An Experimental Study of Tone Value Increase Ratios on Various Printing Combinations

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Keywords: Tone value increase, lithography, flexography, digital printing, screen printing, waterless lithography

Abstract

Stanton and Hutton, who proposed the theory that Tone Value Increase Ratios (TVI Ratios) of CMYK four colors tend to be a constant, did not conduct experiments with different printing processes or with different substrates in their 1999 research paper titled "An Analysis of Sheetfed Lithographic Print Attributes." Based on True Experimental Designs and with various printing processes covering conventional lithography, hybrid lithography, conventional flexography, hybrid flexography, waterless lithography, screen printing and digital printing, this study conducts printing experiments on different substrates including coated paper, uncoated paper, PVC substrate, PP synthetic, (PP) paper, greenback (GB) paper, canvas and compact disc for calculation of TVI Ratios of four-color (C, M, Y, K) printing and analysis of differences among different combinations. Results of the study show that TVI Ratios of different substrates with the same printing process tend to be to a constant. For example, the TVI Ratio of 50:75 for PVC for black digital printing is 1.3127; for GB, 1.3020; for PP, 1.3307; for canvas, 1.3353; all converging to a constant. On the other hand, the same has been found when printing on the same substrate with different printing

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processes, i.e., when printing on coated paper, the TVI ratios of 50:25 for conventional lithography is 1.2490 while for hybrid lithography it is 1.2940. It is therefore reasonable to infer that same can also be observed at the TVI ratios of 50:25 and 50:75 when printing on the same substrate with different printing processes or when printing on different substrate with the same printing processes. Further studies focused on TVI Ratio differences between same printing processes against different substrates as well as TVI Ratio differences between same substrate against different printing processes and further analyses on correlations with Solid Ink Densities and Print Contrast are suggested to follow-up studies aiming at identification of possible relations or prediction model for the printing industry as basis of quality control.

1. Research Background and Objectives

1.1 Research background and motivation

Tone Value Increase (TVI) Ratio is not a popular topic in studies of print attributes. In 2000, Stanton and Hutton of Graphic Arts Technical Foundation (GATF) published a research paper titled “A Proposal for Sheetfed Offset Print Specifications,” in which TVI ratios of 50:75 and 50:25 for K, C, M and Y four colors are studied. Their results show that there is no significant difference in TVI ratios between 50:75 and 50:25, and under all conditions of color, lines per inch (LPI) and paper types, TVI ratio tends to be a constant. In 50:75, the general average is 1.51 and it is 1.28 in 50:25. However, their study was only conducted on coated paper with Sheetfed Lithography. Different printing processes and different substrates were not tested. Still, the sample size was not big enough while sampling was not random. Therefore, whether “TVI Ratios tend to be a constant” can be applied to the printing industry as a quality reference needs further studies.

In order to have an in-depth and careful investigation into the issue described above, this research conducts a study on seven printing processes

(digital printing, conventional lithography, conventional flexography, hybrid lithography, hybrid flexography, screen printing and waterless lithography) and seven substrates (coated paper, uncoated paper, PVC film, PP synthetic paper, greenback paper, canvas and compact disc) commonly employed in the printing industry with an aim at finding out whether TVI Ratios of various printing processes and diverse substrates converge to a constant based on generalizability, representativeness and meticulous experiment design.

1.2 Research objectives

In this study, TVI Ratio of 50:75 (TVI@50% / TVI@75%) is denoted as L_{75} and TVI Ratio of 50:25 (TVI@50% / TVI@25%) is denoted as L_{25}.

1. To analyze L_{75} and L_{25} of KCMY four colors with digital printing on PVC (Polyvinylchloride) film, PP (Polypropylene) synthetic paper, greenback paper and canvas.
2. To analyze L_{75} and L_{25} of KCMY four colors with conventional offset lithography on coated paper and uncoated paper.
3. To analyze L_{75} and L_{25} of KCMY four colors with conventional flexography on coated paper, uncoated paper and PVC film.
4. To analyze L_{75} and L_{25} of KCMY four colors with hybrid lithography on coated paper and uncoated paper.
5. To analyze L_{75} and L_{25} of KCMY four colors with hybrid flexography on coated paper, uncoated paper and PVC film.
6. To analyze L_{75} and L_{25} of KCMY four colors with screen printing on compact disc.
7. To analyze L_{75} and L_{25} of KCMY four colors with waterless lithography on compact disc.

1.3 Significance of this research

Printing industries in Asia has exhibited rapid growth in recent years with an average annual growth rate of 7~8% while the global figure is 3~4%. Worldwide annual consumption on printing per capita is€48, while the same numeral in Asia is €8 except for Japan. As figures speak for themselves,

based on a population of 3.9 billion, or 60% in the world, a sharp rise in Asian printing industries is not a slogan but just around the corner (Chen, Zheng Xiong 2007).

Printing industries in Taiwan has always been local-market-oriented. The increase in capacity leads to nothing but fierce price competition when the market does not expand appropriately. To find outlets for the excess of capacity, the industry has had a clear understanding of the importance of export market development because failing to open up export market may jeopardize the business. However, only limited accomplishment has been achieved due to some weaknesses exist in local printing industries including high material and labor cost, elusiveness of market information and lack of international trade professionals specialized in printing industry. Apart from these is the instability of printing quality which is one of the greatest obstacles in export market development. It will be difficult to compete with overseas printing companies if printing quality does not reach international standard (Hsieh, 2003). Under such circumstances, a set of easy-to-use printing quality reference with representativeness are helpful for the local industries to improve their quality and make breakthroughs in overseas markets. If the TVI Ratios of four-color with different printing processes and diverse substrates studied in this research based on large-sized random sampling can be found converging to a constant, it will be a good reference in determining printing quality.

Capability, a term to describe whether or not stability in printing processes can be maintained, has gradually been attached great importance to by the local printing industries in recent years. Among complicated processes, how to improve capability so as to enhance printing quality and customer satisfaction is not only a foremost goal pursued by major printing companies but a primary issue for the whole industry. As mentioned in “A Proposal for Sheetfed Offset Print Specifications” published by Stanton and Hutton of GATF (2000), the premise for TVI Ratios to converge to a constant is that a stable standard has to be maintained throughout printing

processes. Hence, stability of TVI Ratios can also be an index for stability in printing processes. Nevertheless, Stanton and Hutton conducted their study only on coated paper with sheetfed offset print, not on diverse substrates with different printing processes. Still, the sample size in their study was not large enough. Therefore, whether their theory can be applied to the printing industry as a quality control reference needs further studies.

In view of the background given above, in order to have an in-depth investigation into preliminary results discovered by previous researchers, this research conducts a study on seven printing processes (digital printing, conventional lithography, conventional flexography, hybrid lithography, hybrid flexography, screen printing and waterless lithography) and seven substrates (coated paper, uncoated paper, PVC film, PP synthetic paper, greenback paper, canvas and compact disc) commonly employed in Taiwan's printing industry with an aim at finding out an optimal combination of printing processes and substrate with TVI Ratios converging to a constant based on experiment design with generalizability and representativeness.

