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# STUDY OF THE COLOUR GAMUT VOLUMES AND OTHER REPRODUCTION QUALITY PARAMETERS OF ELECTROPHOTOGRAPHICAL DIGITAL PRINTING SYSTEMS

*Iskren Spiridonov, Simeon Yordanov, Rumyana Boeva, Kostadin Kalchev*
*University of Chemical Technology and Metallurgy, Department of Pulp, Paper and Printing Arts, Sofia, Bulgaria*

Abstract: *The main purpose of this article is to study the various quality indicators of industrial electrophotographical digital printing systems. Several test forms with a large number of test charts and various control elements were printed on the aforementioned digital printing and media systems. For the purpose of the study, one of the most common print media was used - mat and glossy coated papers, uncoated papers, Brigh foil gold, Martele Blanc paper, MC Primecoat, PP Silver, etc. with standard colour profiles FOGRA 39 and FOGRA 51 and offset uncoated paper with standard colour profiles FOGRA 29 and FOGRA 52. Colour gamut (2D and 3D), colour volumes, colour differences, etc. were studied. ICC profiles for specific printing systems and materials have been generated and their 3D volumes, 2D areas of different sections in light, medium and dark tones have been studied. Other indicators of the quality of reproduction have been studied, such as - achieved colour differences in relation to the set / desired colour and ISO standards, accuracy of reproduction - colour and geometric, grey balance TVI, etc.*

Key words: ICC colour profiles, digital printing, printing quality, colour gamut, colour reproduction quality, grey balance, electrophotography

## 1. INTRODUCTION

Over the last decade, with the orders of small, and sometimes medium – sized circulations, the classic offset print in the commercial and packaging printing has been replaced by the high definition electrophotographical print, which allows the obtainment of a rich product set, such as: brochures, books, posters, labels, cardboard packages, some types of flexible packaging, personalized products and many more.

In reality, there aren’t any traditional printing houses, which avoids supplementing its traditional printing techniques with industrial grade electrophotographical printing machines. Practice shows, that clients hold high expectations towards digital print quality, comparing it with the conventional printing in regards to the standard parameters, guaranteeing colour reproduction accuracy, lack of colour variation in printing run, the achievement of Pantone colours, etc. At this point in time the market is saturated with an immense number of digital (electrophotographical) printing machines from the premium and mid-price segments, which, if one was to judge on technical specifications only, must meet the aforementioned quality criteria in full. Experience in the field so far tells a different story, revealing that most of the digital printing systems from the industrial class suffer severe problems and deviations in relation to several quality criteria. This article is a part of a series of works, based on a pure and objective scientific approach and unique methodology, both based on the measurement and assessment of assorted characteristics, definitive of the term print quality. The method offered herein is based on the unbiased measurement and assessment of densitometric and colorimetric parameters, as well as their quantitative correlation to the particularities of human perception and the fundamentals of print quality, as set in the ISO-standards of graphic technology (TC 130).

The methodology, developed and described herein is based on the measurement, analysis and assessment of:

- Colorimetric parameters analysis in the case of single, double, triple, etc. ink overlays (Kašiković et al., 2018). Calculation of colour differences, compared to set desired values and international standards, characteristization data, etc.
- Analysis of the capacity of digital printing system to simulate PANTONE colour and obtained colour differences.
- Complete accuracy analysis of colour and tone reproduction quality of particular digital printing machine (Kašiković et al., 2017).

- Analysis of densitometric parameters in digitally printed images – optical densities, reproduction accuracy of tone values, simulation with Tone Value Increase, etc.
- Assessment and analysis of the volume in 3D and 2D colour gamut of the tested digital printing machine during printing over different media. Comparison of the obtained ranges against the FOGRA standards.
- Research and assessment of colour variation while producing an edition, as well as analysis of colour variance as function of time – printing the same image (complete edition) over a predefined period of time.
- Analysis and comparison of the capabilities to obtain similar colour parameters between the tested digital printing system and a conventional machine – an item of particular importance when the first edition is in offset, for example, and is then supplemented using digital printing machines.
- Generating of ICC profiles for the digital printing system over different media and assessment of the complete reproduction specifications, comparison over standard profiles, research of stability over time, etc.

## 2. EXPERIMENTAL

For the purposes of the experiment we have modelled special test forms with specialized testcharts and control elements for:

- Colorimetric analysis of colour characteristics for a digitally printed image.
- Densitometrical analysis – optical density of solids, TVI (Tone Value Increase), Print Contrast (Spiridonov & Shopova, 2013), etc.
- Charts to generate ICC profiles
- Images with distinct colours
- Precision control scales for colour reproduction, gradient precision, etc.
- Colorimetric tests and assessment of colour characteristics of stock PANTONE colours.

The fundamental task in building a colour profile is the at-most precise reproduction of the digital original. To complete the test, we have used a premium electrophotographical printing system, as offered by one of the segment-leading brands. The derived ICC profiles, on the basis of which we have tested the Fogra 51, Fogra 52, Fogra 29 and Fogra 39 ranges are rooted on the characterization data, as published on the FOGRA website (Fogra, 2022). The profiles are generated with optimal colour separation conditions as per ISO 12647-2/2004/2013 (International Organization for Standardization, 2013).

- Fogra 51 – glossy/matte coated paper
- Fogra 52 – offset uncoated paper
- Fogra 29 – offset uncoated paper
- Fogra 39 – glossy/matte coated paper

Part of the scales used are presented in figure 1.

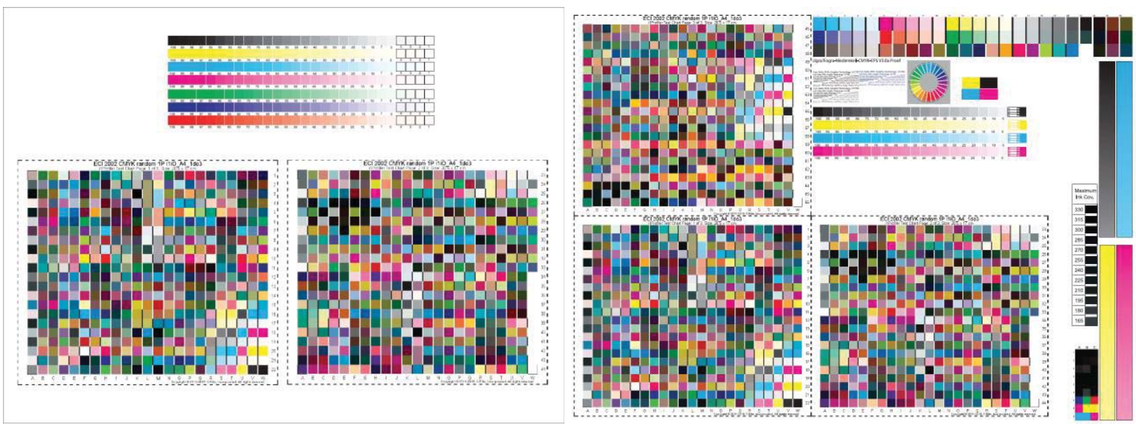

*Figure. 1: Part of the testing forms used during experiments*

The testing forms are printed with settings for different resulting ICC profiles. Before printing the test editions all machines are calibrated according to manufacturer's instructions with the aid of spectrophotometer.

