Simulating color changes due to coating of offset prints

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Abstract

Many printed products, especially in packaging applications, receive a coating with film or varnish, which changes contrast but also hue. Current offset printing standards define only the printing process, but not surface finishing. Standards-based color proofs simulate the uncoated print, but fail to show the final appearance.

One approach is to create ICC profiles from coated prints, which is a press- and substrate-dependent solution. A better way would be to predict the effect of various coatings on the basis of standard offset data sets.

With this goal in mind, this paper examines surface finishing of offset prints with glossy and matte varnishes and OPP films. Sheets were measured before and after coating. Color changes are most prominent for intermediate screen frequencies (120–150 lpi).

A simple model describes the effects of both glossy and matte coatings. Its components are additional dot gain and added stray light for matte surfaces. Measured data before coating were transformed in order to predict the effect of a coating. From this simulation, ICC profiles were created and compared with profiles made from data after coating. For both glossy and matte film, we found an average of 1.5 ΔE_{94}.

This model is not limited to a CMYK process, but can be applied to any colorant combination. It is hoped that these findings can be a starting point for work on a standard for coating offset prints, and for other printing processes.

Introduction

In the offset printing industry, adherence to ISO standard 12647-2 plays an increasing role for manufacturers. Based on published reference data (e.g. www.eci.org, www.swop.org) and derived ICC profiles, contract proofs can simulate the printed result by paper type without knowledge of the printer who will be doing the job. However, existing standards define only uncoated[**] printing in terms of primary colors and dot gain. Many printed products, especially in packaging applications, receive a coating with glossy or matte OPP (oriented polypropylene) film or UV varnish. Lamination with matte OPP film has an overall market share of around 30 % in Europe, reaching 70 % for the dust jackets of hardcover books.[5]

While a glossy finish will enhance colors, a matte coating is known to desaturate. But some colors exhibit also a change in hue. Today, designers can judge possible color shifts only from experience. And a standards-based proof—while useful for adjusting ink zones at the press—fails to show the final appearance. If we could predict the effect of coating, any reference data set (or ICC profile) could be used for simulating the unfinished and finished product.

A previous study[1] examined lamination of offset prints with a 150 lpi screen using two kinds of glossy film and a 1- and a 2-component dispersion glue. Influences on dot gain were found, but it was concluded that coating test prints must remain the recommended way to anticipate unwanted color changes.

In the past, we have attempted to solve the problem by simply coating the proof, but doing so did not match the coated printed product (unpublished work). Finishing of ink jet prints by lamination or spray coatings has been examined with regard to light fastness and durability issues,[2] but not regarding color change.

Materials and Methods

This paper examines finishes with water-based glossy and matte dispersion varnishes, UV varnish, and glossy and matte OPP film. Where possible, the same sheets were measured before and after coating. For ICC profiles, at least three sheets were pulled from a press run with at least 50 sheets in-between. Uncoated and to-be-coated sheets were taken from the same press run, close to each other. Those sheets contained multiple targets for averaging and outlier detection.

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[**] Note: the term *coating* is used in two different ways. A *paper coating* can be applied in the paper manufacturing process and improves the paper surface. Offset standards distinguish between various coated and uncoated paper classes. — After printing, a surface finishing of the printed sheet may follow, which is also termed a *coating*. This is rarely done for uncoated paper. Therefore, all examined papers are coated papers.

Varnished press sheets were produced using a Heidelberg Speedmaster CD102 with inline varnish unit. The following papers have been used:

STA	glossy coated paper (Starline, 135 g/m^2)
INV	coated sulfate cardboard (Invercote, 240 g/m^2)
PAR	ivory-colored matte coated cardboard (Parilux Elfenbein, 250 g/m^2)

Process inks and compatible varnishes are commercially available from Fa. Huber, Munich. Additional material was kindly provided by several offset printing companies in Germany. Those sheets were glossy coated paper. They contained diverse profiling testcharts. The prints covered a variety of euroscale ink systems from different manufacturers, and plate-making both by computer-to-film and computer-to-plate technologies. In a separate experiment, seven different screenings were printed on Parilux cardboard: classic AM screening with 120, 150, 180, and 225 lpi as well as Barco Monet FM screening with a dot size of 50, 35, and 25 µm. Lamination of the printed sheets was kindly made by Fa. Nickert, Neu-Ulm, using 12 µm glossy OPP and 15 µm matte OPP film.

