An Investigation on Print Color Difference for Major Digital Presses in Taiwan

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Abstract: Due to the great demand of the digital process in the printing industry, there is an increasing market for digital presses in Taiwan. Digital printing technology cannot only save printers' production time and cost, but also provide them with flexibility on the short-run, on-demand, and variable-data printing. It has become a major technology trend in the printing industry lately. Print quality is always an important issue associated with the technical development of any printing machine. One of the major quality concerns for most printers is the characteristic of the color reproduction for digital presses.

The purposes of the study were twofold: (1) it intended to investigate the print color differences (ΔE_{ab}) among the four digital presses commonly used by Taiwan's printers, Agfa Chromapress 50i, Indigo E-Print 1000, Xeikon DCP-50D, and MGI Digital Carte Master. (2) It also tried to compare the print color differences among VI digital, conventional (analog) offset (Heidelberg SpeedMaster 102-5), and hybrid (FI digital) presses (Heidelberg Quickmaster DI46-4). A digital test form was designed for the experiment. An experiment was conducted to investigate the values of L*a*b* in Y(Yellow), M(Magenta), C(Cyan), and K(Black) on the sampled sheets, which were printed by the six presses, respectively, and then, CIELab readings on those color patches at various tint values were obtained by an X-Rite 530 and the data were entered onto SPSS and Minitab for computing the color difference (ΔE_{ab}) for the presses. Fifty sheets were systematically random sampled from 100 printed sheets collected from each of the six presses after the presses were determined to be at equilibrium.

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The main conclusions are: (1) t-test results show that the ΔE values of all 12-press pairs in the tonal range from 50% to 90% tints are higher than those in other areas. Generally speaking, the greatest color difference (maximum ΔE) occurred at the 75% tint and the ΔE values increase as the tint values increase. (2). The mechanical design of the Agfa Chromapress 50i and Xeikon DCP 50D are very similar. The result shows that their color difference in YMCK is not significant. (3) The color difference between the hybrid press QuickMaster DI and MGI Digital Carte Master Color is much greater than that between the other press pairs. (4) The color difference performance of the four digital presses is not necessarily inferior to that of the traditional press, Speedmaster102-5; in fact, in some cases the color difference performance of the digital presses is comparable with that of the Speedmaster.

1. Introduction

The terminology digital printing has two basic versions: (1) fixed-image (FI—i.e., commonly DI for direct imaging or direct-to-plate-on-press) printing and (2) variable-image (VI—i.e., direct-to-paper using a digitally controlled imaging device) printing. In both case content is output from an electronic file direct to either a blanket plate on press or direct to paper (substrate). Both fixed and variable imaging printing technologies have been hyped by press manufacturers and the trade magazines as well as industry analysts as the future of print.

The 2002 GATF Technology Forecast shows that taking into account process shifts and volume changes, during the forecast period detailed in Table 1, gravure and flexographic volume is eroded, letterpress almost disappears, while screen and other plate processes are negatively impacted by digital printing. Both FI and VI digital printing increases their market share with explosive growth primarily at the expense of conventional analog lithography (Lamparter, 2002, pp.76-78).

According to Lampater's report, fixed-image (FI) digital printing will grow more slowly than previously forecast, capturing about 10% of total market volume by 2010-2015. Variable-imaging (VI) digital printing using several different processes, collectively called digitalography, is expected to explode over the next ten to fifteen years. It is the combination of FI and VI digital printing that is expected to exceed the volume of work produced by conventional or analog lithography by the 2010-2015 forecast period (Lamparter, 2002, p.75).

Table 1 U. S. Printing Process Market Share

2000-2015 (as a percent of producing printer sales dollars less substrate value)					
	Actual		Forecast		
Printing Processes	2000	2001	2003	2005	2010-2015
All Types of Lithography	48	>48	46	44	40
Conventional Lithography	>47	<47	44	39	30
Direct-Imaging (DI) Lithography i.e., fixed-image or direct-to-press	<1	>1	2	5	10
Gravure	16	16	16	14	11
Flexography	<21	<21	<21	>20	19
Letterpress	4	4	3	3	1
Screen & Other Plate Processes	>5	>5	<5	<5	4
On-Press Digitalography Variable-image printing i.e., direct-to-paper / substrate	6	>6	>9	14	25

Reference: "Press and Print Process." by William C. Lampater, 2002, 2002 GATF Technology Forecast, p.68. PA: Graphic Arts Technical Foundation.

1.1 Problem Statement and Purposes of the Study

The print quality has become a critical issue for digital presses since its technology has been mature and its market share has been increased significantly. Two of the quality issues mostly bothering printers are paper and color reproduction quality of digital presses. Especially the color reproduction consistency of digital presses has caused much trouble for printers. Some printers who have invested in the digital technology report that until now, the only draw back of digital presses has been color consistency (Richardson, 1999, p.1). Understanding the color reproduction differences among various digital presses, therefore, become a must for printers who are interested in investing in the digital technology. This is particularly true for Taiwan's printers. The attitude toward investing in the digital printing technology for most Taiwan's printers is still wait-and-see. There are less than ten digital presses in Taiwan now; one of the major obstacles to their investment is the lack of understanding about the differences in print color quality among various digital presses (both FI and VI) and the uncertainty of the color reproduction consistency of digital presses. Therefore the purposes of the study were to (1) investigate the print color differences (ΔE_{ab}) among the four digital presses used by Taiwan's printers, Agfa Chromapress 50i, Indigo E-Print 1000, Xeikon DCP-50D, and MGI Digital Carte Master; (2) compare the print color differences among VI digital, conventional (analog) offset (Heidelberg Speedmaster 102-5), and hybrid (FI digital) presses (Heidelberg Quickmaster DI46-4).

1.2 Assumptions of the Study

The following assumptions were made in the study:

1. There were no operator effects on color reproduction quality of the prints, although there was only one well-trained operator running each press system during the experiment.
2. There was no paper effect on color reproduction quality of the prints; this study did not provide a standard paper for the press runs because the six printers all have their own requirement for the paper substrate.
3. The paper used in the study for the six presses were all stored and shipped under the recommended conditions by the manufacturers before the experiment.

1.3 Limitations of the Study

The following limitations are important to interpret the conclusions and recommendations of this study:

1. Due to the limited availability of digital presses in Taiwan, there were only four digital presses (Agfa Chromapress 50i, Indigo E-Print 1000, Xeikon DCP-50D, and MGI Digital Carte Master) studied in this experiment.
2. The research used an X-Rite 530 spectrodensitometer to measure color instead of a colorimeter because most printers in Taiwan do not have colorimeters in house. The colorimetric readings might not be as useful as the densitometric reading for them in their practical operation.
3. Due to time constraint, each patch was read only once by the spectrodensitometer.
4. The material, production, and labor costs of the six presses were taken into account in this study. The main interest of the study was solely on the color difference among the presses.

