An Experimental Study to Identify Key Factors Affecting Dot Reproduction on CD Decoration Using UV Offset Printing

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Abstract: The main purposes of this experimental study were to (1) identify the most important factors that influence dot gain of CD-ROM decoration using the UV waterless offset press, and (2) establish optimum process operating conditions so that the minimum yield of dot gain and maximum yield of print contrast could be obtained. The experiment was conducted using a randomized 2^3 factorial design on a waterless offset press using UV inks at a major CD manufacturing and printing plant in Taiwan.

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A total of 800 printed discs were gathered and 50 of them were systematically sampled for each of the eight treatment combinations for a total sample size of 400 (8*50). Overall the results suggested that the interaction effect of the blanket-to-disc pressure and cooling system temperature was the dominant variable affecting on-press dot gain and print contrast. The interaction effect was found to be a significant variable to almost all observations. The study also found that the greatest print contrast and least dot gain could be achieved when the blanket-to-disc pressure was established at 2.95mm and the cooling system temperature was set at 17 °C on the press, while controlling for all other variables. To obtain the widest tonal range in shadows, the press operating condition should be established as: press speed = 50discs/min, blanket-to-disc pressure = 2.95mm, and temperature of the cooling system = 17 °C, while controlling for all other variables.

1. Introduction

Recently, compact disc decorating has become an area of extreme interest for the printers in Taiwan due to the increasing need of the digital market. One of the most exciting developments in compact disc printing over the past two years has been the use of offset printing. CD replicators typically rely on three printing processes to accomplish their disc-printing work—pad printing, screen print, and offset printing. There has been a growing popularity in offset printing for compact discs, especially CD-ROM, not only because of the quality of image that can be achieved but also for several technical reasons which inhibit screen printing on this new format. The ultraviolet (UV) waterless offset printing, an emerging segment of this market, is drawing more and more attention in CD, label and packaging printing. The main considerations of adopting UV waterless offset decorating are for "magazine" quality graphics, economy with longer runs, and finer screen resolution and register.

1.1 Purposes of the Study

This research was an experimental study in nature. Its main purposes were twofold: (1) identify the key factors influencing dot gain, print contrast, and solid ink density of compact disc decorating on the press using a waterless offset presses; (2) establish optimum press operating conditions so that the minimum yield of dot gain and maximum yield of print contrast could be obtained. This experimental study utilized a randomized 2^3 factorial design in which every factor was run at two specified levels (1 = high level, -1 = low level, fixed effects). The factorial levels were determined based upon the practical operating conditions of the waterless offset presses at a major compact disc replicator and printing plant in Taiwan.

1.2 Assumptions of the Study

The following assumptions were made in this study:

1. There were no operator effects on solid ink density, print contrast, and dot gain although only one experienced operator ran the press during the experiment.
2. All the eight sets of plates selected for the press runs had the same readings on dot areas, so that dot gain from the film to the plates remained standardized.
3. The performances of the blankets and ink used for the eight press runs were the same.
4. Since the pressroom temperature and relative humidity were controlled, there were no temperature and humidity effects on discs, ink, and the press.

2. Review of Related Literature

This section will begin with an introduction of CD family and its construction. A typical CD-R family and its application is displayed in Table 1, and a cross section view of CD-R discs is exhibited in Figure 1.

Table 1. Format and application of CD family

FAMILY	FORMAT	CAPACITY		APPLICATION
CD (Compact Disc)	CD-Audio	74min	650MB	Digitalized music – for example, albums from like Kenny G, Tony Braxton, Whitney Houston ,etc.
	Video-CD			Digitalized films – for example, Gone with Wind or music videos.
	CD-I, G			Interactive films – for example, the instruction for computer programs
	CD-Mixed Mode			Computer games
	CD-Extra, -Plus			Be able to be read by non-computer disc players
	CD-ROM			Software programs – for example, the operating system disc for Win98

[On-Line]. Available: http://www.infodisc.com.tw/english/profile/content2.htm

As shown in Figure 1, the CD-R discs are made up of four basic layers beginning with the largest which is an injection molded polycarbonate plastic substrate. On top of the substrate is a sensitive organic dye recording layer (cyanine, pthalocyanine or azo), then a thin metal reflective layer (gold or silver alloy) followed by an outer protective lacquer coating. Unlike a prerecorded molded CD, the substrate of a CD-R disc does not contain a spiral track of pits and lands. Indeed, it contains a shallow spiral groove that extends from the inside to the outside diameter of the disc that is used by the CD-Recorder for motor control, tracking and focus as well as for obtaining address and other encoded information. Rather than having the data molded into the substrate as series of pits and lands at the factory, user write data to the CD-R disc with a CD-Recorder which employs a high power laser to heat and alter the dye in the groove to create a pattern of features that simulate the pits of a prerecorded disc ("DVD-R" 1998, p. 60).

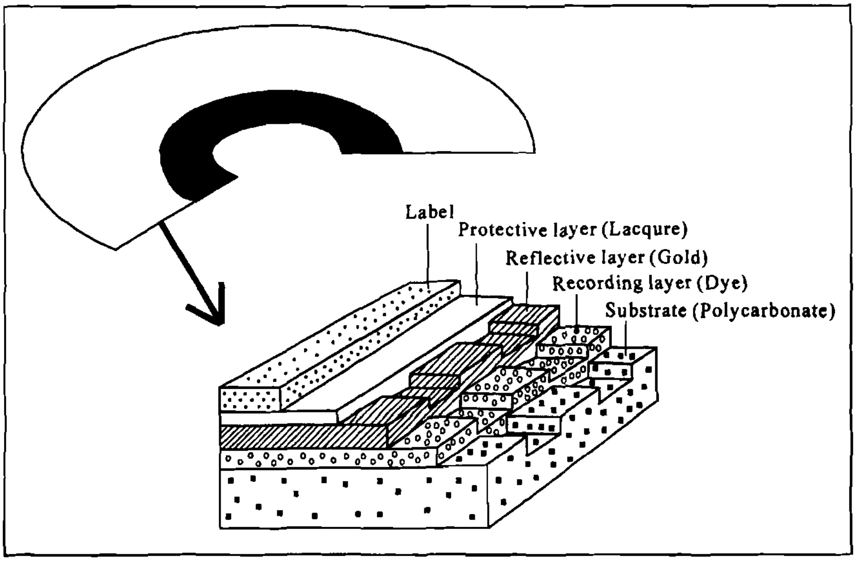

Figure 1. Cross section of CD-R disc

Source: "DVD-R: The new Kid on the Block", 1998, Audio Video & Broadcasting Studio System, p. 60

2.1 Compact Disc Printing Methods

Consumers usually pay little attention to what's printed on a music CD because in most cases it's just the song titles. But as CD-Audio and CD-ROM publishers follow their quests to be noticed among the never-ending flow of titles being released, disc printing has become an area of extreme interest. The CD replicators typically utilize three printing processes to accomplish their disc-printing work—pad printing, screen print, and offset printing.

Pad printing

Pad printing – of the "rubber stamp" method – is the cheapest from of printing and offers the benefit of using less ink than does screen printing. It is a process utilizing a flexible pad to imprint an object. The process was used extensively from 1985 to 1989 to imprint CDs. Today pad printing has been replaced by screen printing, which offers better resolution, does not require a solvent, and has a much faster cycle time. However, the use of a flexible pad to conform to the shape of an object makes it better than screen printing to print on irregular shapes (Block, 1997, p. 44).

Screen printing

Today screen printing is by far the most commonly used method, but the relative cheapness and simplicity of pad printing made it a more popular choice in the early days of CD and CD-ROM. Screen printing offers a viable alternative to pad printing because it allows more colors to be printed on a disc and colors themselves are more vibrant. New developments have emerged in screen-making technology in recent years. New screen fabrics with higher mesh counts and smaller thread diameters have been produced in plain weave configuration. These newer mesh specifications allow printers to print much finer halftone line counts than conventional screen printing methods allow. Screen printing inks have always been a strength of this process. Theoretically, any liquid material that can be forced through screen mesh is printable. Another benefit is that with screen printing, variation of ink deposit can be easily controlled and predicted by using different screen meshes, which becomes necessary when printing lighter colors that need a great deal of opacity against the metallic surface. (Block, 1997, pp. 44-46).

Offset printing

One of the most exciting developments in compact disc printing over the past few years has been the adoption of offset printing; offering unmatched quality and resolution for "picture" type printing. The disadvantage of screen printing is its limitation in providing picture-quality graphics. Although 150 lpi screen printing can be done, 120 or less is more common. In fact, most screen printers like to keep that resolution to 85 lpi to get the best possible picture quality. Printing on plastic, which has qualities different from paper, prevents getting the higher resolution that magazines typically are able to achieve with offset printing, from 100 to 150 lpi. Unlike screen printing, offset printers from each manufacturer are all different. As for set-up times, offset tends to take longer than screen printing, expect for setting up four-color processes. Prepress is the key to quick changeover to different graphics and different disc runs. It is important that plates are made in precise register to each other and that film separations are made to reflect properly the density requirements of each color. Screen printing, on the other hand, allows for on-press color correction. Generally, offset printing is a wet-on-wet process, which is what some replicators do not like about the process because colors can begin to bleed (Block, 1997, p. 46).

