Visual and Numerical Evaluation of Metallic Inks and How They Compare to Numerical Colour Differences

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Abstract

Previous projects in 2010, 2016 and 2017 looked into methods for measuring and controlling metallic inks that have been printed on press. These projects have established controlled ways to measure printed metallic inks. The two most recent studies showed clearly that the M3 measurement condition, as outlined in ISO 13655, can be used to measure and control the printing of metallic inks. In 2009 the ISO released the procedure ISO 13655 that regulates various measurement conditions for the print industry. The measurement conditions are labelled M0, M1, M2 and M3. The M0 condition encompasses all legacy models that do not conform to ISO 13655, M1 uses lighting with a defined amount of UV in it, to excite optical brighteners that are present in the paper, M2 uses the same light source as M1, but without the UV portion and M3 is for the measurement of special effect inks. The M3 measurement condition uses the same light source as M2, but there are 2 polarization filters with orthogonal grating in the machine. One is in front of the light source and the other in front of the measurement sensor. The 2017 study also showed that it also is of no concern if the inks are made for the offset or flexographic printing process. The difference between the metallic inks for these two printing processes is the size of the metallic flakes in the ink. Flexographic ink allows the of use larger metallic flakes than for offset inks. The larger flakes result in a more metallic looking print. These larger flakes have also larger reflecting surfaces than the metallic flakes used in offset inks. These larger metallic flakes do not influence the color measurement under the M3 measurement condition. This has been proven in the 2017 study.

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The follow-up project will consist of two parts. In the first part the metallic inks used in previous studies will be printed on an offset press in two different ways. The first way is to print to the same measured printed ink density read from the Pantone® metallic book. The second way is to achieve visual similarity to the color swatch in the Pantone® book. This test will be repeated three times for repeatability purposes. This can also be used to verify the usability of the M3 measurement condition on press. The printed samples will be marked and presented to human test subjects for evaluation of visual acceptance to the Pantone® metallic book swatch of the test colors. The results from the visual evaluation test will be correlated with the color difference values the samples have to the Pantone® metallic book.

In the 2016 and 2017 study it was established that a spectrodensitometer that is capable of conforming to the M3 measurement condition will be used to evaluate the test samples for their color difference to the reference in the Pantone® metallic book. In the end, the color difference values will be linked to the observations by the test subject. The test subjects will use a Likert-type scale to rate the color difference between the reference and the printed samples. Correlations will be drawn between the perceived color difference and the measured color difference values.

The visual ranking of the prints matching the printed ink density in the Pantone Metallic book did not correspond well with change in printed ink density.

The visual ranking of the prints achieving pleasing visual color corresponded well with the samples evaluated by the test subjects.

Theory & Introduction

Previous studies (Habekost et al. 2016 & 2017) have established that the M3 measurement mode for spectrodensitometers can be used for measuring printed metallic inks. This measurement mode can be used for metallic offset and flexographic inks. In these studies it was also shown that two different measurement instruments from different manufacturers record relatively similar printed ink density values. This in turn means that these two instruments can be used almost interchangeably to record printed ink density values. The ISO 13655 (ISO 13655) standard defines the illuminating and measurement conditions and the M3 measurement mode is one of these measurement conditions that was used in this study. The M-mode measurement conditions are well described in a white paper by Cheydleur & O'Connor (Cheydleur & O'Connor, 2012). The M3 measurement mode uses polarization filters the eliminate the influence of the metallic glare on the color measurement.

Since the evaluation of metallic prints using a spectrodensitometer in M3 mode has been well established it was needed to test the correlation between numerical and visual differences. The visual evaluation of color samples has quite often been the

basis of creating evaluation models or the color response curves that form the basis of today's color science. The visual evaluation of color samples is important to see if the measured color differences correspond with how human observers perceive color differences. This is not done only in the graphic arts industry, but also in dentistry (Braun et. al., 2007), the food industry (Fernandes-Vasquez et al., 2011) and the automotive industry (Gomez et al., 2016).

