Using Wide Format UV Ink-jet Printing for Digital Package Prototyping

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Abstract:

Digital printing technology influences the short-run packaging and prototype market. Packaging work is among the most colour critical in the industry. Matching corporate and brand colours is essential, as is the ability to accurately reproduce spot colours. The main purposes of this experimental study are to (1) study colour reproduction and process capabilities of paperboard and corrugated board, (2) examine the quality of spot colour reproduction using a UV wide-format inkjet printer for digital package prototyping, and (3) establish printing workflows for digital package production. Sets of test samples were prepared to study colour reproduction and process capabilities of paperboards and corrugated boards using the EFI Vutek PV 200 UV ink-jet printer, to examine the spot colour matching capability, and to establish a digital printing workflow for digital package prototyping. Spot colours from the Pantone colour guide were used to design the spot colour test chart for this study. CIE L*a*b* values of Pantone colour swatches were used as target values. Adobe Illustrator CC 2014 was employed to generate the spot colour test chart in digital format. The designed test target was printed on different grades of paperboards and corrugated boards on an EFI Vutek PV 200 UV inkjet printer. The quality of spot colour matching was evaluated in terms of the ΔE2000 in CIE L*a*b* colour space.

1. Introduction

Digital printing influences the short-run packaging and prototype market, creating opportunities for print service providers to expand new services (Donovan, 2011; Balentine, 2013; Balentine, 2015). According to a recent report by Smithers Pira, the global market for digital printed packaging is forecast to be worth over $15.3 billion by 2018 (McEnaney, 2014).

The ability to print on a range of substrates, especially paperboard and corrugated material for the packaging market, makes the UV ink-jet digital printing technology attractive to package printers. Converters who traditionally printed only to paperboard are also leveraging digital platforms with UV-curable inks to explore new opportunities with other media, such as plastic, shrink films or heat-sensitive materials. Printing directly on a substrate gives the user a more accurate representation of the final package (Franklin, 2010; Donovan, 2010; Balentine, 2015).

Digital printing technology certainly provides a number of benefits that drive printers toward digital. Faster turnaround time, significantly lower costs, waste reduction, and greater flexibility are just a few benefits of digital printing technology. Designers can quickly produce variations of packaging designs or experiment with new concepts from design to final mock-up within hours (Franklin, 2010; Balentine, 2015).

The economy also plays a role in driving printers toward digital. Digital printing is critical in the context of the economic downturn, since fewer materials are used. More varieties and packaging sizes are fragmenting the market, leading to shorter runs that digital technology produces more economically. Print service providers can affordably add four-colour capabilities and print customized, variable material on demand. Packaging is also targeted directly to the consumers by placing their names on the packaging and making them feel that it was designed specifically for them (Donovan, 2010; McEnaney, 2014; Franklin, 2011; Balentine, 2015).

Packaging work is among the most colour critical in the industry. A brand's colours not only identify the product but also affect consumers' interactions with it. Prototypes need to be produced on the same media with the same colours and appearance as the final product (Peck, 2012; McEnaney, 2014; Balentine, 2013; Balentine, 2015). This research was conducted to investigate colour reproduction and process capabilities of tested paperboards and corrugated boards and examined the quality of spot colour reproduction using a UV wide-format inkjet printer for digital package prototyping. A digital printing workflow for digital packaging production was established.

2. Experimental Design

Sets of test samples were prepared to study colour reproduction and process capabilities of four types of paperboards and one B-flute corrugated board, to examine the spot colour matching capability, and to establish a printing workflow for UV inkjet digital package prototyping.

Equipment and Materials

An EFI Vutek PV 200 UV inkjet printer with UV-curable inks was employed in this study. This printer uses UV-A spectrum light to cure the inks. The EFI Fiery XF RIP was employed to control the printing processes. Four commercially available paperboards and one corrugated board were tested, which included 12-point, 18-point, and 30-point of solid bleached sulfate (SBS) paperboards, 18-point coated recycled board (CRB), and one B-flute corrugated board. The colourimetric values of the tested paperboards and corrugated board are illustrated in Figure 1. Tested paperboards and corrugated boards have natural shades of paper white, with the exception of 12-point SBS paperboard, which contains an optical brightener agent (OBA).