2. Review of the Related Literature

The first digital presses were introduced at the IPEX show in 1993 by Indigo, Xeikon and Agfa. They caused a great deal of attention because they could print full-color pages without the need for film or plates and they had the ability to print various content from impression-to-impression ("Why Digital Printing Matters," 1999). Therefore, digital printing has character of shorten traditional printing process and variable data printing. Digital printing is a printing process—like gravure, flexography, or lithography-which utilizes a digital press to produce a final printed piece. Digital printing is typically characterized by: fast turnaround, color in short-run printing, high quality in small quantities, increased ROI, customization and personalization, narrower target markets, reduced obsolescence, tighter control of overruns that are vulnerable to change (Banta Corporation and GATF Staff, 1999, pp.37-38). Therefore, the development of digital printing has caught everyone's attention in recent years.

2.1 Heidelberg Quickmaster DI 46-4

At DRUPA 95, Heidelberg introduced its new four-color Quickmaster DI press with common impression cylinder, automated plate loading and press speed of 10,000 sheets per hour, or 233 A4 pages per minute (Bruno, 1995, p.13). Direct imaging (DI) presses, or so-called Fixed-Image (FI) presses, are designed to image cylinders on the press straight from electronic files, and usually all cylinders are imaged simultaneously. Generally speaking, direct imaging presses use conventional lithographic printing techniques (Richardson, 1999, p.2).

The makeready time of Quickmaster DI takes only 10-12 minutes. Combined with the prepress savings achieved in going direct to press, this result in cost savings of more than 65% and time saving of more than 80% compared to conventional offset production (Banta Corporation and GATF Staff, 1999, p.40). The resolutions for imaging the plates in the press are 1270dpi and 2540dpi. The 1270dpi resolution, corresponding to 50 dots per millimeter, is sufficient to print a 150lpi screen in offset quality (Heidelberg Quickmaster DI 46-4, p.6).

2.2 Indigo E-Print 1000

Indigo began developing its true, full color digital press a decade ago. The technology used in Indigo E-Print was under final development for at least three years before it was first introduced in June 1993. It uses the same principles as conventional offset printing, with plates, blankets, and impression cylinders and liquid ink. The image on the plate cylinder is transferred to the blanket surface and then is "offset" to the paper held on the impression cylinder (Romano and Fenton, 1998, pp.255-256).

The Indigo E-Print is a sheetfed digital offset press that prints four to six colors on most of the popular paper stocks at 800 dpi, 11 × 17 in. (279 × 432 mm) in size (A3), at 4,000 sheets per hour, at one color on one side, or 67 sheets per minute. Paper substrates for Indigo presses can be coated or uncoated, varying in thickness from very light sheets to card stocks (Romano & Fenton, 1998, p.255-256). Indigo's patented ink technology is named as ElectroInk. The pigments in ElectroInk are similar to those used in traditional offset inks, but there are two main differences: It acts electroststically (meaning it can be charged), and it drives very quickly (Banta Corporation and GATF Staff, 1999, pp.55-56).

2.3 Xeikon DCP-50D and Agfa Chromapress 50i

Xeikon is located in Belgium, which developed printing engine for AM Multigraphics, Agfa and IBM of North American. After Xeikon introducing the DCP engine, Agfa purchased the printing engine and renew the prepress system and RIP. Therefore, the printing engine of Agfa Chromapress 50i and Xeikon DCP-50D are very similar.

The heart of Agfa Chromapress 50i and Xeikon DCP-50D is a high-speed, four-color, perfecting digital web print unit. This design uses a 600dpi, variable-dot-density (64 gray levels) electrophotographic output engine, which is similar to laser printing, an LED array exposes the charged photoconductor drum to different levels of light, creating conductive areas on the drum (Romano and Fenton, 1998, p.240). Toner particles adhere to those areas, forming an image that is transferred to the paper. The drum is recharged with each rotation, so each sheet can be different. Imaged speed was 2100 pages up A4 size per hour with each side (An introduction to Digital Color Printing, p.4). The Chromapress and Xeikon DCP are capable of varying the printed information of each page on the fly. There are 16 different variable data fields for each page; text and graphics can be personalized (Romano and Fenton, 1998, pp.242-243).

2.4 MGI Digital Carte Master Color

MGI's Carte Master® COLOR is a variable data digital press with the two-stage double-sided printing design at a choice of feed mode of 210 mm or 8.5 inches paper rolls pool or automatic 2000 sheet loader on a wide range of substrate selection. It is also a waterless system using no volatile chemistry, films or plate processing. It uses a single workstation integrating digitizing, page layout, printing and an automated on-line multifunction finishing station (slitting, cutting, scoring, perforating) It means that the Carte Master® Color is the unique one-stop "digital press printing and finishing station" (Digital Carte Master Color).

The Digital Carte Master Color can print adhesive labels (white or colored, in various sizes) including logo and automatic sequential numbering or barcode. It is commonly used to print various types of announcements and menus, letterhead and envelopes, and business cards on short run ("The Product Digital Carte Master 12000® " 2002).

2.5 CIELAB Color

In 1976 the CIE introduced two new color space representations. They are the L*, a*, b* system (also known as CIELAB) and the L*, u*, v* system (also known as CIELUV). Both are more perceptually uniform than the original, X, Y, Z system. These systems are somewhat similar to the Hunter system in that a* or u* indicates redness-greenness and b* or v* indicates yellowness-blueness (Field, 1999, pp.89-90).

The CIELUV color space is recommended by the CIE for applications using additive color mixtures, whereas, the CIELAB color space is widely adopted for surface color measurement applications (e.g., printed products). This study used CIELAB ($L^*a^*b^*$) color model. The solids are obtained by plotting the three values along the axis at right angles to one another. The L^* value represents lightness. The a^* and b^* are the chromatic axes and they adopt the opponent response theory of color vision referred to a^*= red ↔ green, b^*= yellow ↔ blue. Figure 1 shows the CIELAB color space (Tritton, 1997, p.31-32).