2.2 Offset printing V.S. screen printing

The market acceptance of screen printing, especially process work, has been quite good, and we have seen the four-color process evolve in screen printing and show good quality. But, the limitations of the screen printing process have pushed offset press manufacturers to develop improvements to current offset decorating methods. The objective of the offset press manufacturer is not only to provide equipment that produces excellent print quality, but also to offer this system with economics built in so that the process can be affordable to operate. From the viewpoint of economics, ink consumption using offset is four to five times less, and other expendable materials used in offset are far less costly than those used for screen printing. Thus, there is a trend that offset is being pursued as the primary method for printing DVDs (Rao, 1998, p. 39).

Hans P. Lueters (personal communication, August 5, 1999) said that with screen printing, due to the nature of the process, it is possible to achieve an image resolution ranging from approximately 100 to 125 lpi, a so-called newspaper quality, which is acceptable in most cases. If the artwork, however, requires a higher image resolution, the alternative is the offset printing process, offering around 200 lpi or even higher resolutions up to 300 lpi, the so-called magazine quality. However, screen printing allows the use of special colors for special effects, for example, fluorescent or metallic inks, which cannot be done by offset printing. This is also one of the reasons why there are at least two screen printing stations on any offset press, which enable the pre-printing of a white base color and the overprinting with either varnish or any special colors. Arthur W. Lefebvre (1998, p. 22), the executive director of Waterless Printing Association, stated that:

> Ultraviolet (UV) waterless, an emerging segment of this market, is primarily used for CDs, labels and packaging, and it is rapidly displacing flexography as the ideal printing method for these products.

Moreover, Arthur W. Lefebvre (personal communication, July 26, 1999) said that there are a number of CD printers using UV waterless offset technology in the USA, Italy and elsewhere. The advantages for CD-ROM are the same as for conventional printing, higher screen rulings, better print quality etc.

3. Methodology

This study is considered truly experimental in nature. It utilized a randomized 2^3 factorial design in which every factor was run at two specified levels (fixed effects) determined based upon the practical operating conditions using a Kammann UV waterless offset press, at a major CD manufacturing and printing plant in Taiwan. The three factors were press speed (X_1), blanket-to-impression (disc) pressure (X_2), and temperature of the cooling system (X_3). This resulted in a total of eight different treatment combinations (press runs).

3.1 Experimental Design

Table 2 depicts the 2^3 factorial design which contains eight treatment combinations. The run order for the eight treatment combinations was randomly determined by computer (randomized design) to reduce bias introduced by unplanned changes in the experiment. One hundred CD-ROM discs were printed for each press combination after the desired solid ink density being achieved. Therefore, a total of 800 (8*100) discs were printed, then, 50 discs were systematically sampled for each of the eight treatment combinations for a total sample size of 400 (8*50). An X-Rite 528 spectrodensitometer was employed to read the sampled discs.

Table 2. 2^3 factorial design

	Low Speed		High Speed	
	Low Pressure	High Pressure	Low Pressure	High Pressure
Low Temperature				
High Temperature				

Factors	Factor Level	
	—	+
Press Speed (X_1)	40strokes/min	50strokes/min
Blanket-to-disc Pressure (X_2)	2.75mm	2.95mm
Cooling System Temperature (X_3)	13 °C	17 °C

The primary considerations of choosing a factorial design for this experiment include: 1) it was more efficient than one-factor-at-a-time experiments; 2) it was necessary because the factor interactions may be present; and 3) it allowed the effects of a factor to be estimated at two levels of the other factors, yielding conclusions that would be valid over a broad range of experimental conditions (Montgomery, 1997, pp. 512-516).

3.2 Variables of the Study

There are many variables affecting dot gain from film to plate to printed substrate, and most of them are interdependent. It is not possible to study all the variables at the same time. One delimitation of this study was that only those variables suspected of significantly affecting dot gain on offset presses were investigated (experimental variables) and those variables controlled for in everyday practice or other than press factors were held constant. Table 3 summarizes the experimental variables and variables that were controlled and how they were controlled.

Table 3. Experimental and Controlled Variables

Variables	Materials and Equipments	Type
Dot shape	Euclideau	Controlled
Line screen	175 lines per inch (lpi)	Controlled
Imagesetter	Screen FT-R 3050	Controlled
Press	Werner Kammann offset press K-15	Controlled
Substrate	Compact Disc (118*17mm)	Controlled
Plate	Toray waterless offset plate (negative working)	Controlled
Ink	Ruco UV Ink	Controlled
Printing color sequence	K-C-M-Y	Controlled
Exposure control	UGRA plate control wedge, 1300 exposure units	Controlled
Developer	Koning Offset Developer, Temperature 42 °C	Controlled
Blanket	WV transferring blanket	Controlled
Press speed	50 (+), 40 (–) strokes per min	*Experimental*
Plate-to-blanket pressure	3mm	Controlled
Blanket-to-disc pressure	2.95 mm (+), 2.75mm (–)	*Experimental*
Temperature of the cooling system	17 °C (+), 13 °C (–)	*Experimental*
Press room temperature	23 °C	Controlled
Pressure room RH	45-50%	Controlled
Press operator	One experienced operator	Controlled

3.3 Experimental Process and Data Collection

Film output

The imagesetter utilized to output the computer-generated film for this experiment was calibrated and linearized before the experiment. The imagesetter was Screen FT-R 3050, and the measurement of dot area on the film was done with an X-Rite® 361DTP, a transmission densitometer. This densitometer was also used for the imagesetter calibration and linearization. Measuring dot areas on the film generated by the imagesetter using an X-Rite® 361DTP transmission densitometer was an important procedure to insure that the imagesetter was linearized. In other words, there was zero gain for the dots on the computer-generated film because the imagesetter was verified to be at a stage of linearization. For example, 50% dots on the film were read as 50% by the transmission densitometer.

Platemaking

The 2^3 factorial design resulted in eight process-color press runs, which required 32 (8*4) printing plates for the experiment. The offset plates used in this study were Toray waterless offset plate (negative-working). Ten plates were exposed for each process color, therefore, a total of 40 (10 sets of CMYK) were made. Extreme care was taken to standardize the exposure time and development time to achieve the same percentage of dot gain for all of the plates that were used to run the experiment. The UGRA Plate Control Wedge was used to standardize the exposure amount for the plates, and the standardized amount was 1300 units. In addition, an ACME Plate Dot Reader was utilized to read the 50% tints (five times for each 50% patch) of the plates to obtain the midtone dot areas for the purpose of selecting the plates for press runs. The plate dot area readings were then recorded and analyzed for the purpose of assessing the consistency of the platemaking process. The result showed that the platemaking process was very consistent and the best eight sets of plates were determined statistically using X-bar/R control charts by Minitab software package.

Printing

Two print tests were run with the first operation serving as a pilot test to familiarize the press operator with printing the test form, while the second operation served as the actual printing experiment where printed discs were sampled. After each press run, the press was shut down and cleaned, the run counter was set to zero, and the desired materials and conditions were made ready for the next run. Before applying the process color, a white ink film was printed by a screen printing unit built into the press. During each press run, the ink density was balanced out across the discs to 1.0 for the yellow, 1.4 for the magenta, 1.3 for the cyan, and 1.5 for the black.

Measuring and data collection

One hundred printed compact discs were collected for each press run after the press was determined to be at equilibrium and the desired solid ink density was achieved. Consequently, a total of 800 printed discs were gathered for the eight runs, and then, 50 discs were systematically sampled for each of the eight treatment combinations for a total sample size of 400 (8*50). Finally, an X-Rite® 528 reflective spectrodensitometer using Murray-Davies equation (n=1) was applied to measure solid ink density (SID), 75% print contrast (PC), and dot gain (DG) at 10%、25%、50%、75%、90% of the final printed discs for this study. It is important to note that each specific measured area on the sampled disc was read five times to reduce the measuring error. Thus, the final data entered onto computer for the factorial analysis was a mean of five readings from the X-Rite® 528. The tables for recoding the treatment combinations, their run orders, and grand mean values of dot gain, solid ink density, and print contrast are displayed in Appendix I.

4. Results and Findings

This section reports the results and findings grained through analyses of the data obtained from the experiment. The software packages employed to analyze the data were SPSS 8.0 and Minitab 12.0.

4.1 Descriptive Statistics

Table 4 displays the descriptive statistics of the measurements on dot gain percentage, solid ink density, and print contrast. The grand mean value in each cell is obtained form 2000 data (8 treatments * 5 readings * 50 discs). For the black, the dot gain size of 25% tint (33.0365%) is close to that of 50% (33.037%), followed by the 75% (19.91%), 10% (19.63%), and 90% (8.96%). The average of solid ink density of black is 1.53 and the average of print contrast is 22.03%.

