About the Center

Rochester Institute of Technology (RIT) was selected by the Alfred P. Sloan Foundation in 2001 to join the family of Sloan Industry Centers located at prestigious universities across the U.S. The Printing Industry Center at RIT is a joint program of the School of Print Media and RIT's College of Business, emphasizing Sloan's long-standing tradition of applying a broad multidisciplinary approach to industry investigations and findings.

Dedicated to the study of major business environment influences in the printing industry brought on by new technologies and societal changes, the Printing Industry Center at RIT addresses the concerns of the printing industry through educational outreach, research initiatives, and print evaluation services. The Center creates a forum for printing companies and associations worldwide to access a neutral platform for the dissemination of knowledge that can be trusted by the industry, to share ideas, and to build the partnerships needed to sustain growth and profitability in a rapidly changing market.

With the support of RIT, the Alfred P. Sloan Foundation, and our Industry Partners, it is our mission to continue to develop and articulate the knowledge necessary for the long-term economic health of the printing industry.

More information on the Printing Industry Center at RIT and its research activities can be found online at http://print.rit.edu.

Industry Partners

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For Affiliates of the Printing Industry Center at RIT

Exploring the Image Quality Gap

Disputes over the quality of digital printing technologies as compared to offset lithography have been occurring ever since digital technologies were developed. Research conducted at RIT on this topic sought to understand how consumers evaluate the image quality of prints made using both methods in an effort to evaluate the theorized gap that exists. This research resulted in the monograph *Minding the Gap: Evaluating the Image Quality of Digital Print Technologies Relative to Traditional Offset Lithography* (PICRM-2008-08), by Susan Farnand, Staff Scientist at the Carlson Center for Imaging Science at RIT.

The goal of this research was to examine the current gap in image quality between high-end digital printers and offset lithography and to develop an idea of how important or relevant this image quality difference is to the end user through the use of psychophysical experiments. An investigation into image quality parameters that are particularly relevant in comparing print systems technologies was also conducted.

Introduction

Little more than a decade ago, the introduction of the Xeikon and Indigo printers ushered in a new era of print possibilities. These machines offered reasonable image quality at high enough speeds that short-run, on-demand print runs became a possibility. While typical offset presses required upwards of half an hour for makeready,

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R·I·T Printing Industry Center

inside

Democrat and Chronicle Teams with RIT's Printing Industry Center

Industry partner joins eleven others supporting center's operation

The Printing Industry Center at Rochester Institute of Technology announces the addition of the *Democrat and Chronicle* as an industry partner. The Gannett Inc. owned metropolitan daily newspaper serving Rochester, N.Y., joins 11 other companies and associations pledging support to the center's operation.

Supported by the Alfred P. Sloan Foundation, the Printing Industry Center at RIT is dedicated to the growth and profitability of the printing industry. The center addresses industry concerns through research initiatives and educational outreach programs.

"The issues impacting the news publishing industry are top of mind at RIT in both our research and teaching," says Frank Cost, associate dean of RIT's College of Imaging Arts and Sciences and co-director of the Printing Industry Center. "We are excited the *Democrat and Chronicle* has come on board as an industry partner so we can work together to examine the changing newspaper industry."

Brian Ambor, vice president of operations at the *Democrat and Chronicle* adds: "The partnership between the *Democrat and Chronicle* and the Printing Industry Center at RIT comes at an ideal time for us. The newspaper industry is currently being challenged by the economic climate and new technology. This partnership will help us identify and better understand emerging trends and help our multimedia company adapt to those trends. Beyond the Printing Industry Center at RIT this partnership also provides us time for important dialogue with other business partners from an idea, information exchange and relationship-building standpoint. We will truly learn and grow together."

RIT's School of Print Media has altered its curriculum offerings in its news media program and is focused on strengthening its strategic and curriculum partnerships with such entities as the *Democrat and Chronicle*, Chicago Tribune and Scripps Howard Foundation.

Industry partners pledge money to help fund the center's operations and advise RIT's researchers on topics critical to the printing industry. The center's other industry partners are Adobe Systems Inc., Avery Dennison, Eastman Kodak Co., Hewlett-Packard Co., NewPage Corp., NPES, Scripps Howard Foundation, Standard Register, VIGC, U.S. Government Printing Office and Xerox Corp.