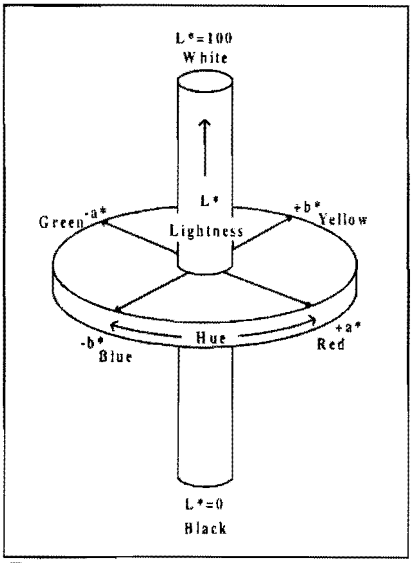

Figure 1. CIELAB color space
Reference: "Color Definition and Measurement," by Kelvin Tritton, 1997, Colour Control in Lithography, p.32. Pira International.

The ΔE value defines the overall color difference, which takes into account both lightness and chromatic differences, and is, therefore, suitable for identifying the permitted variation in color printing. To determine the ΔE^*_{ab}, we need to establish the ΔL^*, Δa^* and Δb^* between the reference and sample and then use the equation of total color difference (Tritton, 1997, pp.34-35). The calculation of the total color difference is given by:

$$\Delta E_{ab}^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$$

Table 2 indicates the ΔE values that might be applicable to different situations. According to Table 2, ΔE value under 4 is acceptable for most printing where side-by-side comparison is possible; above 8 indicates that there exists a significant visual difference between the reference and sample. In addition, Green (1999, p.42) stated that tolerance limits for printing special colors are typically set at around 4-8 ΔE units. Based on the above statements, this study gives the operational definition of significant color difference between two printed sheets when their ΔE value is above 8. The ΔE value of 8 was then used as the "test value" to perform "one sample t test" in the analysis section of this study.

Table 2 Color difference (ΔE) for typical classes of work

Color difference	Description
ΔE = 0.5 to 2	Critical color match, just perceptible
ΔE = 2 to 4	Acceptable for most printing where side by side comparison is possible
ΔE = 4 to 8	Acceptable color match where side by side comparison is not possible
ΔE = above 8	Significant visual difference

Reference: "Color definition and measurement," by Kelvin Tritton, 1997, Colour Control in Lithography, p.35. Pira International.

3. Methodology

This study was an experimental research in nature and intended to investigate the print color difference among major digital presses in Taiwan (both FI and VI printing technology). The study was also aimed to compare the print color difference of digital presses with that of analog offset presses. There were six presses used to run the experiment, categorized in three types, the conventional (analog) offset press, FI digital (hybrid) press, and VI digital presses. These six presses were Heidelberg Speedmaster 102 for the conventional (analog) offset press, Heidelberg Quickmaster DI 46-4 for the hybrid press, and Agfa Chromapress 50i, Indigo E-Print 1000, Xeikon DCP-50D and MGI Digital Carte Master Color for the VI digital presses.

3.1 Variables

The dependent variables of this study were the ΔE values of the sampled printed sheets. The independent variables were types of presses, including FI (hybrid) digital, VI digital, and conventional (analog) offset presses. The controlled variables included the digital test form, spectrodensitometer, room temperature and relative humidity, and operator for each press run. It should be noted that the operational procedure of each press run was standardized based on the press manufacture's recommendations during the experiment. In addition, the imagesetter to output the film for making the PS plates for Speedmaster 102 was linearized and not applied any compensation curves to the test form. The correct amount of time to expose the PS plates was determined by a UGRA Plate Control Wedge.

3.2 Sampling and Measuring Procedures

An experiment was conducted to investigate the values of L*a*b* in Y(Yellow), M(Magenta), C(Cyan), and K(Black) on the sampled sheets, which were printed by the six presses, respectively. A digital test form was designed for the experiment. One hundred printed sheets were collected for each press run after the press was determined to be at equilibrium, and 50 of them were systematically random sampled for the measurement. CIELab readings at various tints (10%, 25%, 50%, 75%, 90% tint) and color patches (cyan, magenta, yellow, black color) of the sampled sheets were then obtained by an X-Rite 530 Spectrodensitometer. The study decided to adopt the CIELab system developed by the CIE of France in 1931 because it has been internationally accepted as a standard for color specification and measurement. The data were then entered onto SPSS and Minitab for computing and analyzing the color difference (ΔE_{ab}) for the six presses.

4. Results and Findings

This section reports the hypothesis-testing results of one sample t test and other findings obtained through analyses of the data obtained from the experiment. The software packages employed to analyze the data were SPSS and Minitab. The alternative hypothesis of this study was stated as "there was a significant print color difference at various tints between the printed sheets of Press X and Press Y, that is, ΔE_{ab} value of two sampled printed sheets was significantly greater than 8. Illustrate the hypothesis in a statistical form:

Null Hypothesis: $\mu_{\Delta Exy} = 8$
Alternative Hypothesis: $\mu_{\Delta Exy} \neq 8$

For reasons of convenience and simplicity, some abbreviations used in this study have to be emphasized: *CP* stands for Agfa Chromapress 50i; *EP* for Indigo E-Print 1000; *DCP* for Xeikon DCP-50D; *MGI* for MGI Digital Carte Master Color; *SM* for Heidelberg Speedmaster 102; and *DI* for Heidelberg Quickmaster DI 46-4.

4.1 Color Difference Analyses for the Four Digital Presses

The overall results of one sample t test with the test value of 8 (t=8) at significant level of .05 (α=0.05) on the color difference (ΔE_{ab}) of Y, M, C, K color at each tint (10%, 25%, 50%, 75%, 90%) among the four digital (VI imaging) presses were summarized in Table 3 to Table 6.

Table 3 The results of one sample t test on ΔE_{ab} of *yellow* at each tint among digital presses (α=0.05)

Tint	CP & EP				CP & DCP				CP & MGI			
	p	Mean	95%CI		p	Mean	95%CI		p	Mean	95%CI	
			lower	upper			lower	upper			lower	upper
10	0.99	7.72	7.467	7.969	1.00	5.56	5.332	5.793	*0.00	17.06	16.818	17.309
25	0.99	7.60	7.283	7.924	1.00	2.32[b]	2.176	2.459	*0.00	16.19	15.739	16.642
50	1.00	5.48	4.856	6.097	1.00	4.95	4.514	5.390	0.98	7.49	6.971	7.998
75	1.00	6.09	5.486	6.691	1.00	3.77[b]	3.528	4.005	*0.00	12.17	11.761	12.581
90	1.00	7.24	6.888	7.591	1.00	4.47	4.298	4.650	1.00	5.14	4.739	5.536
Tint	EP & DCP				EP & MGI				DCP & MGI			
	p	Mean	95%CI		p	Mean	95%CI		p	Mean	95%CI	
			lower	upper			lower	upper			lower	upper
10	1.00	2.75[b]	2.598	2.907	*0.00	9.46	9.272	9.638	*0.00	11.86	11.676	12.038
25	1.00	6.91	6.593	7.231	*0.00	9.03	8.700	9.356	*0.00	15.55	15.114	15.980
50	.076	8.63	7.760	9.500	*0.00	12.21	11.541	12.875	1.00	4.77	4.370	5.167
75	1.00	6.94	6.215	7.663	*0.00	17.67	17.058	18.289	*0.00	11.13	10.703	11.564
90	0.66	7.93	7.583	8.272	1.00	5.51	5.392	5.623	*0.00	8.50	8.215	8.776