For the cyan, the dot gain size of 50% tint is greatest (20.60%), followed by the 25% (14.85%), 75% (13.19%), 10% (10.10%), and 90% (7.07%). The average of solid ink density of cyan is 1.35 and the mean print contrast is 33.12%.

For the magenta, the dot gain size of 50% tint greatest (21.32%), followed by the 25% (16.43%), 75% (15.94%), 90% (8.12%), and 10% (7.71%). The average of solid ink density of magenta is 1.36 and the mean print contrast is 28.26%.

For the yellow, the dot gain size of 50% tint greatest (21.32%), followed by the 75% (14.76%), 25% (14.47%), 90% (8.09%), and 10% (7.29%). The average of solid ink density of magenta is 1.36 and the mean print contrast is 28.26%.

Table 4. Descriptive Statistics of K. C. M. Y

Variable	N	Min.	Max.	Mean	Std. Dev.
Descriptive Statistics of Black					
K_10DG	2000	14.8800	23.196	19.6290	3.081024
K_25DG	2000	24.9080	40.572	33.0365	5.929008
K_50DG	2000	27.9120	38.436	33.0370	3.795671
K_75DG	2000	17.0440	22.028	19.9095	1.871340
K_90DG	2000	8.1080	9.596	8.9645	.546546
K_SID	2000	1.4898	1.579	1.5313	.030318
K_PC	2000	16.1520	30.228	22.0285	5.094512
Descriptive Statistics of Cyan					
C_10DG	2000	5.0000	14.2000	7.6020	2.896303
C_25DG	2000	8.5040	19.6080	14.8545	3.437356
C_50DG	2000	15.8720	22.5600	20.5980	2.236731
C_75DG	2000	11.6560	14.7920	13.1900	1.063400
C_90DG	2000	6.3640	7.9360	7.0700	.551391
C_SID	2000	1.2624	1.4154	1.3545	.043417
C_PC	2000	30.5880	37.1800	33.1175	1.903962
Descriptive Statistics of Magenta					
M_10DG	2000	-.1160	11.7680	7.7130	4.084237
M_25DG	2000	10.9480	20.8880	16.4330	2.933169
M_50DG	2000	20.1120	23.1160	21.3160	1.039384
M_75DG	2000	13.2880	17.4600	15.9390	1.345635
M_90DG	2000	7.4440	8.6560	8.1235	.425745
M_SID	2000	1.3272	1.3901	1.3593	.027105
M_PC	2000	25.7680	32.4600	28.2565	2.187904
Descriptive Statistics of Yellow					
Y_10DG	2000	4.4800	9.6040	7.2895	1.846232
Y_25DG	2000	10.2360	17.8280	14.4680	2.874130
Y_50DG	2000	17.8640	25.1160	21.3145	2.865916
Y_75DG	2000	12.6640	16.8200	14.7595	1.676596
Y_90DG	2000	7.2880	8.7280	8.0885	.518585
Y_SID	2000	.9048	1.0135	.966563	.037935
Y_PC	2000	17.7160	22.7920	20.2195	1.860232

In addition, Table 5 compares the dot gain percentage for the CMYK. As shown in Table 5, the got gain phenomena are very alike for the cyan, magenta, and yellow; the dot gain size of the black is greater than the other three colors at all tints excluding the 90%. This phenomenon can be also found in Figure 2.

Table 5. Dot gain percentage comparison

Dot Gain	K	C	M	Y
10% DG	19.6290	7.6020	7.7130	7.2895
25% DG	33.0365	14.8545	16.4330	14.4680
50% DG	33.0370	20.5980	21.3160	21.3145
75% DG	19.9095	13.1900	15.9390	14.7595
90% DG	8.9645	7.0700	8.1235	8.0885

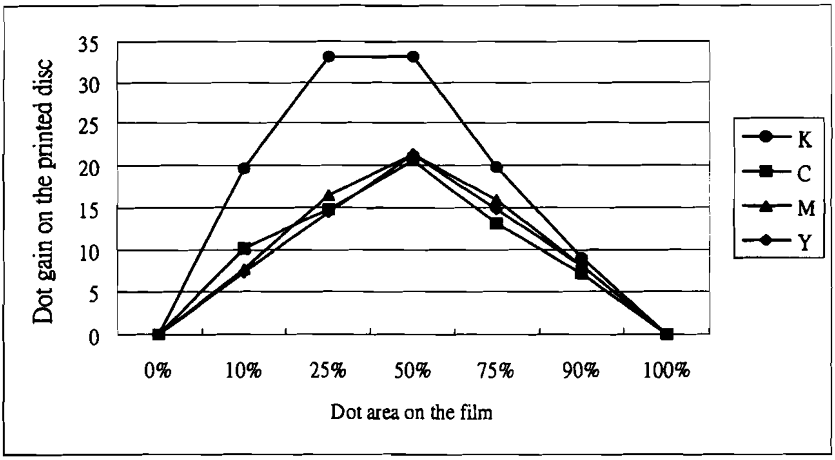

Figure 2. The dot gain curve of KCMY.

4.2 Discussion

This section discusses the results of the ANOVA and Stepwise Regression analyses for the main effects of the independent variables and their interaction effects on the dependent variables for all four colors. It is important to note that the significant level was set to be .05 for all the analyses, i.e., $\alpha = .05$. The full model derived from 2^3 the factorial design is:

$$\hat{Y} = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_1 X_2 + \beta_5 X_1 X_3 + \beta_6 X_2 X_3 + \beta_7 X_1 X_2 X_3 + \varepsilon,$$

Where X_1 = press speed; X_2 = blanket-to-disc pressure; X_3 = cooling system temperature.

The significant effects were selected from the full model by the Factorial analysis procedure using Minitab 12.2 for each observed attribute for all colors. Then those significant effects were included in the reduced model for the regression analysis, factorial analysis, and analysis of variance. Due to the length limitation, the paper would present only the summarized results in the following parts for the observed attributes of all four colors:

1. the significant effects selected to be included in the reduced model and the size and direction (positive or negative) of their effects,
2. the best prediction equation that include all the significant effects in the reduced model to optimize the process operating condition for printing the discs,
3. the best treatment combinations, including their levels, to achieve the most desired print attribute,
4. the estimation of the observed print attributes derived from the best treatment combinations and the prediction equations,
5. the R-square analyses to valid the prediction equation. The R^2 values indicate that the significant effects collectively explained approximately R^2 % of the total variability in the dependent variable.
6. the results of the residual plot diagnostics to evaluate the fitness of the prediction equation. In any designed experiment, it is important to examine the residuals and check for violations of basic assumptions that could invalidate the results. A residual is the difference between the observed value of the dependent variable and the value predicted by the regression line. (Montgomery, 1998, pp. 504-506).

Discussion in print contrast

The summary result of the ANOVA and Stepwise Regression analyses for the main and interaction effects on the print contrast for KCMY is exhibited in Table 6. The Pareto chart of the standardized effects is displayed in Figure 3.

Table 6. ANOVA and Stepwise Regression summary for the Print Contrast

	K	C	M	Y
Sig. Level	$\alpha = 0.05$	$\alpha = 0.05$	$\alpha = 0.05$	$\alpha = 0.05$
Significant Effects	$X_2X_3 = 6.409$ $X_1X_3 = 5.055$ $X_1 = -2.551$ $X_1X_2 = 2.445$ $X_2 = 2.411$ $X_3 = 2.369$ $X_1X_2X_3 = 0.243$	$X_2X_3 = 1.809$ $X_2 = 1.651$ $X_1X_3 = 1.619$ $X_1 = 1.513$ $X_1X_2 = 1.249$ $X_3 = 0.441$ $X_1X_2X_3 = -0.157$	$X_1X_3 = 2.739$ $X_2X_3 = 2.367$ $X_2 = 1.385$ $X_3 = 0.975$ $X_1X_2X_3 = 0.611$ $X_1X_2 = 0.585$	$X_1X_2X_3 = -2.471$ $X_2X_3 = 1.711$ $X_1X_3 = 1.515$ $X_3 = 0.621$ $X_2 = -0.523$ $X_1 = 0.329$
Prediction Equation ($\hat{Y}$)	$22.0 + 3.20 X_2X_3 + 2.53 X_1X_3 - 1.28 X_1 + 1.22 X_1X_2 + 1.21 X_2 + 1.18 X_3 + 0.122 X_1X_2X_3$	$33.1 + 0.905 X_2X_3 + 0.826 X_2 + 0.809 X_1X_3 + 0.756 X_1 + 0.624 X_1X_2 + 0.220 X_3 - 0.0785 X_1X_2X_3$	$28.3 + 1.37 X_1X_3 + 1.18 X_2X_3 + 0.692 X_2 + 0.488 X_3 + 0.306 X_1X_2X_3 + 0.293 X_1X_2$	$20.2 - 1.24 X_1X_2X_3 + 0.855 X_2X_3 + 0.758 X_1X_3 + 0.311 X_3 - 0.261 X_2 + 0.164 X_1$
Best Treatment Combinations	X_1=50 strokes/min X_2=2.95 mm X_3=17 °C (1, 1, 1)	X_1=50 strokes/min X_2=2.95 mm X_3=17 °C (1, 1, 1)	X_1=50 strokes/min X_2=2.95 mm X_3=17 °C (1, 1, 1)	X_1=40 strokes/min X_2=2.75 mm X_3=13 °C (-1, -1, -1)
Estimated Max. Value	30.228%	37.180%	32.5875%	22.8545%
R^2	99.5%	98.8%	93.9%	96.6%
Residual Diagnostics	Satisfactory	Satisfactory	Satisfactory	Satisfactory