1.4 Research Hypotheses

Hypothesis 1

Ho: There is no significant difference in KCMY TVI Ratios L_{25} for all process/substrate combinations based on the same printing processes, same substrate, same operators and same measuring instruments. That is:

Ho:$\mu_{ij\_L25\_K} = \mu_{ij\_L25\_C} = \mu_{ij\_L25\_M} = \mu_{ij\_L25\_Y}$

(μ is the mean of measurements, i is one of the seven printing processes, j is one of the seven substrates)

Ha: Based on the same printing processes, same substrate, same operators and same measuring instruments, at least one pair of process/substrate combination exhibits significant difference in KCMY TVI Ratios L_{25}. That is:

Ha:$\mu_{ij\_L25\_x} \neq \mu_{ij\_L25\_y}$

(μ is the mean of measurements, i is one of the seven printing processes, j is one of the seven substrates, x is one of CMYK, y is one of CMYK, $x \neq y$)

Hypothesis 2

Ho: There is no significant difference in KCMY TVI Ratios L_{75} for all process/substrate combinations based on the same printing processes, same substrate, same operators and same measuring instruments. That is:

Ho: $\mu_{ij\_L75\_K} = \mu_{ij\_L75\_C} = \mu_{ij\_L75\_M} = \mu_{ij\_L75\_Y}$

(μ is the mean of measurements, i is one of the seven printing processes, j is one of the seven substrates)

Ha: Based on the same printing processes, same substrate, same operators and same measuring instruments, at least one pair of process/substrate combination exhibits significant difference in KCMY TVI Ratios L75. That is:

Ha: $\mu_{ij\_L75\_x} \neq \mu_{ij\_L75\_y}$

(μ Is the mean of measurements, i is one of the seven printing processes, j is one of the seven substrate, x is one of CMYK, y is one of CMYK, $x \neq y$)

1.5 Research assumptions and limitations

1. Printing houses participating in this research are carefully selected by the research team but not randomly picked.
2. GATF's (Graphic Arts Technical Foundation) Digital Test Form Version 5.0 is used with modifications in this study.
3. Solid Ink Densities in this study are set as follows; specifications in General Requirements for Applications in Commercial Offset Lithography (GRACoL) are followed in lithography; specifications in Flexographic Image Reproduction Specifications & Tolerances (FIRST) are followed in flexography; standards used by printing houses are followed in digital printing, screen printing and waterless lithography.
4. Specifications of printing plates, printing blankets, damping solution and other printing material and facilities are not to be uniformed in

this study but adhere to standards used by respective printing houses. Effects on the study are neglected.

5. Room temperatures and relative humidity in the printing house adhere to standards used by respective printing houses. Effects on the study are neglected.
6. Different printing combinations are processed by different printing houses with printing presses and proofing presses of different brands, different ages, specifications and physical conditions. Effects of such variables are neglected.
7. Paper used by different printing houses may be of different brands, types, basis weights and basic sizes. Brands of other substrates are not regulated either. But basis weight of paper used is set between 100 lb to 175 lb in principle. Brands and types of the ink used in this study are the same as those used by respective printing houses in routines. Effects of these variables are neglected.
8. Printing houses are requested not to apply any tone compensation curves in plate making.
9. Measurement instruments used in this study, such as GretagMacbeth Eye-One iO Spectrophotometer and X-Rite530 Spectrodensitometer have all been launched and sold in international markets by manufacturers. The reliability and validity of these instruments have been confirmed by both academic and industrial circles and not to be discussed in this study.

2. Literature Review

2.1 Printing quality

In printing, Tone Value Increase refers to the difference in dot area between film and plate or between film and paper. TVI may occur at color separation, film exposure, plate developing and ink transfer from printing presses to the paper. Such changes of area are inevitable in printing processes that involve ink carry and transfer. In lithography, TVI has been confirmed a key factor

influencing printing quality. (Hsieh, 1997) It would be beneficial to a print house to understand the types, causes, influencing factors of, how to calculate and how to control TVI so as to have better control over printing quality (Killeen, 1995).

Tone Value Increase includes Physical Tone Value Increase and Optical Tone Value Increase. Physical Tone Value Increase is mechanical dot area enlargement which may occur during plate-making processes; or when ink, paper and other printing conditions are changed; or during printing processes. Optical Tone Value Increase, a TVI resulted from reflections and refractions of light on paper (substrate) may occur during printing and mock-up processes. Optical Tone Value Increase tends to cause dots of different sizes to enlarge to the same size making dots in highlights, midtones and shadows to change diameters. Since the longer the circumference becomes, the bigger increase is in dot area, the biggest TVI occurs in midtones, or the 50% of the total dot area (Southworth M. & Southworth D., 1989, Ch.14-13 – Ch.14-14), as shown in Figure. 2.

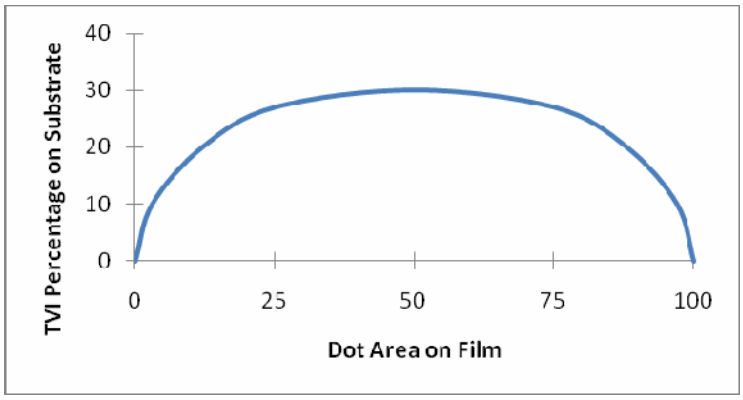

Figure 1. *Tone Value Increase Curve. Source: Quality and Productivity in the Graphic Arts (Ch.14-15) by Miles Southworth & Donna Southworth, 1989, New York: Graphic Arts Publishing Co.*

Inkjet system and toner system are two major imaging systems used by digital printing. Since there is no pressure involved, it is also known as

non-impact printing and there may be no phenomenon of TVI. But after consulting specialists, Richard Adams, Research Scientist and Digital Imaging and Color Reproduction Specialist of GATF, proposed three types of TVI in digital printing: (1) diffusion or haloing of ink or molten toner droplets (Physical TVI), (2) light scattering on substrates (optical TVI), (3) RIP (Raster Image Processing, document to be printed is first transformed into a PostScript program and then dot sizes are calculated by RIP. There will be no TVI if Dot Reproduction Curve is linearized.) For this reason, TVI in digital printing is also analyzed in this study.

2.2 Tone Value Increase Ratios, TVI ratios

The main attribute measured and analyzed in this study is Tone Value Increase Ratio. GATF published a technical report written by Anthony Stanton and Phillip Hutton focused on lithographic print attributes, in which TVI ratios were brought up. That is, regardless of the TVI at 50%, a constant relation exhibit between TVI Ratio at 50% and TVI Ratio at 75% (the quotient derived from TVI Ratio at 75% divided by TVI Ratio at 50%) at all colors, LPI and paper types. A similar constant relation also exhibits between TVI Ratio at 50% and TVI Ratio at 25% at all colors, LPI and paper types. Table 1 shows the average ratios between TVI at 50% and TVI at 75%. Table 2 shows the average ratios between TVI at 50% and TVI at 25%. An error of 0.1 in the ratio will generally result in 1% error in 75% or 25% TVI ratios. As indicated in Table 1, the 50:75 TVI Ratios in all four colors are very similar, with errors less than 0.1. Another point worth mentioning is that the consistence also exists among different types of paper. Average 50:75 and 50:25 TVI Ratios listed in Table 1 and Table 2 indicate that for all types of paper, LPI and ink color, TVI@50%/TVI@75% converge to 1.51 while TVI@50%/TVI@25% converge to 1.28. Based on such findings, once a correct 50% TVI is given, the corresponding 75% TVI can be worked out from the 50:75 TVI Ratios and the corresponding 25% TVI can be worked out from the 50:25 TVI Ratios. In most cases, actual

75% or 25% TVI in lithographic printing shall fall within 2% deviation from the calculations (Stanton et al, 1999).

Table 1. *Average 50:75 TVI Ratios (TVI@50% / TVI@75%)*

50:75 Ratios	CTP/Gloss	IM/Gloss	Matte	Uncoated	Overall Average
Y	1.39	1.53	1.45	1.53	1.50
M	1.48	1.54	1.38	1.43	1.51
C	1.46	1.54	1.30	1.44	1.50
K	1.48	1.52	1.49	1.62	1.52
Note: 1. CTP/Gloss: CTP refers to Computer to Plate, printed on coated paper 2. IM/Gloss: IM refers to Imagesetter, with conventional plate making, printed on coated paper					

Source: "The Sheetfed Lithographic Print Attribute Study," by Anthony Stanton and Phillip Hutton, 2000, GATF Research and Technology Reports, p.13.

