Optimum Flexible Hybrid Screening for Offset Lithography

Dr. Yung-Cheng Hsieh[1] and Dr. Yu-Ju Wu[2]

Keywords: Print attribute, offset lithography, AM screening, FM screening, hybrid screening

Abstract

This study investigated the use of AM/FM (Amplitude Modulation/Frequency Modulation) hybrid screening in conjunction with computer to plate (CTP) technology in order to obtain an optimum hybrid screening combination for the offset lithographic printing process. The study designed nine different hybrid (FM-AM-FM; highlight-midtone-shadow) screening combinations in accordance with one of the few flexible (adjustable) hybrid screening technologies. Hybrid screening and CTP technologies were used in offset lithography to print a digital test form on matte-finish paper. Differences in print attributes between matte-finish paper printed via the nine hybrid screening combinations were measured by a spectrodensitometer, and statistical analyses were used to identify a combination with an optimum FM-AM-FM tone percentage. It was that the most optimum FM-AM-FM screen combination is 10-70-20 (i.e., 0%~10% is FM; 11%~80% is AM; 81%~100% is FM). The hybrid combination of 10-60-30 is identified as the second best combination. It is hoped that the results of this study can help offset lithographic printers to better understand the characteristics of various screening techniques, allowing them to improve printing quality and achieve the highest customer satisfaction. The best hybrid screening combination of FM-AM-FM (highlight-midtone-shadow) found in this study is provided to printers as a reference enabling them to improve production effectiveness and quality, while reducing printing costs and waste, enabling the quality of offset lithography in Taiwan to progress.

---

[1] Professor and Chairperson, Department of Graphic Communication Arts, National Taiwan University of Arts, Taipei, Taiwan
[2] Assistant Professor, School of Technology, Eastern Illinois University, IL, USA

1. Introduction

The screen used in the Amplitude Modulation screening (AM) technology commonly employed by the conventional printing industry, consists of a grid of fixed-pitch dots that are made smaller or larger to simulate continuous tone and to achieve the desired color and contrast. AM screening technology exhibits rich tones in mid-tones, and higher LPI figures yields better details. Nevertheless, confined by environment or capabilities of the printing machine, higher LPI (lines per inch) does not necessarily means a better reproduction result. Moiré, rosette, and tone jumping are problems commonly seen in AM screening technology. Unsatisfactory manifestation in the highlights and shadows may be often observed due to the fact that screen angle, screen ruling and screen shape are all invariable. These problems have given rise to the emergence of Frequency Modulation screening (FM) technology. FM screening achieves color and contrast by clustering dots with the same size. The density of dots then translates into variations in tones. Although FM screening technology is free from moiré and rosette, and exhibits tones better than AM does, it has serious tone value increase and noise problems. AM would have a better performance in mid-tones than FM (Blondal, 2003).

Due to the fact that each screen technology has its advantages, the printing industry sought to employ advantages yet avoid disadvantages from both and gave rise to the emergence of Hybrid screening technology. Flexible (adjustable) hybrid screening technology generates optimal printing quality by integrating advantages of both technologies. FM Screening is used for highlights and shadows while AM Screening for mid-tones. This not only removes noises from FM in highlights but improves the rosette from AM and allows better images to be reproduced (See Table1). By using FM-like screening techniques and random arrangement of dots, hybrid screening technology has been developed to reproduce better details in highlights and shadows and allow an extended tonal spectrum. In addition, flexible hybrid screening offers operators choices to set according to their needs a specific percentage of dot density at which one screening technology (AM or FM) will be transited to the other (FM or AM) (Surprise, 2003).

Table 1. *A comparison among FM, Hybrid and AM screening technology.*

	FM	Hybrid	AM
Fine Details	Yes	Yes	Depending on LPI
Smooth Tones	Smooth	Smooth	High LPI may cause tone jumping
Print Stability	Average	Stable	Stable
Moiré	None	None	Yes
Tone Value Increase	Serious	Average	Average
Noises	In highlights	Vary from different combinations	Less

Although it has advantages from AM and FM, the use of hybrid screening technology does not guarantee a perfect reproduction of images. Drawbacks may include the following:

1. Boundaries between AM and FM tend to be obvious.
2. The technology is complicated and it will take quite some time in calculation.
3. Due to different configuration technologies, noises may be introduced in mid-tones.

The study was designed to apply a flexible (or adjustable) hybrid screening technology to offset lithography on coated paper for the purpose of investigating the optimum hybrid combination to achieve satisfied print attributes. The so-called flexible or adjustable hybrid screening technology in this research means that the transition points (lines) between FM and AM can be freely controlled by the user. The main question that the study tried to answer was whether various flexible hybrid screening combinations in lithography really performed differently on tone reproduction and print contrast. Did any particular FM-AM-FM hybrid combination yield better print attributes than others under the same print condition?

2. Methodology

Based on true experimental methods, this study explores variations in print attributes among different combinations of hybrid screening technologies of offset lithography on matte-finish paper to determine the optimum FM-AM-FM hybrid screening combination through experimental validation. Dependent variables in this study were tone value increase (TVI) and print contrast (PC). Independent variables were nine different hybrid screening combinations.

2.1. Combinations of hybrid screening technology

FM Screening Technology is used at highlights and shadows in this study (say, a% and c% respectively) and AM screening technology is used at mid-tones (say, b%). Since grayscale varies from black at 100% to white at 0%, $a + b + c = 100$. As shown in Figure 1, percentage of AM for mid-tones is set at b%. Nine different hybrid combinations (FM-AM-FM; highlight-midtone-shadow) are shown in Table 2. For example, when $b = 80$, then $a + c = 100 - b = 20$.