According to Figure 3, it is important to note that the dominant effect on the print contrast for the four colors is X_2X_3, that is, the interaction effect of *blanket-to-disc pressure (X_2) and cooling system temperature (X_3)*. The X_2X_3 interaction effect is significant for all observed print attributes for all colors. Its significance is ranked as either the top one or two by the Stepwise Regression analyses for all the observed attributes. As shown in Table 6, the best treatment combination for black is (X_1, X_2, X_3) = (1, 1, 1), (X_1, X_2, X_3) = (1, 1, 1) for cyan, (X_1, X_2, X_3) = (1, 1, 1) for magenta, and (X_1, X_2, X_3) = (-1, -1, -1) for yellow. The estimated print contrasts for KCM derived from the combination of the prediction equations and the best treatment combinations are all greater than 30%, but the estimated print contrast for yellow is about 23%. The R^2 values of the desired equations for KCMY are all greater than 90% and the residual plots of the regression equation are all satisfactory. Therefore the prediction equations in combination with the best treatments displayed in Table 6 are recommended to obtain the maximum print contrast for KCMY.

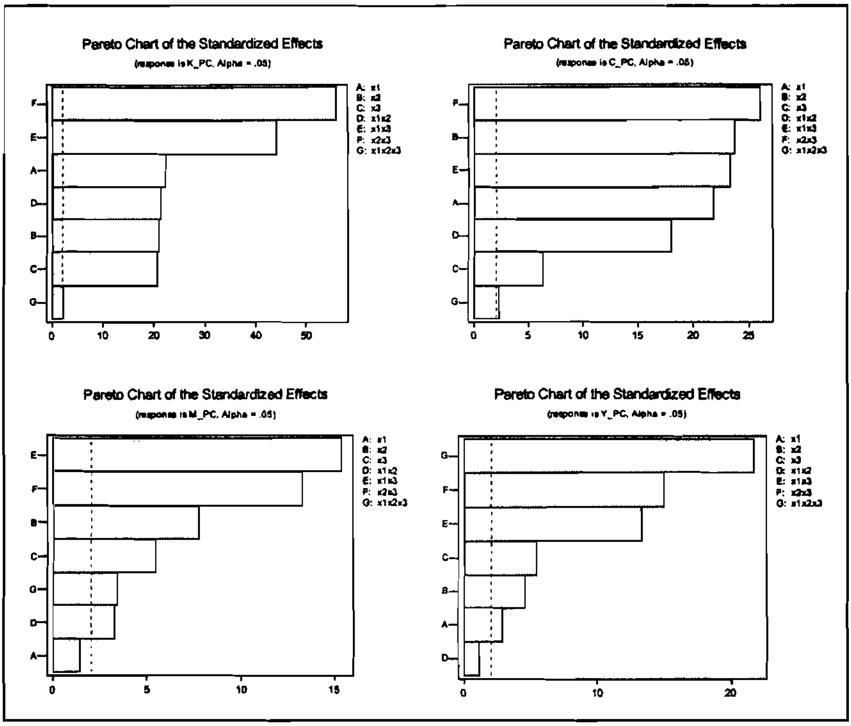

Figure 3. Pareto Chart of the Standardized Effects for the Print Contrast

Discussion in 10% dot gain

The ANOVA and Stepwise Regression summary for the main and interaction effects on the 10% dot gain for KCMY is exhibited in Table 7, and the Pareto chart of the standardized effects computed by Minitab is displayed in Figure 4.

Table 7. ANOVA and Stepwise Regression summary for the 10% Dot Gain

	K	C	M	Y
Sig. Level	$\alpha = 0.05$	$\alpha = 0.05$	$\alpha = 0.05$	$\alpha = 0.05$
Significant Effects	$X_2X_3 = -4.655$ $X_3 = -2.737$ $X_1 = 1.549$ $X_2 = -0.971$ $X_1X_2 = -0.625$ $X_1X_2X_3 = 0.455$ $X_1X_3 = -0.235$	$X_2 = -2.959$ $X_2X_3 = -2.919$ $X_1X_2X_3 = 1.727$ $X_1 = 1.587$ $X_3 = -0.827$ $X_1X_3 = -0.541$	$X_1X_2X_3 = 4.632$ $X_3 = 4.566$ $X_1X_2 = -3.304$ $X_2X_3 = -2.044$ $X_2 = 0.716$ $X_1X_3 = -0.642$	$X_2X_3 = -1.939$ $X_1X_3 = -1.569$ $X_2 = -1.291$ $X_3 = -1.269$ $X_1X_2 = 1.001$ $X_1X_2X_3 = 0.893$ $X_1 = 0.329$
Prediction Equation ($\hat{Y}$)	$19.6 - 2.33 X_2X_3 - 1.37 X_3 + 0.774 X_1 - 0.486 X_2 - 0.313 X_1X_2 + 0.228 X_1X_2X_3 - 0.118 X_1X_3$	$7.66 - 1.48 X_2 - 1.46 X_2X_3 + 0.863 X_1X_2X_3 + 0.794 X_1 - 0.414 X_3 - 0.270 X_1X_3$	$7.71 + 2.32 X_1X_2X_3 + 2.28 X_3 - 1.65 X_1X_2 - 1.02 X_2X_3 + 0.358 X_2 - 0.321 X_1X_3$	$7.29 - 0.970 X_2X_3 - 0.785 X_1X_3 - 0.646 X_2 - 0.635 X_3 + 0.501 X_1X_2 + 0.447 X_1X_2X_3 + 0.398 X_1$
Best Treatment Combinations	X_1=40 strokes/min X_2=2.95 mm X_3=17 °C [-1, 1, 1]	X_1=40 strokes/min X_2=2.95 mm X_3=17 °C [-1, 1, 1]	X_1=50 strokes/min X_2=2.95 mm X_3=13 °C [1, 1, -1]	X_1=40 strokes/min X_2=2.95 mm X_3=17 °C [-1, 1, 1]
Estimated Min. Value	14.880%	2.8675%	3.163%	4.480%
R^2	98.8%	95.7%	98.3%	96%
Residual Diagnostics	Satisfactory	Satisfactory	Acceptable	Satisfactory

In Figure 4, the significant effects are identified and the order of effect strength is also indicated. According to Figure 4, the dominant effect on the 10% dot gain for the four colors tends to be X_2X_3, the interaction effect of blanket-to-disc pressure (X_2) and cooling system temperature (X_3), because its significance is ranked as either the top one or two on the KCY three colors. As shown in Table

7, the best treatment combination for black, cyan, and yellow is $(X_1, X_2, X_3) = (-1, 1, 1)$, on the contrary, $(X_1, X_2, X_3) = (1, 1, -1)$ for magenta. The estimated minimum 10% dot gain size for black is 14.88%, which is much greater than that of the other three colors (2.87% for C, 3.16% for M, and 4.48% for Y). Since the best combination for KCY is opposite to that of magenta, the study would not recommend any particular combination to obtain the minimum dot gain in the highlights for process works. Without the consideration of magenta, the combination of $(X_1, X_2, X_3) = (-1, 1, 1)$ is suggested to achieve the minimum yield of dot gain for the highlights. In addition, the R^2 values of the prediction equations for KCMY are all greater than 90% and the residual plots of the equation are all satisfactory.