Measurements were taken using a GretagMacbeth Spectroscan without filters, 45/0 geometry, D50/2° for CIELab calculation, and using a GretagMacbeth D19C densitometer (Status E density filters, relative to paper white). Because the coatings conduct light by total reflection, a patch size of at least 7 mm × 7 mm was used where possible (except for the externally provided sheets) to decrease an influence of surrounding color patches. The software ColorBlind 4, ITEC, has been used to create ICC profiles from the measured data.

Densitometric Results

The coating of press sheets leads to an additional dot gain on top of the dot gain of the printing process. To give a first overview, long-term production statistics at Ebner&Spiegel are presented in Table 1. Values correspond to the additional dot gain in single color patches of the press control strip (dot value 40 % at 150 lpi).

Table 1. Additional dot gain at 150 lpi

glossy/matte OPP film	11 % ± 2 %
glossy UV varnish	6 % ± 2 %
glossy/matte dispersion varnish	3 % ± 1 %

Regarding the whole range of dot values, it is interesting to note that the shape of this additional dot gain differs from conventional dot gain: it reaches full height rather early. Sample data from a single press run are given in Figure 1.

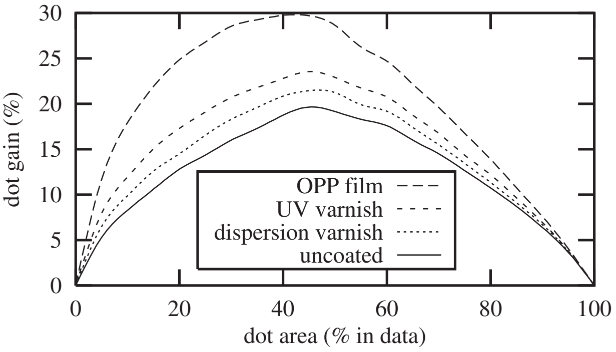

Figure 1. Conventional dot gain curves and coating on top.

These data (for 150 lpi) are averaged across C, M, Y, K. Since there is no significant difference between glossy and matte film, they are grouped together. The same holds for glossy and matte water-based dispersion varnish, and for inline and offline UV varnishing (for inline varnishing, a primer is required, and primer as well as varnish could be expected to interact with the still wet color—but doesn't).

Clearly, film coating has the strongest impact. Even for a dot value as low as 10 %, film coating leads to an additional 10 % gain. Figure 2 shows this increase in the individual C, M, Y, K data of the same data set.

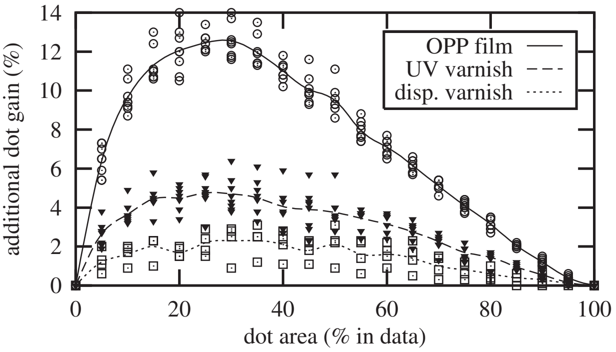

Figure 2. Additional dot gain for various coatings at 150 lpi.

Printed, uncoated samples from other offset printing companies were measured and then coated with glossy or matte OPP film. In spite of different process ink sets, results for 150 lpi screens agreed with the findings at Ebner&Spiegel.

However, one sample had a 175 lpi screen and exhibited marginally lower additional dot gain. At the same time, we tried to match a coated print by coating a proof, and found that the FM-screened proof changed much less. Since conventional dot gain also depends strongly on the screening, we examined the influence of AM screen frequency and FM screens. We used CMYK wedges with steps of 10, 20, 40, 70, and 100 %, and glossy and matte OPP coating. Results are presented in Figure 3.

