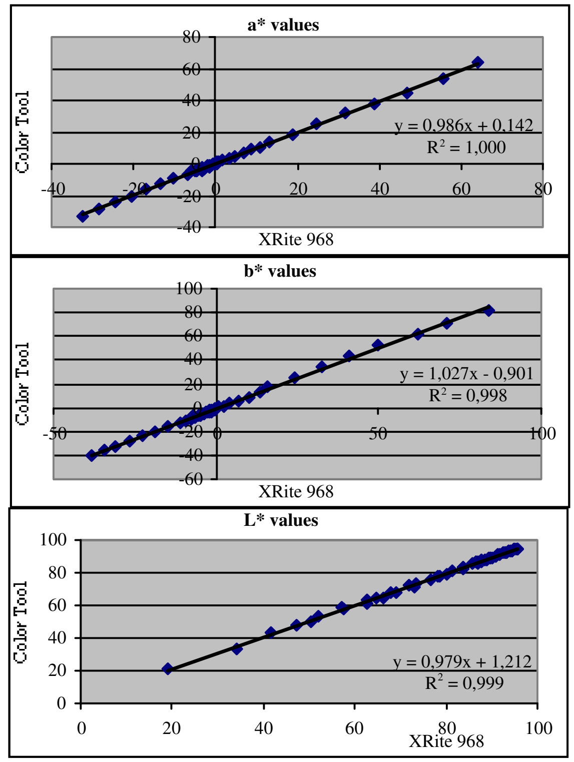


*Figure 1. Calculated versus measured L*a*b**

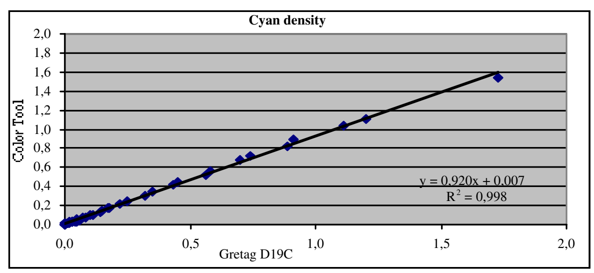


*Figure 2. Calculated versus measured densities (cyan)*

## Colorimetric Results

The values of L*a*b* coordinates corresponding to solid primaries and their overlaps allowed us to calculate the volumes of all the color gamuts for all the paper/device pairs by the classical method of the dodecahedron (1). Nevertheless, by a careful observation of the positions of color points corresponding to a screened area of some given colors, we recognized that assimilating the borders of this volume to straight lines was only approximate. So, it became interesting to develop another calculation method which would take curvature effects into account. We called it the "convex envelope" method (2). Basically, it consists in assuming that the gamut may be modelized as a convex surface - the smallest surface wrapping a given set of points. The computing program is based upon the "Qhull" recursive algorithm. The very first step is to find the extreme points in the six directions of a reference system. All the points inside this parallelepiped do belong to the convex volume but not to the octahedron built on the extreme points. So, we have to analyze the eight tetrahedral regions exterior to this volume, and to again find an extreme point inside each of them. This process is next applied to the remaining points.

**Table B1. Gamut Characteristics (Method (1))**

| | Surface | Volume | Sphericity |
|---|---|---|---|
| D A | 26874 | 269447 | 0.751 |
| D B | 25829 | 252987 | 0.749 |
| D C | 17498 | 145149 | 0.763 |
| D D) | 24060 | 227744 | 0.750 |
| E P | 33627 | 350023 | 0.714 |
| E K | 30524 | 309041 | 0.724 |
| MP | 33262 | 371752 | 0.752 |
| O A | 17447 | 129007 | 0.708 |
| O B | 27995 | 281300 | 0.742 |
| O C | 27931 | 283713 | 0.748 |
| Calib. R | 35128 | 400325 | 0.748 |
| Uncal. R | 39870 | 458089 | 0.721 |

**Table B2. Gamut Characteristics (Method (2))**

| | Surface | Volume | Sphericity |
|---|---|---|---|
| D A | 28966 | 346074 | 0.823 |
| D B | 28350 | 335338 | 0.823 |
| D C | 19089 | 190978 | 0.840 |
| D D | 25944 | 298612 | 0.833 |
| E P | 38866 | 525136 | 0.810 |
| E K | 35176 | 458193 | 0.817 |
| MP | 35331 | 432699 | 0.783 |
| O A | 17520 | 153898 | 0.793 |
| O B | 29551 | 351378 | 0.815 |
| O C | 28488 | 324153 | 0.801 |
| Calib. R | 37036 | 471273 | 0.791 |
| Uncal. R | 42307 | 564580 | 0.781 |