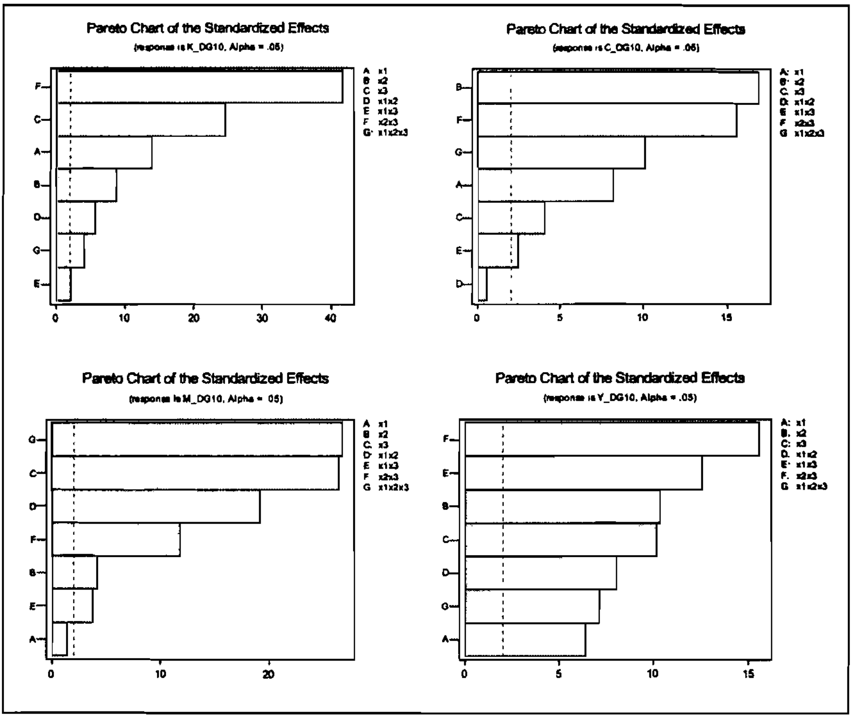

Figure 4. Pareto Chart of the Standardized Effects for the 10% Dot Gain

Discussion in 25% dot gain

Table 8 displays the summary result of the ANOVA and Stepwise Regression analyses for the main effects and interaction effects on the 25% dot gain for KCMY and the Pareto chart of the standardized effects is displayed in Figure 5.

Table 8. ANOVA and Stepwise Regression summary for the 25% Dot Gain

	K	C	M	Y
Sig. Level	$\alpha = 0.05$	$\alpha = 0.05$	$\alpha = 0.05$	$\alpha = 0.05$
Significant Effects	$X_2X_3 = -7.861$ $X_3 = -4.905$ $X_1 = 4.107$ $X_1X_2 = -3.025$ $X_1X_3 = -2.891$ $X_2 = -1.675$	$X_2 = -4.421$ $X_2X_3 = -4.101$ $X_1X_2X_3 = 2.119$ $X_3 = -1.053$ $X_1 = 0.823$ $X_1X_2 = 0.463$	$X_2X_3 = -2.896$ $X_1X_2X_3 = 2.646$ $X_1X_3 = -2.334$ $X_3 = 2.064$ $X_1X_2 = -2.012$ $X_1 = -0.984$	$X_2X_3 = -3.784$ $X_3 = -2.300$ $X_1X_2X_3 = 1.978$ $X_1X_3 = -1.830$ $X_2 = -1.236$ $X_1X_2 = 0.954$ $X_1 = 0.402$
Prediction Equation ($\hat{Y}$)	$33.0 - 3.93 X_2X_3 - 2.45 X_3 + 2.05 X_1 - 1.51 X_1X_2 - 1.45 X_1X_3 - 0.838 X_2$	$14.9 - 2.21 X_2 - 2.05 X_2X_3 + 1.06 X_1X_2X_3 - 0.527 X_3 + 0.411 X_1 + 0.232 X_1X_2$	$16.4 - 1.45 X_2X_3 + 1.32 X_1X_2X_3 - 1.17 X_1X_3 + 1.03 X_3 - 1.01 X_1X_2 - 0.492 X_1$	$14.5 - 1.89 X_2X_3 - 1.15 X_3 + 0.989 X_1X_2X_3 - 0.915 X_1X_3 - 0.618 X_2 + 0.297 X_1X_2 + 0.201 X_1$
Best Treatment Combinations	X_1=50 strokes/min X_2=2.95 mm X_3=17 °C (1, 1, 1)	X_1=40 strokes/min X_2=2.95 mm X_3=17 °C (-1, 1, 1)	X_1=40 strokes/min X_2=2.75 mm X_3=13 °C (-1, -1, -1)	X_1=40 strokes/min X_2=2.95 mm X_3=17 °C (-1, 1, 1)
Estimated Min. Value	24.912%	8.4395%	10.949%	10.236%
R^2	99.3%	97.6%	99%	96.9%
Residual Diagnostics	Satisfactory	Acceptable	To be corrected	Acceptable

As shown in Figure 5, the significant effects and the order of their effect strength are indicated. According to Figure 5, the dominant effect on the 25% dot gain for the four colors is X_2X_3, the interaction effect of blanket-to-disc pressure (X_2) and cooling system temperature (X_3), because its significance is ranked as either the top one or two for the four process colors. As shown in Table 8, the best treatment combination for black is $(X_1, X_2, X_3) = (1, 1, 1)$, $(X_1, X_2, X_3) = (-1, 1, 1)$ for cyan and yellow, and $(X_1, X_2, X_3) = (-1, -1, -1)$ for magenta. The estimated minimum 25% dot gain size for black is 24.91%, which is much greater than that of the other three colors (8.44% for C, 10.95% for M, and 10.24% for Y). Since the best treatment combinations for KCMY are not in common, the study would not recommend any particular combination to obtain the minimum dot gain in the quartertone for process jobs. The R^2 values of the prediction equations for KCMY are all greater than 90%. The residual plots of KCY are all satisfactory, but that of magenta needs to be improved (corrected) to some extent.

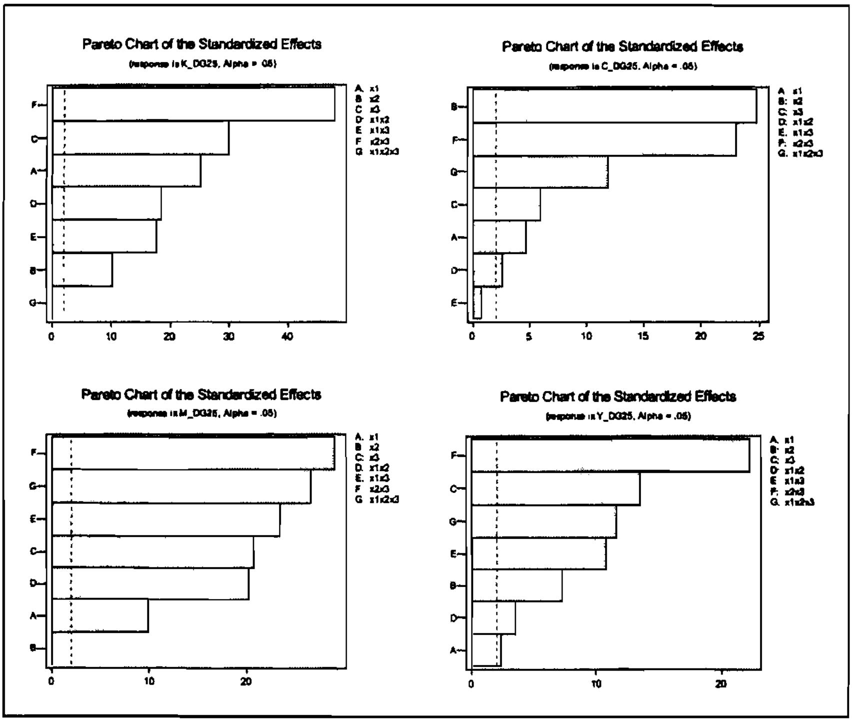

Figure 5. Pareto Chart of the Standardized Effects for the 25% Dot Gain

Discussion in 50% dot gain

Table 9 displays the summary result of the ANOVA and Stepwise Regression analyses for the main effects and interaction effects on the 50% dot gain for KCMY and the Pareto chart of the standardized effects is displayed in Figure 6.

Table 9. ANOVA and Stepwise Regression summary for the 50% Dot Gain

	K	C	M	Y
Sig. Level	$\alpha = 0.05$	$\alpha = 0.05$	$\alpha = 0.05$	$\alpha = 0.05$
Significant Effects	$X_2X_3 = -5.172$ $X_1 = 2.856$ $X_1X_3 = -2.640$ $X_3 = -2.202$ $X_1X_2 = -1.522$ $X_2 = -1.060$ $X_1X_2X_3 = -0.510$	$X_1X_2X_3 = 2.294$ $X_2X_3 = -2.094$ $X_2 = -1.958$ $X_3 = -1.856$ $X_1 = 0.580$ $X_1X_3 = 0.444$ $X_1X_2 = 0.226$	$X_1X_2X_3 = -1.354$ $X_1X_2 = -0.974$ $X_2 = 0.892$ $X_1X_3 = -3.500$	$X_2X_3 = -4.081$ $X_1X_3 = -2.049$ $X_3 = -1.927$ $X_1X_2X_3 = 1.773$ $X_2 = -0.761$ $X_1X_2 = 0.637$ $X_1 = -0.229$
Prediction Equation ($\hat{Y}$)	$33.0 - 2.59 X_2X_3 + 1.43 X_1 - 1.32 X_1X_3 - 1.10 X_3 - 0.761 X_1X_2 - 0.530 X_2 - 0.255 X_1X_2X_3$	$20.6 + 1.15 X_1X_2X_3 - 1.05 X_2X_3 - 0.979 X_2 - 0.928 X_3 + 0.290 X_1 + 0.222 X_1X_3 + 0.113 X_1X_2$	$21.3 - 0.677 X_1X_2X_3 - 0.487 X_1X_2 + 0.446 X_2 - 0.175 X_1X_3$	$21.3 - 2.04 X_2X_3 - 1.02 X_1X_3 - 0.964 X_3 + 0.887 X_1X_2X_3 - 0.380 X_2 + 0.318 X_1X_2 - 0.114 X_1$
Best Treatment Combinations	X_1=50 strokes/min X_2=2.95 mm X_3=17 °C (1, 1, 1)	X_1=40 strokes/min X_2=2.95 mm X_3=17 °C (-1, 1, 1)	X_1=40 strokes/min X_2=2.75 mm X_3=17 °C (-1, -1, 1)	X_1=40 strokes/min X_2=2.95 mm X_3=17 °C (-1, 1, 1)
Estimated Min. Value	27.912%	15.872%	19.881%	17.864%
R^2	99.6%	99%	86.4%	98.7%
Residual Diagnostics	Satisfactory	Satisfactory	Satisfactory	Satisfactory