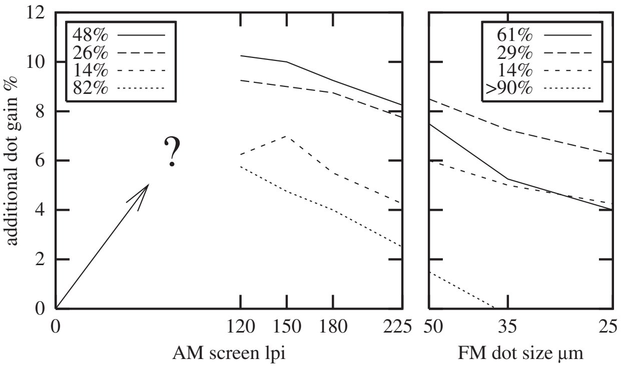

Figure 3. Additional dot gain for glossy OPP coating at various dot percentages (measured on uncoated sheet) and screenings.

Changes are most prominent for intermediate screen frequencies (120 to 150 lpi), and decrease with decreasing dot size. Because solid colors remain almost unchanged (colorimetrically, see below), we expect changes to decrease at coarser screenings. Unfortunately, we lack data below 120 lpi (arrow and question mark).

Colorimetric Results

Spectral readings were taken on 150 lpi profiling targets for INV, PAR, and STA materials with various coatings. As with densitometry, the biggest changes were found for OPP film coatings.

Gamut changes are small. Even matte coatings desaturate colors less than one would assume from the visual impression. The main difference lies in the shadows, which are deepened by glossy coatings, and grayed out by matte coatings. Table 2 shows the influence of OPP coatings on gamut corners (INV, 150 lpi). For these solid colors, the hue change Δh is less than 1 degree.

Table 2. Gamut corners and change due to coating

	uncoated			glossy coated		matte coated	
	L	C	h	ΔL	ΔC	ΔL	ΔC
W	97	2	–	-1	-1	-1	-1
Y	91	92	91	0	3	0	-3
M	51	75	-3	0	1	1	-3
MY	50	85	34	-1	1	1	-6
C	56	61	232	-1	1	1	-2
CY	49	69	157	0	2	2	-6
CM	24	51	299	-1	1	5	-7
K	21	1	–	-4	0	3	0

While solid colors hardly change, others do. Designers and product managers plan for the glossy or matte finish, and may anticipate a changed gradation; but hue changes usually come as a surprise.

Figure 4 illustrates the hue shift due to matte coating. Shown are gamut boundary colors only, with a primary CMY color at 100 % and a secondary color at 0–100 %. Results for glossy coating are almost identical again, and therefore not shown. Around 100Y we find the strongest hue change. With increasing M (left of 100Y), coating makes the hue reddish. With increasing C (right of 100Y), coating makes the hue greenish. The change peaks around 40–50 % of the secondary color, then diminishes again. This sine wave pattern repeats for the other primary colors (if slightly distorted for M).

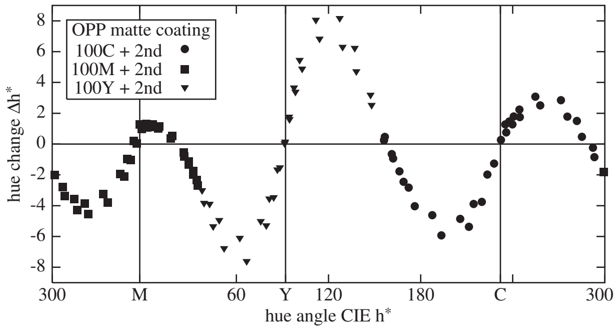

Figure 4. Hue shift for gamut boundary colors. Materials INV and STA, screening 150 lpi round dot, matte coating.

Predicting Glossy Coatings

The colorimetric hue shifts can be interpreted easily along the lines of the densitometric findings. We begin the discussion with glossy coatings and cover matte coatings later. Throughout this section, we assume an AM screening with 150 lpi.

The additional dot gain influences mainly the quarter- and mid-tones in a CMYK combination. For example, this explains a shift from a pale yellow-orange (100Y 10M) uncoated to a salmon-like color with film coating (which appears more like 100Y 20M). Moreover, the gamut remains almost the same, except for richer, deeper shadows. All this suggests that a simple gradation per channel might work good enough to predict the effect of glossy coatings.

However, the densitometric dot gain of 11 % has been measured with a polarization filter. It can be expected that a colorimetric measurement (without polarization filter) will yield a smaller difference. To estimate an appropriate difference, pairs were used of uncoated and coated ICC profiles and their target data.