Table 2 indicates that 50:25 TVI Ratios on coated paper at Y and C tend to be higher than the overall average. Judging from the fact that mean errors at Y, M, C, K and paper types are all within the 0.1 deviation, Stanton and Hutton are of the opinion that errors of coated paper may level down sample value (Stanton and Hutton, 1999).

Table 2. *Average 50:25 TVI Ratios (TVI@50% / TVI@25%)*

50:25 Ratios	CTP/Gloss	IM/Gloss	Matte	Uncoated	Overall Average
Y	1.28	1.22	1.35	1.25	1.24
M	1.32	1.22	1.33	1.24	1.25
C	1.28	1.25	1.53	1.29	1.29
K	1.35	1.22	1.34	1.25	1.26
Note: 1. CTP/Gloss: CTP refers to Computer to Plate, printed on coated paper 2. IM/Gloss: IM refers to Imagesetter, with conventional plate making, printed on coated paper					

Source: "The Sheetfed Lithographic Print Attribute Study," by Anthony Stanton and Phillip Hutton, 2000, GATF Research and Technology Reports, p.13.

3. Research Methods

3.1 Research design

Using True Experimental Designs in quantitative research, this study explores TVI Ratios of K, C, M, Y four colors on diverse substrates with different printing processes and analyzes differences, if any, among the four

colors, or whether they converge to a constant. Based on True Experimental Method, major high quality printing houses are solicited for processing the experiments of this study. Data are then collected through measurement with instruments and analyzed with statistical software. Research hypotheses and research objectives are verified and discussed through experimental validation.

3.2 Research Variables

Dependent Variable

Tone Value Increase Ratios (TVI Ratios)

Independent Variable

1. Different printing processes (digital printing, conventional lithography, conventional flexography, hybrid lithography, hybrid flexography, screen printing and waterless lithography)
2. Different substrates (coated paper, uncoated paper, PVC film, PP synthetic paper, greenback paper, canvas and compact disc)

3.3 Measuring instruments

1. **GretagMacbeth Eye-One iO Spectrophotometer**

   Used in this study, GretagMacbeth Eye-One iO Spectrophotometer is an automated measuring instrument that reads out densities of color patches in the test form. This is a major measuring instrument in this study used for measuring densities of 25%, 50%, 75% and 100% of K, C, M, Y four colors and then for calculation of TVI Ratios of 50:75 and 50:25.

2. **X-Rite530 Spectrodensitometer**

   Equipped with special microscope features, X-Rite530 Spectrodensitometer used in this study is able to measure color targets as narrow as 1.6mm. This device has all other functions in the 500-Series including density, dot area, trap, print contrast, hue error, grayness, color, match, paper functions and compare. This spectrodensitometer is used to measure K, C, M, and Y Solid Ink Densities during test runs to confirm density stability before actual printing, which is a key procedure to identify and clear any

abnormality that may affect the experiment such as insufficient/excess ink, uneven cylinder pressure, etc. In addition, this instrument is also used to measure density, TVI and print contrast on compact discs.

3. **X-Rite 341 Transmission Densitometer**

   X-Rite 341 Transmission Densitometer is used in this study to verify dot area repeatability on films after electronic original files output to films. The X-Rite 341 device are zeroed and calibrated before measurement. Measuring dot areas after output with a densitometer is also a key procedure to avoid tone value increase during output and verify linearization of the imagesetter to achieve stable printing processes.

4. **GretagMacbeth IC-Plate‖Plate Scope**

   GretagMacbeth IC-Plate‖ Plate Scope is used to analyze dot areas, screen rulings and screen angles of conventional PS plates, CTP plates, positive/negative working lithographic plates and AM/FM screens. The device in this study is for measuring dot areas in lithographic plates to avoid tone value increase.

3.4 Experiment samples

Printers participating in the study are selected based on the printing quality and processes they specialized in. They are high quality commercial printers in Taiwan. The criteria for selecting the participants in this study as high quality were: printers were active member companies of PIT (Printing Industry of Taiwan) or PTRI (Printing Technology Research Institute); they established themselves as commercially successful printers; and they were quality-conscious enough to have invested considerable time, materials, and effort in participating in this study without monetary compensation.

As for sampling, the population size for each printing processes is 1000 sheets, i.e., each participating printer was asked to print 1000 copies of the test form provided by the research team, and 50 experimental sheets are sampled by systematic random sampling. After 50 experimental samples have been picked, densities of 25%, 50%, 75% and 100% of K, C, M, Y four

colors in each sample are measured with GretagMacbeth Eye-One iO Spectrophotometer. TVI Ratios of 50:25 and 50:75 are then obtained through calculation in Microsoft Office Excel 2007. The substrate of compact disc is measured with X-Rite530 Spectrodensitometer. The parameter n is set at n=1.14 (Hsieh, 2002). Data obtained are collected and recorded for follow-up analyses.

3.5 Analyses

Data collected and recorded are then analyzed with SPSS 14.0 and Minitab 14.0 to identify differences, if any, among TVI Ratios of four colors. Items analyzed are listed hereunder:

1. TVI Ratios L_{75} and L_{25} of CMYK color on PVC, PP, GB and canvas with digital printing.
2. TVI Ratios L75 and L25 of CMYK color on coated paper and uncoated paper with conventional lithography.
3. TVI Ratios L75 and L25 of CMYK color on coated paper, uncoated paper and PVC with conventional flexography.
4. TVI Ratios L75 and L25 of CMYK color on coated paper and uncoated paper with hybrid lithography.
5. TVI Ratios L75 and L25 of CMYK color on coated paper, uncoated paper and PVC with hybrid flexography.
6. TVI Ratios L_{75} and L_{25} of CMYK color on compact discs with screen printing.
7. TVI Ratios L_{75} and L_{25} of CMYK color on compact discs with waterless lithography.

3.6 Research procedures

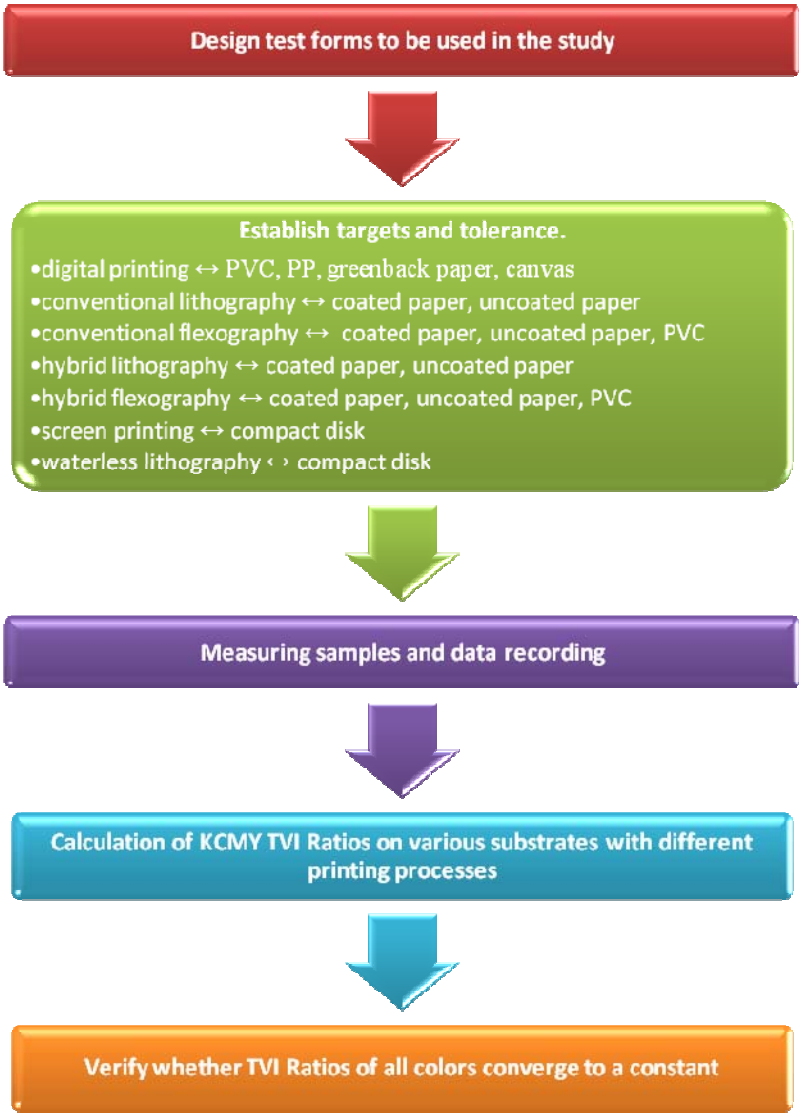

Figure 2. *Research procedures.*

1. Design of test forms for experiments

As shown in Figure 3, GATF's (Graphic Arts Technical Foundation) Digital Test Form Version 5.0 with modifications is the test form used in this study of dimensions 28×45(cm) for all the substrates other than compact discs.