### 2.1 Test materials

We have used two types of printing media. They are one of the most common stocks in printing houses and come with good printing specifications (whiteness, opacity, mechanical properties, etc.), as well as with great price/quality ratio.
1. Coated paper
2. Uncoated paper
In this case the main goal we set is to observe the colour gamut of used digital systems while working with the used printing stocks.
In order to perform a comparison of the colour range for the used materials in the used digital machines, it is necessary to get both 2D and 3D visualization with a standard ICC profile FOGRA 29 and FOGRA 52 for uncoated papers and FOGRA 39 and FOGRA 51 for coated papers, so that one can gain visual idea of available colour ranges. To get the 2D and 3D visualizations of the ICC colour profiles we have used the PROFILE MAKER5.0 and ColorThink Pro 3.0.3 software products.
Test conditions include the use of three electrophotographical printing systems from the mid and high price tiers with identical print stocks. This article is based on widely used machines, which are in fact preferred in polygraphy printing, well-established as auxiliary printing systems in offset printing houses and as main digital printing systems. Other articles from this series focus on different contenders in these price brackets, ink-jet systems and others.

### 2.2 The test completion comprehends the following parameters:

- Testing and comparing the volume and shape of 3D colour gamutof CANON imagePRESS C750, Xerox Versant 180 Press and HP Indigo WS 6800 against Fogra standards.
- Calculation and comparison of the colour gamut volume – ΔE (Spiridonov, Shopova & Boeva-Spiridonova, 2012).
- Testing and comparing the 2D cross sections of colour gammuts CANON imagePRESS C750, Xerox Versant 180 Press and HP Indigo WS 6800 against Fogra standards.

## 3. RESULTS AND DISCUSSION

To test and compare the volume of colour gamut we have combined several specialized $\Delta E^3$ software products, which yielded generally more accurate result representation. Please note that this is the maximal colour ranges, which is reproducible by the digital printing systems CANON imagePRESS C750, Xerox Versant 180 Press and HP Indigo WS 6800. This is why colour volume is one of the cornerstone specifications. With the aid of the different software products we were able to calculate the colour volumes from the printing results for the used substrate and to compare them against the reference values for the corresponding Fogra standard.
This research and graphic representation of 2D cross-sections and 3D volumes of colour gamut is aided by these specialized software products: X-Rite Profile Editor 5.0 and ColorThink Pro 3.0.3.
To test and compare the volume of colour volumes, we have made use of two specialized $\Delta E^3$ software products - CHROMIX ColorThink 3.0.3 and Gamut Vision 1.4.

### 3.1 Investigation of colour gamut volumes and comparison of 2D and 3D colour gamut of different digital printing systems

One important function, which is used to visualise the colours, as reproduced by any given machine, is the 2D and 3D representation of the respective colour gamut. This paper also uses 2D and 3D representations. The 2D representation of colour gamut with different cross-sections along the L-axis of the CIE Lab colour space allows for good visual comparison of colours in light, mid and dark tones, as well as comparison of a large number of colour gamut at once. The 3D representation of colour gamut allows a complex visual assessment for the 3D body of the colour gamut. It is appropriate for the visualisation and comparison of ore or two-coloured gamut's.

In order to perform the comparison for the colour gamut of the examined prints from the corresponding digital printing presses – CANON imagePRESS C750, XEROX Versant 180 Press and HP Indigo WS 6800 it is necessary to provide a 3D visualisation with a standard ICC profile FOGRA 29 and FOGRA 52 for uncoated papers and FOGRA 39 and Fogra51 for coated papers with the ultimate goal to achieve visual representation for the colour gamut. The 3D visualisation of the ICC colour profiles was performed using the software X-Rite Profile Editor 5.0.
To compare the colour gamut on offset uncoated paper, a standard ICC profile was used FOGRA 29 and FOGRA 52.

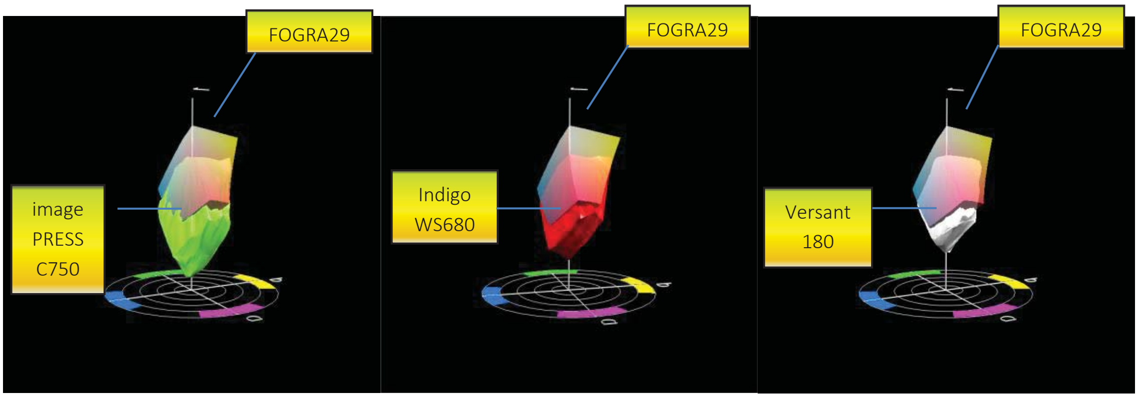


*Figure 2: 3D visualisation (Lab system) of an ICC profile of offset paper printed through CANON imagePRESS C750, HP Indigo WS 6800 and Xerox Versant 180 Press and FOGRA29*