For this study two sets of samples are required. One set of samples strictly follows densitometric measurements. The printed ink densities of the six test colors from the Pantone® metallic book are recorded and used as aim points for the press runs. Once these aim points have been achieved twenty consecutive sheets were printed. These sheets were in turn analyzed for their color difference to the Pantone® book. The press sheet that has the closest DE00 value to the Pantone® metallic book was marked as the first sample. The next sample had to have a DE00 value that was 1 unit higher than the previous sample. All five test samples were obtained in this way, with the last sample having a DE00 value that was by five units higher than the first sample. Each press run was repeated three times to verify repeatability.

For the set of samples visually pleasing color was achieved on press. Once this had been done, the ink ductor from the press was shut-off and the ink depleted from the rollers. This allowed to achieve prints with a declining ink film thickness. The printed sheets were measured for their DE00 to the visually pleasing color press sheet. This helped to obtain samples with DE00 values from 1 - 5.

Experimental

Before the experimental procedures will be introduced and results analyzed, a list of the equipment and materials is shown.

List of equipment:

- Heidelberg QM46-2 offset press
- X-Rite eXact
- GTI MiniMatcher MM1e desktop viewing station

List of materials:

- Paper for prints:
  - Supreme Gloss Offset 24 x 36, 100lb, 148g/m2
- Background measurement paper:
  - Kromekote Offset C1S, 23 x 25 102M, 60Ib, 89g/m2, uncoated side

List of materials (cont)

- Inks:
  - P8202 Blue from Hubergroup Canada
  - P8682 Green from Hubergroup Canada
  - P8063 Pink from Hubergroup Canada
  - P877 Silver from Hubergroup Canada
  - P874 Gold from Hubergroup Canada
  - P8824 Purple from Hubergroup Canada
- Pantone®® Metallic Ink Book

List of software:

- X-Rite eXact DataCatcher (1.0 2580)
- MS-Excel for PC/Mac
- MacBook Pro with OSX 10.13.3

This study encompassed several parts. In the first part of the study the six lithographic metallic inks listed above, which were also used in the previous studies (Habekost, 2016 & 2017), were printed on coated paper on the QM46 offset press. The target density of these colors were determined by measuring the corresponding swatch in the Pantone®® metallic ink book with an X-Rite eXact in M3 mode. Once the target density has been achieved, twenty consecutive sheets were printed. Next, the density and L*a*b* values of the printed samples were measured using the eXact in M3 mode. This was the starting point to find the samples with DE00 values from 1 - 5 for the visual comparison against the corresponding swatch in the Pantone® Metallic book.

The a*, b* plot of the tested colors can be seen in the figure below.

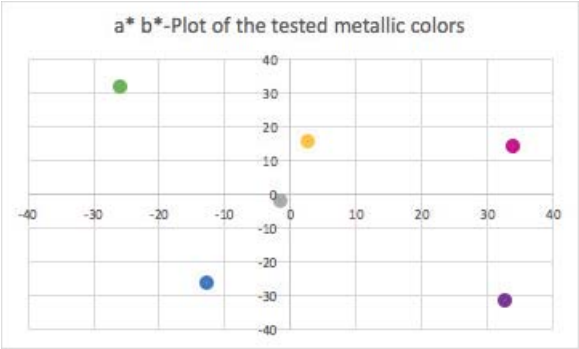

Figure 1: *a*, b* plot of the test metallic inks*

The test form used for this project can be seen in figure 2 below.