As shown in Figure 6, the significant effects and the order of their effect strength are indicated. According to Figure 6, the dominant effect on the 50% dot gain for the four colors tends to be X_2X_3, the interaction effect of blanket-to-disc pressure (X_2) and cooling system temperature (X_3), because its significance is ranked as either the top one or two on the KCY three colors. As shown in Table 9, the best treatment combination for black is (X_1, X_2, X_3) = (1, 1, 1), (X_1, X_2, X_3) = (-1, 1, 1) for cyan, (X_1, X_2, X_3) = (-1, -1, 1) for magenta, and (X_1, X_2, X_3) = (-1, 1, 1) for yellow. The estimated minimum 50% dot gain size for black is 27.91%, which is much greater than that of the other three colors (15.87% for C, 19.88% for M, and 17.86% for Y). Since the best treatment combinations for KCMY are not identical, the study would not recommend any particular combination to obtain the minimum dot gain in the midtone for process jobs. The R^2 values of the prediction equations for KCY are all greater than 90%; for magenta, the value R^2 is 86.4%. The residual plots of KCMY are all satisfactory.

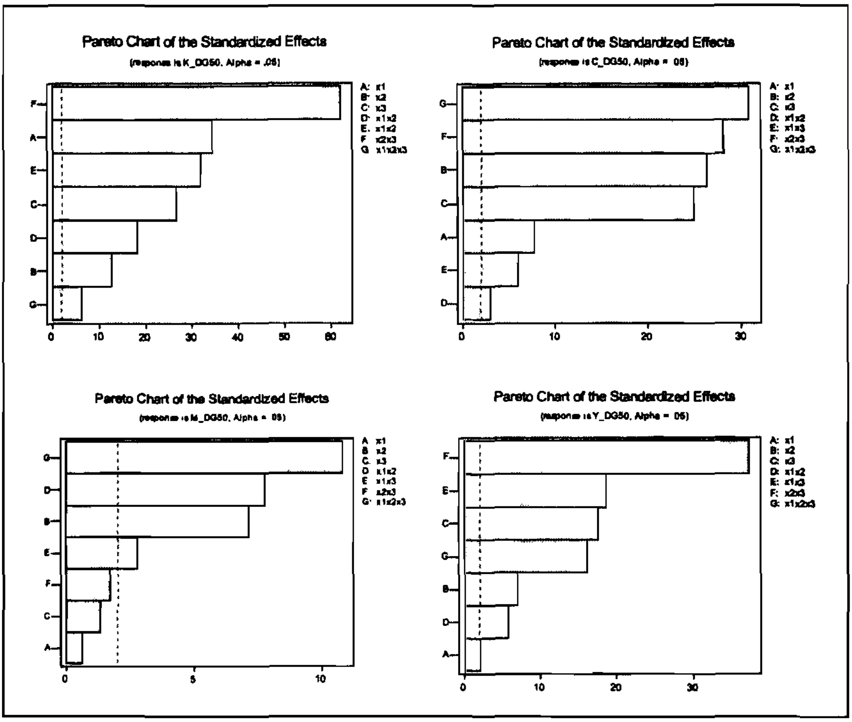

Figure 6. Pareto Chart of the Standardized Effects for the 50% Dot Gain

Discussion in 75% dot gain

The summary result of the ANOVA and Stepwise Regression analyses for the main effects and interaction effects on the 75% dot gain for KCMY is exhibited in Table 10 and the Pareto chart of the standardized effects is displayed in Figure 7.

Table 10. ANOVA and Stepwise Regression summary for the 75% Dot Gain

	K	C	M	Y
Sig. Level	$\alpha = 0.05$	$\alpha = 0.05$	$\alpha = 0.05$	$\alpha = 0.05$
Significant Effects	$X_2X_3 = -2.557$ $X_1X_3 = -1.619$ $X_1X_2 = -1.035$ $X_1 = 0.935$ $X_3 = -0.855$ $X_2 = -0.647$	$X_2X_3 = -1.282$ $X_2 = -1.054$ $X_1X_2X_3 = 0.738$ $X_3 = -0.662$ $X_1 = -0.450$ $X_1X_3 = -0.250$	$X_2X_3 = -1.770$ $X_1X_3 = -1.456$ $X_3 = -0.704$ $X_2 = -0.608$ $X_1X_2 = -0.372$ $X_1X_2X_3 = -0.242$	$X_2X_3 = -2.069$ $X_1X_2X_3 = 1.883$ $X_3 = -1.011$ $X_3 = -0.931$ $X_1X_2 = 0.313$ $X_1 = 0.115$
Prediction Equation ($\hat{Y}$)	$19.9 - 1.28 X_2X_3 - 0.809 X_1X_3 - 0.517 X_1X_2 + 0.468 X_1 - 0.427 X_3 - 0.323 X_2$	$13.2 - 0.641 X_2X_3 - 0.527 X_2 + 0.369 X_1X_2X_3 - 0.331 X_3 - 0.225 X_1 - 0.125 X_1X_3$	$15.9 - 0.885 X_2X_3 - 0.728 X_1X_3 - 0.352 X_3 - 0.304 X_2 - 0.186 X_1X_2 - 0.121 X_1X_2X_3$	$14.8 - 1.03 X_2X_3 + 0.942 X_1X_2X_3 - 0.505 X_1X_3 - 0.466 X_3 + 0.156 X_1X_2 + 0.0575 X_1$
Best Treatment Combinations	X_1=50 strokes/min X_2=2.95 mm X_3=17 °C (1, 1, 1)	X_1=40 strokes/min X_2=2.95 mm X_3=17 °C (-1, 1, 1)	X_1=50 strokes/min X_2=2.95 mm X_3=17 °C (1, 1, 1)	X_1=40 strokes/min X_2=2.95 mm X_3=17 °C (-1, 1, 1)
Estimated Min. Value	17.021%	11.687%	13.363%	12.6095%
R^2	99.6%	98.4%	96.9%	98.8%
Residual Diagnostics	Satisfactory	Satisfactory	Satisfactory	Satisfactory

The significant effects and the order of their effect strength are indicated in Figure 7. As shown in Figure 7, the dominant effect on the 75% dot gain for the four colors is X_2X_3, the interaction effect of blanket-to-disc pressure (X_2) and cooling system temperature (X_3), because its effect size is ranked as the top one for all the KCMY colors. As shown in Table 10, the best treatment combination for black is $(X_1, X_2, X_3) = (1, 1, 1)$, $(X_1, X_2, X_3) = (-1, 1, 1)$ for cyan, $(X_1, X_2, X_3) = (1, 1, 1)$ for magenta, and $(X_1, X_2, X_3) = (-1, 1, 1)$ for yellow. The estimated minimum 75% dot gain size for black is 17.02%, which is greater than that of the other three colors (11.69% for C, 13.36% for M, and 12.61% for Y). It is interesting to note that the best treatment combinations for black and magenta are identical, and those for cyan and yellow are the same. Moreover, the result shows that the treatment of $(X_2, X_3) = (1, 1)$ is in common among the four colors to obtain the minimum dot gain in the three-quartertone for process jobs. The R^2 values of the prediction equations for KCMY are all greater than 95% and the residual plots of KCMY are all satisfactory.