Note: CP: Agfa Chromapress 50i EP: Indigo E-Print 1000
DCP: Xeikon DCP 50D MGI: MGI Digital Carte Master Color
a: $0<\Delta E_{ab}\leq 2$, critical color match, just perceptible
b: $2<\Delta E_{ab}\leq 4$, acceptable for most printing
*: $\Delta E_{ab}>8$, significant visual difference

As shown in Table 3, there was no significant color difference in yellow between the printed sheets of CP and EP at all five tints. Likewise, the same result was found in the press pairs of CP & DCP and EP & DCP. On the other hand, there existed significant color difference in yellow patch between the printed sheets of CP and MGI at 10%, 25%, and 75% tints. Similarly, there existed significant color difference between the printed sheets of EP and MGI at three different tints at least. Moreover, the largest mean value of ΔE_{ab} occurred at the 75% tint of the press pair of EP and MGI. It is interesting to note that 10%, 25%, and 75% yellow of MGI samples significantly differed from those of CP, EP, and DCP. In other words, the print color differences of yellow at 10%, 25%, and 75% tints between MGI Digital Carte Master and Agfa Chromapress 50i, Indigo E-Print 1000, Xeikon DCP-50D were significant respectively.

According to Table 4, there was no significant color difference in magenta between the printed sheets of CP and DCP at all five tints. As to the press pairs of EP & CP and EP & DCP, there was no significant color difference in magenta at all five tints excluding the 50% tint of EP & CP pair (mean ΔE_{ab}= 9.73) and the 90% tint of EP & DCP pair (mean ΔE_{ab}= 10.33). On the other hand, there existed significant color difference in magenta between the printed sheets of MGI and CP, EP, DCP respectively at 25%, 50%, 75%, and 90% tints. Especially, the mean values of ΔE_{ab} between MGI & CP, MGI & EP, and MGI & DCP at the 50%, 75%, and 90% tints (midtone to shadow areas) were all higher than 20. This means that the print color differences of magenta in from midtones to shadows between MGI Digital Carte Master and Chromapress 50i, E-Print 1000, DCP-50D were relatively significant respectively.

Table 5 reveals that there was no significant color difference in cyan between the printed sheets of CP & DCP and CP & MGI press pair at all five tints. The similar results could be found in the pairs of EP & MGI, except at the 75% tint. As for the pairs of EP & CP and EP & DCP, there was no significant print color difference in cyan at the 25%, 50%, and 75% tints. Even if the mean values of ΔE_{ab} of those pairs at highlights (10% tints) and shadows (75% to 90%) were all higher than 8.0, their deviation from 8.0 are trivial. It appears that the print color differences of cyan among the four digital presses were not as significant as those of yellow and magenta.

Table 4 The results of one sample t test on ΔE_{ab} of *magenta* at each tint among digital presses (α=0.05)

Tint	CP & EP				CP & DCP				CP & MGI			
	p	Mean	95%CI		p	Mean	95%CI		p	Mean	95%CI	
			lower	upper			lower	upper			lower	upper
10	1.00	4.78	4.529	5.033	1.00	1.75[a]	1.652	1.846	1.00	6.09	5.959	6.219
25	1.00	2.61[b]	2.482	2.741	1.00	3.90[b]	3.616	4.184	*0.00	8.69	8.461	8.915
50	*0.00	9.73	9.161	10.295	1.00	6.25	5.876	6.617	*0.00	25.86	25.378	26.339
75	1.00	5.02	4.858	5.186	0.97	7.62	7.234	8.006	*0.00	27.10	26.737	27.466
90	1.00	7.29	7.010	7.568	1.00	5.45	5.203	5.692	*0.00	22.08	21.745	22.410
Tint	EP & DCP				EP & MGI				DCP & MGI			
	p	Mean	95%CI		p	Mean	95%CI		p	Mean	95%CI	
			lower	upper			lower	upper			lower	upper
10	1.00	4.86	4.656	5.054	1.00	5.13	5.041	5.213	1.00	6.72	6.607	6.823
25	1.00	2.87[b]	2.670	3.074	*0.00	9.23	9.091	9.370	*0.001	8.16	8.083	8.245
50	1.00	4.46	4.115	4.810	*0.00	20.47	20.116	20.831	*0.00	20.71	20.274	21.136
75	0.40	8.06	7.635	8.475	*0.00	27.20	26.891	27.506	*0.00	22.23	22.025	22.443
90	*0.00	10.33	10.232	10.421	*0.00	20.91	20.788	21.022	*0.00	20.40	20.293	20.507

Note: CP: Agfa Chromapress 50i EP: Indigo E-Print 1000
DCP: Xeikon DCP 50D MGI: MGI Digital Carte Master Color

Table 5 The results of one sample t test on ΔE_{ab} of *cyan* at each tint among digital presses (α=0.05)

Tint	CP & EP				CP & DCP				CP & MGI			
	p	Mean	95%CI		p	Mean	95%CI		p	Mean	95%CI	
			lower	upper			lower	upper			lower	upper
10	*0.00	9.03	8.790	9.270	1.00	2.23^{h}	2.143	2.306	1.00	6.45	6.289	6.611
25	1.00	2.484^{h}	2.262	2.707	1.00	3.852^{h}	3.712	3.992	1.00	6.021	5.798	6.243
50	0.83	7.795	7.375	8.215	1.00	5.398	5.191	5.606	1.00	7.202	6.848	7.555
75	1.00	6.960	6.815	7.104	1.00	3.377^{h}	3.184	3.570	1.00	7.289	7.061	7.516
90	*0.00	10.065	9.829	10.302	1.00	2.639^{h}	2.453	2.825	1.00	4.806	4.609	5.002