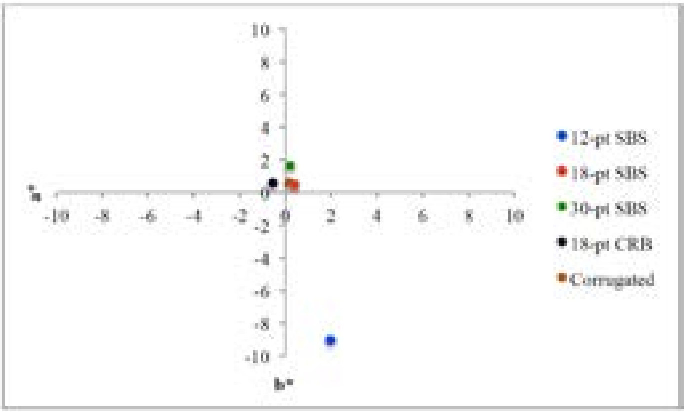

Figure 1: The colourimetric values (a* and b*) of tested paperboards and corrugated board

Test Target Design

Spot colours from the Pantone colour guide were used to design the spot colour test chart (Figure 2) for this study. L*a*b* values of Pantone colour swatches were used as target values. Adobe Illustrator CC 2014 was employed to generate the spot colour test chart in digital format. The spot colour test chart was saved as a PDF file.

Creating and Optimizing Profiles

The Fiery XF RIP provides a set of tools for improving the colour reproduction of output devices. For each tested paperboard and corrugated board, the tested charts were printed. The measurement device used in the study was an X-Rite i1iO Spectrophotometer. The following procedures were applied:

- Create a new base linearization file: a base linearization file forms the basis for a media profile, which contains details of the quantities of ink that are necessary to achieve the maximum density of colour for a specific combination of output device and media type.
- Create a media profile, which characterizes the tested paperboards and corrugated board.
- Load Pantone spot colour library so that spot colours can be automatically detected in Fiery XF RIP.

Print Modes

An EFI Vutek PV 200 UV inkjet printer was used in the study. The following print settings were kept consistent throughout the test runs:

- Shutter mode: double cure
- Lamp cure setting: medium
- Speed: standard
- Smoothing: heavy
- Printer output resolution: 360*600 dpi

Data Collection

Fifty test targets were printed and collected for each of the tested paperboards and corrugated board. Colour Reproduction Consistency and Process Capability Analysis.

