Review of Research at RIT Comparing the Print Value and Permanence of Digital Prints vs. Offset Lithography and Silver-Halide Prints

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Abstract

Both print value and permanence are critical to consumer satisfaction of printed images. Over the last four years, the Printing Industry Center and Image Permanence Institute at the Rochester Institute of Technology have published a variety of studies evaluating the print value and permanence of inkjet and electrophotographic prints and compared their performance to the traditional printing technologies of offset lithography and color silver-halide photography. This paper reviews the published work to date.

In the print value studies comparing electrophotographic digital press and offset lithography, it was found that the media had the greatest impact on perceived value. There were significant differences in the perceived value between electrophotographic and offset lithographic prints on coated media, with those made on offset equipment being generally preferred. For prints on uncoated media, the differences were less significant. Another study evaluated the perceived print value of inkjet (desktop and wide format) and electrophotographic photofinishing relative to digital silver-halide prints. Targets were generated to resemble photo album pages and photobooks. The results indicated that observers generally found higher value in full-size photobooks and inkjet prints as compared to electrophotographic prints and mini photobooks.

The print permanence experiments subjected inkjet, electrophotographic, digital silver-halide, and offset prints to a variety of environmental and user stresses including heat, light, humidity, pollutants, abrasion, and water fastness. The electrophotographic prints were generally more resistant to environment and use forces than offset lithography except for the liquid-toner electrophotographic system which was less water resistant. Because inkjets prints are made with a greater variety of possible colorant and paper combinations, they showed extremely varied responses to deterioration forces. Some were more robust than electrophotography or color silver-halide and others more vulnerable.

In comparing the two lines of inquiry, the primary significance was the fact that the prints with the highest perceived value are not necessarily the prints of the highest permanence. Print equipment, colorants, and papers need to be selected for both perceived value and permanence, but no clear metrics exist on which consumers can base such decisions. An understanding of all the key factors and access to the critical information will likely not be possible for end users, so they must rely on knowledgeable photo fulfillment providers to help guide them to the right decisions.

Introduction

Both print value and permanence are critical to consumer satisfaction of printed images. Studies on print value and image permanence are usually published separately in the literature. This makes it difficult for users to understand how these two important issues relate to each other. Over the last four years, the Printing Industry Center (PIC) and Image Permanence Institute (IPI) at the Rochester Institute of Technology (RIT) have published a variety of studies evaluating the print value [1-3] and permanence [5-12] of inkjet and electrophotographic prints and compared their performance to prints made from the traditional technologies of offset lithography and color silver-halide photography.

The purpose of this paper is to evaluate the combined significance of both these lines of research. Various questions can arise when these data sets are compared including the following: "does perceived print value correlate with print permanence?" or, if not, "how do you select print systems that simultaneously produce great looking and long-lasting prints?"

It is important to note that image quality and perceived print value are not the same. Image quality usually refers to that which can be objectively measured: color, line quality, uniformity etc. In these experiments image quality is a subjective assessment of how "good" an image "looks" to an observer (such as a customer of prints from a photofinishing lab). Perceived value is a combination of this subjective assessment of image quality with the price to purchase the print. A print may be a fantastic representation of the image the user captured with their camera, but if it costs $100 per print, it would not likely be considered of high value. Oppositely, a print with low resolution and poor color rendition that could be purchased at $0.01 each could be considered an acceptable value to some.

Likewise, print permanence and image permanence are also not the same. Often permanence studies focus solely on image permanence which addresses the questions of whether an image will fade or yellow over time. Both are important factors to understand but print permanence goes beyond that to include other factors including the stability of the support such as cracking or delamination, other image problems such as abrasion and scratch sensitivity, and water fastness. Print permanence is therefore, a better indicator of how a print will perform under customer use over time.

RIT's PIC is a neutral platform for printing companies and associations worldwide to access 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 its industry partners, the PIC mission has been to continue to develop and articulate the knowledge necessary for the long-term economic health of the printing industry.