Tint	EP & DCP				EP & MGI				DCP & MGI			
	p	Mean	95%CI		p	Mean	95%CI		p	Mean	95%CI	
			lower	upper			lower	upper			lower	upper
10	*0.00	9.39	9.198	9.584	1.00	4.93	4.771	5.091	1.00	5.92	5.805	6.040
25	1.00	6.178	6.014	6.342	1.00	4.975	4.822	5.128	*0.00	8.485	8.313	8.656
50	1.00	7.059	6.855	7.262	1.00	4.198	4.098	4.298	1.00	4.368	4.220	4.517
75	*0.00	8.862	8.681	9.042	*0.00	8.889	8.743	9.035	1.00	5.294	5.097	5.491
90	1.00	7.715	7.573	7.857	1.00	7.546	7.418	7.674	1.00	3.682^{h}	3.510	3.853

Note: CP: Agfa Chromapress 50i EP: Indigo E-Print 1000
DCP: Xeikon DCP 50D MGI: MGI Digital Carte Master Color

Table 6 compares the print color difference of black among the four digital presses. As shown in Table 6, there was no significant color difference of black among the printed sheets of CP, EP, and DCP at all five tints. As to the press pairs of CP & MGI, EP & MGI, and DCP & MGI, there was one phenomenon in common; i.e., there existed significant print color difference of black at the 50%, 75%, and 90% tints. In particular, the mean values of ΔE_{ab} of those pairs at the three-quarter tone areas were fairly high ($\Delta E_{ab} \geq 18$). In summary, the print color differences of black in the midtone to shadow areas (50% to 90% tints) between MGI Digital Carte Master and Indigo E-Print 1000, Agfa Chromapress 50i, Xeikon DCP-50D were significant respectively.

Table 6 The results of one sample t test on ΔE_{ab} of *black* at each tint among digital presses (α=0.05)

Tint	CP & EP				CP & DCP				CP & MGI			
	p	Mean	95%CI		p	Mean	95%CI		p	Mean	95%CI	
			lower	upper			lower	upper			lower	upper
10	1.00	0.81 [a]	0.705	0.914	1.00	1.20 [a]	1.079	1.315	1.00	5.33	5.205	5.461
25	1.00	1.69 [a]	1.500	1.886	1.00	2.84 [b]	2.697	2.977	1.00	2.49 [b]	2.366	2.608
50	0.42	8.04	7.590	8.497	1.00	3.05 [b]	2.828	3.273	*0.00	18.34	18.014	18.670
75	1.00	2.67 [b]	2.360	2.969	1.00	4.80	4.633	4.960	*0.00	20.56	20.217	20.893
90	1.00	3.88 [b]	3.573	4.194	1.00	4.55	4.421	4.684	*0.00	13.17	12.815	13.519
Tint	EP & DCP				EP & MGI				DCP & MGI			
	p	Mean	95%CI		p	Mean	95%CI		p	Mean	95%CI	
			lower	upper			lower	upper			lower	upper
10	1.00	1.50 [a]	1.389	1.615	1.00	5.30	5.148	5.448	1.00	4.73	4.626	4.824
25	1.00	2.72 [b]	2.621	2.825	1.00	3.37 [b]	3.202	3.539	1.00	3.65 [b]	3.510	3.796
50	1.00	6.77	6.353	7.195	*0.00	10.33	9.994	10.663	*0.00	16.91	16.560	17.266
75	1.00	5.76	5.595	5.925	*0.00	18.60	18.141	19.061	*0.00	20.98	20.737	21.229
90	1.00	5.99	5.826	6.163	*0.00	10.21	9.856	10.554	*0.00	14.10	13.909	14.292

Note: CP: Agfa Chromapress 50i EP: Indigo E-Print 1000
DCP: Xeikon DCP 50D MGI: MGI Digital Carte Master Color

4.2 Color Difference Analyses between Heidelberg Quickmaster DI 46-4 and the four VI digital presses

The study compared not only the color difference among the four VI digital presses, but also that between a major FI and the four VI digital presses. Table 7 to Table 10 summarize the overall results of one sample t test with the test value of 8 (t=8) at significant level of .05 (α=0.05) on the color difference (ΔE_{ab}) of yellow (shown in Table 7), magenta (shown in Table 8), cyan (shown in Table 9), black (shown in Table 10) color at each tint (10%, 25%, 50%, 75%, 90%) between the Heidelberg Quickmaster DI 46-4 (FI) and four digital (VI imaging) presses.

Table 7 The results of one sample t test on ΔE_{ab} of *yellow* at each tint between Heidelberg Quickmaster DI 46-4 and digital presses (α=0.05)

Tint	DI & CP				DI & EP			
	p	Mean	95%CI		p	Mean	95%CI	
			lower	upper			lower	upper
10	0.070	8.15	7.950	8.344	1.00	1.11 a	0.966	1.263
25	*0.00	10.13	9.805	10.515	1.00	2.95 b	2.719	3.176
50	*0.00	14.873	14.872	15.329	*0.00	10.027	10.027	10.798
75	*0.00	15.55	15.118	15.988	*0.00	9.94	9.396	10.490
90	*0.00	13.24	12.884	13.598	*0.00	15.80	15.258	16.340
Tint	DI & DCP				DI & MGI			
	p	Mean	95%CI		p	Mean	95%CI	
			lower	upper			lower	upper
10	1.00	3.34 b	3.139	3.547	*0.00	9.26	9.072	9.447
25	*0.00	9.40	9.033	9.766	0.82	7.85	7.514	8.184
50	*0.00	18.424	18.424	18.972	*0.00	22.137	22.137	22.553
75	*0.00	15.92	15.252	16.578	*0.00	26.91	26.411	27.400
90	*0.00	9.51	9.028	9.988	*0.00	17.62	17.234	18.007

Note: CP: Agfa Chromapress 50i EP: Indigo E-Print 1000
DCP: Xeikon DCP 50D MGI: MGI Digital Carte Master Color
DI: Heidelberg Quickmaster DI 46-4

Table 7 shows that there were significant print color difference of yellow at 50%, 75%, and 95% tints between the Quickmaster DI and four VI digital presses. In addition, it appears that the color differences at highlights (10% tints) were less significant than those at shadows (75% to 95% tints).

Table 8 shows that there existed no significant color difference in magenta at all five tints of the press pairs of DI & CP and DI & DCP. As for the pair of DI & EP, the significant color difference of magenta occurred only at the 50% tint. On the other hand, there existed significant color difference of magenta at all the 5 tints excluding the 10% tint of the pair of DI and MGI.