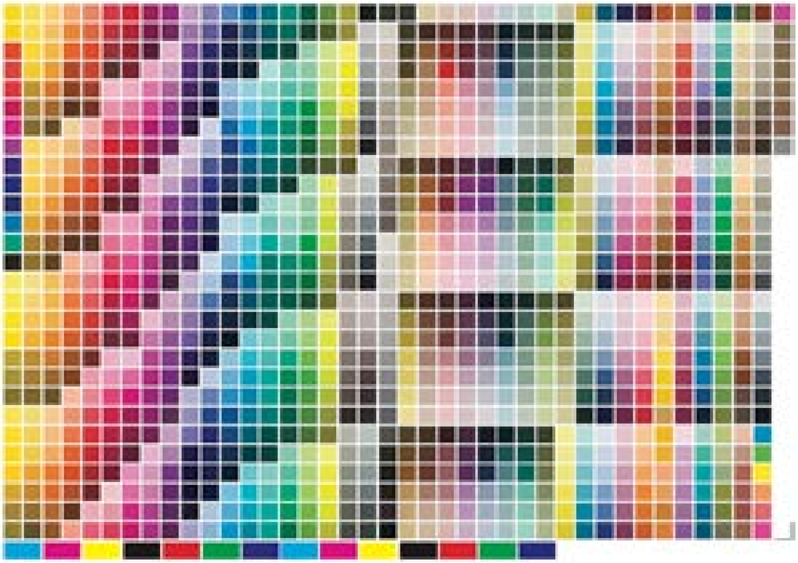

Figure 2: Spot Colour Test Chart

The colour reproduction consistency and capability of tested paperboards and corrugated board were discussed. This study uses the Cp index to measure process capability, which is defined as the ratio of the designated specification range to the individual paperboard and corrugated board process range, for optical density and colour gamut parameters. The Cp index is calculated as (upper specification limit - lower specification limit)/(6*Sigma). In other words, this ratio expresses the proportion of the range of the normal curve for each paper type that falls within those specification limits (Montgomery, 1997). For this study, a relative specification range was determined based on data for the selected paperboards and corrugated board and used to calculate the Cp indices, as described below.

Spot Colour Matching Capability Analysis
The spot colour test chart was measured by an X-Rite i1iO spectrophotometer at illuminant D50 and 2° observer. The quality of spot colour matching was evaluated in terms of the colour difference (ΔE2000) in L*a*b* colour space. The colour gamuts of the tested paperboards and corrugated board were compared using ColourThink Pro 3.0.3 software.

3. Colour-related Attributes

Tables 1 to 4 summarize descriptive statistics on the optical density values among the paperboards and corrugated board. The optical density values of the tested paperboards and corrugated board range from 1.54 to 1.80 for cyan (C), 1.23 to 1.30 for magenta (M), 0.76 to 0.83 for yellow (Y), and 1.56 to 1.87 for black (K). Among the tested paperboards and corrugated board, 18-point SBS paperboard has higher optical density values for colours cyan and black, while corrugated board has lower optical density values for colours cyan and yellow. 30-point SBS paperboard tends to have larger colour reproduction variability.

Factor	N	Mean	StDev	95% CI
SBS 12 point	50	1.62	0.05	(1.60, 1.64)
SBS 18 point	50	1.80	0.06	(1.78, 1.82)
SBS 30 point	50	1.60	0.05	(1.58, 1.62)
CRB 18 point	50	1.70	0.05	(1.68, 1.72)
Corrugated boards	50	1.55	0.04	(1.53, 1.57)

Table 1: Descriptive statistics for the cyan optical density

Factor	N	Mean	StDev	95% CI
SBS 12 point	50	1.28	0.02	(1.26, 1.29)
SBS 18 point	50	1.23	0.02	(1.22, 1.24)
SBS 30 point	50	1.28	0.04	(1.27, 1.29)
CRB 18 point	50	1.30	0.02	(129, 1.31)
Corrugated boards	50	1.28	0.03	(1.27 1.29)

Table 2: Descriptive statistics for the magenta optical density

Factor	N	Mean	StDev	95% CI
SBS 12 point	50	0.77	0.01	(0.76, 0.77)
SBS 18 point	50	0.76	0.01	(0.76, 0.77)
SBS 30 point	50	0.83	0.01	(0.83, 0.84)
CRB 18 point	50	0.81	0.01	(0.80, 0.81)
Corrugated boards	50	0.76	0.03	(0.75, 0.76)

Table 3: Descriptive statistics for the yellow optical density

Factor	N	Mean	StDev	95% CI
SBS 12 point	50	1.56	0.02	(1.55, 1.57)
SBS 18 point	50	1.87	0.02	(1.86, 1.88)
SBS 30 point	50	1.63	0.03	(1.62, 1.64)
CRB 18 point	50	1.73	0.02	(1.72, 1.74)
Corrugated boards	50	1.77	0.02	(1.76, 1.77)

Table 4: Descriptive statistics for the black optical density

Table 5 shows that the 12-point SBS paperboard produces a wider colour gamut. The 18-point CRB paperboard yields a smaller colour gamut. Overall, tested SBS paperboards produce wider colour gamut volumes, compared to 18-point CRB paperboard or corrugated board. However, 18-point CRB paperboard has smaller colour reproduction variability.