In order to compare the performances of our pairs, a first approach consists in evaluating the volumes and surfaces of their respective gamuts by both methods (1) and (2). All the results are gathered in Table B1 and B2. It is obvious that the volumes calculated according to method (2) are systematically higher than by method (1). Nevertheless, the two methods give similar classifications. Moreover, we have introduced a third parameter we have called “sphericity”; it is defined as the ratio between the surface of a sphere with the same volume as the gamut under consideration and the real surface of this gamut. This parameter gives an idea of a kind of “roundness” of the gamut shape. As it can be seen in the tables B1 and B2, the sphericity of the gamuts are higher by the convex envelope method (2), which is an awaited result. These tables also show that the uncalibrated Rainbow printer yields the biggest gamut, a result which is in agreement with Ref. 1. Let us add that calibrating this device causes a significant lowering (around 15%) of its gamut.

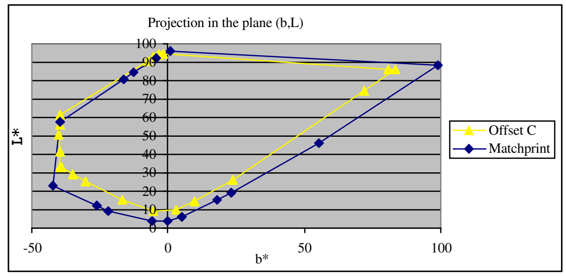


*Figure 3. Gamuts: Matchprint and Offset C (method 2)*

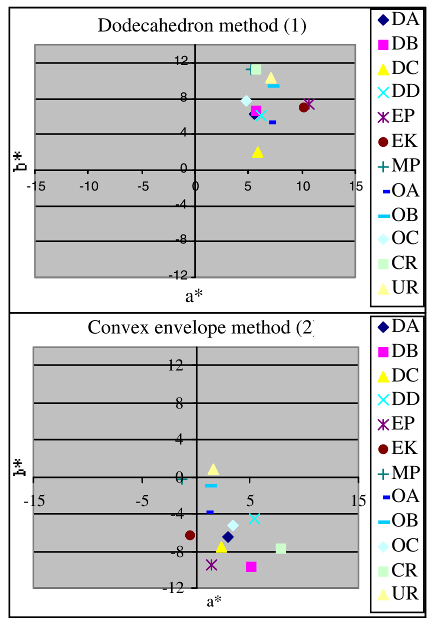


*Figure 4. Geometric centers of the 11 gamuts*

From our global results, we are able to draw the following observations:

- the analog contractual Matchprint proof system is confirmed to yield a gamut which involves those of the offset papers (figure 3); this is an awaited result;
- Digital printing systems (Docucolor, Epson and Rainbow) seem to have interesting properties; for offset printing simulation, a calibration is necessary by taking the paper characteristics into account (a feature which is likely to lead to lower their performances); in fact, a problem remains: how to correctly simulate the screen ruling of the offset process (except for the Docucolor device);
- Each paper/device pair exhibit a mean color deviation in comparison to the others; figure 4 shows the

positions of the 11 geometrical center of the gamuts in the (a*, b*) planeas they are obtained by both calculation methods; considering a correction for compensating the deviations of each pair might be a first step towards the calibration of digital devices in offset printing simulation; figure 4 also shows the results given by the 2 methods are different: the offset C sample is situated near the middle of the diagram.

We think the lower shift from the origin of the global set of points yielded by method (2) is likely to be an argument giving support to the concept of convex envelope, but this feature remains to be verified.

## Densitometric Results

In tables C1 and C2, we have gathered all the densito-metric data corresponding to all the tested pairs paper/process (offset press, Docucolor printer, Matchprint analog system and Rainbow device).