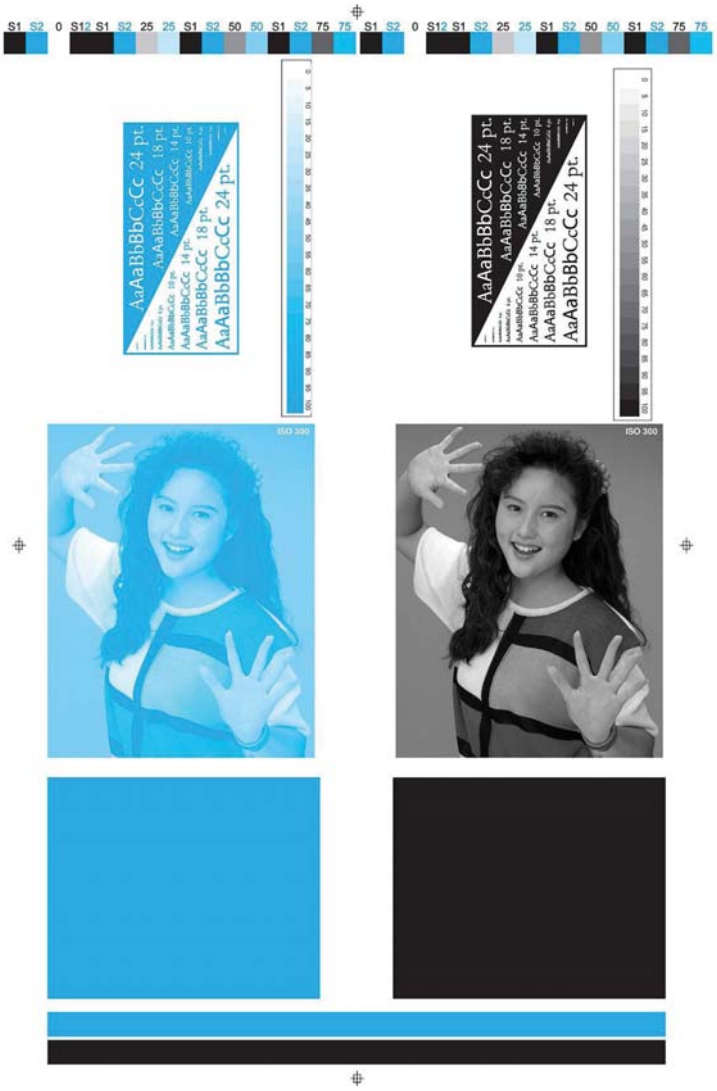

Figure 2: *Test form used in this project*

When the press runs were completed, the density and colorimetric values were all measured at the middle of the solid square area on the printed sheets (refers to the blue and black area on Figure 2). Once the DE00 values of the measured samples was five units higher than the first sample for density set or a DE00 range from 1-5 for the visual test, a small rectangle (1 ½" x 2") was cut out from the center of the solid square area for each color. All the test samples were tried to measure at the same area to ensure consistency.

The target densities for the test colors can be seen in the table below.

Color	Target density	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
P 877 Silver	1.13	1.14	1.08	1.22	1.27	1.31
P 874 Gold	1.64	1.63	1.75	1.80	1.85	1.91
P 8063 Pink	1.57	1.59	1.64	1.67	1.69	1.69
P 8682 Green	1.65	1.58	1.59	1.64	1.64	1.66
P 8824 Purple	2.19	2.21	2.31	2.32	2.38	2.37

Table 1: *Density values of the ink swatches in the Pantone® book and the corresponding sample densities*

In the following table the same inks are listed with their DE00 values.

Color	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
P 877 Silver	0.71	1.74	2.55	3.72	4.63
P 874 Gold	1.01	2.17	3.04	3.93	4.90
P 8063 Pink	0.40	1.44	2.37	3.22	4.46
P 8682 Green	4.11	5.02	6.19	7.05	8.19
P 8824 Purple	6.59	7.78	8.71	9.62	10.24

Table 2: *DE00 values of the ink swatches in the Pantone® book and the corresponding sample densities*

It was tried to keep the DE-values between 1 and 5, but for P8682 Green and P8824 Purple the supplied inks were off-color to the Pantone® book and the first samples had to the closest density values in comparison to the reference swatch in the Pantone® book, as can be seen in table 1.