Visit the *D&C* website at:
www.democratandchronicle.com

Printing Industry Center Releases First 2008–2009 Monograph

A newly released research monograph from the Printing Industry Center at RIT analyses the overall job satisfaction of recent RIT graduates and their perceptions of their future careers. Titled *Correlates of Job Satisfaction of Early Career Employees in Printing and Publishing Occupations* (PICRM-2009-01), the monograph is authored by Ashley Walker, M.B.A., Communications Coordinator for the Center, and Patricia Sorce, Ph.D., Center co-director and administrative chair of the RIT School of Print Media.

The survey-based study queried samples of recent RIT School of Print Media (SPM) and RIT School of Design (SD) graduates in order to allow for comparisons to a control group. The report includes demographic analyses of each of these groups. Analyses of other survey results—such as satisfaction with key job facets and potential generational differences in satisfaction—are also reported for the SPM sample.

Key findings include:

- A regression analysis of the predictors of overall job satisfaction for SPM respondents revealed six pertinent correlating factors that account for 47.8% of the variation in overall job satisfaction. The top two factors were personal gratification obtained from doing one's job and satisfaction with the organization's goal, mission, and/or vision.
- Within the SPM sample, no statistically significant differences were found between the overall job satisfaction of age groups (generations). However, differences among age groups for four of the 23 job facet satisfaction scores were found to be statistically significant. Consistent with the stereotypes of Gen Y, the younger employees were more dissatisfied than the older groups on three of the four facets.

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under the 2008-2009 research heading

Image Quality Gap *continued*

economically precluding runs of less than a few thousand, this new equipment required minimal set-up time, making runs of even one print feasible. With the addition of variable data printing (VDP)—in which each document in a print run can contain different information allowing personalization of documents—life in the printing world became considerably more interesting.

In the past decade, the equipment has evolved, offering increased reliability and the capability of printing on a wider range of substrates. But—what about image quality?

Certainly, the wider range of substrates has helped. Other technological advances have boosted the quality of the images being generated on digital printing equipment to the point where some might argue that it is now in the realm of offset. Henry Freedman of Technologe Watch™ (2004, 2006a, 2006b) has demonstrated that higher-end digital printers such as the Kodak NexPress 2100 and the Xerox Docucolor 8000 can be set up to produce image quality comparable to that of offset lithography. While Freedman has shown that it is possible to achieve image quality comparable to offset on high-end digital printing equipment, it is telling that there exists a great deal of information on "designing for digital." Googling "designing for digital print" results in about 209,000,000 hits, including whole books on the topic as well as websites and articles.

Background

Much work in evaluating digital print quality has been undertaken by researchers in technical, marketing, and academic milieus. A number of these efforts have focused on printing digital photographs; this is an application where image quality is of particular concern. In one of these studies, Swanson (2000) found four "significant issues" in assessing image quality: "color reproduction, uniformity, resolution, and artifacts."

The same issues are among those listed by the INCITS W1.1 Image Quality for Printer Systems ad hoc committee working to establish a standard for perceptually measuring image quality (INCITS, 2004). (The INCITS W1.1 committee was established by W1, the Office Equipment subcommittee of INCITS. This is also the ANSI Technical Advisory Group for ISO/IEC Joint Technical Committee 1, which is responsible for the standardization in the arena of Information Technology.) This committee has identified gloss, color rendition, uniformity, text and line quality, and sharpness and effective resolution as the essential characteristics for measuring image quality on prints.

In their study on digital print quality, Chung and Rees (2006) generated lists of attributes of interest in evaluating image quality for both digital and offset print. Most of the print attributes identified as being of key concern in evaluating digital images, including color rendition, resolution, text quality, and artifacts, also appear on the offset list. However, Chung and Rees point out that, "while many of the attribute names are shared, the difference in the two technologies results in different visual appearances." It is this difference in the visual appearance that is of interest in this study. While efforts have been made to evaluate the measured differences in such items pertaining to print appearance as solid area density, dot gain, colorimetric values, and color gamut volume (Xu & Kellogg, 2007), it is the focus of this research to evaluate actual perceived differences in the quality of prints produced on high-end digital printing equipment relative to those printed via offset lithography.