IPI was founded in 1985 through the combined sponsorship of the Rochester Institute of Technology and the Society for Imaging Science and Technology. The institute provides significant preservation research, publications, consulting services, practical tools and preservation technology to libraries, archives, and museums worldwide. The imaging and consumer preservation industries also use IPI's consulting, testing and educational services. Funding for IPI's preservation research and outreach efforts has come primarily from the National Endowment for the Humanities, the Institute of Museum and Library Services, and the Andrew W. Mellon Foundation.

Review of Print Value Research

Comparing Print Value of Digital Print Presses and Traditional Offset Lithography

Little more than a decade ago, the introduction of dry- and liquid-toner electrophotographic presses ushered in a new era of print possibilities. These machines offered reasonable image quality at speeds high enough that short-run, on-demand print runs became a possibility. While typical offset presses required upwards of half an hour for make-ready, 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 personalization of documents became possible. In the past decade, the equipment has evolved, offering increased reliability and the capability of printing on a wider range of substrates. But the question of image quality and consumer acceptance remained. 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.

Experimental Method

The study conducted to evaluate the print value differences between offset and digital press was executed in two experiments involving different paper types. Creating the stimuli for the experiments involved selecting the image sets, the paper, and the printing equipment. The image sets included representatives from four usage categories: direct mail, marketing and promotional materials, business communications, and photobooks [4]. A fifth category, 'Photos for Display', was added. The same image sets were used for both experiments. The substrates used in the first experiment included one coated and one uncoated cover stock. For the second experiment, three papers were used, one coated and two uncoated. For both experiments, prints were made on a sheet-fed lithographic press, a liquid-toner electrophotographic press, and two dry-toner electrophotographic presses.

For the first experiment, the participants were shown the prints in sets where each set consisted of the prints made on just one media, either coated or uncoated paper, for each image. For example, one set would be the direct mail images 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 image (direct mail, marketing and promotional material, business communication, or photobook).

In the second experiment, the sets included all of the prints of a given image (direct mail, marketing and promotional material, business communication, or photobook) on all media on all printers. For example, one set would be the direct mail images made on all papers on each of the four printers. Again, at the start of the evaluation of each set, the participant was told of the purpose of the image.

The observers were asked what they would be willing to pay for a given print. When the participants were shown the reference print, they were told that they paid a dollar for this page. They were then presented with the set of comparison prints, one at a time. They were told that, for each of these prints, if the quality was significantly better than the reference such that it would justify paying more for the document, they would specify a value greater than a dollar. If the quality was judged worse than the reference such that they would not want to pay as much for the document as they had for the reference, they would specify a value less than a dollar, and if they thought the quality was essentially comparable, even if the prints looked quite different, they were to state that it had the same, one dollar, value as the reference.

For the first experiment, the prints made on the offset lithographic press served as the reference print for each image on each paper. For the second experiment, only the offset print on coated paper served as the reference. For more information on each experiment, see the original papers [1-2].

Results and Discussion

The results of the first experiment indicated that the offset press prints on coated paper had comparable or higher perceived value than those printed digitally, for all of the images tested. On uncoated media, however, most of the prints from two of the digital printers, especially of the photobook pages and marketing materials, were assigned higher value.

The observers were questioned regarding their criteria in making image assessments. The attributes most frequently mentioned as important in assessing the quality of the images were uniformity and contrast. Other relevant attributes were color saturation, gloss, paper quality, sharpness, and text and line quality. 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.

In the second experiment, in which the coated, offset print was used as the reference for both the coated and uncoated prints, the results indicate a significant difference in the perceived value with prints on coated media generally being given a higher value irrespective of the print equipment used to make them.

Perceived Print value of Digital Print Technologies for Photofinishing

Today the majority of images are now captured digitally, and though digital silver halide certainly remains an important player in the photofinishing market, a great many images are printed at home on inkjet printers. Images also are being printed in forms other than 4"x6" prints. Electrophotographic printing technology is being used to generate photobooks, cards, and calendars. Intuitively, it seems that the representation of an image as part of a book or a photo album page, rather than a 5"x7" print, may add to the perceived value of that individual image. It was the objective

of this study to understand the perceived print value being achieved using the various printing technologies and formats available today.