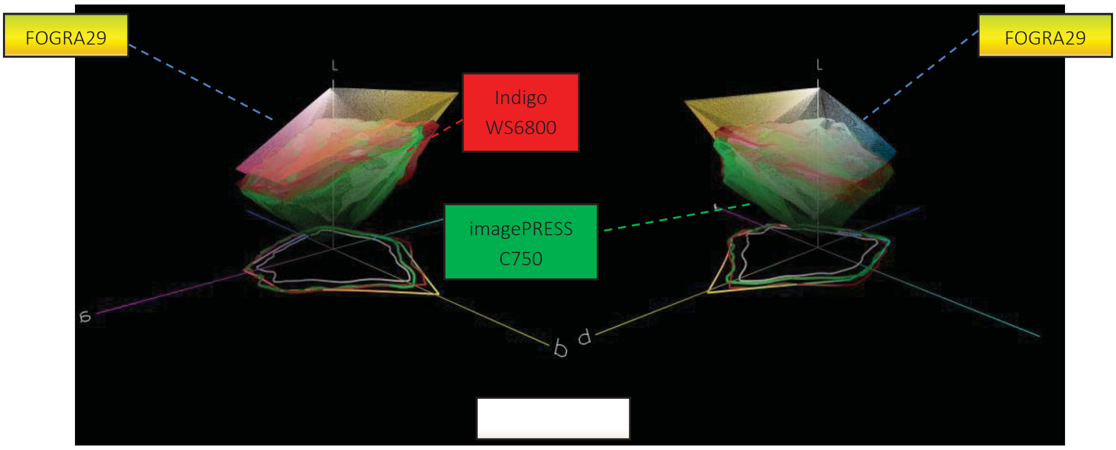


*Figure 3: 3D visualization (lab system) of ICC profile of offset paper printed by all printing systems compared to FOGRA29*

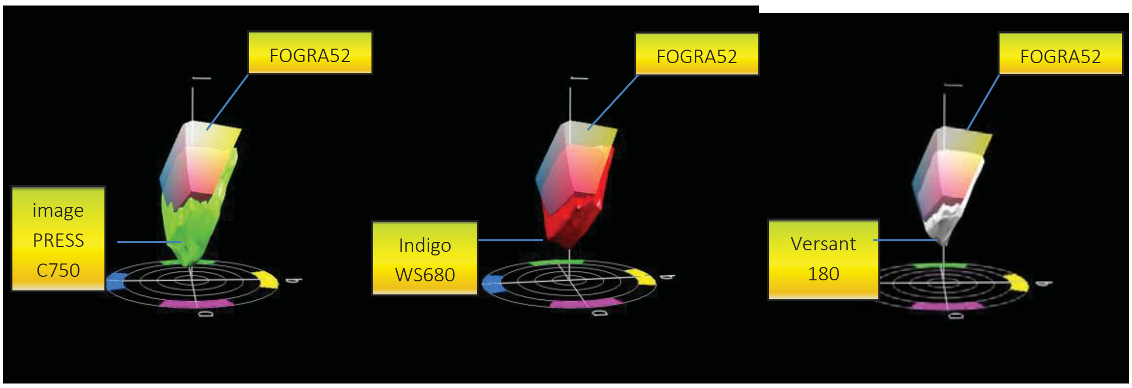


*Figure 4: 3D visualisation (Lab system) of an ICC profile of offset paper printed through CANON imagePRESS C750, HP Indigo WS 6800 and Xerox Versant 180 Press and FOGRA52*

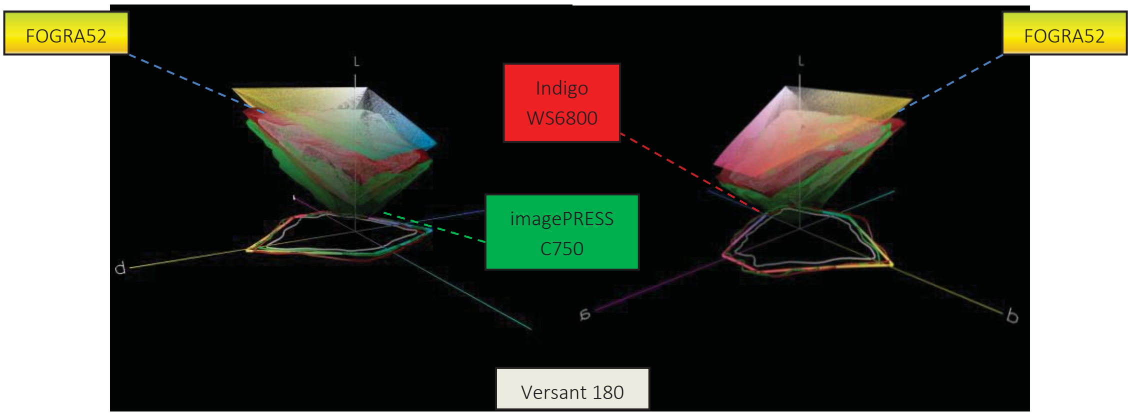


*Figure 5: 3D visualization (lab system) of ICC profile of offset paper printed by all printing systems compared to FOGRA52*

From figures 2, 3, 4 and 5 one can observe that the colour range of FOGRA29, as well as the one of FOGRA52 are considerably larger (in the conditions of conducted experiment) in the lighter tones in offset paper, which has been printed with CANON imagePRESS C750, HP Indigo WS 6800 and Xerox Versant 180 Press. Also one can observe, that certain regions of the colour range, for the printing systems tested, there is reproduction which is unattainable for FOGRA29 and FOGRA52. It is also clear, that offset paper generally yields better colour reproduction in lighter tones. With FOGRA29 and FOGRA 52, however one observes better reproduction in the lighter hues.
As a comparison platform for the colour gamut of coated paper the ICC FOGRA39 and FOGRA51 profile has been used:

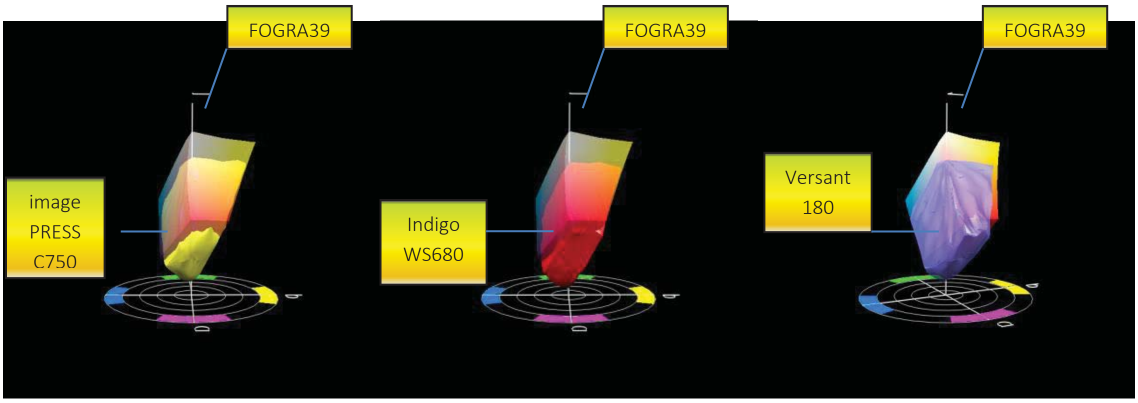


*Figure 6. 3D visualisation (Lab system) of an ICC profile of coated paper printed through CANON imagePRESS C750, HP Indigo WS 6800 and Xerox Versant 180 Press and FOGRA39*

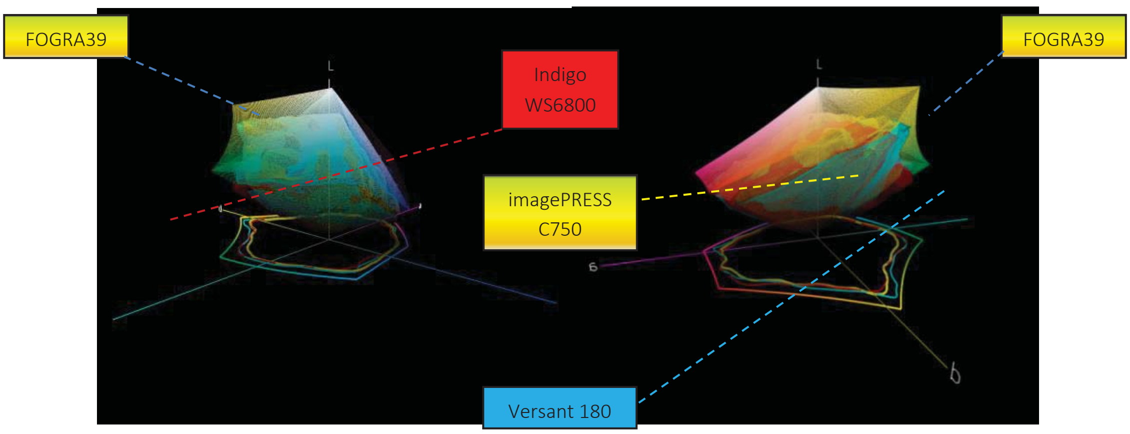


*Figure 7: 3D visualization (lab system) of ICC profile of coated paper printed by all printing systems compared to FOGRA39*

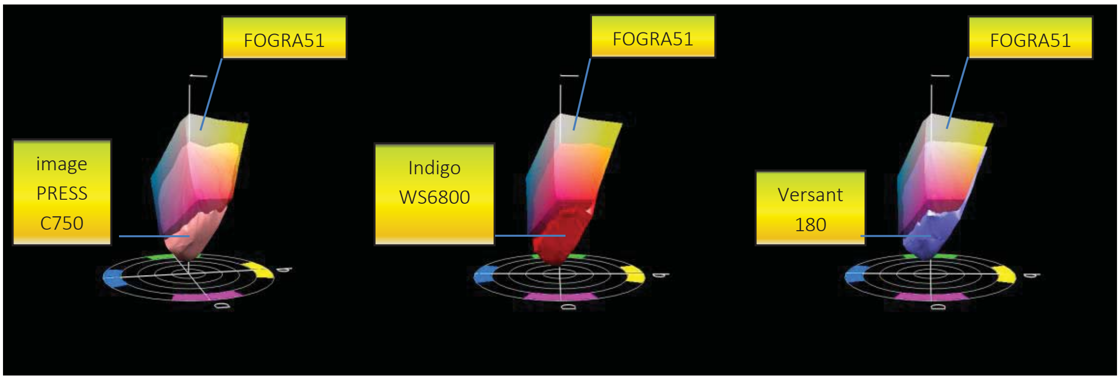


*Figure 8: 3D visualisation (Lab system) of an ICC profile of coated paper printed through CANON imagePRESS C750, HP Indigo WS 6800 and Xerox Versant 180 Press and FOGRA51*

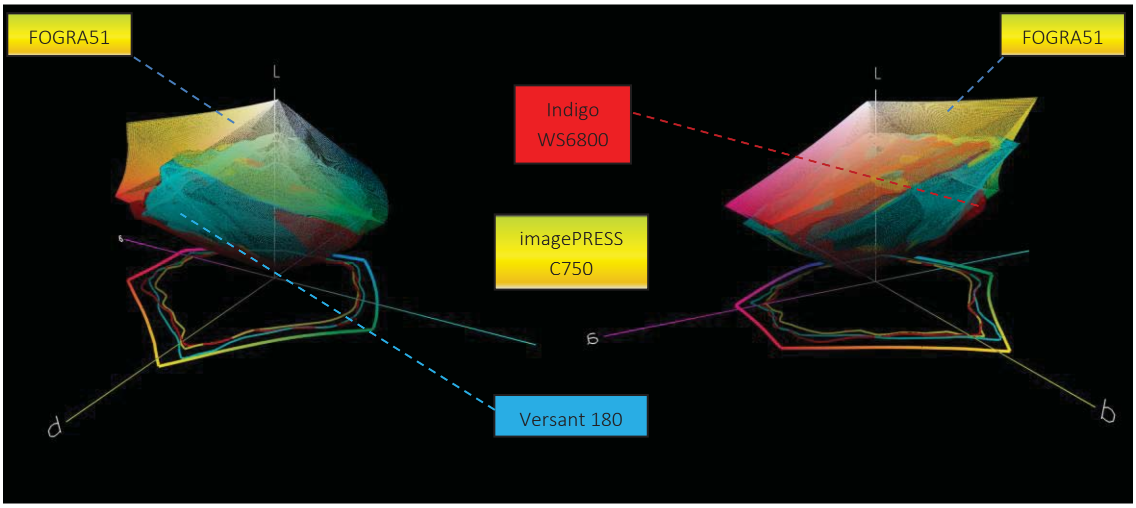


*Figure 9: 3D visualization (lab system) of ICC profile of coated paper printed by all printing systems compared to FOGRA51*

Figures 6, 7, 8 and 9 show that the colour gamuts of FOGRA39 and FOGRA51 are considerably larger (in the conditions of conducted experiment), compared to coated paper, again printed with CANON imagePRESS C750, HP Indigo WS 6800 and Xerox Versant 180 Press. Also one can observe, that certain regions of the colour gamut, for the printing systems tested, there is reproduction which is unattainable for FOGRA39 and FOGRA51. It is also clear that the coated paper aids better colour reproduction of the lighter nuances of yellow-green and blue-red regions. With FOGRA39 and FOGRA 51 a better reproduction of lighter hues has been noted.