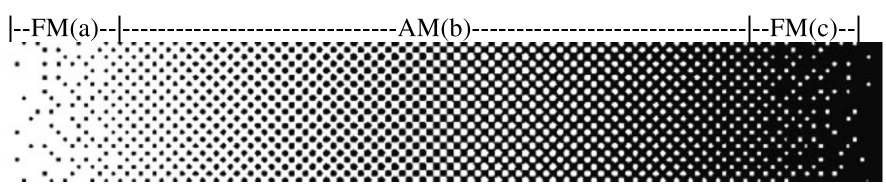

Figure 1. *Hybrid screening technology combination.*

Table 2. *Nine hybrid screening technology combinations used in this study.*

Combination	a + b + c = 100			Highlights setting	Shadows setting
	a	b	c		
1	10	60	30	46um	80um
2	10	70	20	46um	65um
3	10	80	10	46um	46um
4	20	50	30	65um	80um
5	20	60	20	65um	65um
6	20	70	10	65um	46um
7	30	40	30	80um	80um
8	30	50	20	65um	65um
9	30	60	10	80um	46um
	Total of 9 combinations				

2.2. Design of test form

A digital four-color test form for each screen technology combination was designed for this study. The test form is 11x7-in. in size which includes photographic images, CMYKRGB gradients, and CMYK tint patches of 10%, 25%, 50%, 75%, and 100%. In order to avoid any variations may cause from different test runs, nine test forms were arranged in one press form (40 x 31-in). Figure 2 shows the arrangement of nine hybrid screening technology combinations.

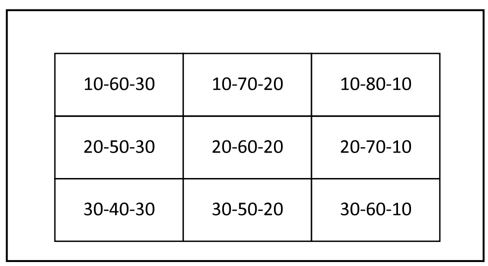

Figure 2. *The arrangement of nine hybrid screening technology combinations on the press form.*

2.3. Experiment Procedures

The original press form for experiments was output for plate-making via computer-to-plate. One set of four-color (C, M, Y, K) printing plates are output by using a Screen PlateRite PTR-8600 Platesetter with 175 lpi. The CTP plate used in this study was Fujifilm LH-PA Thermal Plate, thickness of 0.3 mm.

Matte-finish paper used in this study was 158.2 pound coated paper. The ink used in this study was CERVO ZIPSET from Tokyo Printing Ink. The Printing press used in this study was Heidelberg Speedmaster equipped with infrared drying system. The print test was run at a speed of 10,000 sheets/hr. The temperature of the printing house was set at 23°C with relative humidity of 69%. During press run, the ink density was balanced out across the paper to 0.98 for the yellow, 1.34 for the magenta, 1.20 for the cyan, and 1.48 for the black.

2.4. Sampling and Data Analysis

Systematic random sampling is conducted on 200 copies of printed sheets. Considering possible uneven ink spreading, the first and the last 50 copies were removed and 50 copies were systematically sampled from the remaining 100 copies. 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 tone value increase (TVI) at 10%、25%、50%、75%、90% of the final printed sample for this study. Data collected and recorded were then analyzed with statistical software to investigate the optimum hybrid screening combination. Statistical analysis methods used in this study include one-way analysis of variance and capability analysis.

3. Results and Discussion

3.1. One-way Analysis of Variance

One-way ANOVA and box-plot statistical procedures were employed to determine whether the differences in tone value increase and print contrast of nine hybrid screening combinations were significant. The significant level (α) was set at 0.05 for all tests. The results are summarized in Table 3. As shown in Table 3, the significant value of p is 0.000 < 0.05 (α) for all observed print attributes, that is, at least one pair of the mean print attribute values is significantly different at 0.05 levels. Table of descriptive statistical data of the nine hybrid screnning combinations is displayed in Appendix I.

Table 3. *Summary of One-way Analysis of Variance.*

	K		C		M		Y	
	P-value	Sig.	P-value	Sig.	P-value	Sig.	P-value	Sig.
10% TVI	0.000	yes	0.000	yes	0.000	yes	0.000	yes
25% TVI	0.000	yes	0.000	yes	0.000	yes	0.000	yes
50% TVI	0.000	yes	0.000	yes	0.000	yes	0.000	yes
75% TVI	0.000	yes	0.000	yes	0.000	yes	0.000	yes
90% TVI	0.000	yes	0.000	yes	0.000	yes	0.000	yes
PC	0.000	yes	0.000	yes	0.000	yes	0.000	yes

The box-plots for the KCMY hybrid screening combinations are exhibited in Figure 3, Figure 4, Figure 5, and Figure 6, respectively. According to Figure 3, for the black, the combination of 10-80-10 yielded the greatest PC and smallest TVI for all tone levels, with the exception of 90% TVI. For the cyan, Figure 4 shows that the combination of 10-80-10 reproduced smaller TVI values for 10%, 25%, and 50% tints. The greatest PC for cyan occurred when the 10-70-20 combination was applied. For the magenta (Figure 5), the combination of 10-70-20 yielded smaller TVI values for 10%, 25%, 50%, and 90% tints. The combination of 30-40-30, on the other hand, yielded the greatest PC for magenta. In terms of yellow, the combination of 10-60-30 yielded the greatest PC and smallest TVI values for 75% and 90% tints.