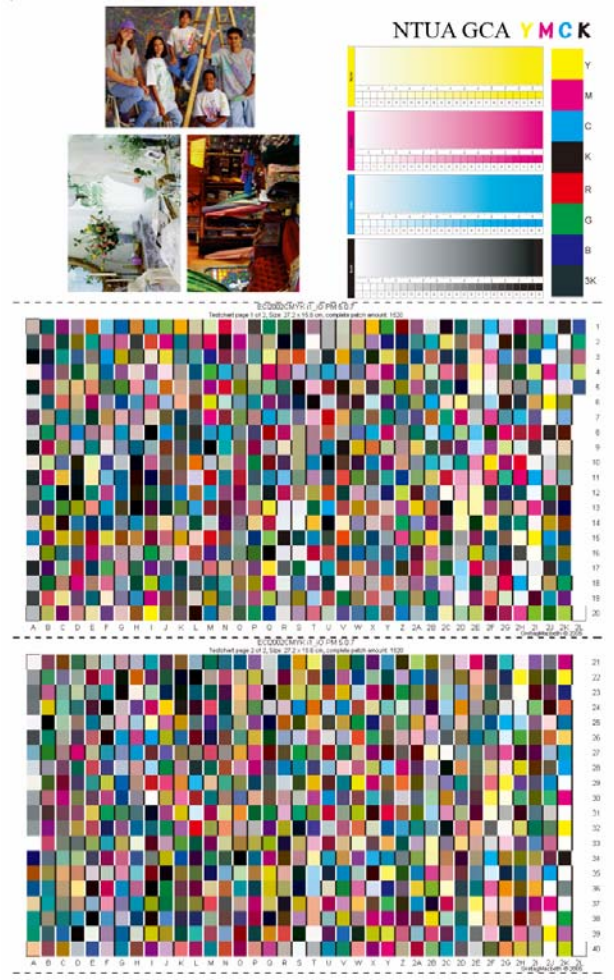

Figure 3. Test form used in this study.

Since substrates used in the study include compact discs for waterless lithography and screen printing, a special test form is designed to fit the size of 8.27×11.7 (inch). The special design for compact disc printing includes C, Y, M, K test forms and images for verification of color performance. Refer to Figure 4 for details.

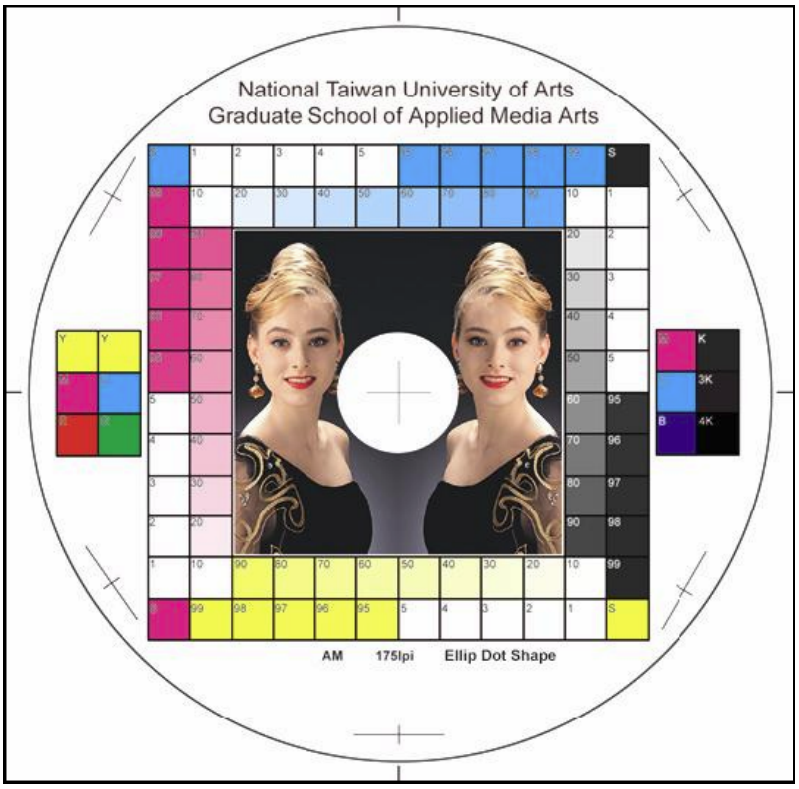

Figure 4. *Test forms for printing on CDs.*

2. Printers participating in the research

A project proposal is sent to printing houses participating in the research describing significance and benefits of this research followed up by emails and telephone calls to gain support from these printers. Test forms when completed are provided to respective printing house of lithography, flexography, screen printing, waterless lithography and digital printing and various substrates. Since some local printers still employs conventional CTF printing processes, CTP platemaking is not required. Screen rulings are set at 175 lpi (lines per inch); specification of anilox roller in flexography is 875 lpi or above; screen printing is set at 150 threads/in; while resolution of digital printing is set at 750 dpi (dots per inch).

3. Platemaking

Printing plates are made either through conventional platemaking processes or through CTP. Both are with screen rulings of 175lpi. One set of four printing plates (one plate for each color of K, C, M, and Y) and made for each printing technique. In order to ensure stable dot repeatability, GretagMacbeth IC-PlateⅡPlate Scope is used to measure specific dot areas (5%, 25%, 50%, 75%, 100%) on printing plates so that tone value increase can be controlled under a certain percentage. Register marks for printing on compact discs (as shown in Figure 5) are incorporated into films prior to printing down to metal. For all printing processes other than CTP, routine operation procedures and requirements of respective printing houses are respected and fulfilled aiming for maintaining smooth platemaking processes. Measurement data are recorded, collected and plotted into charts. Table 3 shows dimensions and quantities of test forms for each printing processes.

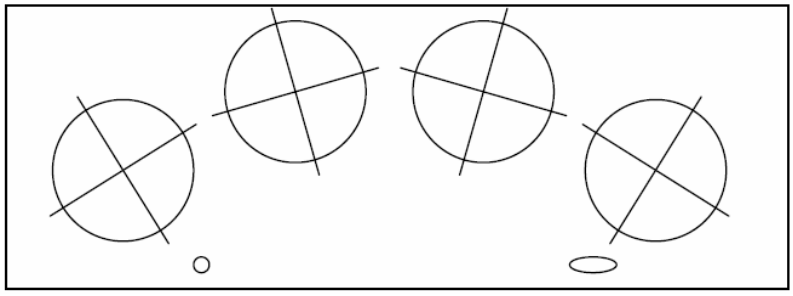

Figure 5. *Register marks for printing on compact discs.*

Table 3. *Dimensions and quantities of test form and plate size for each printing process.*

Printing Process	Substrate	Test form size	Printing plate size	Quantity
Conventional lithography	coated paper	28×45 cm	25×38 inch	4
	uncoated paper	28×45 cm	25×38 inch	4
Hybrid lithography	coated paper	28×45 cm	25×38 inch	4
	uncoated paper	28×45 cm	25×38 inch	4
Conventional flexography	coated paper	28×45 cm	11×18 inch	4
	uncoated paper	28×45 cm	11×18 inch	4
	PVC	28×45 cm	11×18 inch	4
Hybrid flexography	coated paper	28×45 cm	11×18 inch	4
	uncoated paper	28×45 cm	11×18 inch	4
	PVC	28×45 cm	11×18 inch	4
Digital printing	canvas	28×45 cm	25×35 inch	null
	PVC	28×45 cm	25×35 inch	null
	GB	28×45 cm	25×35 inch	null
	PP	28×45 cm	25×35 inch	null
Waterless lithography	compact disc	12cm in diameter	8.27×11.7 inch	1
Screen printing	compact disc	12cm in diameter	8.27×11.7 inch	4

4. Printing

Printing with different processes on various substrates is conducted after platemaking is completed. Coated paper and uncoated paper are then printed with conventional and hybrid lithography. Coated paper, uncoated paper and PVC are printed with conventional and hybrid flexography. Compact discs are printed with waterless lithography and screen printing. PVC, PP, GB and canvas are printed with digital printing. Printing conditions and operation environment follow printers' standard operational production settings with test runs prior to actual printings.