Experimental Method

In these experiments, two image sets were created on a variety of printing equipment. One set consisted of images created by the authors. These two will collectively be referred to as the "third person" image set, as the test observers evaluating the prints had no personal attachment to the contents in the prints. It included images representative of various typical consumer photographs such as children, vacation pictures, wedding pictures, and natural scenery.

A second set was generated by collecting one image from each of the students in an undergraduate imaging course at RIT. This set of images will be referred to as the "first person" set, since these images were used when the students served as the observers and were, consequently, seeing their own images. Again, an effort was made to select a variety of images representing the types seen in consumer photography.

Prints were made on digital silver halide, inkjet, and electrophotographic digital presses at RIT. The digital silver halide and wide format inkjet were 5"x7" prints. The desktop inkjet and electrophotographic prints were designed as photo album pages, with two 5"x7" pictures on an $8^1/_2$" x11" page. The photobooks were purchased through photofinishing websites. For the full-size books, which had a format of approximately 6"x9", one image was placed on each page. This resulted in images that were close to the 5"x7" format used for the silver halide, inkjet, and electrophotographic prints. A simple white background with a drop shadow border was selected. Additionally, one pocket portfolio format was selected. This is a soft-cover, saddle-stitched book containing full-bleed images about the size of a typical business card. All of the photobooks were printed on electrophotographic digital presses.

The observers were shown prints from each of the photofinishing technologies in random order and asked to compare them to a reference which was the digital silver halide print. The book pages were shown as a two-page spread, the inkjet and electrophotographic prints were shown as a single print (intended to represent a photo album page), and the wide-format inkjet prints were shown as 5"x7" prints. The observers were then questioned regarding what they would be willing to pay for each print type compared to the reference print. For more information on each experiment, see the original paper [3].

Results and Discussion

The results showed that observers generally rated the full-size photo books and inkjet prints higher and the pocket portfolio and electrophotographic prints lower than the digital silver halide prints. The first person observers rated the test prints significantly higher than the third person observers. This difference may have been the result of the undergraduates being younger and less experienced than the other observers, or it may have been that the first-person image set contained more images than the third-person set for which the digital silver halide process simply did not render as well as other print processes.

The observers in the study were also asked to comment on the print characteristics that most influenced their value ratings. Color was the characteristic most often identified as important in value decisions. After, color, the print attribute most often identified as important was format, including print size. Most preferred the full-size books, one liked the photo-album-style pages with two images per page, and, though several observers stated that they felt that the small size of the pocket portfolio correlated to lower value, one was enthusiastic about this format, remarking that she liked the portability of this mini-book.

The inkjet prints were preferred over the electrophotographic prints, and this may have been related to gloss. Nearly half of the observers sited the quality of the paper or the gloss level as something that mattered most in making their quality assessments. The substrate, therefore, is a key factor for print value.

The overall conclusion of the studies investigating print value from digital equipment relative to either offset presses or silver halide photofinishing is that the digital printers can achieve perceived print values somewhat comparable to that of the more traditional printing methods. In all of the studies, the media generally played a more significant role in the overall perceived print value than the printer selection. When making a decision regarding printing of photographs, the selection of the paper outweighs the selection of the print engine.

Review of Image Permanence Research

Concern regarding the permanence of photographs has been around since the beginning of photography itself. As each new photographic process entered the market, questions about its longevity eventually had to be answered. Today's new digital imaging systems are no different, and there is little historical experience upon which to reassure consumer worries about the safety of their printed images. To address the lack of information on how these prints (in general as opposed to by specific products) will age over time, experimental work comparing the long-term stability of the various new print types to each other and to traditional prints was needed.

In 2007, the Image Permanence Institute (IPI) at the Rochester Institute of Technology (RIT) began investigations into the preservation of inkjet, electrophotography, and dye sublimation prints. This included both desktop printing systems as well as digital presses. The project specifically dealt with the effects of heat, light, pollution, abrasion, extremes of humidity, and water on these materials. To provide a context for the results traditional offset lithographic and color silver-halide prints were also tested.