The viewing booth was modified by lining the walls with matt black construction paper, available from an art supplies store, to reduce any visual distraction when the samples were evaluated. This modification was done based on a study done by Rich et al. (Rich et al, 2017). The following image shows the comparison of a printed sample to the corresponding swatch in the Pantone® book.

Figure 3: *Samples being evaluated in the viewing booth*

For the visual evaluation of the samples 20 volunteers were recruited in the School of Graphic Communications Management. The volunteers had some experience judging color. From the 20 volunteers 14 were female and 6 were male. The volunteers covered the age range from 18 to 52. For both samples sets each volunteer had to evaluate 60 samples in total. On average the volunteers needed 30 - 40 minutes for both sample sets.

Before each volunteer could participate in the study they had to take the online Ishihara test. http://www.color-blindness.com/ishihara-38-plates-cvd-test/#prettyPhoto. The volunteers completed the test in the presence of the second author before evaluating the samples.

In the second part, the same set of metallic inks were printed again on the offset press. When the appearance of the colors matched the color swatch in the Pantone®® book, the ink ductor was shut off and consecutive prints with declining ink density were produced. This was repeated three times for each color to ensure repeatability. The visual correspondence was determined by the authors of this study. In the following tables the density and corresponding DE00 values of the second sample set are shown.

Color	Density in the Pantone® book	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
P 877 Silver	1.13	1.07	1.03	0.98	0.95	0.94
P 874 Gold	1.64	1.74	1.62	1.58	1.52	1.54
P 8063 Pink	1.57	1.48	1.46	1.40	1.37	1.33
P 8202 Blue	1.91	1.83	1.78	1.73	1.7	1.69
P 8682 Green	1.65	1.59	1.59	1.54	1.51	1.50
P 8824 Purple	2.19	2.16	2.04	1.98	1.94	1.89

Table 3: *Density values of the ink swatches in the Pantone® book and the corresponding sample densities for the visual evaluation*

Color	DE00 difference to the Pantone® Book	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
P 877 Silver	1.45	1.16	1.91	3.08	4.21	5.05
P 874 Gold	2.73	1.29	2.05	2.92	3.99	4.97
P 8063 Pink	1.10	1.20	2.05	3.13	3.93	4.87
P 8202 Blue	6.23	0.94	1.99	3.10	3.94	5.19
P 8682 Green	4.74	1.16	2.20	2.97	4.19	4.93
P 8824 Purple	4.89	1.07	2.09	3.03	4.04	5.04

Table 4: *DE00 values of the ink swatches in the Pantone® book and the corresponding sample densities for the visual evaluation*

Results

Results for the samples that were matched by density measurements to the Pantone® book

The first set of samples that the volunteers looked at were matched by density to the density readings of the corresponding color swatch in the Pantone® book. The target density values and the density values of the samples can be seen in table 1. The first sample had a printed ink density closest to the density of the Pantone® color swatch. The following samples had a DE00 value that increased by one unit from sample to sample. Ideally sample 5 would have a DE00 value of 5 to the swatch in the Pantone® book.

The following figure shows how the volunteers ranked the samples. The ranking choices were the following:

- Best Match
- Match
- Somewhat matches
- Bad Match
- Worst Match

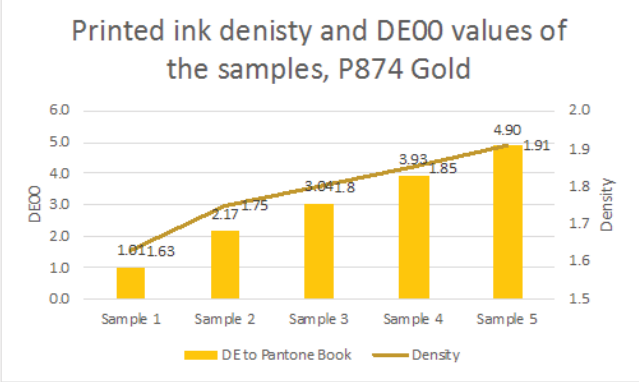

Figure 4: *The printed ink density and DE00 values of the density samples for P874 Gold*