Printing conditions and operation environment settings for flexography follow Flexographic Image Reproduction Specifications & Tolerances (FIRST) stipulated in Basic Requirements for International Design and Graphic Solutions (BRIDGS') General Printing Guidelines,

2007 issued by Flexographic Technical Association (FTA). Actual experimental printing were conducted with narrow sheetfed printing machines after SID in test runs reaching certain levels; 1.5 (K), 1.35 (C), 1.25 (M) and 1.0 (Y). Since there is no SID specification for PVC films, the SID of which follow that for paper. Printing conditions and operation environment settings for lithography follow General Requirements for Applications in Commercial Offset Lithography (GRACoL) formulated jointly by Graphic Communications Association (GCA), International Prepress Association (IPA) and GATF. Actual experimental printings were conducted on different types of paper after SID in test runs reaching certain levels as per GRACoL standard. SIDs of the paper used in the study are as follows: first and second class matte: 1.70 (K), 1.40 (C), 1.50 (M) and 1.05 (Y); uncoated paper: 1.25 (K), 1.0 (C), 1.12 (M) and 0.95 (Y); compact disc: 1.5 (K), 1.25 (C), 1.35 (M) and 1.00 (Y). (GRACoL Specifications, 2007)

X-Rite530 Spectrodensitometer is used in the study for measuring ink density. Actual printings are not started until the inks have been optimized to achieve even distribution and smooth transfer. One set of printing plates were made for each printing technique and 1000 (population size) sheets are printed for each substrate. Digital printing does not involve film and platemaking and the printing of 1000 copies starts directly from electronic files. After the printing with different processes on various substrates is completed, 17,000 printed copies and 850 printed compact discs are obtained.

5. Sampling of prints

Systematic random sampling is employed in this study with 50 samples picked out of the population of 1000. The 1000 copies in the population were numbered 1 to 1000. Since the interval is 1000 (total number in the population) divided by 50 (sample size), one sample was picked every 20 copies. The first sample was picked by simple random sampling from the population No. 1 ~ No. 1000 and then one sample was picked every 20

copies. This is sampling in the second stage. Detail numbers of printed sheets and sample size during stages 1 and 2 are listed in Table 4.

Table 4. *Numbers of printed sheets and sample size in this study.*

Printing process	Substrate	No. of test forms in each printed sheet	Population size	Sample size
Conventional lithography	coated paper	3	1000	50
	uncoated paper	3	1000	50
Hybrid lithography	coated paper	3	1000	50
	uncoated paper	3	1000	50
Conventional flexography	coated paper	1	1000	50
	uncoated paper	1	1000	50
	PVC	1	1000	50
Hybrid flexography	coated paper	1	1000	50
	uncoated paper	1	1000	50
	PVC	1	1000	50
Digital printing	canvas	3	1000	50
	PVC	3	1000	50
	GB	3	1000	50
	PP	3	1000	50
Waterless lithography	compact discs	1	1000	50
Screen printing	compact discs	1	1000	50
Total			17000	850

6. Measurement and statistics

Sampling stage was followed by measurement with GretagMacbeth Eye-One iO Spectrophotometer to generate various density data. Data obtained were input to a TVI conversion equation in Microsoft Office Excel for calculation of the TVI values at 25%, 50% and 75%. TVI values were then entered to SPSS 14.0 and Minitab14.0 to produce TVI Ratios of 50:25 and 50:75. Compact discs were measured by X-Rite530 Spectro-densitometer. The TVI values obtained were also recorded to statistical software for calculation of TVI Ratios of 50:25 and 50:75. TVI Ratios were then analyzed with One-way Analysis of Variance (one-way ANOVA) and

Independent Sample T Test to identify whether significant differences exist, if any, of K, C, M, Y TVI Ratios among different printing processes and various substrates, and verify whether or not TVI Ratios converge to a constant. ANOVA level of significance (α) in this study is set at 0.05, or, whether they are significantly associated within a confidence interval of 95%.

4. Results and Discussion

4.1 TVI Ratios in digital printing

1. PVC

50:25 TVI Ratios

As shown in Table 5, 50:25 TVI Ratios of four colors do not converge to a constant, while the diagram shows no significant difference between K and C. T test shows that 50:25 TVI Ratios of K and C on PVC converge to a constant of 1.2629 (the mean of TVI Ratios of K and C).

Table 5. *One-way ANOVA of 50:25 TVI Ratios of PVC with digital printing.*

	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/25	1.2450	0.0888	(--*---)
C_50/25	1.2808	0.1258	(--*--)
M_50/25	1.4140	0.1083	(--*---)
Y_50/25	1.0978	0.1202	(--*--)
P-values	0.000		----1.1--------1.2----------1.3----------1.4--------

50:75 TVI Ratios

As shown in Table 6, 50:75 TVI Ratios of four colors do not converge to a constant. T test shows that TVI Ratios on PVC with digital printing do not converge to a constant.

Table 6. *One-way ANOVA of 50:75 TVI Ratios of PVC with digital printing.*

	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/75	1.3106	0.0552	(--*-)
C_50/75	1.2624	0.0633	(--*-)
M_50/75	1.2042	0.0731	(--*-)
Y_50/75	1.4822	0.0788	(-*--)
P-values	0.000		----1.2---------1.28-----------1.36----------1.44--------

2. GB

50:25 TVI Ratios

As shown in Table 7, 50:25 TVI Ratios of four colors do not converge to a constant. T test shows that TVI Ratios on GB with digital printing do not converge to a constant.

Table 7. *One-way ANOVA of 50:25 TVI Ratios of GB with digital printing.*

	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/25	1.3228	0.1181	(-*--)
C_50/25	1.2332	0.1126	(--*-)
M_50/25	1.4572	0.1183	(-*--)
Y_50/25	1.6008	0.1188	(-*--)
P-values	0.000		----1.2--------1.32-------------1.44------------1.56--------

50:75 TVI Ratios

As shown in Table 8, 50:75 TVI Ratios of four colors do not converge to a constant, while the diagram shows no significant difference in statistical analysis among K, C and Y colors. T test shows that 50:75 TVI Ratios of K, C and Y on GB converge to a constant of 1.2707 (the mean of TVI Ratios of K, C and Y colors).

Table 8. *One-way ANOVA of 50:75 TVI Ratios of GB with digital printing.*

	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/75	1.2904	0.0547	(----*----)
C_50/75	1.2682	0.0771	(----*----)
M_50/75	1.1872	0.0629	(----*----)
Y_50/75	1.2536	0.0575	(----*----)
P-values	0.000		--------1.19---------1.225--------1.26----------1.295--------

3. PP

50:25 TVI Ratios

As shown in Table 9, 50:25 TVI Ratios of four colors on PP with digital printing do not converge to a constant, while the diagram shows no significant difference on in statistical analysis between color K and C; M and Y. T test shows that 50:25 TVI Ratios of color K and C; M and Y on PP converge to constant of 1.3909 (the mean of TVI Ratios of K and C) and 1.5141 (the mean of TVI Ratios of M and Y) respectively.