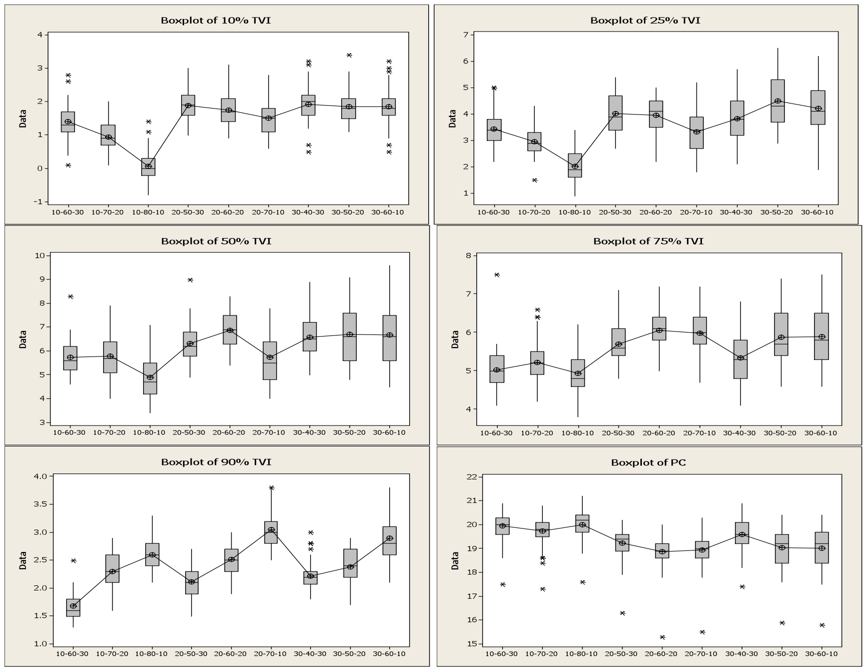

Figure 3. *The box-plot of hybrid screening combinations for the black.*

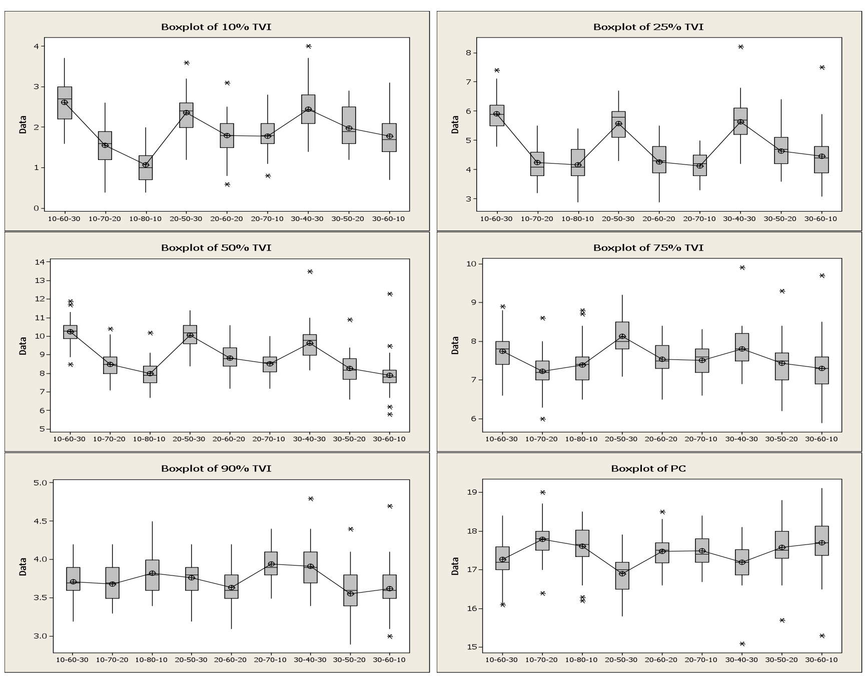

Figure 4. *The box-plot of hybrid screening combinations for the cyan.*

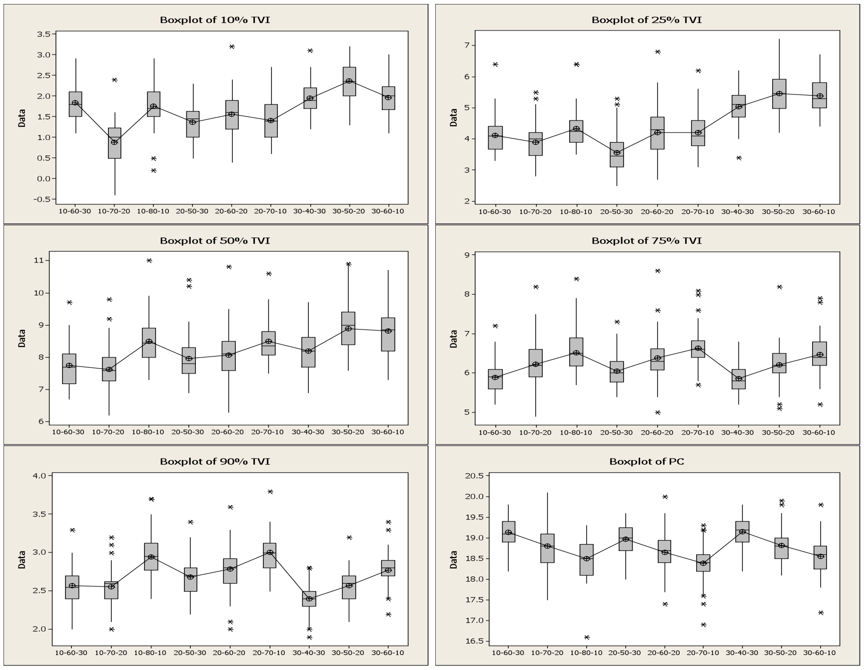

Figure 5. *The box-plot of hybrid screening combinations for the magenta.*

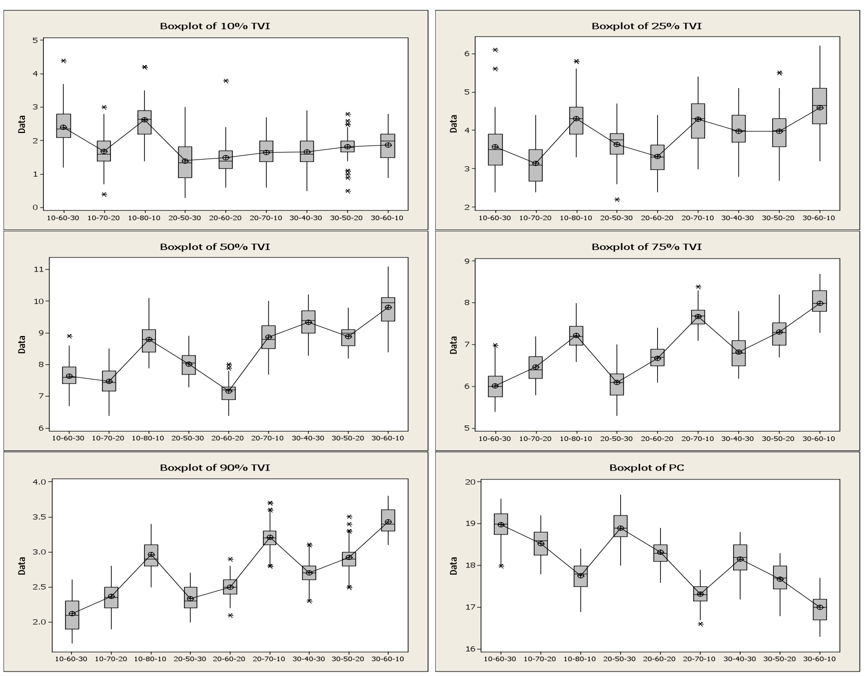

Figure 6. *The box-plot of hybrid screening combinations for the yellow.*

3.2. Capability Analysis

The section is to discuss the process consistency and capability of the observed attributes for the nine different hybrid screening combinations. The tools used to analyze the consistency for each variable are Individual Control Chart (I Chart), Moving Range Charts (MR Chart), and Capability Analysis. Process capability ratio (PCR or Cp index) is a measure of how capable a process is of meeting specifications. A Cp index of 1 means that a process is exactly capable of meeting specifications, while less than 1 means that it is outside specification limits. Ideally, one would like to see a Cp much larger than 1, because the larger the index, the more capable the process. Some practitioners consider *1.33* to be a minimum acceptable value for this statistic, and few believe that a value less than 1 is acceptable.