Figure 4 shows the density values of the five test samples and their corresponding DE00 values in comparison to the color swatch in the Pantone® metallic book. This shows that with increasing ink density the DE00 values increase as well. The DE00 values range from 1.01 to 4.90, covering the targeted range of desired DE00 values for the test samples.

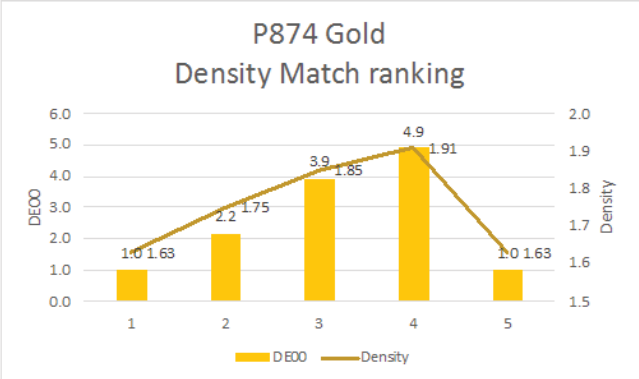

Figure 5: *The density match ranking for P874 Gold with corresponding density and DE00 values*

For unknown reasons the volunteers ranked the sample with the lowest DE00 value as the best match and also as the worst match. Otherwise the samples were ranked corresponding to their increasing DE00 value.

The next color to look at in regard to the visual ranking by the volunteers is P877 Silver. The reason for this is that P877 Silver and P874 Gold are manufactured by Eckart and contain no colorants that have been added by an ink manufacturer.

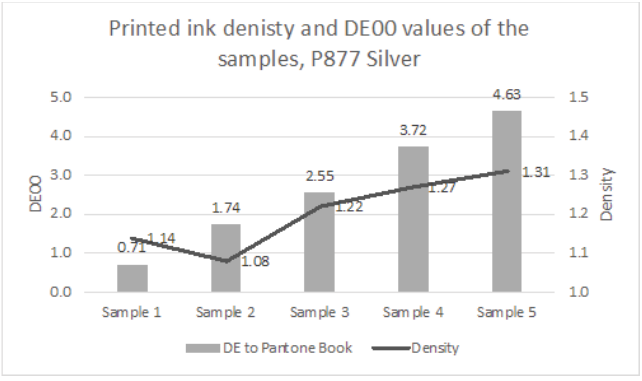

Figure 6: *The printed ink density and DE00 values of the density samples for P877 Silver*

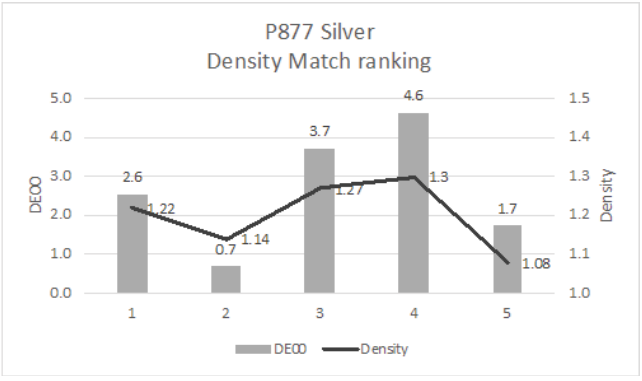

Figure 7: *The printed ink density and DE00 values of the density samples for P877 Silver*

Figure 6 shows that even though the densities of the samples don't increase in a linear fashion the DE00 values of the samples do. From figure 7 it can be depicted that the volunteers chose the sample with a DE00 value of 2.6 as the best match, while the sample with a DE00 value of 0.7 was chosen as just a match (2nd best color match). Also the sample with the highest DE00 value of 4.6 was given a better ranking than the sample with half the DE.