Table 9. *One-way ANOVA of 50:25 TVI Ratios of PP with digital printing.*

	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/25	1.3774	0.0664	(---*----)
C_50/25	1.4044	0.1058	(----*---)
M_50/25	1.5302	0.0634	(---*----)
Y_50/25	1.4980	0.0825	(----*---)
P-values	0.000		----------1.40--------1.45------------1.5-----------1.55--

50:75 TVI Ratios

As shown in Table 10, 50:75 TVI Ratios of four colors do not converge to a constant, while the diagram shows no significant difference in statistical analysis between M and Y. T test shows that TVI Ratios of color M and Y on

PP with digital printing converge to a constant of 1.2347 (the mean of TVI Ratios of M and Y).

Table 10. *One-way ANOVA of 50:75 TVI Ratios of GB with digital printing.*

	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/75	1.3382	0.0364	(-*-)
C_50/75	1.1570	0.0401	(-*-)
M_50/75	1.2322	0.0354	(*-)
Y_50/75	1.2372	0.0436	(-*-)
P-values	0.000		----------1.2----------1.26--------1.32----------1.38------

4. Canvas

50:25 TVI Ratios

As shown in Table 11, 50:25 TVI Ratios of four colors do not converge to a constant, while the diagram shows no significant difference in statistical analysis between C and M. T test shows that 50:25 TVI Ratios of color C and M on canvas with digital printing converge to a constant of 1.7562 (the mean of TVI Ratios of C and M).

Table 11. *One-way ANOVA of 50:25 TVI Ratios of canvas with digital printing.*

	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/25	1.4397	0.1081	(--*--)
C_50/25	1.6697	0.4675	(---*--)
M_50/25	1.8427	0.2067	(--*---)
Y_50/25	1.0193	0.0414	(--*--)
P-values	0.000		----------1.20----------1.5----------1.8----------2.1--

50:75 TVI Ratios

As shown in Table 12, 50:75 TVI Ratios of four colors do not converge to a constant, while the diagram shows no significant difference in statistical analysis between K and Y. T test shows that TVI Ratios of K and Y on canvas with digital printing converge to a constant of 1.3335 (the mean of TVI Ratios of K and Y).

Table 12. *One-way ANOVA of 50:75 TVI Ratios of canvas with digital printing.*

	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/75	1.3353	0.0861	(----*----)
C_50/75	1.0937	0.1665	(----*----)
M_50/75	1.1963	0.0943	(----*---)
Y_50/75	1.3117	0.0434	(----*----)
P-values	0.000		----------1.12-------1.2----------1.28----------1.36----

4.2 TVI Ratios in conventional lithography

1. Coated paper

50:25 TVI Ratios

As shown in Table 13, 50:25 TVI Ratios of four colors do not converge to a constant, while the diagram shows no significant difference in statistical analysis between K and M; C and Y. T test shows that 50:25 TVI Ratios of color K and M; C and Y on coated paper with conventional lithography converge to constant of 1.2302 (the mean of TVI Ratios of K and M) and 1.3613 (the mean of TVI Ratios of C and Y) respectively.

Table 13. *One-way ANOVA of 50:25 TVI Ratios of coated paper with conventional lithography.*

	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/25	1.2490	0.0534	(---*---)
C_50/25	1.3705	0.1091	(---*---)
M_50/25	1.2113	0.0617	(---*---)
Y_50/25	1.3520	0.0732	(---*---)
P-values	0.000		----1.2------1.26-----------1.32-----------1.38--------

50:75 TVI Ratios

As shown in Table 14, 50:75 TVI Ratios of four colors on coated paper with conventional lithography do not converge to a constant. T test shows that TVI Ratios of coated paper with conventional lithography do not converge to a constant.

Table 14. *One-way ANOVA of 50:75 TVI Ratios of coated paper with conventional lithography.*

	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/75	1.5448	0.0256	(*-)
C_50/75	1.4580	0.0383	(-*-)
M_50/75	1.3643	0.0390	(*-)
Y_50/75	1.4868	0.0283	(-*-)
P-values	0.000		-----1.38---------1.44-----------1.5----------1.56--------

2. Uncoated paper

50:25 TVI Ratios

As shown in Table 15, 50:25 TVI Ratios of four colors on uncoated paper with conventional lithography do not converge to a constant. T test shows that 50:25 TVI Ratios of uncoated paper with conventional lithography do not converge to a constant.

Table 15. *One-way ANOVA of 50:25 TVI Ratios of uncoated paper with conventional lithography.*

	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/25	1.0773	0.0258	(-*)
C_50/25	1.3023	0.0413	(*)
M_50/25	1.1290	0.0331	(*-)
Y_50/25	1.1703	0.0222	(*-)
P-values	0.000		----------1.12---------1.19----------1.26----------1.33------

50:75 TVI Ratios

As shown in Table 16, 50:75 TVI Ratios of four colors on uncoated paper with conventional lithography do not converge to a constant. T test shows that 50:75 TVI Ratios of uncoated paper with conventional lithography do not converge to a constant.

Table 16. *One-way ANOVA of 50:75 TVI Ratios of uncoated paper with conventional lithography.*

	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/75	1.6462	0.0371	(-*-)
C_50/75	1.5158	0.0432	(-*-)
M_50/75	1.4653	0.0400	(-*-)
Y_50/75	1.6138	0.0351	(-*-)
P-values	0.000		----------1.5---------1.56----------1.62----------1.68-----

4.3 TVI Ratios in conventional flexography

1. Coated paper

50:25 TVI Ratios

As shown in Table 17, 50:25 TVI Ratios of four colors do not converge to a constant, while the diagram shows no significant difference in statistical analysis between C and Y. T test shows that 50:25 TVI Ratios of C and Y on

coated paper with conventional flexography converge to a constant of 5.020 (the mean of TVI Ratios of color C and Y).

Table 17. *One-way ANOVA of 50:25 TVI Ratios of coated paper with conventional flexography.*

	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/25	2.466	0.264	(-*--)
C_50/25	4.731	1.667	(--*-)
M_50/25	9.119	1.941	(--*-)
Y_50/25	5.309	1.403	(--*-)
P-values	0.000		--2.0----------4.0----------6.0----------8.0--------

50:75 TVI Ratios

As shown in Table 18, 50:75 TVI Ratios of four colors do not converge to a constant, while the diagram shows no significant difference in statistical analysis between K and C. T test shows that 50:25 TVI Ratios of K and C on coated paper with conventional flexography converge to a constant of 1.613 (the mean of TVI Ratios of color K and C).

Table 18. *One-way ANOVA of 50:75 TVI Ratios of coated paper with conventional flexography.*

	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/75	1.6655	0.0776	(*-)
C_50/75	1.5605	0.1192	(*-)
M_50/75	2.9553	0.4808	(-*-)
Y_50/75	1.1845	0.1846	(-*)
P-values	0.000		----------1.5----------2.0----------2.5---------3.0--------

2. Uncoated paper

50:25 TVI Ratios

As shown in Table 19, 50:25 TVI Ratios of four colors do not converge to a constant. T test shows that 50:25 TVI Ratios of uncoated paper with conventional flexography do not converge to a constant.

Table 19. *One-way ANOVA of 50:25 TVI Ratios of uncoated paper with conventional flexography.*

	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/25	1.9523	0.1538	(--*---)
C_50/25	1.6383	0.1616	(--*---)
M_50/25	1.7750	0.2049	(--*---)
Y_50/25	1.4625	0.1652	(--*---)
P-values	0.000		---------1.50----------1.65--------1.8----------1.95--------

50:75 TVI Ratios

As shown in Table 20, 50:75 TVI Ratios of four colors do not converge to a constant, while the diagram shows no significant difference in statistical analysis between K and C. T test shows that 50:75 TVI Ratios of color K and C on uncoated paper with conventional flexography converge to a constant of 1.9084 (the mean of TVI Ratios of K and C).

Table 20. *One-way ANOVA of 50:75 TVI Ratios of uncoated paper with conventional flexography.*

	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/75	1.8550	0.1764	(--*-)
C_50/75	1.9618	0.2684	(-*--)
M_50/75	2.4845	0.3393	(--*-)
Y_50/75	1.5255	0.1712	(--*-)
P-values	0.000		---1.5----------1.8----------2.1----------2.4--------

3. PVC film

50:25 TVI Ratios

As shown in Table 21, the diagram shows no significant difference in statistical analysis between K、C and Y. T test shows that 50:25 TVI Ratios of K、C and Y on PVC film with conventional flexography converge to a constant of 1.7629 (the mean of TVI Ratios of K, C, and Y).