Determination of the Lower Specification Limits (LSL) and Upper Specification Limits (USL)

Due to the lack of historical parameters of LSL and USL for the observed attributes (TVI and PC) for hybrid screening combinations, a method of determining the proper LSL and USL is necessary. In this study, the LSL and USL for each attribute are determined based on the following procedures (Hsieh, 2003; Montgomery, 1997):

1. Construct the trial I and MR control chart of each attribute for the nine hybrid screening combinations.
2. Examine every control chart; if it is in control, then use the lower control limit (LCL) and upper control limit (UCL) as the LSL and USL. If it is in out-of-control condition (for most cases), reconstruct the control chart after eliminating all out-of-control points in the initial charts to obtain the revised values for mean, LCL, and UCL.
3. For each attribute, the difference between revised LCL and UCL of each plate obtained in the previous step is computed and named $6\sigma_{\mathbf{revised}}$, i.e., $UCL_{\mathbf{revised}} - LCL_{\mathbf{revised}} = 6\sigma_{\mathbf{revised}}$. Then $3\sigma_{\mathbf{revised}}$ of each plate is computed for the purpose of obtaining the "average $3\sigma_{\mathbf{revised}}$" of the nine hybrid screening combinations, $3\hat{S}_{\mathbf{revised}}$ namely, i.e.,

$$\mathbf{3\hat{S}_{revised} = (3\sigma_{revised/10\text{-}60\text{-}30} + 3\sigma_{revised/10\text{-}70\text{-}20} + 3\sigma_{revised/10\text{-}80\text{-}10} + 3\sigma_{revised/20\text{-}50\text{-}30} + 3\sigma_{revised/20\text{-}60\text{-}20} + 3\sigma_{revised/20\text{-}70\text{-}10} + 3\sigma_{revised/30\text{-}40\text{-}30} + 3\sigma_{revised/30\text{-}50\text{-}20} + 3\sigma_{revised/30\text{-}60\text{-}10}) / 9.}$$

4. For each attribute, the final LSL and USL are obtained by subtracting from and adding to the $3\hat{S}_{\mathbf{revised}}$, the revised mean of each combination, i.e.,

$$\mathbf{LSL_{final} = Mean_{revised} - 3\hat{S}_{revised}}$$
$$\mathbf{USL_{final} = Mean_{revised} + 3\hat{S}_{revised}}$$

The LSL_{final} and USL_{final} were then used to assess the relative Process Capability Ration (PCR) for the *revised* individual measurement control chart (I-Chart) of each attribute for the nine hybrid screening combinations (see Appendix II).

Figure 7, Figure 8, Figure 9, and Figure 10 provide a graphical presentation of the process capability comparison of hybrid screening combinations for the observed print attributes. For the black, the combination of 10-60-30 has the largest relative PCR (Cp = 1.72) for the 25% tint.

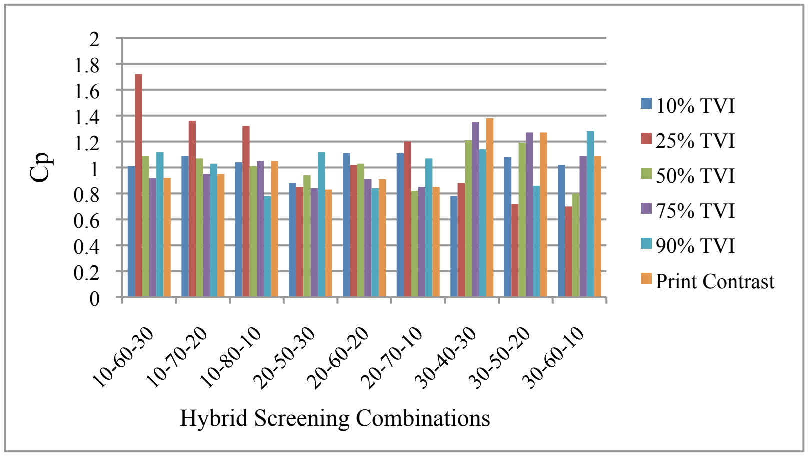

Figure 7. *Process capability comparison of hybrid screening combinations for the black.*

For the cyan, the combination of 20-50-30 has the largest relative PCR (Cp = 1.92) for the 90% tint, followed by the 30-50-20 combination for 75% tint (Cp = 1.83), the 10-80-10 combination for 10% tint (Cp = 1.55), and the combination of 10-60-30 for 50% tint (Cp = 1.47).

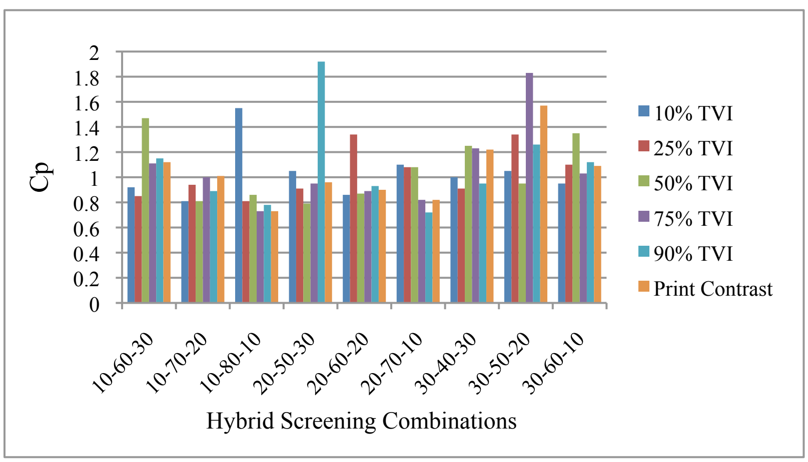

Figure 8. *Process capability comparison of hybrid screening combinations for the cyan.*

For the magenta, the combination of 10-70-20 has the largest relative PCR for the 25% (Cp = 2.06) and 50% tints (Cp = 1.52), followed by the 20-70-10 combination for 50% tint (Cp = 1.42), and the combination of 10-60-30 for 10% tint (Cp = 1.40).