The results from the visual evaluation of P877 were discouraging and made the authors doubt the way the samples were prepared or that the volunteers were not qualified enough to evaluate the samples.Unfortunately out of the five tested colors only the P874 Gold samples were ranked in the way one would expect. In the following two images the ranking for P8063 Pink are shown.

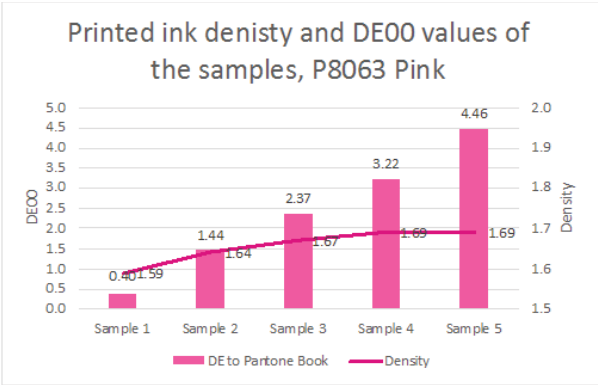

Figure 8: *The printed ink density and DE00 values of the density samples for P8063 Pink*

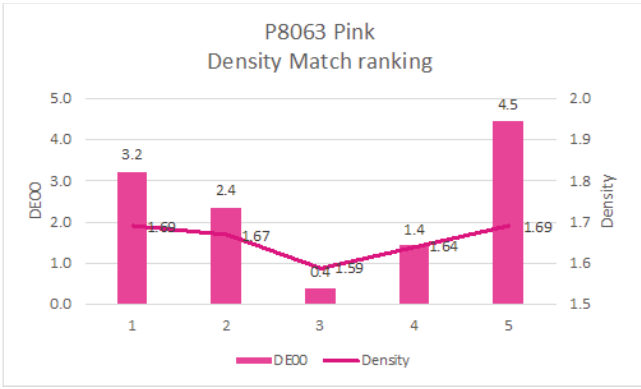

Figure 9: *The density match ranking for P8063 Pink with corresponding density and DE00 values*

From figure 8 it can be seen that the printed ink densities of the samples increased and that the DE values of the samples also increased from 0.4 to 4.46. Yet from figure 9 the volunteers chose sample 4 with a DE00 value of 3.2 to be closest visual match.

Figure 10: *Comparison of the swatches from the Pantone® Metallic book with sample 1 for the density samples*

This might have to do with the fact that the supplied ink was not an exact color match to the Pantone® Metallic book. This can be seen in figure 10.

The samples shown in figure 10 on the right to the Pantone® book have a printed ink density that is similar to the printed ink density of the swatch in the Pantone® book. It is clearly visible, especially for the P8682 Green, that the supplied colour is off-shade.

The was a disappointing result from this round of testing. Most likely it is possible to attribute this to fact that the supplied metallic inks did not match the Pantone® book very well.

Results for the samples that were matched visually to the Pantone® book

For the next part of the study the authors chose the best visual match to the Pantone® metallic book, even if the color was off-shade to the Pantone® book (see figure 10). Once the best visual match had been achieved on press, the ink ductor on the offset press was shut off and the remaining ink on the rollers depleted, resulting in declining printed ink densities and increasing DE00 values. This was repeated three times to ensure repeatability of the way the samples were prepared for this part of the study.

The first color to be looked at are the plain metallic inks that contain only aluminum, P877 Silver, and bronze, P874 Gold.