Table 8 The results of one sample t test on ΔE_{ab} of *magenta* at each tint between Heidelberg Quickmaster DI 46-4 and digital presses (α=0.05)

Tint	DI & CP				DI & EP			
	p	Mean	95%CI		p	Mean	95%CI	
			lower	upper			lower	upper
10	1.00	2.87[b]	2.686	3.063	1.00	2.04[b]	1.868	2.221
25	1.00	3.08[b]	2.830	3.3213	1.00	4.08	3.869	4.2950
50	1.00	2.55[b]	2.302	2.799	*0.00	10.39	9.906	10.884
75	1.00	2.80[b]	2.626	2.976	1.00	3.07[b]	2.905	3.227
90	1.00	3.88[b]	3.573	4.191	1.00	4.09	3.832	4.345
Tint	DI & DCP				DI & MGI			
	p	Mean	95%CI		p	Mean	95%CI	
			lower	upper			lower	upper
10	1.00	3.18[b]	3.052	3.317	1.00	5.252	5.194	5.314
25	1.00	6.51	6.312	6.712	*0.00	10.91	10.630	11.182
50	1.00	7.64	7.403	7.880	*0.00	27.75	27.254	28.243
75	1.00	7.04	6.730	7.356	*0.00	27.03	26.746	27.310
90	1.00	7.13	7.036	7.217	*0.00	20.56	20.291	20.839

Note: CP: Agfa Chromapress 50i EP: Indigo E-Print 1000
DCP: Xeikon DCP 50D MGI: MGI Digital Carte Master Color
DI: Heidelberg Quickmaster DI 46-4

Table 9 shows that there were significant print color difference of cyan at 50% and 75% tints between the Quickmaster DI and four VI digital presses. It is interesting to note that that the color differences at highlights and quartertones were less significant than those at midtones and shadows.

Table 9 The results of one sample t test on ΔE_{ab} of *cyan* at each tint between Heidelberg Quickmaster DI 46-4 and digital presses (α=0.05)

Tint	DI & CP				DI & EP			
	p	Mean	95%CI		p	Mean	95%CI	
			lower	upper			lower	upper
10	1.00	4.26	4.088	4.426	1.00	4.80	4.565	5.027
25	1.00	6.55	6.301	6.793	1.00	4.59	4.351	4.835
50	*0.00	9.02	8.686	9.357	*0.00	14.98	14.589	15.368
75	*0.00	11.93	11.605	12.254	*0.00	9.24	9.012	9.463
90	*0.00	13.65	13.260	14.048	1.00	6.80	6.537	7.072
Tint	DI & DCP				DI & MGI			
	p	Mean	95%CI		p	Mean	95%CI	
			lower	upper			lower	upper
10	1.00	4.87	4.736	5.005	1.00	3.70[h]	3.625	3.774
25	*0.00	9.74	9.569	9.916	1.00	3.82[h]	3.742	3.902
50	*0.00	14.31	14.009	14.609	*0.00	15.66	15.344	15.977
75	*0.00	14.94	14.580	15.307	*0.00	17.32	17.087	17.549
90	*0.00	11.49	11.105	11.867	*0.00	13.10	12.834	13.369

Note: CP: Agfa Chromapress 50i EP: Indigo E-Print 1000
DCP: Xeikon DCP 50D MGI: MGI Digital Carte Master Color
DI: Heidelberg Quickmaster DI 46-4

Table 10 shows that there existed no significant color difference in black at all five tints of the pres pairs of DI & CP, DI & DCP, and DI & EP. As for the pair of DI & MGI, the significant color difference of black occurred only at from 50% to 95% tints.

From Table 7 to 10, it is important to mention that the color difference results of black between DI and the four VI digital presses are very similar to those of magenta. On the other hand, the color difference results of yellow and cyan are comparable.

Table 10 The results of one sample t test on ΔE_{ab} of *black* at each tint among Heidelberg Quickmaster DI 46-4 and digital presses (α=0.05)

Tint	DI & CP				DI & EP			
	p	Mean	95%CI		p	Mean	95%CI	
			lower	upper			lower	upper
10	1.00	2.50[b]	2.173	2.827	1.00	2.69[b]	2.400	2.978
25	1.00	3.56[b]	3.043	4.069	1.00	2.19[b]	1.766	2.624
50	1.00	6.54	5.651	7.360	1.00	2.77[b]	2.264	3.285
75	1.00	3.47[b]	2.771	4.159	1.00	2.93[b]	2.403	3.462
90	1.00	4.90	4.402	5.405	1.00	3.46[b]	3.153	3.765
Tint	DI & DCP				DI & MGI			
	p	Mean	95%CI		p	Mean	95%CI	
			lower	upper			lower	upper
10	1.00	2.72[b]	2.477	2.958	1.00	7.29	7.054	7.522
25	1.00	3.39[b]	3.109	3.666	1.00	4.61	4.163	5.066
50	1.00	5.53	4.878	6.189	*0.00	11.91	11.106	12.716
75	1.00	6.29	5.928	6.644	*0.00	17.45	16.792	18.107
90	1.00	7.21	6.967	7.449	*.006	8.46	8.107	8.822

Note: CP: Agfa Chromapress 50i EP: Indigo E-Print 1000
DCP: Xeikon DCP 50D MGI: MGI Digital Carte Master Color
DI: Heidelberg Quickmaster DI 46-4

4.3 Color Difference Analyses between Heidelberg Speedmaster 102-5 and four VI digital presses

One of the major purposes of this study was to investigate the print color difference between the conventional (analog) offset press and digital press. Due to the financial constraint, the conventional press used to run the experiment was limited to a Heidelberg Speedmaster 102-5. Table 11 to Table 14 summarize the overall results of one sample t test with the test value of 8 (t=8) at significant level of .05 (α=0.05) on the color difference (ΔE_{ab}) of yellow (shown in Table 11), magenta (shown in Table 12), cyan (shown in Table 13), black (shown in Table 14) color at each tint (10%, 25%, 50%, 75%, 90%) between Heidelberg Speedmaster 102-5 (analog) and four digital (VI imaging) presses.

Table 11 reveals an important result; that is, there were no significant print color differences of yellow at any of the five tints between the analog Speedmaster 102 and VI digital Agfa Chromapress, Indigo E-Print, and Xeikon DC. As for the yellow color difference between the Speedmaster 102 and MGI Digital Carte Master, the mean ΔE_{ab} value of this pair was greater than 8 at the 10%, 25%, and 75% tints.