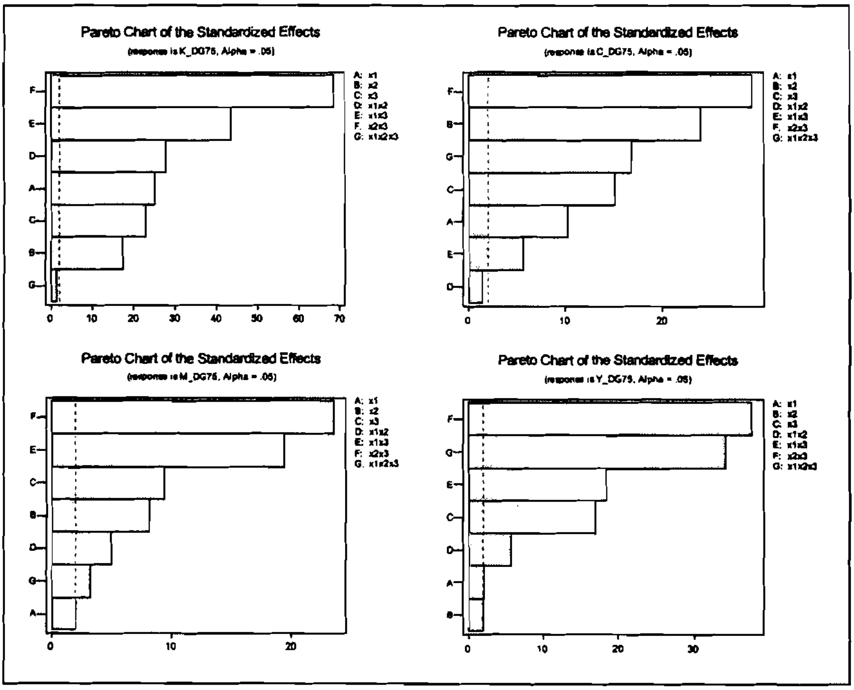

Figure 7. Pareto Chart of the Standardized Effects for the 75% Dot Gain

Discussion in 90% dot gain

The summary result of the ANOVA and Stepwise Regression analyses for the main effects and interaction effects on the 90% dot gain for KCMY is displayed in Table 11 and the Pareto chart of the standardized effects is shown in Figure 8.

Table 11. ANOVA and Stepwise Regression summary for the 90% Dot Gain

	K	C	M	Y
Sig. Level	$\alpha = 0.05$	$\alpha = 0.05$	$\alpha = 0.05$	$\alpha = 0.05$
Significant Effects	$X_1X_3 = -0.687$ $X_2X_3 = -0.533$ $X_1X_2 = -0.365$ $X_1 = 0.325$ $X_3 = -0.207$ $X_1X_2X_3 = 0.067$ $X_2 = -0.057$	$X_2X_3 = -0.636$ $X_1 = -0.582$ $X_1X_2X_3 = 0.358$ $X_2 = -0.334$ $X_1X_2 = -0.180$ $X_3 = -0.174$ $X_1X_3 = 0.136$	$X_2X_3 = -0.601$ $X_1X_3 = -0.365$ $X_2 = -0.251$ $X_1X_2X_3 = -0.179$ $X_3 = 0.165$ $X_1X_2 = -0.133$	$X_1X_2X_3 = 0.659$ $X_2X_3 = -0.561$ $X_3 = -0.337$ $X_2 = -0.247$ $X_1X_3 = -0.117$
Prediction Equation ($\hat{Y}$)	$8.96 - 0.344 X_1X_3 - 0.266 X_2X_3 - 0.183 X_1X_2 + 0.163 X_1 - 0.104 X_3 + 0.0335 X_1X_2X_3 - 0.0285 X_2$	$7.07 - 0.318 X_2X_3 - 0.291 X_1 + 0.179 X_1X_2X_3 - 0.167 X_2 - 0.0900 X_1X_2 - 0.0870 X_3 + 0.0680 X_1X_3$	$8.12 - 0.301 X_2X_3 - 0.182 X_1X_3 - 0.126 X_2 - 0.0895 X_1X_2X_3 + 0.0825 X_3 - 0.0665 X_1X_2$	$8.09 + 0.329 X_1X_2X_3 - 0.280 X_2X_3 - 0.169 X_3 - 0.123 X_2 - 0.0585 X_1X_3$
Best Treatment Combinations	X_1=40 strokes/min X_2=2.75 mm X_3=13 °C [-1, -1, -1]	X_1=50 strokes/min X_2=2.95 mm X_3=17 °C [1, 1, 1]	X_1=50 strokes/min X_2=2.95 mm X_3=17 °C [1, 1, 1]	X_1=40 strokes/min X_2=2.95 mm X_3=17 °C [-1, 1, 1]
Estimated Min. Value	8.108%	6.364%	7.4451%	7.245%
R^2	98.1%	96%	95.8%	91.7%
Residual Diagnostics	Acceptable	Acceptable	Acceptable	Acceptable

The significant effects and the order of their effect strength are specified in Figure 8. As shown in Figure 8, the dominant effect on the 90% dot gain for the four colors is X_2X_3, the interaction effect of blanket-to-disc pressure (X_2) and cooling system temperature (X_3), because its effect size is ranked as either the top one or two for all the four colors. According to Table 11, the best treatment combination for black is (X_1, X_2, X_3) = (-1, -1, -1), (X_1, X_2, X_3) = (1, 1, 1) for cyan, (X_1, X_2, X_3) = (1, 1, 1) for magenta, and (X_1, X_2, X_3) = (-1, 1, 1) for yellow. The estimated minimum 90% dot gain size for black is 8.11%, which is greater than that of the other three colors (6.36% for C, 7.45% for M, and 7.25% for Y). Since there are no best treatment combinations in common among the four colors, the study would not recommend any particular combination to obtain the minimum dot gain in the shadows for process works. The R^2 values of the prediction equations for KCMY are all greater than 90% and the residual plots of the equation are all acceptable.

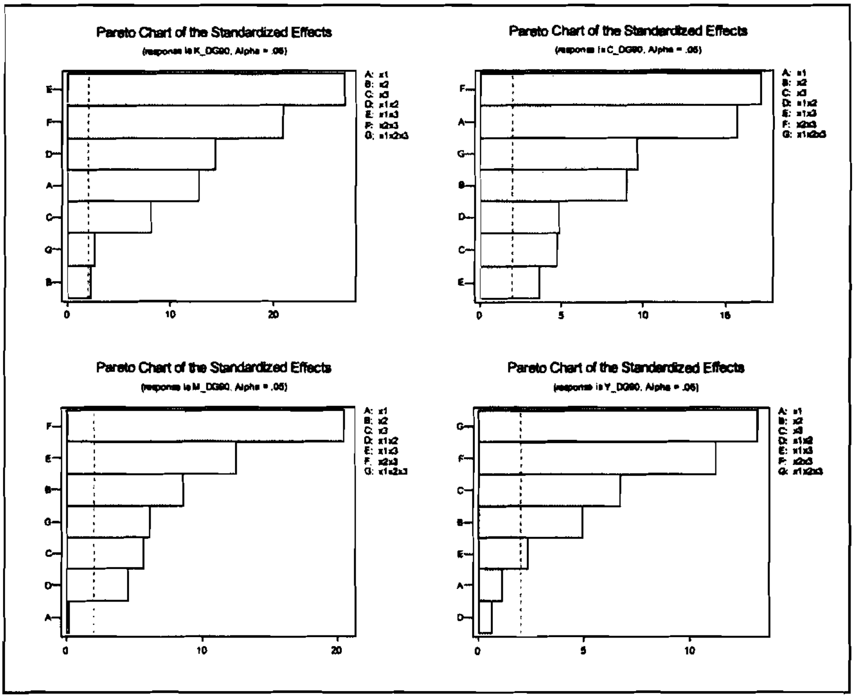

Figure 8. Pareto Chart of the Standardized Effects for the 90% Dot Gain

5. Conclusions

This experimental study utilized a randomized 2^3 factorial design in which every factor was run at two specified levels (1 = high level, -1 = low level, fixed effects) determined based upon the practical operating conditions using the Germany UV waterless offset press, at a major CD replication and decoration plant in Taiwan. The three factors were *press speed* (X_1), *blanket-to-impression pressure* (X_2), and *temperature of the cooling system* (X_3). The major results and important findings of the study are summarized below:

Dot gain phenomenon

According to Table 5 and Figure 2, the greatest dot gain size was occurred at the 25% tints (33.04%) to 50% tints (33.04%) of the black color. Conversely, the least dot gain size was found at 90% tints of cyan (7.07%) and 10% tints of yellow (7.29%).

Print contrast phenomenon

For printers, a maximum print contrast is usually desirable. To obtain the maximum print contrast, as shown in Table 6, the treatment combination for black, cyan, and magenta is X_1(press speed) = 50strokes/min, X_2(blanket-to-disc pressure) = 2.95mm, X_3(cooling system temperature) = 17 °C, i.e., (X_1, X_2, X_3) = (1, 1, 1); with this combination, the estimated print contrast for yellow is 20.75%. On the other hand, the combination to achieve maximum print contrast for yellow is (X_1, X_2, X_3) = (-1, -1, -1), and its estimated maximum print contrast is 22.85%. There is only about 2% difference in the print contrast estimation for yellow between the two combinations. Therefore, the study recommends (X_1, X_2, X_3) = (1, 1, 1) as the optimum press operating condition to achieve the greatest yield of print contrast for the four process colors using the Kammann offset press, while controlling for other variables. In other words, all the three independent variables (factors) should be set at the high level, while controlling for all other variables.