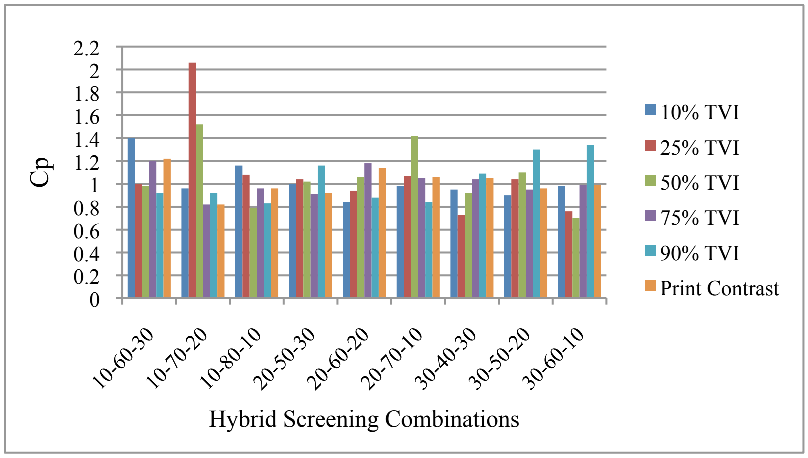

Figure 9. *Process capability comparison of hybrid screening combinations for the magenta.*

For the yellow, the combination of 30-60-10 has the largest relative PCR (Cp = 2.13) for the 50% tint, followed by the 20-70-10 combination for 90% tint (Cp = 1.68), and the combination of 30-50-20 for 10% tint (Cp = 1.52).

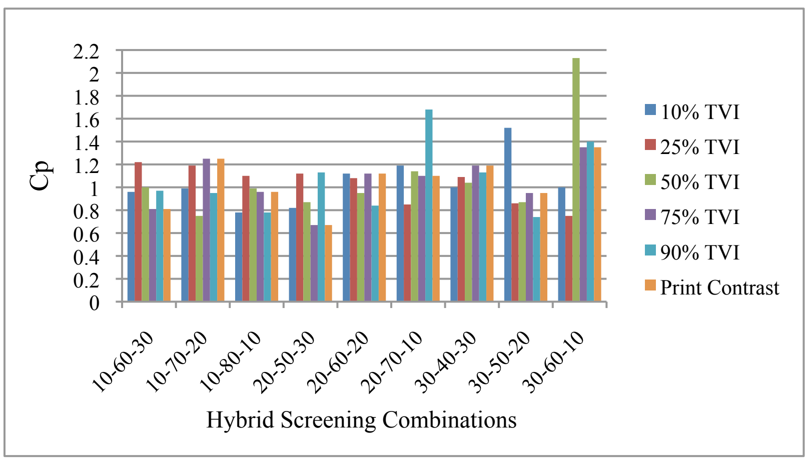

Figure 10. *Process capability comparison of hybrid screening combinations for the yellow.*

As shown in those figures, the relative PCR values for majority hybrid screening combinations are in the range of 0.7 to 1.3. In other words, most hybrid screening combinations are acceptable, but not necessary satisfied for printing consistent dots and producing consistent print contrast.

3.3. Identifying the Optimum Hybrid Screening Combination

A ranking system was applied to each observed print attribute (1 for smallest TVI, largest PC, or the largest relative PCR; 9 for largest TVI, smallest PC, or the smallest relative PCR). Then, the optimum hybrid screening combination was identified by adding up ranking numbers in each print attribute. A smaller ranking number in ranking indicates superiority. Scores and ranking of each print attribute are listed in Table 4. It shows that the hybrid combination of 10-70-20, with the least of sum of ranking numbers, is the best among all combinations. In terms of general print attributes, the nine combinations are ranked as ***10-70-20 > 10-60-30 > 30-40-30 > 20-50-30 > 20-60-20 = 30-50-20 > 20-70-10 > 10-80-10 = 30-60-10***.

Table 4. *Overall scores and ranking of nine hybrid combinations.*

		10-60-30		10-70-20		10-80-10		20-50-30		20-60-20		20-70-10		30-40-30		30-50-20		30-60-10	
K	10% TVI	3	6	2	2	1	4	8	7	5	1	4	1	9	8	6	3	7	5
	25% TVI	4	1	2	2	1	3	7	7	6	5	3	4	5	6	9	8	8	9
	50% TVI	2	3	4	4	1	6	5	7	9	5	3	8	6	1	8	2	7	9
	75% TVI	2	6	3	5	1	4	5	9	9	7	8	8	4	1	6	2	7	3
	90% TVI	2	3	1	5	7	8	3	3	6	7	9	4	4	2	5	6	8	1
	PC	2	6	3	5	1	4	5	9	9	7	8	8	4	1	6	2	7	3
C	10% TVI	8	7	2	9	1	1	6	3	4	8	3	2	7	5	5	4	3	6
	25% TVI	9	7	3	4	2	8	7	5	4	1	1	3	8	6	6	1	5	2
	50% TVI	9	1	4	8	2	7	8	9	6	6	5	4	7	3	3	5	1	2
	75% TVI	6	3	1	5	8	9	9	6	5	7	4	8	7	2	3	1	2	4
	90% TVI	5	3	4	7	7	8	6	1	3	6	9	9	8	5	1	2	2	4
	PC	3	3	9	5	7	9	1	6	4	7	5	8	2	2	6	1	8	4
M	10% TVI	6	1	1	5	5	2	2	3	4	8	3	4	7	6	9	7	8	4
	25% TVI	3	5	2	1	6	2	1	4	5	6	4	3	7	8	9	4	8	7
	50% TVI	2	6	1	1	7	8	3	5	4	4	6	2	5	7	9	3	8	9
	75% TVI	2	1	5	9	8	6	3	8	6	2	9	3	1	4	4	7	7	5
	90% TVI	3	5	2	5	7	8	4	3	6	6	8	7	1	4	3	2	5	1
	PC	2	1	5	8	8	6	3	7	6	2	9	3	1	4	4	6	7	5
Y	10% TVI	8	6	5	5	9	8	1	7	2	3	3	2	4	4	6	1	7	4
	25% TVI	3	1	1	2	8	4	4	3	2	6	7	8	6	5	5	7	9	9
	50% TVI	3	4	2	8	5	5	4	7	1	6	6	2	7	3	6	7	8	1
	75% TVI	1	8	3	2	6	6	2	9	4	4	8	5	5	3	7	7	9	1
	90% TVI	1	4	3	5	7	7	2	3	4	6	8	1	5	3	6	8	9	2
	PC	1	8	3	2	6	6	2	9	4	4	8	5	5	3	7	7	9	1
Total Score		189		185		260		241		242		253		221		242		260	
Ranking		2		1		7		4		5		6		3		5		7	