Table 11 The results of one sample t test on ΔE_{ab} of *yellow* at each tint between Heidelberg Speedmaster 102-5 and four digital presses (α=0.05)

Tint	SM & CP				SM & EP			
	p	Mean	95%CI		p	Mean	95%CI	
			lower	upper			lower	upper
10	1.00	3.88^{b}	3.657	4.108	1.00	3.99^{b}	3.808	4.167
25	1.00	2.98^{b}	2.726	3.240	1.00	4.95	4.677	5.219
50	1.00	2.98^{b}	2.726	3.240	1.00	5.62	4.854	6.388
75	1.00	3.36^{b}	3.161	3.554	1.00	6.93	6.228	7.638
90	1.00	2.94^{b}	2.821	3.063	1.00	5.47	5.197	5.743
Tint	SM & DCP				SM & MGI			
	p	Mean	95%CI		P	Mean	95%CI	
			lower	upper			lower	upper
10	1.00	1.80^{a}	1.680	1.919	*0.00	13.32	13.193	13.449
25	1.00	2.12^{b}	1.891	2.342	*0.00	13.75	13.349	14.156
50	1.00	3.31^{b}	2.977	3.640	0.99	7.31	6.753	7.869
75	1.00	1.01^{a}	0.877	1.141	*0.00	10.96	10.637	11.279
90	1.00	2.99^{b}	2.728	3.247	1.00	5.67	5.515	5.829

Note: CP: Agfa Chromapress 50i EP: Indigo E-Print 1000
DCP: Xeikon DCP 50D MGI: MGI Digital Carte Master Color
SM: Heidelberg Speedmaster 102-5

Table 12 shows the print color difference results of magenta between Heidelberg Speedmaster 102-5 and the four VI digital presses. It reveals similar results to those of yellow color (see Table 10). According to Table 12, there were no significant print color differences of magenta for all five tints except for the 90% tints between the analog Speedmaster 102 and Agfa Chromapress, Indigo E-Print, and Xeikon DC. As for the magenta color difference between the SM & MGI pair, their mean ΔE_{ab} value was greater than 8 at 10%, 25%, and 75% tints; that is, the significant color difference of magenta occurred only at 10%, 25%, and 75% tint.

Table 12 The results of one sample t test on ΔE_{ab} of *magenta* at each tint between Heidelberg Speedmaster 102-5 and four digital presses (α=0.05)

Tint	SM & CP				SM & EP			
	p	Mean	95%CI		p	Mean	95%CI	
			lower	upper			lower	upper
10	1.00	1.52 [a]	1.393	1.641	1.00	4.23	4.042	4.426
25	1.00	1.72 [a]	1.483	1.949	1.00	2.35 [b]	2.220	2.473
50	1.00	4.44	4.046	4.827	1.00	6.59	6.171	7.000
75	0.89	7.75	7.330	8.161	1.00	7.46	7.075	7.836
90	*0.00	10.46	10.085	10.839	1.00	7.70	7.573	7.835
Tint	SM & DCP				SM & MGI			
	p	Mean	95%CI		p	Mean	95%CI	
			lower	upper			lower	upper
10	1.00	1.81 [a]	1.695	1.915	1.00	5.11	5.016	5.204
25	1.00	3.40 [b]	3.174	3.625	1.00	7.62	7.401	7.838
50	1.00	2.88 [b]	2.593	3.164	*0.00	21.82	21.357	22.275
75	1.00	5.49	5.280	5.697	*0.00	19.93	19.613	20.252
90	*0.00	10.64	10.513	10.765	*0.00	13.31	13.188	13.426

Note: CP: Agfa Chromapress 50i EP: Indigo E-Print 1000
DCP: Xeikon DCP 50D MGI: MGI Digital Carte Master Color
SM: Heidelberg Speedmaster 102-5

Table 13 shows the print color difference results of cyan between Speedmaster 102 and the four VI digital presses. According to Table 13, there were no significant print color differences of cyan at all five tints between the analog Speedmaster 102 and Agfa Chromapress, Indigo E-Print, and Xeikon DC, respectively, with two exceptions: 90% tint of SM & CP pair and 10% tint of SM & EP pair. Examining the mean ΔE_{ab} value for each pair, this study concludes that the print color at all five tints between Speedmaster 102-5 and the four VI presses tends to be no visual difference.

Table 13 The results of one sample t test on ΔE_{ab} of *cyan* at each tint between Heidelberg Speedmaster 102-5 and four digital presses (α=0.05)

Tint	SM & CP				SM & EP			
	p	Mean	95%CI		p	Mean	95%CI	
			lower	upper			lower	upper
s10	1.00	1.20[a]	1.111	1.294	*0.00	8.63	8.371	8.899
25	1.00	1.27[a]	1.135	1.415	1.00	2.19[b]	1.969	2.403
50	1.00	2.79[b]	2.508	3.075	1.00	5.86	5.446	6.274
75	1.00	5.66	5.479	5.872	1.00	2.40[b]	2.285	2.507
90	*0.00	9.68	9.423	9.937	1.00	2.50[b]	2.425	2.566

Tint	SM & DCP				SM & MGI			
	p	Mean	95%CI		p	Mean	95%CI	
			lower	upper			lower	upper
10	1.00	1.97[a]	1.855	2.088	1.00	5.68	5.551	5.818
25	1.00	4.45	4.323	4.584	1.00	5.53	5.279	5.781
50	1.00	5.64	5.767	6.117	1.00	6.07	5.684	6.461
75	1.00	7.38	7.152	7.605	.056	8.17	7.957	8.388
90	1.00	7.22	7.034	7.413	1.00	7.31	7.202	7.419

Note: CP: Agfa Chromapress 50i EP: Indigo E-Print 1000
DCP: Xeikon DCP 50D MGI: MGI Digital Carte Master Color
SM: Heidelberg Speedmaster 102-5

Table 14 shows the print color difference results of black between Heidelberg Speedmaster 102-5 and the four VI digital presses. It illustrates that there were significant print color differences of black in shadow areas (75% to 90% tints) between the Speedmaster and Agfa Chromapress, Indigo E-Print, and Xeikon DC respectively. As for the black color difference between SM & MGI, the mean ΔE_{ab} value of this pair was all less than 8 at the five tints; in other words, the significant print color difference of black at any tint value was not found between Heidelberg Speedmaster 102-5 and MGI Digital Carte Master.