Experimental Method

To answer questions around image quality differences, it is essential to first establish an image set that will be effective for evaluating image quality. This can often be the most difficult part of a productive image quality evaluation. The set must comprise images that will provide a measurable signal of the difference that exists between technologies. The set should also be representative of various types of images that may be encountered. To address this, images representing the four categories included in Frey, Christensen, and DiSantis' (2006) monograph were used: direct mail, marketing and promotional materials, business communications, and photo books. Six test images were created, and can be seen under the "Images Used in Research" heading later in this summary.

In the marketing and promotional materials category, a brochure, entitled "Train," created as part of the Technology Practicum printing course offered each spring at the Rochester Institute of Technology, was used. In the direct mail category, a mailer obtained from the Village Sports center was used. For photo books, two photo pages were created, one entitled "Sarah" and one entitled "China." The latter image includes vacation-type photos and Chinese text as well as copyright text. For business communications, a text and graphics document was created and IS&T's NIP23 Print Gallery image was used.

With the image set in hand, prints were made on high-end digital equipment, including an HP Indigo 5000, a NexPress 2100, and an iGen3. Prints were also made on the Heidelberg Speedmaster 74 sheetfed press in the Printing Applications Lab at RIT. An image of the text print on uncoated paper on a desktop color printer was also included.

Two substrates were used on each device, one coated (Titan Plus Dull digital 100lb. cover) and one uncoated (HP Indigo printing paper 80 lb premium cover) cover stock. The text image on the coated stock was not used in the experiment. Two prints, one from early in the run (typically the fifth print) and one from later in the run (typically the ninety-fifth print), were used for each printer on each paper for each image. With two prints on two papers of five images on four printers plus two prints of one image on one paper on five printers (though only one print from the desktop printer), the complete test set consisted of 89 prints.

With the print database generated, psychophysical experimentation was conducted that examined effective image quality differences; essentially, the impact of any apparent differences on perceived quality or value. The experiment was initiated by showing the participant prints of the Print Gallery image made on the desktop printer and the Heidelberg Speedmaster sheet-fed press. These prints represented a clearly visible range in image quality. Various aspects of image quality that the participants could use in making their print quality decisions were described. The participants were specifically instructed not to consider hue shifts in their decisions on print quality. The rationale for this comes from three factors: Freedman has shown

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that printing equipment can be set up to match in color; the images used had little high chroma content (and therefore gamut mapping was not an issue); and color management did not function adequately during the execution of the print runs.

After speaking with each participant briefly regarding image quality, the participants were shown the prints in sets, where each set consisted of the prints made on either coated or uncoated paper for each image. For example, one set would be the prints of the Village Sports brochure made on coated paper on each of the four printers. At the start of the evaluation of each set, the participant was told of the purpose of the document.

For the photo book pages, the participants were told that the prints represented photo book pages of pictures that they may have taken on vacation and that were for their personal use to share with family and friends. For the Village Sports brochure, each was told that he or she was the owner of Village Sports, and that this was a mailer that had been commissioned to send to prospective customers. For the Train brochure, each was told that they were the owner of Georgetown Loop Railroad, and that the prints represented sales brochures used to generate business. For the text document and the Print Gallery page, the participants were told that these were business communications documents that would be used within an office environment (perhaps to be sent to a supervisor or another company), and that, although the main purpose of the document was to convey information, the documents still needed to be presentable.

To address the question of impact, the observers were questioned regarding what they would be willing to pay for a given print. For each set, one of the prints made on the Heidelberg Speedmaster 74 sheet-fed press was selected to be the reference print. When the participants were shown the first reference print, they were told that they paid a dollar for this page. The participants were given the following instructions: for each of the comparison prints, if the quality was sufficiently higher than the reference to justify paying more for the document, they were to specify how much more they would be willing to pay. If the quality was sufficiently worse than the reference (so that they would not want to pay as much for the document as they had for the reference), they were asked to tell how much less they felt it was worth. If they thought the quality was essentially comparable (even if the prints looked quite different), they were to state that it had the same value as the reference. With this explanation, the first comparison print of the first set was presented, and each participant proceeded through the document sets in random order.