Note: Left column represents the ranking of dot reproduction capability
Right column represents the ranking of process consistency

4. Conclusions

This study investigated the optimum hybrid combination to achieve satisfied print attributes in terms of dot reproduction capability and process consistency. The former is judged based upon the minimum yield of tone value increase and maximum yield of print contrast could be obtained. The latter uses statistical techniques to measure and analyze the variation in processes and provides a process capability ratio to identify how capable a process is of meeting specifications. It was found that the hybrid combination of 10-70-20, that is, the use of FM at highlights from 0%~10%, the use of AM at mid-tones from 21%~0% and the use of FM again at shadows from 81%~100%, exhibits fair average performance in most print attributes. The hybrid combination of 10-60-30, with similar score, is identified as the second best combination. These two combinations are suggested to local academic and industrial circles. The other two combinations of 10-80-10 and 30-60-10, with total score as high as 260, are the least suitable ones for offset lithography.

Due to limitations of time and manpower, experiments of print attributes of hybrid screening technology conducted by this study cover offset lithography and one substrate only. It is suggested that follow-up studies would include more substrates and conduct more research on other printing processes, such as flexography, to find out optimum hybrid combinations thereof and compare with our findings for offset lithography. Furthermore, more extensive analyses can be conducted on the comparison between the optimum hybrid combinations discovered by this study and printed sheets with AM and/or FM Screening Technology in terms of print attributes.

Acknowledgments

The authors thank National Science Council grant (NSC Control No. 95-2221-E-144-001-MY2) for this study. Sincere appreciation is also expressed to the sponsorship from Kodak Taiwan Ltd., Tong Yi Color Reproduction Co., Ltd., Sunlea Label Printing CO., LTD., Red & Blue Color Printing CO., LTD., and Hung Chong Corp.

References

Blondal, D.
2003 "The Lithographic Impact of Microdot Halftone Screening," TAGA Proceedings, p. 608.

Hsieh, Y. C.
2003 "A Capability Study of Dot Reproduction for CTP Plates," Visual Communications Journal 2003, pp. 27–40.

Montgomery, D. C.
1997 "Introduction to statistical quality control (3rd ed.)," New York: John Wiley & Sons, Inc.

Surprise, C.
2003 “ Flexo CtP Developments Announced by Creo. Retrieved October 13, 2003, from http: http://www.printondemand.com/MT/archives/001522.html

Appendix I

Descriptive statistical data of the nine hybrid screnning combinations.

	Combination	10% TVI		25% TVI		50% TVI		75% TVI		90% TVI		Print Contrast	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
K	10-60-30	1.40	0.50	3.44	0.66	5.75	0.73	5.03	0.54	1.68	0.23	19.95	0.57
	10-70-20	0.94	0.40	2.96	0.54	5.80	0.90	5.22	0.56	0.07	0.44	19.73	0.66
	10-80-10	0.07	0.44	2.03	0.55	4.89	0.90	4.94	0.53	2.60	0.28	20.00	0.63
	20-50-30	1.88	0.47	4.03	0.70	6.31	0.81	5.71	0.50	2.11	0.25	19.23	0.66
	20-60-20	1.75	0.47	3.95	0.63	6.88	0.76	6.06	0.48	2.51	0.27	18.86	0.71
	20-70-10	1.51	0.47	3.34	0.79	5.75	1.03	5.99	0.56	3.05	0.26	18.94	0.75
	30-40-30	1.93	0.53	3.82	0.84	6.57	0.98	5.34	0.72	2.30	0.62	19.62	0.79
	30-50-20	1.85	0.47	4.50	0.96	6.70	1.15	5.88	0.74	2.38	0.31	19.05	0.86
	30-60-10	1.86	0.56	4.21	0.92	6.68	1.22	5.90	0.79	2.89	0.42	19.04	0.91
C	10-60-30	2.62	0.49	5.91	0.60	10.26	0.67	7.75	0.45	3.71	0.21	17.25	0.45
	10-70-20	1.56	0.48	4.26	0.56	8.48	0.72	7.23	0.50	3.69	0.24	17.77	0.50
	10-80-10	1.08	0.38	4.17	0.58	7.99	0.67	7.9	0.55	3.83	0.24	17.61	0.55
	20-50-30	2.37	0.46	5.58	0.62	10.07	0.69	8.13	0.50	3.77	0.23	16.87	0.50
	20-60-20	1.80	0.49	4.27	0.59	8.83	0.75	7.54	0.46	3.64	0.27	17.46	0.46
	20-70-10	1.78	0.41	4.14	0.50	8.54	0.70	7.50	0.40	3.94	0.23	17.50	0.40
	30-40-30	2.45	0.52	5.64	0.76	9.65	0.88	7.81	0.53	3.92	0.28	17.19	0.53
	30-50-20	1.98	0.47	4.64	0.67	8.29	0.79	7.44	0.58	3.56	0.31	17.56	0.58
	30-60-10	1.78	0.51	4.46	0.77	7.92	0.96	7.31	0.63	3.63	0.28	17.69	0.63
M	10-60-30	1.84	0.43	4.12	0.60	7.75	0.68	5.89	0.38	2.57	0.24	19.11	0.39
	10-70-20	0.88	0.52	3.89	0.59	7.63	0.70	6.23	0.59	2.56	0.24	18.77	0.59
	10-80-10	1.75	0.51	4.33	0.62	8.50	0.70	6.52	0.52	2.94	0.30	18.48	0.52
	20-50-30	1.37	0.44	3.56	0.63	7.97	0.70	6.05	0.42	2.68	0.21	18.95	0.42
	20-60-20	1.56	0.52	4.21	0.77	8.07	0.77	6.39	0.60	2.79	0.30	18.61	0.60
	20-70-10	1.40	0.49	4.20	0.62	8.49	0.65	6.63	0.48	3.01	0.25	18.37	0.48
	30-40-30	1.95	0.40	5.04	0.57	8.20	0.65	5.86	0.36	2.40	0.19	19.14	0.36
	30-50-20	2.37	0.47	5.47	0.68	8.89	0.74	6.22	0.52	2.57	0.23	18.78	0.52
	30-60-10	1.97	0.46	5.38	0.58	8.82	0.78	6.48	0.49	2.78	0.21	18.52	0.49
Y	10-60-30	2.40	0.57	3.58	0.68	7.65	0.45	5.92	0.74	2.12	0.25	19.08	0.74
	10-70-20	1.69	0.53	3.14	0.48	7.47	0.45	6.48	0.34	2.37	0.22	18.52	0.34
	10-80-10	2.62	0.59	4.30	0.59	8.79	0.45	7.25	0.33	2.96	0.20	17.75	0.33
	20-50-30	1.40	0.57	3.64	0.53	8.02	0.40	6.09	0.37	2.34	0.16	18.91	0.37
	20-60-20	1.50	0.55	3.32	0.45	7.17	0.39	6.67	0.28	2.50	0.18	18.33	0.28
	20-70-10	1.65	0.47	4.29	0.59	8.88	0.55	7.68	0.27	3.21	0.20	17.32	0.27
	30-40-30	1.67	0.54	3.99	0.54	9.34	0.49	6.83	0.36	2.70	0.16	18.17	0.36
	30-50-20	1.82	0.44	3.98	0.63	8.88	0.39	7.31	0.37	2.92	0.21	17.69	0.37
	30-60-10	1.87	0.49	4.59	0.64	9.82	0.61	7.99	0.34	3.43	0.17	17.01	0.34