For each C,M,Y patch of the coated target subset, C',M',Y' values with a colorimetric match in the uncoated ICC profile were determined. This was done by iteration with an absolute-colorimetric profile lookup compared to the measured CIELab values of the coated target. For simplicity, patches containing K were ignored. The resulting differences were fitted to the symmetric parabola

$$C' - C = a\,(C/100)\,(1 - C/100) \qquad (1)$$

(same for M and Y). For both glossy UV varnish and glossy film coating, the maximum gain (height of the vertex) was around 6 % for all three inks. For water-based dispersion varnish, a value around 2 % was found.

From this starting point, cubic splines were used to create identical per-channel gradation curves (now including K again), which were used as input 1D-LUTs in the A2B1 table of the uncoated ICC profile. With some trial and error, it was found sufficient to use the following base points for the spline (see Table 3):

Table 3. Spline points for A2B1 input LUTs

glossy...	OPP film/UV varnish	dispersion varnish
map 0 % to	0 %	0 %
map 40 % to	46 %	42 %
map 80 % to	83 %	82 %
map 100 % to	100 %	100 %

This modification of the uncoated ICC profile, which should predict the colorimetric effect of glossy coatings, was compared to the coated profile by taking a CMYK grid (3526 samples) and calculating the ΔE_{94} color difference between the absolute-colorimetric profile lookups. Results are given in Table 4. The left column shows the difference due to the coating itself (i. e. uncoated vs. coated profile), the right column shows the accuracy of the prediction (i. e. modified uncoated vs. coated profile).

Table 4. Comparison of predicted to actual coated ICC profile

material, coating	ΔE_{94} uncoated	ΔE_{94} predicted
INV, glossy OPP film	3.5 ± 1.1	1.5 ± 0.6
PAR, glossy OPP film	3.9 ± 1.2	1.5 ± 0.5
STA, glossy OPP film	4.0 ± 1.3	1.5 ± 0.5
INV, glossy UV varnish	2.8 ± 0.8	1.7 ± 0.5
PAR, glossy UV varnish	3.4 ± 0.9	1.7 ± 0.6

Predicting Matte Coatings

In terms of additional dot gain, it seems that glossy and matte coatings have much in common. What makes matte surfaces special is the way they reflect light in all directions. When looking at matte coated prints, a varying amount of ambient light will blot out the colors of the print. Therefore I tried to describe matte coatings by mixing stray light into measured XYZ values and creating profiles from these; then inserting the above gradation curve into the input LUTs of the A2B1 table.

The amount of stray light had to be determined empirically, since the measuring device covered the patch, thereby blocking ambient light ("flare-free"), whereas typical viewing conditions will include a lot of ambient light. This indicates that a spherical diffuse measurement geometry might have been more appropriate for matte and glossy surfaces.

An additive mixture of 2 % of D50 light with 98 % of the measured flare-free XYZ values was found to give reasonable proofs, when viewed perpendicular to the surface, side-by-side with a laminated print. In spite of this subjective approach, the absolute-colorimetric comparison between predicted and actual matte coated profile still shows a big improvement (Table 5).

Table 5. Comparison of predicted to actual coated ICC profile

material, coating	ΔE_{94} uncoated	ΔE_{94} predicted
INV, matte OPP film	3.7 ± 1.3	1.4 ± 0.5
STA, matte OPP film	4.0 ± 1.4	1.4 ± 0.5

Discussion

A simple model has been used to transform measured data or ICC profiles of uncoated prints, in order to predict the effect of a coating. When applied to reference data and combined with an appropriate glossy or matte proofing substrate, a reliable proof of the final, finished product, is possible.

An ICC-absolute colorimetric comparison of synthetic profiles with corresponding profiles made from coated prints (150 lpi) yields an average of 1.5 ΔE_{94}, maximum 4.7, for glossy film; an average for 1.4 ΔE_{94}, maximum 5.3, for matte film. To reduce diversity as much as possible, it is recommended to use the glossy film parameters also for UV varnish (with slightly inferior results), and not to do anything about glossy water-based dispersion varnish, since a correction of 2 % is well within the usual bandwidth of press production. It was also decided that a compensation of the minimally darker white point of coated material was not necessary, since the eye adapts relative to whites anyhow.