Note that the papers used for the offset and digital presses were all of the same type – coated 80# text. Permanence of paper is generally well understood and is dependent primarily on the chemical makeup of the sheet. The pH of the paper is usually given as prime determinant of paper stability because acidic paper degrades much quicker than neutral or alkaline papers. Other ingredients or impurities such as lignin, metals, and recycled content can also reduce the life of paper. Because these problems are already understood paper type was held constant, so the focus for these technologies would be on the colorants. The following is a brief summary of the various experiments and their results. For more information on each experiment, see the original papers.

Methods and Results

Thermal Yellowing

Usually the first step in understanding the long-term behavior of a print material is to establish its thermal stability which is its natural decay rate (change absent light, pollution, handling, etc.). Small studies from manufacturers and some preliminary work at IPI had suggested that digital print colorants would be very robust with respect to thermal aging at room temperature and moderate relative humidity, but that the paper supports may yellow severely. To study this phenomenon, 37 different print examples were incubated at six elevated temperatures and three humidity levels (dry, moderate, and moist) for one to ninety-four weeks. The time to reach a noticeable level of yellowing for each temperature under each humidity was then used to extrapolate the time it should take to reach that same level of yellowing at room temperature at that humidity. Most papers were predicted to last centuries at room conditions before yellowing. The shortest prediction was 58 years [5]. This suggests that anecdotal reports of yellowing may have been caused by light or air pollution and not natural decay.

High-humidity Induced Bleed of Colorants

Some inkjet prints may bleed during short-term exposures to high humidity resulting in color shift, blurring, and loss of detail. To examine this effect, 33 different prints were exposed to high humidity for two and four weeks. Only the dye inkjet prints bled. The rate of bleed was initially rapid and then declined over time suggesting that most damage is done early upon exposure to high humidity. It was usually the magenta colorant that bled the most. This often led to a magenta fringing around dark lines. The bleed also caused a decrease in image sharpness making the images look "out of focus". The bleed damage was greater in the shadow areas than highlight areas of some images, so it is more likely the detail in the darker areas of some images will be lost [6].

Light-induced Fading and Yellowing

Concerns about the stability of digital prints on display have been around since the beginning of digital printing when consumers voiced frustration about their prints fading in weeks or months. In these experiments, 37 different print examples were exposed to two different types of lighting; simulated daylight through window glass or fluorescent office illumination. Given the widespread view that digital prints are extremely sensitive to light, it was surprising to find that, *on average*, the digital prints were less sensitive to light than traditional prints; however each digital printing technology produced at least one example that was worse (and sometimes considerably worse) than traditional prints. It was also found that light sometimes caused delamination of print surface layers or increased print sensitivity to scratch. Offset lithography, dye sublimation, color-silver halide, and some dye inkjet were the most sensitive to light [7].

Pollution-induced Fading and Yellowing

Early study of digital print permanence focused almost solely on light fade. It was later determined that some of the fade reported for images on display was in fact due to atmospheric pollutants especially ozone. There was also concern for print yellowing by nitrogen dioxide. As a result, IPI exposed 36 different prints to ozone and 35 to nitrogen dioxide for several weeks each at 25ºC and 50% RH. It was found that digital prints were generally more sensitive to ozone than color silver halide photos, or offset lithographic prints. Both dye and pigment inkjet prints faded, but the dye inkjet prints were significantly more sensitive than pigment inkjet. In addition, some inkjet photo papers were prone to cracking when handled after ozone exposure. Even slight flexing of these prints caused severe cracking and flaking of the image layers. Color electrophotography (dry and liquid toner) was resistant to ozone. Yellowing was the biggest problem for prints exposed to nitrogen dioxide with the traditional color photographic, the digital press, and the offset lithographic papers being the most sensitive. Unexpectedly, some dye inkjet prints bled during nitrogen dioxide exposure causing the prints to become discolored and blurred. A chemical reaction between the pollutant, the colorants, and the papers base may be the cause. Bleed has not been previously reported with ozone exposures [8-9].