10% dot gain phenomenon

A minimum dot gain size is usually desirable for printers. For dot gain phenomenon in highlights, as shown in Table 7, the best treatment combination for black, cyan, and yellow is X_1(press speed) = 40strokes/min, X_2(blanket-to-disc pressure) = 2.95mm, X_3(cooling system temperature) = 17 °C, i.e., (X_1, X_2, X_3) = (-1, 1, 1); with this combination, the estimated 10% dot gain for magenta is 9.112%. On the other hand, the combination to achieve minimum 10% dot gain for magenta is (X_1, X_2, X_3) = (1, 1, -1), and its estimated minimum dot gain at 10% is 3.163%. There is an about 6% difference in the estimation of 10% dot gain between the two combinations. The study recommends that printers make their own decisions based on the original and economic consideration for establishing the optimum operating conditions to obtain the minimum dot gain in highlights for process works.

75% dot gain phenomenon

For dot gain phenomenon in shadows, as shown in Table 10, there is no particular treatment combination in common among the four colors to achieve the minimum dot gain size at the three-quarter tone. Therefore, the study does not recommend any particular treatment. With a close examination of the best treatment combinations for KCMY at the 75% dot gain, one can tell that black and magenta have the same combination (1, 1, 1); likewise, cyan and yellow have the same combination (-1, 1, 1). It is interesting to note that the treatment (X_2, X_3) = (1, 1) is identical for KCMY, regardless of the level of X_1. Therefore this study recommends X_2(blanket-to-disc pressure) = 2.95mm and X_3(cooling system temperature) = 17 °C, i.e., (X_1, X_2, X_3) = (±1, 1, 1) as the optimal operating condition to achieve the minimum 75% dot gain. As to X_1 (press speed), printers should make their own decision to set it to either 40 or 50 discs per minute based on the considerations of productivity and quality.

Interaction of blanket-to-disc pressure and cooling system temperature

Overall the results suggested that the interaction effect of the blanket-to-disc pressure and cooling system temperature (X_2X_3) was the dominant variable affecting on-press dot gain and print contrast. The X_2X_3 interaction effect was significant at .05 level for all observed attributes of all colors. Furthermore, its significance was ranked as either top one or two by the Stepwise Regression analysis for all the observed attributes of all colors, except for the 50% dot gain of magenta. The information is particularly useful for those printers who strive to improve the print quality of their CDs by maximizing the print contrast and minimizing the dot gain size.

Furthermore, regardless of the press speed factor (X_1), the close examination on the X_2X_3 interaction suggests that the greatest print contrast and least yield of dot gain at the 10%, 25%, 50%, 75%, and 90% tints could be achieved when the blanket-to-disc pressure was established at 2.95mm ($X_2 = 1$) and the cooling system temperature was set at 17°C ($X_3 = 1$) on the Kammann UV offset press, while controlling for all other variables (see Table 6 to Table 11).

6. Recommendation

The findings of the study not only suggest the optimum operating conditions to minimize the yield of dot gain at various tints and maximize the print contrast, but also propose the following recommendations:

1. The use of precise control scales in combination with statistical process control (SPC) tools should enable offset printers to make more informed decisions. Densitometers in combination with SPC should become basic

tools in promoting standards in offset printing by both the printers and their customers because the ability to communicate with numbers is the real power of densitometry.

2. There is a need to study the accuracy, consistency, and inter-instrument agreement for the reflection densitometers designed specially for reading musical CDs, CD-ROMs, DVDs, etc. Further research is also needed to determine whether the Yule-Nielsen equation with an appropriate "n" factor is a better method for measuring dot areas on compact discs than the Murray-Davies equation, which was used in this study.

3. For those CD printers utilizing Kammann offset presses who are suffering from undesirable dark color printed on the discs, especially on the shadow areas, the blanket-to-disc pressure and cooling system temperature are the two key factors to be investigated.

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Appendix 1. Table for Recording the Experimental Data

Table for Recording the Experimental Data for Black

No	Factor			Treatment Combination	Run order	Mean DG at 10%	Mean DG at 25%	Mean DG at 50%	Mean DG at 75%	Mean DG at 90%	Mean SID Value	Mean PC Value
	A	B	C									
1	–	–	–	(1)	2	17.692	27.388	28.828	17.564	8.108	1.4989	27.756
2	+	–	–	a	3	20.592	37.404	35.336	21.200	9.552	1.5244	17.948
3	–	+	–	b	7	22.492	36.592	33.952	20.556	9.016	1.5542	21.556
4	+	+	–	ab	6	23.196	40.572	38.436	22.028	9.596	1.5790	16.152
5	–	–	+	c	8	20.336	33.228	33.928	20.932	9.188	1.5158	18.904
6	+	–	+	ac	5	21.820	37.476	36.176	21.236	9.124	1.5540	18.648
7	–	+	+	bc	4	14.880	26.724	29.728	18.716	8.896	1.4982	25.036
8	+	+	+	abc	1	16.024	24.908	27.912	17.044	8.236	1.5350	30.228

Factor	Factor Level	
	–	+
(A) Press Speed	40strokes/min	50strokes/min
(B) Blanket-to-disc Pressure	2.75mm	2.95mm
(C) Cooling System Temperature	13 °C	17 °C

Table for Recording the Experimental Data for Cyan

No	Factor			Treatment Combination	Run order	Mean DG at 10%	Mean DG at 25%	Mean DG at 50%	Mean DG at 75%	Mean DG at 90%	Mean SID Value	Mean PC Value
	A	B	C									
1	–	–	–	(1)	2	6.164	14.312	20.356	13.184	7.096	1.3701	33.732
2	+	–	–	a	3	10.016	16.920	22.560	13.660	6.916	1.3636	32.220
3	–	+	–	b	7	7.848	15.648	22.560	14.088	7.936	1.3594	32.168
4	+	+	–	ab	6	7.852	14.944	20.628	13.212	6.680	1.3669	33.468
5	–	–	+	c	8	10.488	19.608	22.444	14.792	7.780	1.3641	30.588
6	+	–	+	ac	5	9.840	17.120	20.948	13.292	7.156	1.3343	32.628
7	–	+	+	bc	4	2.916	8.504	15.872	11.656	6.632	1.2624	32.956
8	+	+	+	abc	1	5.692	11.780	19.416	11.756	6.364	1.4154	37.180

Factor	Factor Level	
	–	+
(A) Press Speed	40strokes/min	50strokes/min
(B) Blanket-to-disc Pressure	2.75mm	2.95mm
(C) Cooling System Temperature	13 °C	17 °C

Table for Recording the Experimental Data for Magenta

No	Factor A	Factor B	Factor C	Treatment Combination	Run order	Mean DG at 10%	Mean DG at 25%	Mean DG at 50%	Mean DG at 75%	Mean DG at 90%	Mean SID Value	Mean PC Value
1	–	–	–	(1)	2	-0.116	10.948	20.732	14.992	7.704	1.3333	29.744
2	+	–	–	a	3	8.216	16.956	20.624	16.428	8.028	1.3352	26.776
3	–	+	–	b	7	10.580	18.504	21.460	16.284	8.008	1.3898	28.788
4	+	+	–	ab	6	3.040	15.196	22.112	17.460	8.424	1.3895	25.768
5	–	–	+	c	8	11.768	20.888	20.112	17.272	8.656	1.3901	26.224
6	+	–	+	ac	5	9.552	16.936	22.012	16.280	8.608	1.3514	27.512
7	–	+	+	bc	4	9.112	17.360	23.116	15.508	8.116	1.3578	28.780
8	+	+	+	abc	1	9.552	14.676	20.360	13.288	7.444	1.3272	32.460

Factor	Factor Level –	Factor Level +
(A) Press Speed	40strokes/min	50strokes/min
(B) Blanket-to-disc Pressure	2.75mm	2.95mm
(C) Cooling System Temperature	13 °C	17 °C

Table for Recording the Experimental Data for Yellow

No.	Factor A	Factor B	Factor C	Treatment Combination	Run order	Mean DG at 10%	Mean DG at 25%	Mean DG at 50%	Mean DG at 75%	Mean DG at 90%	Mean SID Value	Mean PC Value
1	–	–	–	(1)	2	6.472	12.536	19.140	12.788	7.724	0.9431	22.792
2	+	–	–	a	3	8.728	16.152	22.096	15.484	8.476	0.9823	19.260
3	–	+	–	b	7	7.012	16.468	23.596	16.536	8.728	0.9810	18.212
4	+	+	–	ab	6	9.484	17.316	24.280	16.092	8.100	1.0082	19.372
5	–	–	+	c	8	9.604	17.828	25.116	16.820	8.724	1.0135	17.716
6	+	–	+	ac	5	6.936	13.828	20.428	13.728	7.924	0.9703	22.156
7	–	+	+	bc	4	4.480	10.236	17.864	12.664	7.288	0.9048	21.500
8	+	+	+	abc	1	5.600	11.380	17.996	13.964	7.744	0.9392	20.748

Factor	Factor Level –	Factor Level +
(A) Press Speed	40strokes/min	50strokes/min
(B) Blanket-to-disc Pressure	2.75mm	2.95mm
(C) Cooling System Temperature	13 °C	17 °C