Factor	N	Mean	StDev	95% CI
SBS 12 point	50	281412	8485	(277699, 285124)
SBS 18 point	50	270686	5927	(266974, 274398)
SBS 30 point	50	276262	23975	(272550, 279974)
CRB 18 point	50	249494	1434	(245782, 253206)
Corrugated boards	50	250819	14281	(247107, 254531)

Table 5: Descriptive statistics for the colour gamut

4. Colour Reproduction Consistency and Process Capability Analysis

The following tools in the Minitab 16.0 software were used to analyze the consistency for optical density and colour gamut measurements: individual control charts, moving range charts, and capability analysis. The individual control charts and moving range charts were used to remove the outlier data. The capability analysis tool was used to calculate the Cp index for each paper type. In order to perform the capability analysis, lower specification limits (LSL) and upper specification limits (USL) are required input parameters. However, due to a lack of historical parameters of LSL and USL for colour-related attributes of paperboards and corrugated boards, relative specification limits were determined using test data. In this study, the LSL and USL for each attribute are determined based on the following procedures:

1. Construct the trial individual control chart and moving range chart of each attribute for the tested paperboards and corrugated board.

2. Examine control charts; if the data is in control, then use the lower control limit (LCL) and upper control limit (UCL) as the LSL and USL. If it is in out-of-control condition, reconstruct the control chart after eliminating all the outlier data in the

initial charts to obtain the revised values for mean, LCL, and UCL.

3. For each attribute, the difference between revised LCL and UCL of each paperboard/corrugated board obtained in the previous step is computed and named 6σ_revised, i.e., UCL_revised – LCL_revised = 6σ_revised. Then 3σ_revised of each paperboard/corrugated board is computed for the purpose of obtaining the "average 3σ_revised" of the four tested paperboards and one corrugated board, 3Ŝ_revised namely, i.e., 3Ŝ_revised = (3σ_revised_12-point SBS + 3σ_revised_18-point SBS + 3σ_revised_30-point SBS + 3σ_revised_18-point CRB + 3σ_revised_corrugated board) / 5

4. For each attribute, the final LSL and USL are obtained by subtracting from and adding to the 3Ŝ_revised, the revised mean of each paperboard/corrugated board, i.e.,
   LSL_final = Mean_revised – 3Ŝ_revised
   USL_final = Mean_revised + 3Ŝ_revised

5. The LSL_final and USL_final (as shown in Table 6) were used to assess the relative Process Capability Ratio (PCR) for the revised individual measurement control chart of each attribute for the tested paperboards and corrugated board.

Using LSLfinal and USL final values in Table 6, the relative Cp indices were calculated (as shown in Table 7). A higher Cp index indicates greater capability of delivering more consistent results in the printing process. As shown in Table 7, the corrugated board had the largest relative Cp index for optical density magenta (Cp = 1.35) and cyan (Cp = 1.32). The 12-point SBS paperboard had the largest relative Cp for the optical density yellow (Cp = 1.90), while 30-point SBS paperboard had the largest relative Cp for the optical density black (Cp = 1.90). It is interesting to note that the 18-point CRB paperboard had the largest relative Cp for the colour gamut (Cp = 2.69), followed by 12-point SBS (Cp = 2.48) and 18-point SBS (Cp = 2.23). That is, the 18-point CRB paperboard was the most capable paperboard for delivering consistent results in colour gamut. It was assumed that the tested 18-point CRB paperboard has a more uniform coating layer. The tested 12-point SBS and 18-point SBS paperboards also have capability for delivering consistent results in colour gamut.

		12 point SBS		18 point SBS		30 point SBS		18 point CRB		Corrugated	
		LSL	USL	LSL	USL	LSL	USL	LSL	USL	LSL	USL
Optical Density	Y	0.74	0.80	0.74	0.79	0.80	0.86	0.78	0.83	0.73	0.79
	M	1.21	1.34	1.17	1.29	1.22	1.34	1.24	1.36	1.23	1.35
	C	1.45	1.80	1.62	1.98	1.43	1.78	1.52	1.88	1.37	1.73
	K	1.49	1.63	1.80	1.94	1.57	1.70	1.66	1.80	1.70	1.83
Colour Gamut		271115	297192	259812	285889	274181	300258	236456	262533	237781	263858