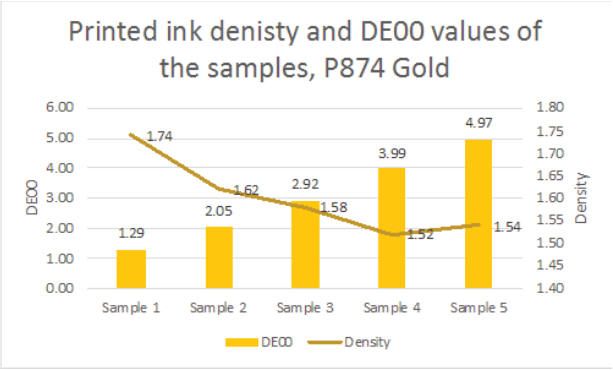

Figure 11: *The printed ink density and DE00 values of the density samples for P874 Gold visual samples*

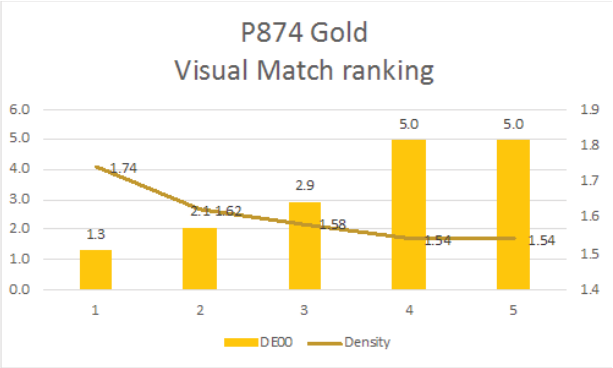

Figure 12: *The visual match ranking for P874 Pink with corresponding density and DE00 values*

From figure 11 and 12 it can been that with declining printed ink density DE00 values between 1.3 and 5 were achieved. The volunteers ranked the sample corresponding their DE values. Sample 5 was chosen to be a bad match and also as the worst match. This might have to do with the fact that sample 4 and 5 were quite close together in their printed ink density.

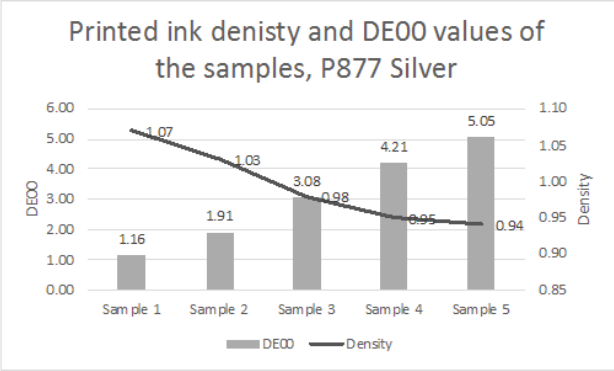

Figure 13: *The printed ink density and DE00 values of the density samples for P877 Silver visual samples*

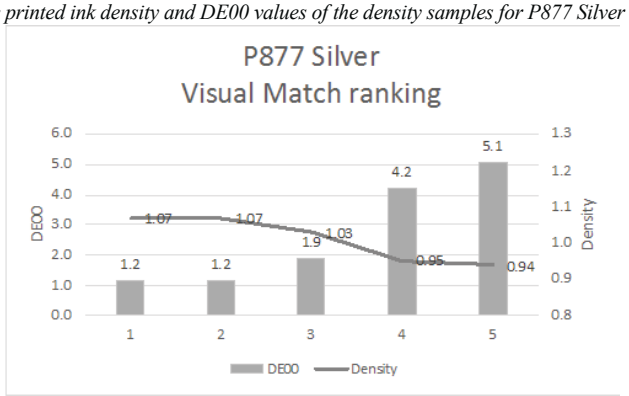

Figure 14: *The visual match ranking for P874 Pink with corresponding density and DE00 values*

From figure 13 and 14 it can be seen that the prepared samples for visual evaluation showed an even decline in the printed ink density resulting in almost evenly spaced DE00 values for the samples. Sample 1 with a DE00 of 1.2 was chosen as best match and also as a match. Otherwise an increase in the DE00 value resulted also in a lower ranking by the volunteers.