The experiment was conducted under D50 lighting conditions within the Vision Lab of the Color Science building at RIT. Thirty-eight people of varied backgrounds participated, including twenty-five students from an undergraduate psychology course. The students' majors ranged from Computer Science and Liberal Arts to Photography and Biotechnology. The remainder of the participants consisted of Imaging Science and Color Science undergraduates, graduate students, and faculty. Eleven females participated along with twenty-seven males. At least three participants had color vision anomalies; this was self-reported, so others may have been present. The age range of the participants was approximately 20 to 50 years of age. None of the participants were involved in any way with the printing industry.

Results & Discussion

In the summary of his paper on measuring digital image quality, Swanson (2000) states that "the consumers of digital imaging output are as varied as their definition of image quality." It seems a comfortable extrapolation to include all printed output in this statement. This is one of the reasons that participants with varied backgrounds were sought out for this experimentation. The results would indicate that this effort was successful, as opinions on the quality of given prints varied widely. Standard deviations on the responses to the digitally produced prints ranged from about 9¢ for one of the Village Sports mailers on coated paper to over 44¢ for one of the China photo pages on uncoated paper. The difference in responses for a single print ranged from 50¢ for a Village Sports mailer on coated stock, for which the pickiest participant assigned a value of 70¢ and the most delighted participant felt it was worth $1.20, to a $2.30 difference for one of the "Sarah" photo pages on uncoated media, for which one disgusted participant offered 20¢ and another impressed participant assigned a value of $2.50.

The correlation coefficients of the individual responses with the mean response for each of the comparison prints averaged approximately 0.6 and varied from approximately 0.24 to 0.8. Interestingly, the three participants who reported color vision anomalies all had correlation coefficients that were higher than the average of 0.64, 0.68, and 0.68.

Most of the participants having lower correlation coefficients tended to either have relatively flat responses – they tended to assign values around $1.00 for all of the comparison prints as shown in Figure 1 – or they had one or two responses that did not fit in well with the majority of their responses, as shown in Figure 2. In the case of the participant having the lowest correlation coefficient (and for a few other participants), both of these things occurred. However, removing participants whose responses correlated poorly with the mean responses or the few outliers had little impact on the results. Therefore, all of the results were retained in the analysis.

Figure 3 shows that the uncoated media had higher variability than the coated media for the train brochure, the Village Sports mailer, and the "Sarah" photo book page. For the remaining images, the variability is essentially the same between the coated and uncoated media sets. Figure 4 shows the variability by printer. Variability is highest for Printers 2 and 3 on uncoated media.

The exact reason why the assigned values had increased variability on uncoated stock is uncertain. However, the differences between the reference and comparison prints were more apparent for the prints on uncoated

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Figure 1. Data for a participant who exhibited a relatively flat response