Table 6: The LSL and USL for each attribute

		12 point SBS	18 point SBS	30 point SBS	18 point CRB	Corrugated
Optical Density	Y	**1.90**	0.95	1.68	0.85	0.61
	M	1.31	1.00	0.74	0.88	**1.35**
	C	0.85	0.91	1.16	0.91	**1.32**
	K	0.72	1.21	**1.26**	0.94	1.09
Colour Gamut		2.48	2.23	1.92	**2.69**	0.31

Table 7: The relative PCR (Cp) values for the tested paperboards and corrugated boards

5. Spot Colour Matching Analysis

Figure 3 illustrates the graphs of colour gamut with L*a*b* values of target spot colour data for the tested four paperboards and one corrugated board. Around 40-45% of Pantone spot colours are located within the colour gamut of tested paperboards and corrugated board. In other words, with limited colour gamut, those highly saturated spot colours will be difficult to be reproduced on those paperboards and corrugated board.

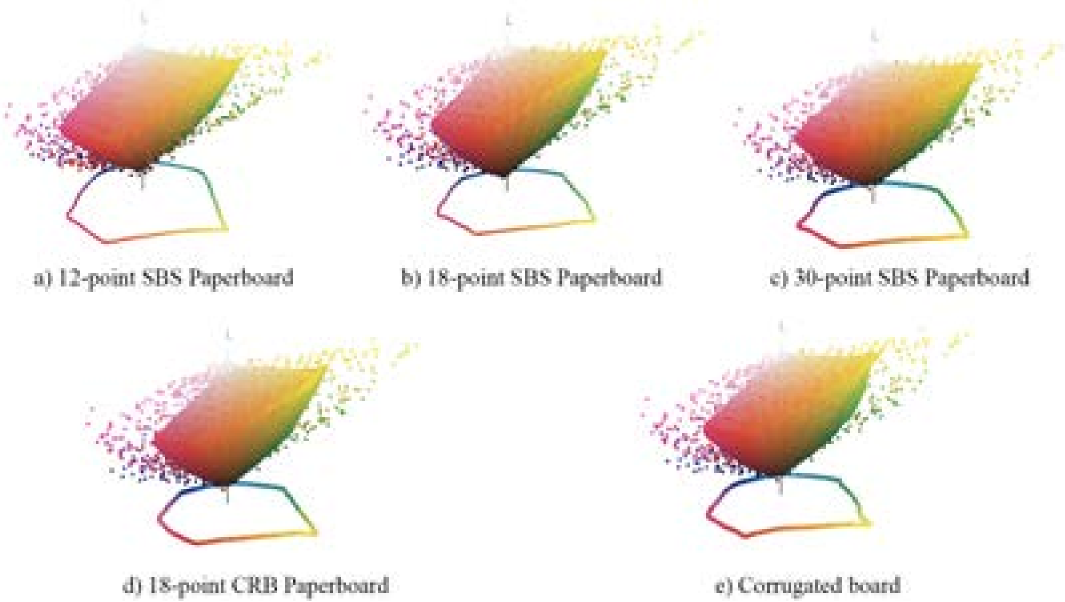

Figure 3: Colour Gamut of tested paperboards and corrugated boar (With L*a*b* values of spot colour original data for reference)

Figure 4 shows spot colour matching capability of tested paperboards and corrugated board. It shows that 30-point SBS paperboard can reproduce about 12% of Pantone spot colours with ΔE2000 lower than 4.0, while the 18-point SBS and 18-point CRB paperboards can only reproduce around 3% to 4.5% of Pantone spot colours with ΔE2000 lower than 4.0. Around 31% of Pantone spot colours can be reproduced with ΔE2000 lower than 8.0 when the 30-point SBS paperboard is used.