The following figures show the samples for the P8063 Pink and how the samples were ranked by the volunteers.

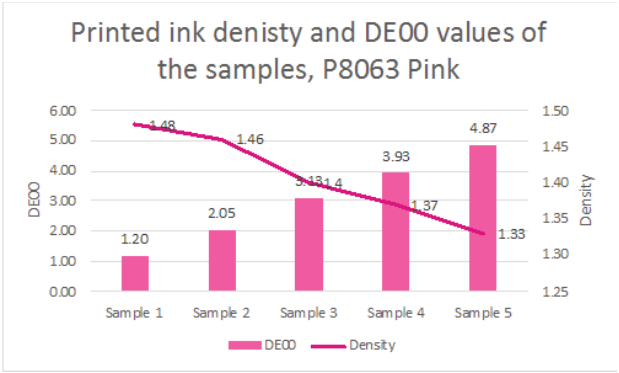

Figure 15: *The printed ink density and DE00 Values of the visual matching samples for P8063*

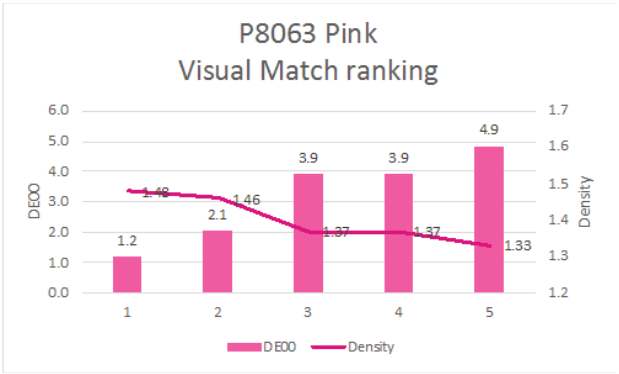

Figure 16: *The visual match ranking from 1-5 for P8063 Pink with corresponding ink density and DE00 values*

From figure 15 and 16 it can be seen that the samples were almost evenly spaced out in regards to their DE00 values. Like with the previous colors a slight change in density can result in a DE00 value difference of 1. For P8063 Pink this is clearly visible between sample 1 and sample 2. For the P8063 Pink sample 3 was chose as a sample that somewhat matches the standard, but also as a sample that is a bad match.

The graphs for P8202 Blue, P8682 Green and P8824 Purple showed similar trends then the three colors shown here. All colors showed a decline in printed ink density and an almost spacing of a DE00 value of 1 between the samples. Overall it can be said that there was a good correlation between printed samples, density values, DE values and visual ranking by the volunteers.

Conclusions

The main challenge for this project was the preparation of the samples. Especially printing of P8824 Purple proved to be quite challenging. The color had to be printed at such a high density that once the press was stopped to look at a sample the blanket had to be washed immediately, otherwise the next press sheets would stick to the blanket and sometimes would even wind up on the ink rollers.

The next challenge was the fact that some of the provided inks were off-shade to the Pantone® Metallic swatch book. This was most likely the contribution factor to the discouraging results to the part of the study that had the volunteers evaluate the samples that were printed to the same ink density as the Pantone® Metallic swatch.

The positive outcome of this study was the fact that the printed samples that were matched visually as good as possible to the metallic swatch book were ranked in order of increasing DE00 values to the color standard.

What does this mean for controlling metallic inks on press? First of all the best visual color match needs to be achieved for the metallic color that is being printed. Once this has been achieved the density of the OK sheet needs to measured with a spectrodensitometer that supports the M3 measurement mode. This density is now target density can be controlled via the spectrodensitometer during the press run.

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Xiaoying Ma, Research Assistant at the School of Graphic Communications Management, who prepared the ink samples and compiled all the measurements.

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