Table 14 The results of one sample t test on ΔE_{ab} of *black* at each tint between Heidelberg Speedmaster 102-5 and four digital presses (α=0.05)

Tint	SM & CP				SM & EP			
	p	Mean	95%CI		p	Mean	95%CI	
			lower	upper			lower	upper
10	1.00	2.37[b]	2.142	2.603	1.00	2.62[b]	2.359	2.872
25	1.00	5.01	4.602	5.417	1.00	3.48[b]	3.083	3.868
50	*0.00	11.43	10.671	12.196	1.00	3.57[b]	2.867	4.266
75	*0.00	12.88	12.318	13.441	*0.00	10.96	10.316	11.601
90	*0.00	12.97	12.594	13.353	*0.00	9.93	9.500	10.353
Tint	SM & DCP				SM & MGI			
	p	Mean	95%CI		p	Mean	95%CI	
			lower	upper			lower	upper
10	1.00	2.56[b]	2.379	2.731	1.00	7.14	6.972	7.309
25	1.00	4.16	3.884	4.440	1.00	6.09	5.723	6.458
50	*0.00	10.02	9.388	10.644	1.00	6.96	6.307	7.614
75	*0.00	13.57	13.151	13.981	0.93	7.68	7.259	8.105
90	*0.00	13.85	13.606	14.103	1.00	0.91[a]	0.768	1.046

Note: CP: Agfa Chromapress 50i EP: Indigo E-Print 1000
DCP: Xeikon DCP 50D MGI: MGI Digital Carte Master Color
SM: Heidelberg Speedmaster 102-5

4.4 Color Difference Analyses for Heidelberg Speedmaster 102-5 and Heidelberg Quickmaster DI 46-4

The overall results of one sample t test with the test value of 8 (t=8) at significant level of .05 (α=0.05) on the color difference (ΔE_{ab}) of Y, M, C, K color between the conventional offset Heidelberg Speedmaster 102-5 and FI digital Heidelberg Quickmaster DI 46-4 were summarized in Table 15. As shown in Table 15, the print color differences were not significant at 10% and 25% tints between theses two presses in all Y. M. C. K colors. Particularly, there existed no print color difference at all five tints in magenta. It is interesting to note that the color difference is generally lesser in highlights and quartertones between the two presses, but greater in from midtones to shadows; that is, the color difference tends to become significant after midtones except the magenta color.

Table 15 The results of one sample t test on ΔE_{ab} of yellow, magenta, cyan, and black at each tint between Heidelberg Speedmaster 102-5 and Quickmaster DI 46-4 (α=0.05)

SM & DI (C)					SM & DI (M)			
Tint	p	Mean	95%CI		p	Mean	95%CI	
			lower	upper			lower	upper
10	1.00	3.95[b]	3.786	4.108	1.00	2.63[b]	2.457	2.808
25	1.00	6.25	5.978	6.519	1.00	3.88[b]	3.588	4.169
50	*0.00	9.72	9.312	10.134	1.00	6.01	5.692	6.334
75	*0.00	9.43	9.174	9.691	1.00	7.24	6.888	7.585
90	1.00	6.92	6.695	7:142	0.58	13.31	7.720	8.228
SM & DI (Y)					SM & DI (K)			
Tint	p	Mean	95%CI		p	Mean	95%CI	
			lower	upper			lower	upper
10	1.00	4.51	4.298	4.726	1.00	4.51	4.298	4.726
25	1.00	7.43	7.105	7.761	1.00	7.43	7.105	7.761
50	*0.00	15.19	14.660	15.714	*0.00	15.19	14.660	15.714
75	*0.00	16.02	15.480	16.567	*0.00	16.02	15.480	16.567
90	*0.00	12.10	11.738	12.471	*0.00	12.10	11.738	12.471

Note: SM: Heidelberg Speedmaster 102-5
DI: Heidelberg Quickmaster DI 46-4

5. Conclusions and Recommendations

From Table 3 to Table 15, the following main conclusions can be drawn:

1. Overall t test results show that the ΔE_{ab} values of all 12-press pairs in the tonal range from 50% to 90% tints are higher than those in other tonal areas. Generally speaking, the greatest color difference (maximum ΔE_{ab}) occurred at the 75% tint and the mean ΔE_{ab} values tend to increase as the tint values increase.
2. The VI digital presses Agfa Chromapress 50i and Xeikon DCP 50D both use dry toner and are similar in mechanical design. The result shows that their print color difference in yellow, magenta, cyan, and black tends to be not significant. The print color differences in Y, M, C, K of this press pair (CP & DCP) appears to be smaller than those of the other five VI press pairs (CP & EP, CP & MGI, EP & DCP, EP & MGI, and DCP & MGI) (see Table 3 to Table 6).
3. From Table 3 to Table 6, the print color differences of the MGI & DCP and MGI & CP press pairs are greater than those of the other four VI digital press pairs (CP & EP, CP & DCP, EP & DCP, and EP & MGI) (see Table 3 to Table 6).
4. Generally speaking, the print color differences of Y. M. C. K between Quickmaster DI (FI digital press) and the VI digital presses (CP, EP, DCP, MGI) were less significant at from the highlights to quartertones than from the midtones to shadows (see Table 7 to Table 10). Additionally, the color

difference results of black between Quickmaster DI and the four VI digital presses are very similar to those of magenta; the color difference results of yellow and cyan are also comparable.

5. Table 11 to Table 14 compare the print color differences of Y. M. C. K between the conventional offset (analog) Speedmaster 102-5 (SM) and the four VI digital presses. The overall results indicate that the print color difference of SM & EP (Indigo E-Print) press pair is less than that of the other three press pairs, SM & CP, SM & DCP, and SM & MGI (see Table 11 to Table 14).
6. As for the color difference phenomenon between DI and analog presses, the study found that the maximum ΔE_{ab} values of the Speedmaster 102-5 (conventional offset) and Quickmaster DI 46-4 (FI digital) in M, C, K color are all lower than 10.0 excluding the 90% of magenta (ΔE_{ab}=13.31). Furthermore, the mean ΔE_{ab} values of the two presses in Y. M, C, K at the 10% and 25% tints are even lower than 8.00 (see Table 15).
7. The color reproduction performance of the four VI digital presses is not necessarily inferior to that of the conventional (analog) offset press Speedmaster102-5; in fact, in some cases the color reproduction performance of the digital presses is comparable with that of the traditional Speedmaster in terms of color difference.

According to the results, this study proposes the following recommendations for further studies:

1. Due to the constraint of research instrument, an X-Rite 530 was used in this study to measure the L*a*b value of color patches of every single color. The study suggests that further researchers might want to use Spectrophotometer, such as Gretag Macbeth Spectrolino, to measure L*a*b* and L*C*h° values of color patches in combination with automatically scanning methods.
2. Since the selection of paper was very critical for digital print quality, the study recommends that printers should conduct experiments to find out the most suitable paper for every kind of digital presses by using different papers for digital presses.
3. The ink used by digital presses was most of electronic ink, which had to be imported from other countries currently in Taiwan. Therefore, the study suggests that further studies should be conducted to produce and test domestic inks for various digital presses to find out the most suitable ink for every type of digital presses. In addition, a series of paper and ink standard combinations should be established by suppliers for their printers to improve their digital printing quality.

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