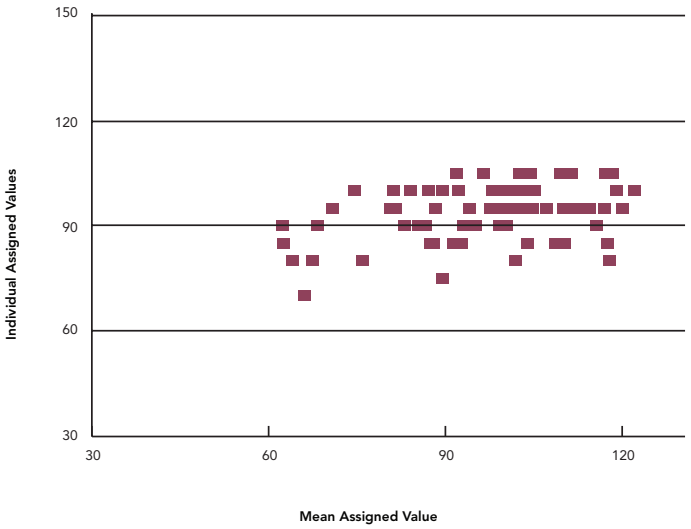


Figure 2. Data for a participant who exhibited a few outlier responses

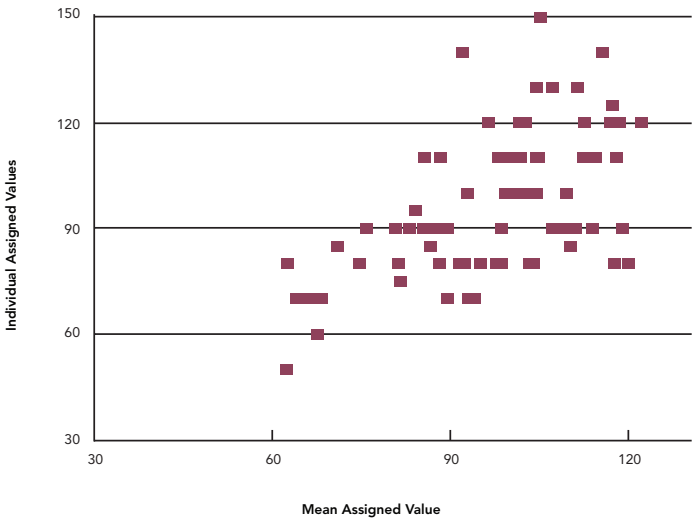


Figure 3. Standard deviation values for each of the image sets on coated and uncoated media averaged over all images

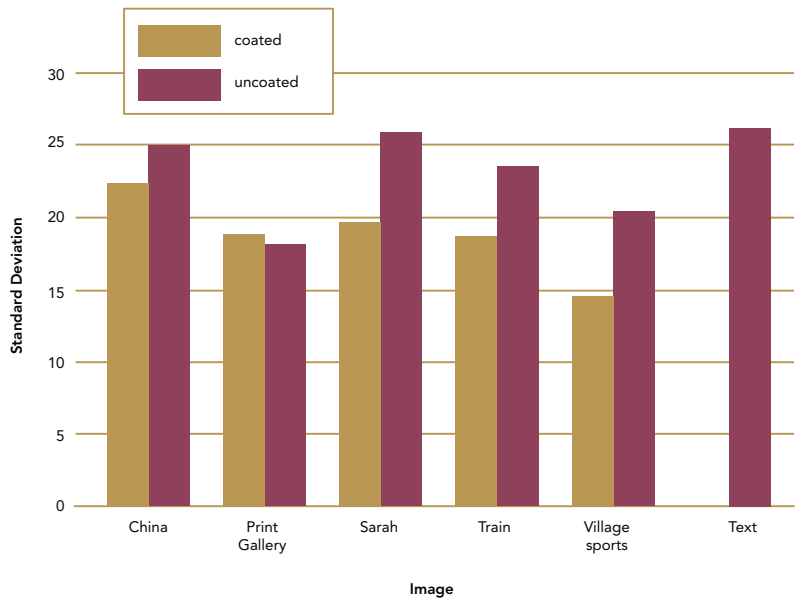
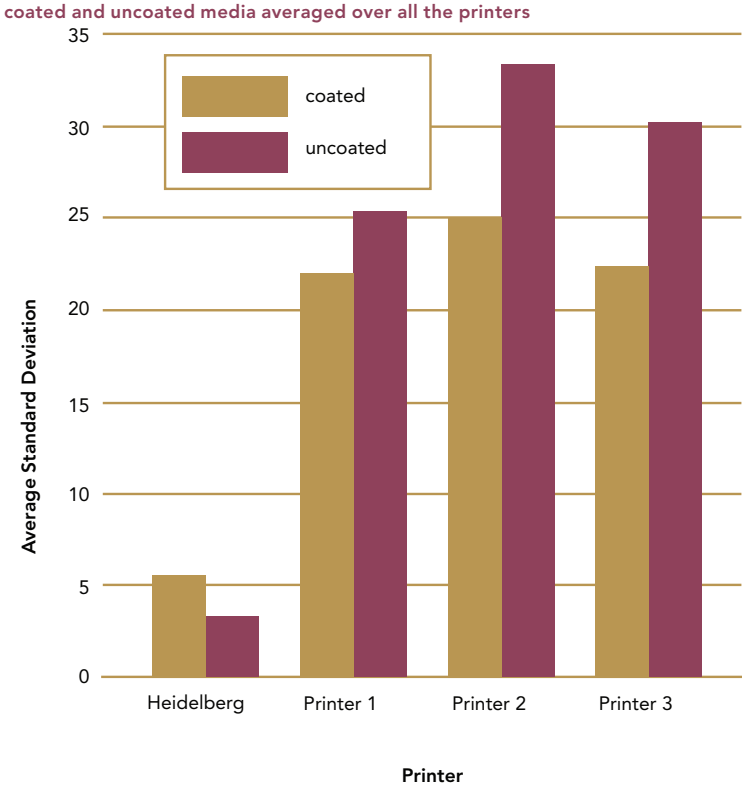


Figure 4. Standard deviation values for each of the image sets on coated and uncoated media averaged over all the printers



media than those on the coated media, just as the prints on the digital prints had much greater differences than those made on the Heidelberg Speedmaster. As the difference from the reference increased, so did the variability in how the participants valued those prints; some thought the differences were inconsequential, some found they added to the value, and others occasionally felt the differences rendered the prints worthless.