An interesting aspect is the difference between measurements with and without polarization filter. For both kinds of OPP film, the additional dot gain from densitometric results is twice as large as the colorimetrically determined tonal correction. This is not the case for the varnishes, at least for UV varnish—the dot gain for dispersion varnish is too small compared to its uncertainty anyway. This factor close to two might be due to the polarizing properties of the OPP film (thereby suppressing one half of the intensity) compared to the unoriented UV-hardened polymer mesh.

For glossy coatings, it appears feasible just to compensate the dot gain (the colorimetric value of 6 %!) in the platemaking calibration. Indeed this has been done successfully over years of production at Ebner&Spiegel. A closer look reveals that there is some interaction between the inks. Presence of other inks makes the change for one ink smaller than expected from compensation above. This effect may be due to decreased background contrast, or simply loss of sharpness of the wet-in-wet overprinted dots.

At the same time, matte coatings cannot be compensated by simple one-dimensional gradation curves. In this case, the ability to predict color changes and loss of rich shadows and saturation is particularly important.

This method of dot gain adjustment and stray light mixing is not limited to a CMYK process, but can be applied to any colorant combination, if the dot gain changes can be confirmed. Some work remains to be done to determine the spline points (the “colorimetric” additional dot gain) for other screen frequencies.

The additional dot gain appears to be independent of ink sets, and to an extent, even of substrates. This suggests a purely optical effect, which depends on the average pathlength of light in the medium in relation to the dot size. Coatings increase the pathlength of light by conducting it with total reflection. For OPP film, a typical index of refraction would be around 1.3, corresponding to a grazing angle of 50°.

Rays will pass from the air through the coating down into the substrate (with an even higher index of refraction). Coming back from below at all angles, some rays cannot pass the film-air interface and are conducted away.

For a coarse screen with a large dot area to circumference ratio, the additional trapping of light is negligible, similar to the low optical dot gain of the screen itself. For very small dots, as in FM screens, the increase in pathlength due to coating is much larger than the dot diameter, so that the trapping probability becomes independent of where the light enters the substrate. Only for dot sizes a bit larger than the increase in pathlength, there is an additional possibility to trap incident light around the dot.

This explains why laminating the (FM-screened) proof is just not enough to simulate a coated print. However, it appears that an extension of this work for ink jet systems would have to take additional microscopic effects into account. It was found that with pigment inks, a lamination would decrease light scattering of the pigment particles on the paper surface by encapsulation, thus giving much brighter, cleaner colors.[2]

Future work might be directed toward an extended Kubelka-Munk model of halftone prints[3] with an additional coating layer, similar to recent work by Hébert *et al.*[4] for varnished metallic plates.

Conclusion

It was found that a simple empirical model can describe the effects of both glossy and matte coatings. For gloss, color changes can be mainly attributed to an additional dot gain which depends on screen frequency. Its curve is different from conventional dot gain, in that it reaches full height very early. This confirms and extends the findings by Eggelmann.[1]

Matte coatings can be described by adding a diffuse stray light to the measured tristimulus values.

It is hoped that these findings can be a starting point for work on a standard for coating prints.

Acknowledgments

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References

1. V. Eggelmann, Untersuchung der densitometrischen und farbmetrischen Qualitätsparameter vor und nach dem Kaschierprozeß, diploma thesis, University of Wuppertal, Germany, 1996, in German; title translates roughly to "Examining densitometric and colorimetric quality parameters before and after the lamination process."
2. R. A. Work III, E. S. Iracki, Finishing! How Does It Affect Ink Jet Photo Prints?, NIP 18: International Conference on Digital Printing Technologies, pg. 356–359, 2002.
3. S. Mourad, Color Predicting Model for Electrophotographics Prints on Common Office Paper, Ph. D. Thesis, École Polytechnique Fédérale de Lausanne, 2003.
4. M. Hébert, P. Emmel, and R. D. Hersch, A Prediction Model for Reflection on Varnished Metallic Plates, CGIV 2002: The First European Conference on Colour Graphics, Imaging, and Vision, pg. 453–458 (2002).
5. P. Barth, Fa. Achilles, Germany; personal communication.

Biography

Johannes Hoffstadt received his Ph. D. in biophysics from the University of Gießen, Germany. With a fancy for typesetting and computer graphics, he turned to the publishing industry in 1998. Starting as technical prepress manager for the book manufacturer Ebner&Spiegel, he became interested in color science, and a member of IS&T and the ECI. In 2002, he joined Color Solutions Software as manager of research and development, focusing on color management applications.