Abrasion Sensitivity

Abrasion is the most widely reported form of damage in digital prints in the collections of museums, libraries and archives [10]. For the first tests, the abrading material remained constant while the digital print material was varied (57 different digital prints) in order to rank the sensitivity of the various digital print types. Second, 15 different prints were tested against a variety of common enclosures (interleave tissue, envelope paper, and polyester sleeving) as well as the backs of prints (to simulate stacks of prints) in order to rank the abrader's potential to cause damage to all print types. Just two types of abrasion damage were expected: loss of colorant and gloss. However, it was found that the colorants on some prints could also be smeared from the dark areas to the light areas. A small perceptual study of this issue showed that this new factor, colorant smear, was by far the most significant form of damage in the eyes of the observers, so it was used as the determining factor in all further tests. Pigment inkjet was by far the most sensitive to abrasion. Some dye inkjet printers were also sensitive if the black ink contained the pigment carbon black. In general, the backs of prints were the most abrasive surfaces, so this will be problematic for some prints stored in stacks. However, they varied considerably in their roughness, so some were safe while others extremely harmful. Polyester sleeves were the least abrasive enclosure material [11]. In addition, 27 of the prints tested for abrasion were also tested for sensitivity to scratch. It was found that scratch and abrasions sensitivity do not correlate well, so while some prints were sensitive to abrasion they might not also be sensitive to scratch and vice versa. Pigment ink jet on photo paper and AgX prints were the most sensitive to scratch [12].

Water Resistance

Since the very beginning of digital printing, it has been known that some print types are sensitive to water damage. To evaluate this, 28 different prints were exposed to simulated flood. All of the digital print types were damaged to some degree, either catastrophic damage, such as color bleed or delamination, or less severe damage, such as loss of gloss or paper cockling. The dye inkjet prints were the most sensitive to flood, often being completely destroyed. The liquid-toner prints cracked in the image areas as the paper expanded and contracted during wetting and drying, causing the image areas to tear and in some cases

delaminate. Some dye sublimation prints delaminated completely after prolonged water exposure. Color silver halide photo were the most resistant to damage by water, which makes sense since they were designed to be wet processed [13-14].

Comparison of Digital to Traditional Prints

On average, the digital print materials were more stable than the traditional prints, but this does not tell the whole story. There are some individual digital print types that are dramatically weaker than traditional prints when exposed to certain deterioration forces. It will be important for print fulfillment providers to know which print materials are sensitive to which forces of decay. For example, pigment inkjet can be sensitive to abrasion while dye inkjet is much less so, yet dye inkjet is often sensitive to light while pigment inkjet is not. Also, the individual products within a given category sometimes varied more than the categories did themselves. This means that the prime determinant of a given print's stability will sometimes be the specific products (brands of colorants and paper) from which it was made rather than any class or category to which it can be ascribed. For this, photo fulfillment providers will need to rely on accurate information from manufacturers on the overall stability of their materials.

Conclusions

Comparison of the two sets of studies leads to the conclusion that print value does not correlate with print permanence. The offset lithographic and electrophotographic digital presses produced prints with near equivalent value, but the offset prints were prone to fade under light. The inkjet prints were visually considered a better value than electrophotographic, when not in photobooks, and color silver halide prints but dye inkjet was more sensitive (and in some cases dramatically so) to light and pollution, and pigment inkjet more sensitive to abrasion and pollution.

Selecting a print system that creates good prints at a good price will not automatically result in prints that last a long time. Prints of the highest perceived value to consumers may end up being those destined to shortest lives. However, an understanding of all the key factors and access to the critical information will likely not be easy or even possible for end users, so they will have to rely on information from manufacturers as well as knowledgeable photo fulfillment providers to help guide them to the right decisions.

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Susan Farnand received her BS in physics from Cornell University and her Masters in Imaging Science from the Rochester Institute of Technology. After beginning her career at Eastman Kodak, she moved to RIT where she works as a Research Scientist in the Center for Imaging Science. Her research interests include image quality, human vision and perception, and color science. She is a member of IS&T and serves as an Associate Editor for the Journal of Imaging Science and Technology, and has served as co-chair of the IQSP conference at EI and guest editor for the Journal of Electronic Imaging.