Appendix II

The LSL_{final} and USL_{final} of the attributes for the hybrid screening combinations.

	Combination	10% TVI		25% TVI		50% TVI		75% TVI		90% TVI		Print Contrast	
		LCL_{final}	UCL_{final}	LCL_{final}	UCL_{final}	LCL_{final}	UCL_{final}	LCL_{final}	UCL_{final}	LCL_{final}	UCL_{final}	LCL_{final}	UCL_{final}
K	10-60-30	0.37	2.40	2.13	4.50	4.16	7.23	3.78	6.16	1.07	2.25	18.84	21.21
	10-70-20	-0.09	1.95	1.75	4.13	4.05	7.12	4.00	6.38	1.74	2.92	18.63	21.00
	10-80-10	-0.99	1.05	0.76	3.14	3.15	6.22	3.73	6.11	2.01	3.19	18.90	21.27
	20-50-30	0.87	2.90	2.85	5.22	4.72	7.79	4.52	6.90	1.51	2.69	18.11	20.48
	20-60-20	0.68	2.72	2.80	5.17	5.38	8.44	4.87	7.25	1.92	3.10	17.75	20.12
	20-70-10	0.40	2.43	1.96	4.33	4.08	7.14	4.80	7.17	2.43	3.61	17.83	20.20
	30-40-30	0.97	3.00	2.55	4.93	4.74	7.80	4.03	6.41	1.57	2.74	18.45	20.82
	30-50-20	0.78	2.81	3.19	5.56	4.65	7.72	4.48	6.86	1.79	2.97	18.15	20.52
	30-60-10	0.83	2.87	3.08	5.45	5.03	8.10	4.57	6.95	2.19	3.37	18.05	20.43
C	10-60-30	1.52	3.68	4.48	7.34	9.33	11.83	6.80	8.64	3.24	4.20	18.22	18.22
	10-70-20	0.49	2.64	2.80	5.66	7.15	9.65	6.29	8.13	3.19	4.15	17.84	17.84
	10-80-10	-0.07	2.09	2.74	5.60	6.69	9.19	6.42	8.26	3.33	4.29	17.58	17.58
	20-50-30	1.29	3.44	4.13	6.99	8.84	11.34	7.14	8.98	3.33	4.29	18.01	18.01
	20-60-20	0.70	2.85	2.84	5.69	7.61	10.11	6.63	8.47	3.11	4.07	17.64	17.64
	20-70-10	0.75	2.91	2.72	5.58	7.10	9.60	6.58	8.42	3.46	4.43	17.48	17.48
	30-40-30	1.31	3.46	4.16	7.02	8.44	10.94	6.94	8.78	3.37	4.34	18.19	18.19
	30-50-20	0.89	3.04	3.14	6.00	7.06	9.56	6.64	8.48	3.14	4.10	17.83	17.83
	30-60-10	0.68	2.83	2.93	5.79	6.56	9.06	6.36	8.20	3.14	4.10	17.58	17.58
M	10-60-30	0.63	2.87	2.82	5.28	6.28	9.16	4.90	6.83	2.03	3.11	18.22	20.16
	10-70-20	-0.25	1.99	2.65	5.11	6.08	8.95	5.22	7.16	1.99	3.08	17.84	19.78
	10-80-10	0.62	2.86	3.02	5.48	7.02	9.89	5.49	7.42	2.35	3.44	17.58	19.52
	20-50-30	0.28	2.52	2.21	4.66	6.43	9.31	5.06	6.99	2.11	3.20	18.01	19.95
	20-60-20	0.43	2.67	2.91	5.37	6.53	9.41	5.38	7.32	2.24	3.33	17.64	19.58
	20-70-10	0.24	2.48	2.91	5.37	6.90	8.44	10.06	11.68	13.30	14.92	17.48	19.42
	30-40-30	0.83	3.07	3.81	6.27	6.74	9.61	4.88	6.81	1.85	2.94	18.19	20.13
	30-50-20	1.25	3.49	4.23	6.68	7.35	10.23	5.23	7.17	2.03	3.11	17.83	19.77
	30-60-10	0.83	3.07	4.15	6.61	7.35	10.22	5.48	7.41	2.22	3.31	17.58	19.52
Y	10-60-30	0.98	3.74	2.10	4.88	6.59	8.65	5.19	6.84	1.64	2.61	18.16	19.81
	10-70-20	0.33	3.09	1.72	4.50	6.44	8.51	5.62	7.27	1.87	2.85	17.73	19.38
	10-80-10	1.24	4.00	2.80	5.58	7.75	9.82	6.41	8.06	2.47	3.45	16.94	18.59
	20-50-30	0.02	2.78	2.25	5.03	6.98	9.05	5.27	6.92	1.85	2.83	18.08	19.73
	20-60-20	0.12	2.88	1.93	4.71	6.13	8.20	5.85	7.50	2.01	2.99	17.50	19.15
	20-70-10	0.27	3.03	2.90	5.68	7.84	9.91	6.86	8.51	2.72	3.70	16.49	18.14
	30-40-30	0.29	3.05	2.60	5.38	8.31	10.38	6.01	7.66	2.21	3.19	17.38	19.03
	30-50-20	0.44	3.20	2.59	5.37	7.85	9.92	6.49	8.14	2.43	3.41	16.88	18.53
	30-60-10	0.49	3.25	3.20	5.98	8.93	11.00	7.21	8.86	2.94	3.91	16.14	17.79