**Table C1. Solid Densities**

| | C | M | Y | K |
|---|---|---|---|---|
| D A | 1.01 | 1.16 | 1.14 | 1.60 |
| D B | 1.04 | 1.17 | 1.18 | 1.64 |
| D C | 0.67 | 0.82 | 0.80 | 1.17 |
| D D | 0.94 | 1.07 | 1.07 | 1.57 |
| E P | 2.07 | 1.59 | 1.63 | 2.14 |
| E K | 1.61 | 1.38 | 1.48 | 1.72 |
| MP | 1.15 | 1.35 | 1.42 | 1.63 |
| O A | 0.95 | 1.00 | 0.92 | 1.06 |
| O B | 1.08 | 1.51 | 1.01 | 1.48 |
| O C | 1.10 | 1.26 | 1.03 | 1.41 |
| Uncal. R | 1.45 | 1.50 | 1.74 | 1.61 |
| Calib. R | 1.15 | 1.20 | 1.64 | 1.58 |

We can make some comments about these data:

- the offset papers exhibit solid densities and NCI relative contrast which increase with smoothness (see Table A), and correlatively decrease with PPS roughness; at the same time the corresponding dot gain decreases; a similar behavior is observed in the case of the Docucolor samples
- the tendency for dot gain to decrease with smoothness (and relative contrast to increase) is confirmed by comparing processes to each other (see, in particular, the values for Matchprint and Rainbow which show very high values of their Bekk index);
- it is again obvious that the calibration process significantly lowers the performances of the Rainbow system;
- it is rather difficult to compare solid densities among the various processes due to the difference in their pigment (or colorant) nature;
- let us also notice the surprisingly high solid densities of the two ink jet samples;
- Matchprint and offset C have similar dot gain and NCI, which is a rather attended result for a “contractual” proof system in comparison to an offset printed coated paper.

**Table C2. Densitometric Data**

| | % Dot gain (50%) | | | | % NCI (70%) | | | |
|---|---|---|---|---|---|---|---|---|
| | C | M | Y | K | C | M | Y | K |
| D A | 29 | 24 | 34 | 32 | 22 | 30 | 13 | 35 |
| D B | 30 | 23 | 34 | 28 | 21 | 30 | 17 | 41 |
| D C | 26 | 15 | 26 | 17 | 21 | 32 | 21 | 45 |
| D D | 29 | 21 | 31 | 25 | 23 | 32 | 19 | 43 |
| E P | 24 | 15 | 21 | 30 | 57 | 61 | 51 | 50 |
| E K | 29 | 19 | 26 | 33 | 39 | 50 | 40 | 36 |
| MP | 14 | 12 | 12 | 10 | 48 | 53 | 57 | 61 |
| O A | 29 | 23 | 23 | 29 | 21 | 28 | 28 | 21 |
| O B | 14 | 12 | 10 | 14 | 45 | 53 | 47 | 53 |
| O C | 9 | 10 | 13 | 15 | 49 | 53 | 44 | 52 |
| Uncal. R | 10 | 15 | 14 | 12 | 39 | 48 | 56 | 59 |
| Calib. R | 8 | 16 | 19 | 16 | 42 | 47 | 47 | 49 |

## Conclusion

Our work was intended to propose a method for comparing various printing processes by taking the printed paper into account. It is based on the use of only one measuring device (a spectrophotometer connected to a microcomputer). A specific program allows to handle large quantities of data. This program uses physical characteristics of optical components to calculate colorimetric L*a*b* values and optical densities. The agreement with experiments is quite good for colorimetric data, but it remains to be improved for optical densities determinations even though comparative studies are already possible.

The concept of convex envelope was successfully tested and seems to permit more reliability for the descriptions of color gamuts than the dodecahedron method. Nevertheless, a question arises whether the distribution of the experimental color points (obtained from the IT8 standard test chart) is regular within the gamut or not: investigations are necessary to validate this assumption. It may be a good tool for a calibration procedure including paper as a significant parameter.

On a global level, colorimetric data are coherent with densitometric determinations: the two approaches give similar comparative results. Digital devices have good potentialities, even if the analog Matchprint remains the only useful system for “contractual” proofing.

## References

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## Biography

Gerard Baudin graduated from INSA-Lyon (France) in 1966 achieving Physical Engineering. He obtained his PhD from the University of Lyon in 1970. In 1978, he joined the French Engineering Faculty for Papermaking and Printing (EFPG - Grenoble) where he became a Professor in Process Engineering applied to Graphic Arts, directing Master- and PhD theses, and teaching basic prepress and printing techniques. He is a member of IS&T.