The visualization of 2D cross-sections with different values of L yields a rich fact set on how the colour gamut varies, with the media used, against the reference values as per the corresponding FOGRA standard. This allows for a deeper insight into the colour volume and also aids tracking the corresponding values of L, which can be in the range 0 to 100. The next figures show the comparison of 2D cross-sections across different media, as printed with CANON imagePRESS C750, HP Indigo WS 6800 and Xerox Versant 180 Press, compared with the corresponding FOGRA standard.

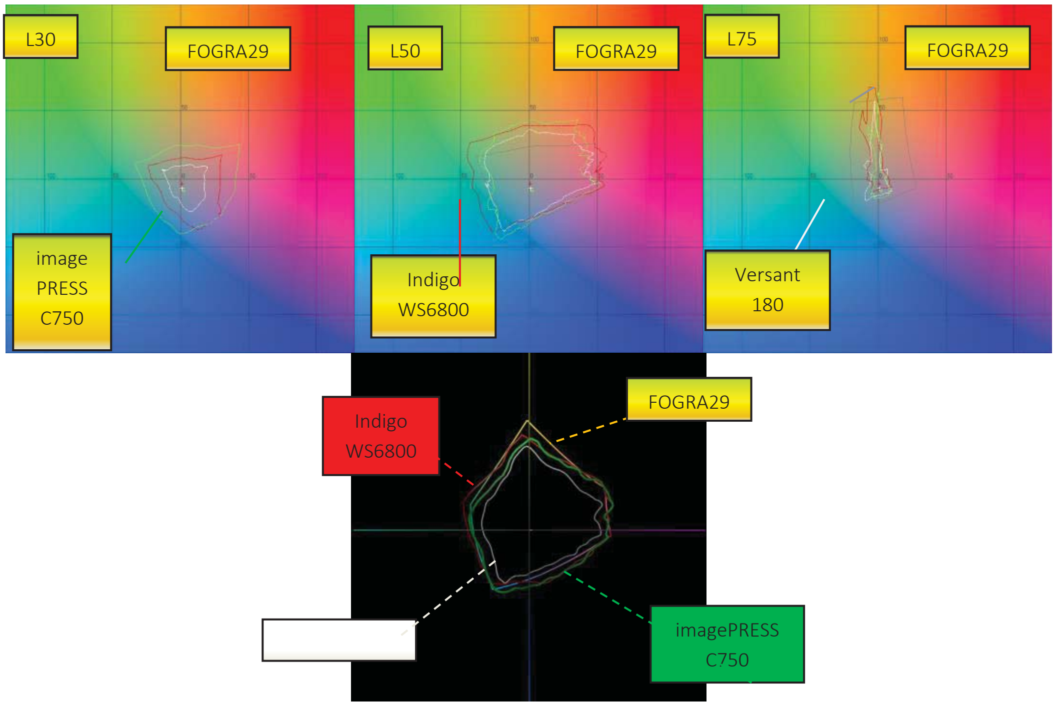


*Figure 10: Graphic representation and comparison of 2D colour gamut with different values of L over uncoated paper, as printed with CANON imagePRESS C750, HP Indigo WS 6800 and Xerox Versant 180 Press compared with reference values as per FOGRA29*

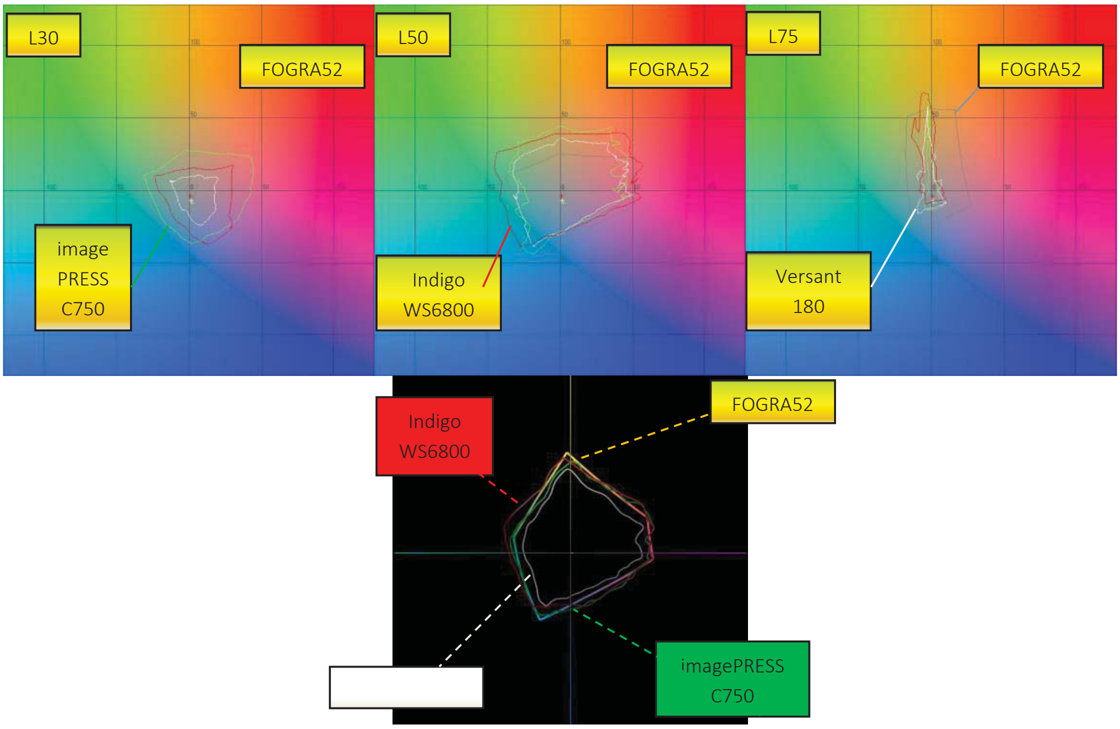


*Figure 11: Graphic representation and comparison of 2D colour gamut with different values of L over uncoated paper, as printed by CANON imagePRESS C750, HP Indigo WS 6800 and Xerox Versant 180 Press compared with reference values as per FOGRA52*