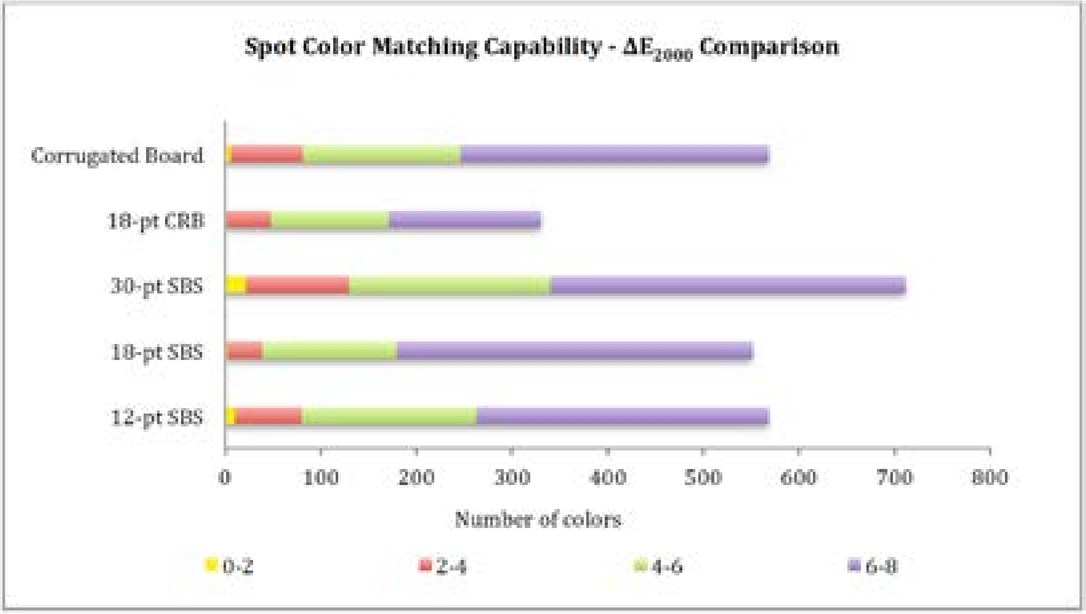

Figure 4: Spot colour matching capability for the teste paperboards and corrugated board

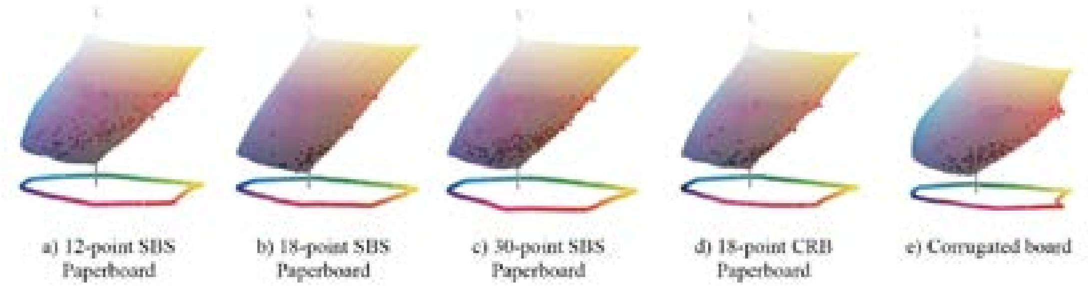

Figure 5: Colour gamut of tested paperboards and corrugated board (with ΔE_{2000} lower than 4.0)

6. Conclusions

Colour consistency is a must in packaging. Brand colours must be spot on. Printed with standard CMYK ink systems, the colour gamut volumes of tested paperboard and corrugated board are in the range of 249,500 and 282,000. With small colour gamut produced on the tested paperboards and corrugated board, spot colour matching capability is limited. It was found that the 12-point SBS, 18-point SBS, and 18-point CRB paperboard were capable paperboards for delivering consistent results in colour gamut. Spot colours with ΔE2000 lower than 4.0 can be found in the lower portion of the colour gamut. Overall, it was found that 30-point SBS paperboard has better spot colour matching capability (with 12% of spot colours having ΔE2000 lower than 4.0). Further investigation will include possible testing on a UV ink-jet printer with extended ink systems to pursue a wider colour gamut.

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