Table 21. *One-way ANOVA of 50:25 TVI Ratios of PVC with conventional flexography.*

Combinstion	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/25	1.8062	0.0738	(-*-)
C_50/25	1.8142	0.1146	(-*-)
M_50/25	2.9692	0.4632	(-*-)
Y_50/25	1.6683	0.1324	(-*-)
P-values	0.000		---1.6--------2.0----------2.4----------2.8----------

50:75 TVI Ratios

As shown in Table 22, 50:75 TVI Ratios of four colors on PVC film with conventional flexography do not converge to a constant, while the diagram shows no significant difference in statistical analysis between C and Y. T test shows that 50:75 TVI Ratios of C and Y on PVC film with conventional

flexography converge to a constant of 1.0942 (the mean of TVI Ratios of C and Y).

Table 22. *One-way ANOVA of 50:75 TVI Ratios of PVC with conventional flexography.*

	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/75	1.3768	0.0712	(--*-)
C_50/75	1.0818	0.0712	(-*--)
M_50/75	1.5680	0.1947	(--*-)
Y_50/75	1.1065	0.1174	(--*-)
P-values	0.000		-----1.05----------1.20----------1.35----------1.5--------

4.4 TVI Ratios in hybrid lithography

1. Coated paper

50:25 TVI Ratios

As shown in Table 23, 50:25 TVI Ratios of four colors do not converge to a constant, while the diagram shows no significant difference in statistical analysis between C and Y. T test shows that 50:25 TVI Ratios of color C and Y on coated paper with hybrid lithography converge to a constant of 1.4484 (the mean of TVI Ratios of C and Y).

Table 23. *One-way ANOVA of 50:25 TVI Ratios of coated paper with hybrid lithography.*

	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/25	1.2940	0.0466	(---*--)
C_50/25	1.4413	0.0805	(--*---)
M_50/25	1.3855	0.0647	(--*--)
Y_50/25	1.4555	0.0659	(---*--)
P-values	0.000		----------1.32---------1.38---------1.44---------1.5--------

50:75 TVI Ratios

As shown in Table 24, 50:75 TVI Ratios of four colors do not converge to a constant, while the diagram shows no significant difference in statistical analysis between K and C. T test shows that 50:75 TVI Ratios of K and C on coated paper with hybrid lithography converge to a constant of 1.5734 (the mean of TVI Ratios of C and Y).

Table 24. *One-way ANOVA of 50:75 TVI Ratios of coated paper with hybrid lithography.*

	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/75	1.5710	0.0464	(-*-)
C_50/75	1.5758	0.0423	(--*-)
M_50/75	1.3918	0.0445	(-*-)
Y_50/75	1.4830	0.0355	(-*-)
P-values	0.000		--1.38---------1.44-----------1.5----------1.56--------

2. Uncoated paper

50:25 TVI Ratios

As shown in Table 25, 50:25 TVI Ratios of four colors on uncoated paper with hybrid lithography do not converge to a constant. T test shows that 50:25 TVI Ratios of uncoated paper with hybrid lithography do not converge to a constant.

Table 25. *One-way ANOVA of 50:25 TVI Ratios of uncoated paper with hybrid lithography.*

	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/25	1.0605	0.0329	(-*-)
C_50/25	1.2305	0.0362	(-*-)
M_50/25	1.1853	0.0397	(-*-)
Y_50/25	1.1345	0.0274	(-*-)
P-values	0.000		--1.05---------1.1----------1.15----------1.2--------

50:75 TVI Ratios

As shown in Table 26, 50:75 TVI Ratios of four colors on uncoated paper with hybrid lithography do not converge to a constant. T test shows that 50:75 TVI Ratios of uncoated paper with hybrid lithography do not converge to a constant.

Table 26. *One-way ANOVA of 50:75 TVI Ratios of uncoated paper with hybrid lithography.*

	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/75	1.6138	0.0280	(-*-)
C_50/75	1.5310	0.0539	(-*-)
M_50/75	1.4895	0.0365	(-*-)
Y_50/75	1.6770	0.0353	(--*-)
P-values	0.000		-------1.5------------1.56-----------1.62----------1.68--------

4.5 TVI Ratios in hybrid flexography

1. Coated paper

50:25 TVI Ratios

As shown in Table 27, 50:25 TVI Ratios of four colors do not converge to a constant, while the diagram shows no significant difference in statistical analysis between color K and C. T test shows that 50:25 TVI Ratios of color

K and C on coated paper with hybrid flexography converge to a constant of 2.442 (the mean of TVI Ratios of color K and C).

Table 27. *One-way ANOVA of 50:25 TVI Ratios of coated paper with hybrid flexography.*

	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/25	2.472	0.217	(-*--)
C_50/25	2.412	0.285	(-*-)
M_50/25	8.724	2.129	(--*-)
Y_50/25	5.312	1.727	(--*-)
P-values	0.000		--2.0----------4.0----------6.0----------8.0--------

50:75 TVI Ratios

As shown in Table 28, 50:75 TVI Ratios of four colors do not converge to a constant, while the diagram shows no significant difference in statistical analysis between color K and C. T test shows that 50:75 TVI Ratios of color K and C on coated paper with hybrid flexography converge to a constant of 1.631 (the mean of TVI Ratios of K and C).

Table 28. *One-way ANOVA of 50:75 TVI Ratios of coated paper with hybrid flexography.*

	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/75	1.6290	0.1016	(-*-)
C_50/75	1.6330	0.1512	(-*--)
M_50/75	2.4263	0.3419	(-*-)
Y_50/75	1.3670	0.1419	(--*-)
P-values	0.000		----------1.5----------1.8----------2.1--------2.4--------

2. Uncoated paper

50:25 TVI Ratios

As shown in Table 29, 50:25 TVI Ratios of four colors do not converge to a constant. T test shows that 50:25 TVI Ratios of color on uncoated paper with hybrid flexography do not converge to a constant.

Table 29. *One-way ANOVA of 50:25 TVI Ratios of uncoated paper with hybrid flexography.*

	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/25	1.7865	0.2024	(--*---)
C_50/25	1.4835	0.1546	(---*--)
M_50/25	1.6390	0.1849	(--*---)
Y_50/25	1.3135	0.1317	(---*--)
P-values	0.000		--------1.35-----------1.5-----------1.65----------1.8--------

50:75 TVI Ratios

As shown in Table 30, 50:75 TVI Ratios of four colors do not converge to a constant, while the diagram shows no significant difference in statistical analysis between K and C,. T test shows that 50:75 TVI Ratios of color K, C and M on uncoated paper with hybrid flexography converge to a constant of 1.7085 (the mean of TVI Ratios of K, C and M).

Table 30. *One-way ANOVA of 50:75 TVI Ratios of uncoated paper with hybrid flexography.*

	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/75	1.7523	0.1247	(----*---)
C_50/75	1.8493	0.2541	(---*----)
M_50/75	1.9265	0.2540	(---*----)
Y_50/75	1.5240	0.1685	(----*---)
P-values	0.000		---1.5-----------1.65--------1.8--------1.95--------

3. PVC film

50:25 TVI Ratios

As shown in Table 31, 50:25 TVI Ratios of four colors do not converge to a constant. T test shows that 50:25 TVI Ratios of PVC with hybrid flexography do not converge to a constant.

Table 31. *One-way ANOVA of 50:25 TVI Ratios of PVC with hybrid flexography.*

	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/25	2.4080	0.2169	(-*-)
C_50/25	2.8378	0.3630	(*-)
M_50/25	4.9923	0.5298	(*-)
Y_50/25	3.9650	0.6924	(-*)
P-values	0.000		--------2.4-----------3.2-----------4.0----------4.8--------

50:75 TVI Ratios

As shown in Table 32, 50:75 TVI Ratios of four colors do not converge to a constant. T test shows that 50:75 TVI Ratios of PVC film with hybrid flexography do not converge to a constant.