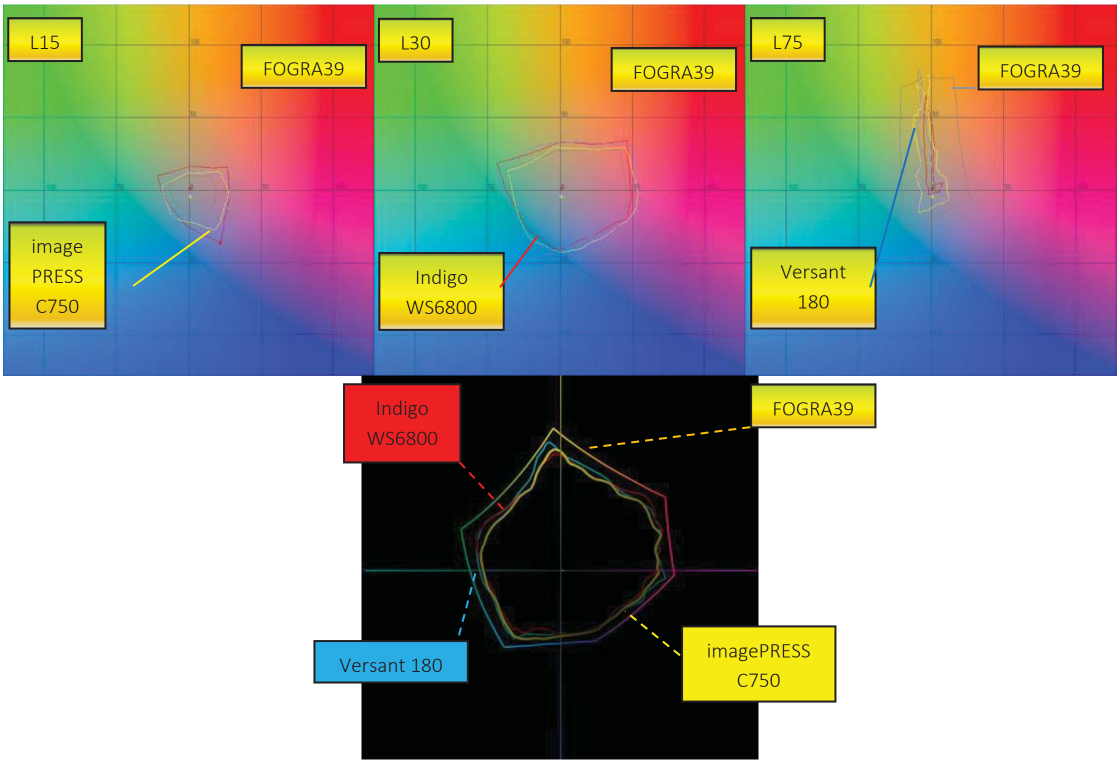


*Figure 12: Graphic representation and comparison of 2D colour gamut with different values of L over coated paper, as printed by CANON imagePRESS C750, HP Indigo WS 6800 and Xerox Versant 180 Press compared with reference values as per FOGRA39*

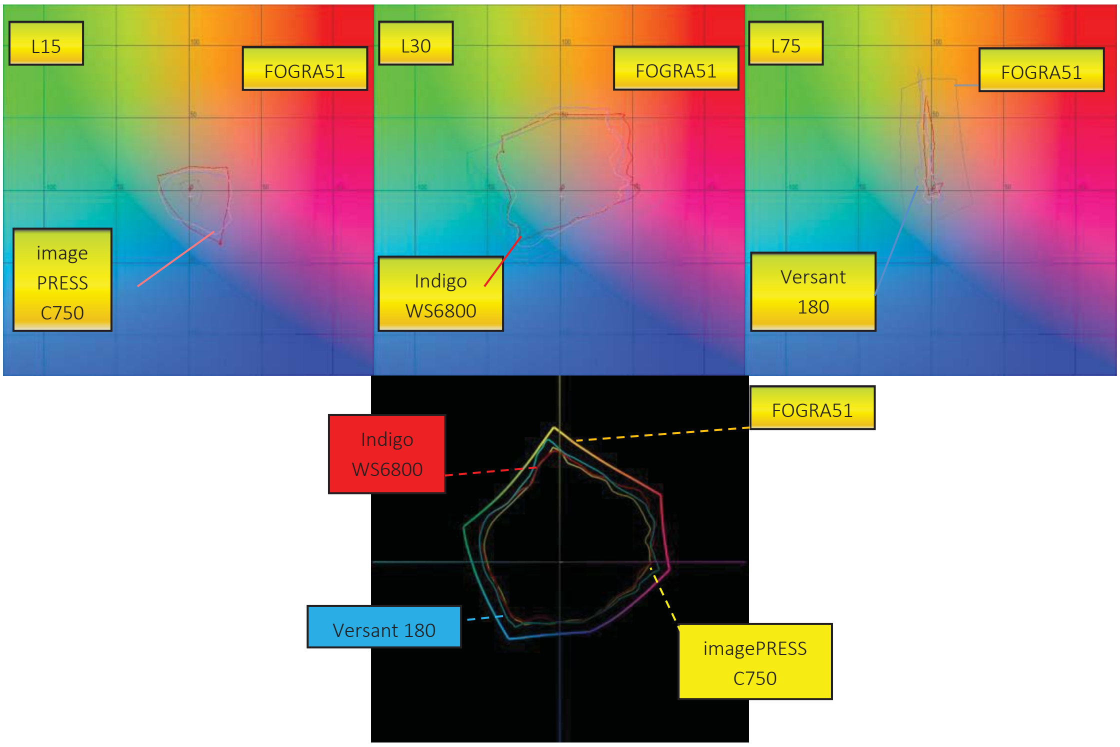


*Figure 13: Graphic representation and comparison of 2D colour gamut with different values of L over coated paper, as printed by CANON imagePRESS C750, HP Indigo WS 6800 and Xerox Versant 180 Press compared with reference values as per FOGRA39*

Figures 10 to 13 show the 2D visualisation of colour gamut over the tested media, as printed with CANON imagePRESS C750, HP Indigo WS 6800 and Xerox Versant 180 Press. Data shows that the most precise

tone and colour reproduction is showing with coated papers as the latter match with the references in almost all regions. the smallest colour range is obtained with offset uncoated papers, used with the same systems.
Tables 1 and 2 show the calculated values of the received ICC profiles for the media printed through CANON imagePRESS C750, HP Indigo WS 6800 and Xerox Versant 180 Press compared with the reference values as per the corresponding FOGRA standard. Two specific software products have been used to calculate the volume of the colour range. Each of them has a proprietary algorithm to calculate $\Delta E^3$, which accounts for the difference between the two software products.