Further investigation reveals other interesting differences between the coated and uncoated media sets. For the coated media, the offset prints are consistently rated higher than the digital prints for all images, as shown in Figure 5. Only the "China" images from Printer 3 and the "Train" images from Printer 1 are rated approximately the same as the offset reference for coated media. However, for the uncoated media, prints produced on the high-end digital printers often rated higher than the offset prints on average, as shown in Figure 6. Many of the prints made on Printers 1 and 3 were rated at a higher value than the offset reference. The train brochure, the Village Sports mailer, and the photo book pages show this shift to higher perceived quality for digital printers 1 and 3. Figure 7 shows the comparison of the coated and uncoated media by printer averaged over all of the image sets.

Given the high variability of the participants' responses, it would be reasonable to ask whether or not any of the differences exhibited in Figures 5 and 6 are significant. For the coated images, a difference of about 14¢ would be needed to be significant at a 95% confidence level. With this requirement, all of the prints made on Printer 2, the Print Gallery, Village Sports, and one of the "Sarah" prints made on Printer 1, and the "Sarah" prints made on Printer 3, are significantly worse than those made on the Speedmaster.

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Image Quality Gap *continued*

For the uncoated images, a difference of about 18¢ would be needed to be significant at a 95% confidence level. With this requirement, the photo book pages and Village Sports brochures made on Printer 3 and the text images and one of the Village Sports brochures made on Printer 1 were all rated of significantly higher value than the prints made on the Speedmaster. The single text print made on a desktop printer was not considered to be of comparable quality level as the prints made on the offset press or the high-end digital printers.

It is interesting to note that there were two instances where one of the two prints of an image on a given media made on Printer 1 was significantly different and the other one was not. Further investigation revealed that Printers 1 and 2 showed more variation between the two prints of a given image on a given media within the run (about 5¢ on average) than did either Printer 3 or the offset press, which showed an average within-run difference of about 2¢. While the levels of variation were too small to be statistically significant (although the "Sarah" photo page on coated media for Printer 1 had a difference between the mean responses for the two prints of 12¢ and was close to being significant), the run lengths were relatively short. The increased variation for two of the digital printers may signal that within-run variability is an important factor to monitor.

The data indicate that statistically significant differences between prints made on digital equipment and those made on an offset press existed in this experiment. What factors led to these perceived differences in print quality?

The comments made by the participants as they made their assessments are instructive.

The three most common comments dealt with uniformity, including things like grain, banding, and smooth gradations; contrast; and text and line quality, especially when regarding arcs and white text. Lack of uniformity was the most common complaint for the prints made using digital equipment, with concerns regarding text and line quality ranking second. However, many participants preferred the higher contrast of the digital printer output, especially for the photo book pages and marketing material on the uncoated media. Although there were few comments specific to gloss, it seems reasonable to posit that the higher gloss appearance of the prints created on the digital equipment added to the perception of higher value on the uncoated media. Certainly, the higher gloss added to the higher contrast and the higher color saturation of these prints, which was appealing to many participants.

In their work on digital and offset print quality, Chung and Rees (2006) report that the problems with offset printing relate to issues with the materials used while the problems with digital printers relate to the technology and lack of standards making the "use of formal quality assurance procedures difficult." The results of this survey seem to support this conclusion. The main problem with the offset prints seemed to relate to the uncoated media used. The prints on this media generated by the offset press used in this research were lower in contrast and gloss, giving them a flat, dull appearance. Conversely, the digital prints had problems with uniformity and, to a lesser extent, text and line quality, that were the result of technical constraints and limitations.