Table 32. *One-way ANOVA of 50:75 TVI Ratios of PVC film with hybrid flexography.*

	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/75	1.5647	0.0581	(*-)
C_50/75	1.3803	0.0642	(-*-)
M_50/75	2.0048	0.1462	(*-)
Y_50/75	1.4925	0.1172	(-*)
P-values	0.000		-----1.4----------1.6----------1.8----------2.0--------

4.6 TVI Ratios in Screen Printing

1. Compact disc

50:25 TVI Ratios

As shown in Table 33, 50:25 TVI Ratios of C and Y converge to a constant. T test shows that 50:25 TVI Ratios of C and Y on compact discs with screen printing converge to a constant of 1.7788 (the mean of TVI Ratios of C and Y).

Table 33. *One-way ANOVA of 50:25 TVI Ratios of compact discs with screen printing.*

	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/25	1.3744	0.2086	(--*-)
C_50/25	1.7410	0.3064	(-*-)
M_50/25	0.9484	0.0970	(--*-)
Y_50/25	1.8166	0.3313	(--*-)
P-values	0.000		---0.9----------1.2----------1. 5----------1.8--------

50:75 TVI Ratios

As shown in Table 34, 50:75 TVI Ratios of C and M converge to a constant. T test shows that 50:75 TVI Ratios of color C and M on compact discs with screen printing converge to a constant of 0.2317 (the mean of TVI Ratios of C and M).

Table 34. *One-way ANOVA of 50:75 TVI Ratios of compact disc with screen printing.*

	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/75	0.3540	0.05993	(--*-)
C_50/75	0.2394	0.02419	(--*--)
M_50/75	0.2240	0.03720	(--*--)
Y_50/75	0.3054	0.02735	(-*--)
P-values	0.000		-------0.24----------0.28----------0.32----------0.36--------

4.7 TVI Ratios in Waterless Lithography

1. Compact discs

50:25 TVI Ratios

As shown in Table 35, 50:25 TVI Ratios of four colors do not converge to a constant. T test shows that 50:75 TVI Ratios of PVC film with hybrid flexography do not converge to a constant.

Table 35. *One-way ANOVA of 50:25 TVI Ratios of compact discs with waterless lithography.*

	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/25	1.0004	0.0266	(*
C_50/25	1.3882	0.0329	(*
M_50/25	1.2984	0.0411	(*
Y_50/25	1.4750	0.0352	*)
P-values	0.000		-----1.05----------1.2----------1.35----------1.5--------

50:75 TVI Ratios

As shown in Table 36, 50:75 TVI Ratios of four colors do not converge to a constant. T test shows that 50:75 TVI Ratios of compact disc with waterless lithography do not converge to a constant.

Table 36. *One-way ANOVA of 50:75 TVI Ratios of compact disc with waterless lithography.*

	mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
K_50/75	1.6594	0.0122	(*)
C_50/75	1.5602	0.0156	(*)
M_50/75	1.3372	0.0386	(*
Y_50/75	1.4438	0.0240	*)
P-values	0.000		-----1.4----------1.5----------1.6----------1.7--------

5. Major Findings and Suggestions

5.1 Major findings

After actual printing and data measurement, calculation and analyses, TVI Ratios of various substrates with different printing processes obtained are shown in Table 37. As shown in the table, one can easily find that there is significant difference in TVI ratios between 50:75 and 50:25. In addition, significant difference exist among TVI Ratios of K, C, M, Y four colors on various substrates, which means 50:75 and 50:25 TVI Ratios do not converge to a constant. Since this study was conducted on various printing processes without any application of tone compensation curves, it can be inferred from the findings that there are no significant evidence of that TVI Ratios of four color printing on any substrate with any printing process may converge to a constant.

Table 37. *TVI Ratios of different printing processes on various substrate in this study.*

	TVI Ratios		digital printing	conventional lithography	conventional flexography	hybrid lithography	hybrid flexography	screen printing	waterless lithography
coated paper	50:25	K		**1.2490**	2.466	1.2940	**2.472**		
		C		*1.3705*	**4.731**	**1.4413**	**2.412**		
		M		**1.2113**	9.119	1.3855	8.724		
		Y		*1.3520*	**5.309**	**1.4555**	5.312		
	50:75	K		1.5448	**1.6655**	**1.5710**	**1.6290**		
		C		1.4580	**1.5605**	**1.5758**	**1.6330**		
		M		1.3643	2.9553	1.3918	2.4263		
		Y		1.4868	1.1845	1.4830	1.3670		
uncoated paper	50:25	K		1.0773	1.9523	1.0605	1.7865		
		C		1.3023	1.6383	1.2305	1.4835		
		M		1.1290	1.7750	1.1853	1.6390		
		Y		1.1703	1.4625	1.1345	1.3135		
	50:75	K		1.6462	**1.8550**	1.6138	**1.7523**		
		C		1.5158	**1.9618**	1.5310	**1.8493**		
		M		1.4653	2.4845	1.4895	**1.9265**		
		Y		1.6138	1.5255	1.6770	1.5240		
PVC	50:25	K	**1.2450**		**1.8062**		2.4080		
		C	**1.2808**		**1.8142**		2.8378		
		M	1.4140		2.9692		4.9923		
		Y	1.0978		**1.6683**		3.9650		
	50:75	K	1.3127		1.3768		1.5647		
		C	1.2624		**1.0818**		1.3803		
		M	1.2042		1.5680		2.0048		

	TVI Ratios		digital printing	conventional lithography	conventional flexography	hybrid lithography	hybrid flexography	screen printing	waterless lithography
		Y	1.4822		**<u>1.1065</u>**		1.4925		
PP	50:25	K	**1.3774**						
		C	**1.4044**						
		M	*<u>1.5302</u>*						
		Y	*<u>1.4980</u>*						
	50:75	K	1.3307						
		C	1.1570						
		M	**1.2322**						
		Y	**1.2372**						
GB	50:25	K	1.3228						
		C	1.2332						
		M	1.4572						
		Y	1.6008						
	50:75	K	**1.3020**						
		C	**1.2682**						
		M	1.1872						
		Y	**1.2536**						
canvas	50:25	K	1.4397						
		C	**1.6697**						
		M	**1.8427**						
		Y	1.0193						
	50:75	K	**1.3353**						
		C	1.0937						
		M	1.1963						
		Y	**1.3117**						
compact disc	50:25	K						1.3744	1.0004
		C						**<u>1.7410</u>**	1.3882
		M						0.9484	1.2984
		Y						**<u>1.8166</u>**	1.4750
	50:75	K						0.35400	1.6594
		C						**<u>0.23940</u>**	1.5602
		M						**<u>0.22400</u>**	1.3372
		Y						0.30540	1.4438

Note: **Boldfaced** and <u>underlined</u> TVI Ratios indicate that there is no significant difference between the two or among the three. *Italicized* and <u>underlined</u> TVI Ratios indicate that there is no significant difference between the two. For example, 50:25 TVI Ratios of K and M on coated paper with conventional lithography are boldfaced and underlined, **<u>1.2490</u>** and **<u>1.2113</u>**, which means there is no significant difference within 95% confidence, or they do not converge to a constant.

5.2 Recommendations

Further observation of Table 37 reveals that TVI Ratios of different substrates with same printing process tend to converge to a constant. For

example, for digital printing, 50:75 TVI Ratios of color K on PVC (1.3127), GB (1.3020), PP (1.3307) and canvas (1.3353) tend to be a constant. On the other hand, TVI Ratios of same substrate with different printing processes also tend to converge to a constant. For example, for coated paper, 50:25 TVI Ratios of K with conventional lithography (1.2490) is very close to that of hybrid lithography (1.2940); 50:75 TVI Ratios of Y with conventional lithography (1.4868) is very close to that of hybrid lithography (1.4830). One can speculate that 50:25 and 50:75 TVI Ratios of same substrate with different printing processes, of different substrates with same printing process tend to be a constant. This study suggests follow-up studies to focus on investigation of differences, if any, among different substrates with same printing process, or among different printing processes on the same substrate as well as associations with solid ink density and print contrast so that relations among these factors can be identified as the references to quick quality control specification for the printing industry.

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