*Table 1: Colour gamut volume $\Delta E^3$ for Uncoated Paper*

| Uncoated Paper $\Delta E^3$ | | | | | |
|---|---|---|---|---|---|
| | FOGRA 29 | FOGRA 52 | CANON imagePRESS C750 | HP Indigo WS 6800 | Xerox Versant 180 Press |
| Color Think 3.0.3 | 181382 | 163565 | 184096 | 174144 | 109143 |
| Gamut Vision 1.4 | 187079 | 162620 | 285724 | 315783 | 197341 |

*Table 2: Colour gamut volume $\Delta E^3$ for Coated Paper*

| Coated Paper $\Delta E^3$ | | | | | |
|---|---|---|---|---|---|
| | FOGRA 39 | FOGRA 51 | CANON imagePRESS C750 | HP Indigo WS 6800 | Xerox Versant 180 Press |
| Color Think 3.0.3 | 402279 | 386692 | 271565 | 264155 | 285899 |
| Gamut Vision 1.4 | 444027 | 448088 | 458882 | 501624 | 491149 |

According these results, one can obtain the graphics as shown in figures 14 and 15.

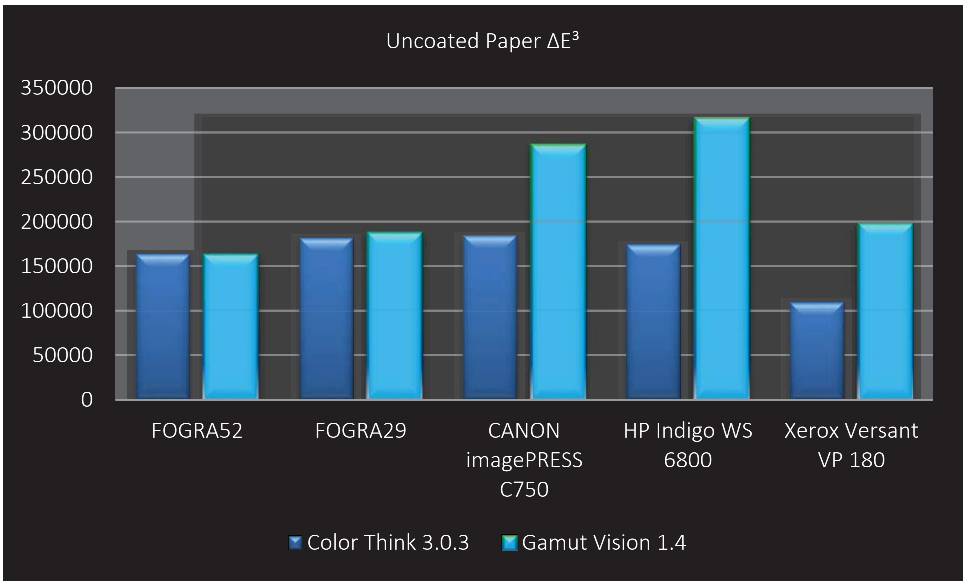


*Figure 14: Graphic representation of the colour gamut $\Delta E^3$ for Uncoated Paper as printed by CANON imagePRESS C750, HP Indigo WS 6800 and XeroxVersant 180 compared with reference values as per FOGRA calculated with CHROMIX Color Think 3.0.3 and Gamut Vision 1.4*

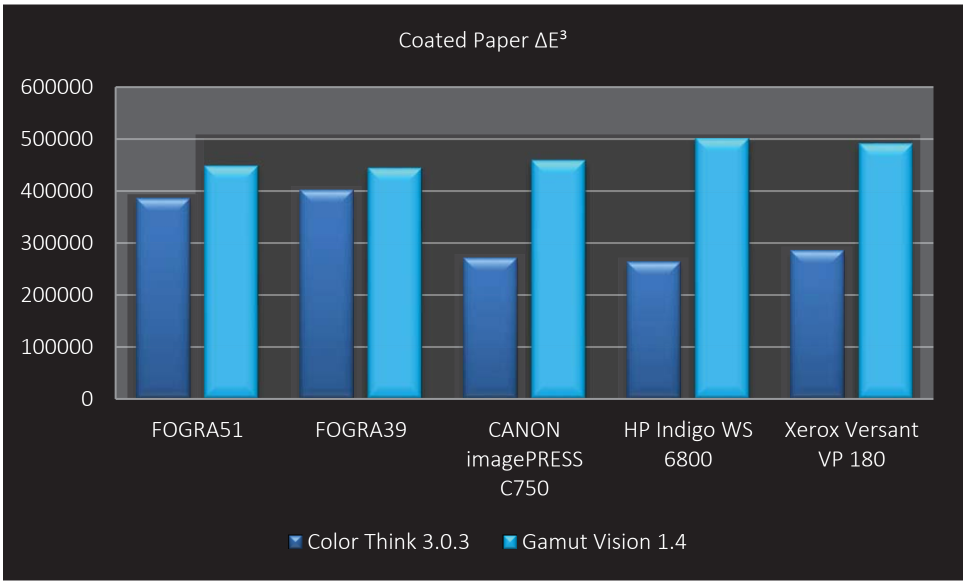


*Figure 15: Graphic representation of the colour gamut $\Delta E^3$ for Coated Paper as printed by CANON imagePRESS C750, HP Indigo WS 6800 and XeroxVersant 180 compared with reference values as per FOGRA calculated with CHROMIX Color Think 3.0.3 and Gamut Vision 1.4*

## 4. CONCLUSIONS

From the tests performed in relation to this article, we have arrived at the following conclusions:

1. It is suggested complete method to evaluate digital print quality, based on scientific approach and unbiased analysis of a great number of colorimetric and densitometric parameters for the printed image such as: achieved colour differences in relation to the set / desired colours and ISO standards, accuracy of reproduction - colour and geometric, grey balance, TVI, Colour Gamut, etc. The color gamut volume and 3D and 2D cross section surface analysis part of complete methodology is included in this article.
2. In real-world conditions, using widespread printing media, we have tested some of the wide used electrophotographical digital printing systems, as the obtained unbiased results have been dully compared with the FOGRA standards.
3. All of obtained results for color gamut volumes, 3D and 2D cross section surface analysis are valid for the studied printing conditions and used materials. The authors do not claim general evaluations of the investigated digital presses.
4. From the obtained 3D visualizations with generation of ICC colour profiles and comparing them to the FOGRA 29 and FOGRA 52 standards (for uncoated media) and FOGRA 39 and FOGRA 51 (for coated media), as printed by the tested electrophotographical printing machines, and using all mentioned media, we have established that CANON imagePRESS C750, HP Indigo WS 6800 and XeroxVersant 180, we have better colour reproduction in lighter and medium hues, compared to FOGRA 29 and FOGRA 52. The darker tones of the colour profiles for the tested electrophotographical printing systems go beyond the scope of the standard profiles as per FOGRA 29 and FOGRA 52. Data shows that when uncoated media is used, the best results against FOGRA 29 and FOGRA 52 belongs to XeroxVersant 180, followed by HP Indigo WS 6800 and CANON imagePRESS C750. From the results of the 3D volume range for coated paper (gloss, matte), as printed with the tested machines, we can establish that FOGRA 39 and FOGRA 51 standards have bigger colour scale in lighter hues, compared to the prints as done with the tested machines. Better colour reproduction is observed with coated media, especially in colour transmission for green-blue and blue-red regions.
5. From the 2D visualization we have made certain cross-sections of colour gamut over tested media with different values of L and it is clearly visible that with L=30, for uncoated paper, the greatest colour range belongs to CANON imagePRESS C750, and the smallest to XeroxVersant 180. With L=50 all three tested machines show similar results, as greater colour range is observed with the green-yellow and yellow-red regions as compared with FOGRA 29 and FOGRA

52 standards. With L=75 the lowest colour range belongs to CANON imagePRESS C750, as it is worth noting, that all three tested machines show circa two-fold smaller colour gamutcompared with FOGRA 29 and FOGRA 52. For coated paper (matte, gloss), and with L=15, CANON imagePRESS C750 and HP Indigo WS 6800 show greater colour ranges, compared with XeroxVersant 180 and the FOGRA 39 and FOGRA 51. With L=30 all three machines show similar colour ranges, which are smaller than the colour range per FOGRA. With L=75 again all three machines yield out a colour range which is about two-three-fold smaller than FOGRA 39 and FOGRA 52 ranges.

6. We have made use of two specialized software solutions to obtain the colour volume. Each of them uses its own $\Delta E^3$ algorithm, due to which one sees variance in the calculated values.

Colour gamut's and their volume are of special significance when the print quality is defined. Calculating $\Delta E^3$ using CHROMIX Color Think 3.0.3 showed the following result:

- For uncoated paper the largest colour gamut was obtained with CANON imagePRESS C750 ($\Delta E^3$ =184096), followed from HP Indigo WS 6800 $\Delta E^3$ =174144) and XeroxVersant 180 Press ($\Delta E^3$ =109143). The standard colour gamut's of FOGRA29 ($\Delta E^3$ =181382) and FOGRA52 ($\Delta E^3$ =163565) were best met by the CANON imagePRESS C750 Press (1,5% > $\Delta E^3$ FOGRA29 and 11% > $\Delta E^3$ FOGRA52), followed by HP Indigo WS 6800 Press (4% < $\Delta E^3$ FOGRA29 and 6,5% > $\Delta E^3$ FOGRA52) and XeroxVersant 180 Press (40% < $\Delta E^3$ FOGRA29 and 33% < $\Delta E^3$ FOGRA52).

- For coated paper the largest colour gamut was obtained with XeroxVersant 180 Press ($\Delta E^3$ =285899), followed from CANON imagePRESS C750 ($\Delta E^3$ =271565) and HP Indigo WS 6800 ($\Delta E^3$ =264155). The standard colour gamut's of FOGRA39 ($\Delta E^3$ =402279) and FOGRA51 ($\Delta E^3$ =386692) were best met by the XeroxVersant 180 Press (29% < $\Delta E^3$ FOGRA39 and 26% < $\Delta E^3$ FOGRA51), followed by CANON imagePRESS C750 (33% < $\Delta E^3$ FOGRA39 and 30% < $\Delta E^3$ FOGRA51) and HP Indigo WS 6800 (34% < $\Delta E^3$ FOGRA39 and 32% < $\Delta E^3$ FOGRA51).

Calculating $\Delta E^3$ using Gamut Vision 1.4 showed the following result:

- For uncoated paper the largest colour gamut was obtained with HP Indigo WS 6800 ($\Delta E^3$ =315783), followed from CANON imagePRESS C750 ($\Delta E^3$ =285724) and XeroxVersant 180 Press ($\Delta E^3$ =197341). The standard colour gammuts of FOGRA29 ($\Delta E^3$ =187079) and FOGRA52 ($\Delta E^3$ =162620) were best met by the HP Indigo WS 6800 (41% > $\Delta E^3$ FOGRA29 and 49% > $\Delta E^3$ FOGRA52), followed by CANON imagePRESS C750 (35% > $\Delta E^3$ FOGRA29 and 43% > $\Delta E^3$ FOGRA52) and XeroxVersant 180 Press (3% > $\Delta E^3$ FOGRA29 and 18% > $\Delta E^3$ FOGRA52).
- For coated paper the largest colour gamut was obtained with HP Indigo WS 6800 ($\Delta E^3$ =501624), followed from XeroxVersant 180 Press ($\Delta E^3$ =491149) and CANON imagePRESS C750 ($\Delta E^3$ =458882). The standard colour gammuts of FOGRA39 ($\Delta E^3$ =444027) and FOGRA51 ($\Delta E^3$ =448088) were best met by the HP Indigo WS 6800 (22% > $\Delta E^3$ FOGRA39 and 11% > $\Delta E^3$ FOGRA51), followed by XeroxVersant 180 Press (10% > $\Delta E^3$ FOGRA39 and 9% >$\Delta E^3$ FOGRA51) and CANON imagePRESS C750 (3% > $\Delta E^3$ FOGRA39 and 2% > $\Delta E^3$ FOGRA51).

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