Figure 5. Average assigned value for each media on coated paper, shown by printer

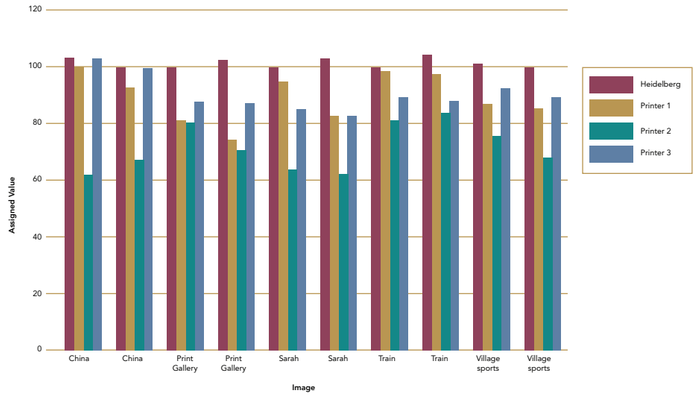


Figure 6. Average assigned value for each media on uncoated paper, shown by printer

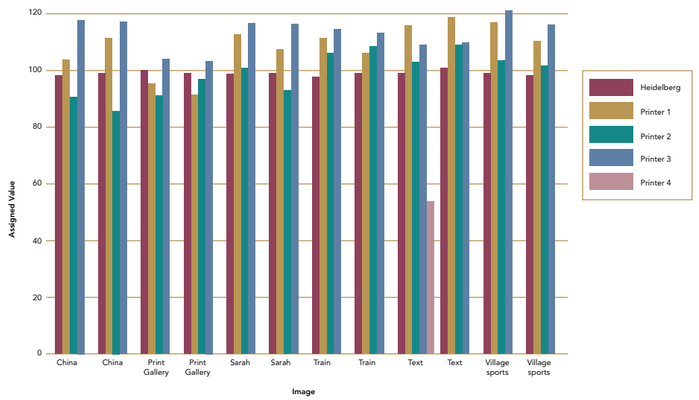
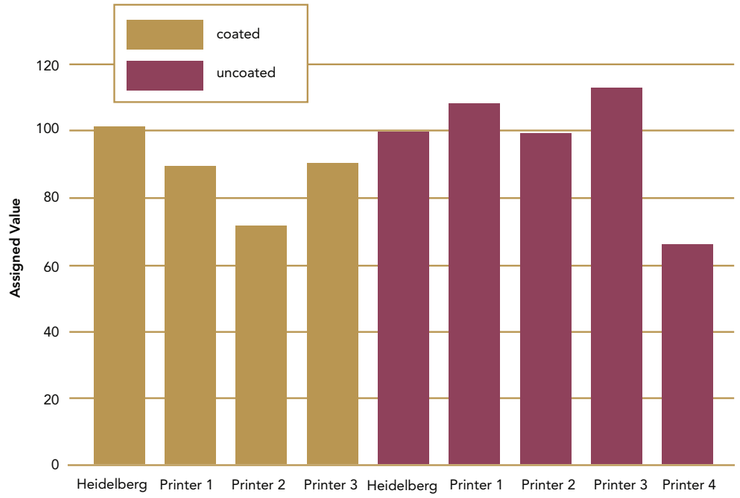


Figure 7. Mean assigned values for the images on coated versus uncoated media for each printing device



Conclusions

It is important to remember that prints were made on only one offset press and only one machine for each of three different high-end digital printer vendors. Different results may be obtained using different equipment, even if it is from the same vendor and has the same model number. Different results could be obtained on this same equipment run by different people or on different days. Therefore, drawing conclusions from this work must be done with some caution. In all actuality, the best that can be hoped for is a better understanding of existing trends.

For this set of participants with this set of images, it was found that the offset press produced prints on coated paper that had comparable or higher perceived value for all of the images tested. On uncoated paper, the story was somewhat different. On uncoated media, some of the prints from two of the digital printers—especially those of the photo book pages and marketing materials—were found to be of higher value. Participants generally liked the uniformity and high quality lines and text of the offset prints, while they tended to prefer the higher contrast of the digital prints—at least for some applications—on the uncoated paper. These results are in general agreement with Chung and Rees' (2006a) findings that offset printing image quality issues tend to be related to materials problems, while image quality issues for digital printing equipment tend to involve technical limitations of the equipment.

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