Appendix III

Summarized Relative PCR (Cp Value) and Pp of the attributes for the hybrid screening combinations.

	Combination	10% TVI		25% TVI		50% TVI		75% TVI		90% TVI		Print Contrast	
		Cp	Pp	Cp	Pp	Cp	Pp	Cp	Pp	Cp	Pp	Cp	Pp
K	10-60-30	1.01	0.88	1.72	1.06	1.09	0.80	0.92	0.97	1.12	1.01	0.92	0.97
	10-70-20	1.09	0.91	1.36	0.90	1.07	0.82	0.95	0.75	1.03	0.70	0.95	0.75
	10-80-10	1.04	0.91	1.32	0.91	1.01	0.72	1.05	0.79	0.78	0.70	1.05	0.78
	20-50-30	0.88	0.72	0.85	0.56	0.94	0.72	0.84	0.79	1.12	0.93	0.83	0.79
	20-60-20	1.11	0.85	1.02	0.68	1.03	0.69	0.91	0.82	0.84	0.72	0.91	0.81
	20-70-10	1.11	0.89	1.20	0.74	0.82	0.56	0.85	0.71	1.07	0.89	0.85	0.71
	30-40-30	0.78	0.66	0.88	0.56	1.21	0.77	1.35	0.89	1.14	0.99	1.38	1.17
	30-50-20	1.08	0.89	0.72	0.46	1.19	0.79	1.27	0.83	0.86	0.63	1.27	0.82
	30-60-10	1.02	0.79	0.70	0.51	0.80	0.48	1.09	0.68	1.28	0.89	1.09	0.68
C	10-60-30	0.92	0.75	0.85	0.79	1.47	1.19	1.11	0.96	1.15	0.83	1.12	0.97
	10-70-20	0.81	0.74	0.94	0.89	0.81	0.66	1.00	0.71	0.89	0.69	1.01	0.72
	10-80-10	1.55	1.10	0.81	0.82	0.86	0.70	0.73	0.64	0.78	0.73	0.73	0.64
	20-50-30	1.05	0.92	0.91	0.77	0.79	0.64	0.95	0.77	1.92	1.18	0.96	0.77
	20-60-20	0.86	0.79	1.34	1.08	0.87	0.65	0.89	0.70	0.93	0.65	0.90	0.70
	20-70-10	1.10	0.92	1.08	0.96	1.08	0.86	0.82	0.77	0.72	0.70	0.82	0.77
	30-40-30	1.00	0.83	0.91	0.71	1.25	0.82	1.23	0.87	0.95	0.67	1.22	0.85
	30-50-20	1.05	0.77	1.34	0.79	0.95	0.67	1.83	1.30	1.26	0.87	1.57	0.99
	30-60-10	0.95	0.76	1.10	0.81	1.35	0.93	1.03	0.71	1.12	0.81	1.09	0.75
M	10-60-30	1.40	1.10	1.00	0.85	0.98	0.81	1.20	1.18	0.92	0.90	1.22	1.20
	10-70-20	0.96	0.83	2.06	1.29	1.52	0.99	0.82	0.71	0.92	0.82	0.82	0.71
	10-80-10	1.16	1.05	1.08	0.89	0.79	0.79	0.96	0.79	0.83	0.73	0.96	0.80
	20-50-30	1.00	0.88	1.04	0.84	1.02	1.00	0.91	0.84	1.16	1.04	0.92	0.84
	20-60-20	0.84	0.82	0.94	0.67	1.06	0.90	1.18	0.90	0.88	0.80	1.14	0.85
	20-70-10	0.98	0.84	1.07	0.79	1.42	1.11	1.05	0.88	0.84	0.74	1.06	0.88
	30-40-30	0.95	0.93	0.73	0.71	0.92	0.75	1.04	0.96	1.09	0.99	1.05	0.97
	30-50-20	0.90	0.78	1.04	0.71	1.10	0.75	0.95	0.77	1.30	0.86	0.96	0.78
	30-60-10	0.98	0.83	0.76	0.70	0.70	0.63	0.99	0.86	1.34	1.18	0.99	0.86
Y	10-60-30	0.96	0.92	1.22	0.91	1.00	0.83	0.81	0.77	0.97	0.66	0.81	0.77
	10-70-20	0.99	0.89	1.19	1.03	0.75	0.76	1.25	0.88	0.95	0.75	1.25	0.88
	10-80-10	0.78	0.78	1.10	1.02	0.99	0.76	0.96	0.89	0.78	0.82	0.96	0.89
	20-50-30	0.82	0.80	1.12	0.97	0.87	0.85	0.67	0.73	1.13	1.04	0.67	0.73
	20-60-20	1.12	1.03	1.08	1.03	0.95	0.89	1.12	0.96	0.84	0.88	1.12	0.96
	20-70-10	1.19	0.97	0.85	0.78	1.14	0.81	1.10	1.02	1.68	1.29	1.10	1.02
	30-40-30	1.00	0.89	1.09	0.86	1.04	0.77	1.19	0.90	1.13	1.00	1.19	0.90
	30-50-20	1.52	1.28	0.86	0.73	0.87	0.88	0.95	0.79	0.74	0.76	0.95	0.79
	30-60-10	1.00	0.94	0.75	0.72	2.13	1.73	1.35	1.11	1.40	1.02	1.35	1.11