An Investigation into Papers for Digital Printing

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A Research Monograph of the

Printing Industry Center at RIT

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Executive Summary

This study is designed to identify constraints and potential solutions for improved performance and quality of digitally printed papers. The targeted market segment is high-end digital production in the U.S. In the first phase a survey of print providers has been conducted, the sample drawn from the network of printing companies currently engaged with Printing Industry Center research activities. The second phase will be to follow up observations from the survey with a case study approach, working with both print providers and with digital press manufacturers. In order to understand the characteristics of this digital printing market segment, a demographic study of the respondent group was conducted as part of the survey. This was followed by an exploration of the considerations and paper characteristics that are involved in the paper grade selection decision. The role that paper characteristics and press requirements play in production efficiency and document quality was investigated. The change in paper costs to printers over the last few years was also explored.

Specific research objectives included:

- identifying the paper grades commonly used for the market segment of production digital printing,
- identifying the number of brands used and the nature of printing companies' relationships to suppliers,
- determining the factors that affect brand and purchase decisions,
- discovering the relative importance of different paper properties and characteristics,
- assessing the deficiencies in currently-available paper grades, and
- determining what improvements are required by digital printers, and what limitations are currently imposed by press design.

The leading digital paper grades used in digital printing production were found to be coated gloss, premium uncoated, uncoated calendered, coated matte, uncoated uncalendered, and premium bond. The median number of paper brands used by this sample is five, with a wide range indicating varied practices. When making the paper purchase decision, almost half the time print providers and print purchasers collaborate on the selection of paper grades.

Leading factors involved in the paper purchase decision were identified as runnability and print quality, followed in importance by availability of grade, appearance properties, price, multipurpose functionality across different technologies, and product range. The leading paper characteristics considered when making a purchase decision were found to be, in order of importance, toner/ink adhesion, accurate sheet dimensions, dimensional stability, and moisture level. Performance- and runnability-related factors were found to be more important than appearance-related factors in the purchase decision.

Overall, the price of papers charged by manufacturers to print producers seems not to be a leading factor in making the paper selection decision. Price was not a key driver in selecting brand or grade type, even though most printers have experienced paper cost increases in the last few years.

The area of improvement that printers want to see most is an extended product range, with more sizes, finishes, and basis weights available for their digital presses. The presses currently owned impose paper choice limitations on size, basis weight, thickness, and surface treatment requirements.

In general, it appears that there is room for product development to meet the developing potential for production digital printing applications. The survey data will be used to construct a case-study research project to further explore the observations and inferences.

Introduction

Discussion of the Background and Philosophy of the Survey

In any industry, the purchase of supplies and components is driven by both technical considerations such as product quality and attributes, and by business parameters such as price and availability. Both the printing and paper industries are significant in size and well established, and for many years the two industries have been connected by conventional procurement and supply chain structures. These structures may have worked well for traditional printing technologies, but it is interesting to consider whether they are efficient and effective for the different end-use markets and workflows used by successful digital print providers. Paper manufacturers do sell digital grades directly to digital print providers who understand the technical requirements of papers, but the bulk of their sales is to value-added resellers (VARs) and distributors, who may be primarily focused on price and not on product attributes. Thus there may be multiple steps and a communication gap between the hands-on user of the product (the printer) and the technical designers at the paper mills who understand the differences between digital and offset papers.

On the basis of these considerations a study has been undertaken to assess the relative importance of the different properties of digital papers, and the reasons why certain grades are selected by print providers. Additionally the gaps in currently-available digital grades are assessed.

In the first phase of the study, a survey of U.S. print providers who currently use digital technology has been conducted. Secondly, on the basis of the initial survey findings, a case study approach will be taken to explore the responses of the print providers in more depth. Additionally, press manufacturers will be interviewed to understand the limitations of press design imposed by currently-available digital paper grades. Finally, in a future phase of the research, an overall assessment of current digital paper prop-

erties and the potential development of new or improved grades will be linked to the potential to develop genetically-modified fiber sources to enhance product properties (White, Peter, & Evans, 2004).

The objective of this study is to identify constraints and potential solutions for improved performance and quality of digitally printed papers. This was accomplished through a survey of the network of printing companies currently engaged with the Printing Industry Center research activities. The survey was designed to gain an overall impression of how and why different papers are selected for digital printing jobs, and to examine the relative importance of paper characteristics in the selection decision.

Specific research objectives included:

- identifying the paper grades commonly used for the market segment of production digital printing,
- identifying the number of brands used and the nature of printing companies' relationships to suppliers,
- determining the factors that affect brand and purchase decisions,
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Literature Review

Digital Printing Overview

Generally, digital printing is defined as any printing technology with a digital file as input and no fixed plate—therefore each impression can be different. This includes a multiplicity of technologies from inkjet to dry toner electrophotography to thermography and beyond. This study is directed towards the production segment of electrophotographic digital printing, and does not include the SOHO (small office and home office) and graphic arts inkjet markets. Direct-to-press and direct imaging (DI) equipment is not included in the scope of this phase of the research.[1]

Over the past ten years, digital printing technology has become mature and the market for digitally printed documents has soared, becoming a significant part of the graphic communications industry (Digital Dots, 2004). The first full-color digital presses arrived with the launch of Indigo and Xeikon presses at Drupa 1995. Other manufacturers followed with product launches aimed towards commercial print production, and

1 It was evident in the survey responses that this definition of digital printing is not universal, since some respondents did use DI and computer-to-plate (CTP) technology.

monochrome digital production presses became established in business, financial, and production markets. Digital printing was predicted to revolutionize the world of print production. However, the new technologies were met with skepticism since many printers were still struggling to embrace the "desktop shock" (Digital Dots, 2004). Besides the constraints of unreliable runnability, lower-than-offset print quality and high cost per impression, an additional barrier was the limited availability of papers that were compatible with these emerging technologies. As time progressed, print providers began to comprehend the unique opportunities and advantages enabled by digital printing, including short run, variable data, and fast make-ready. Yet for some years, digital printing remained on the periphery of the commercial production segment, and for some time Indigo and Xeikon were the only manufacturers of full-color digital production presses. At Drupa 2000 new full-color production systems were introduced by Xerox and other manufacturers, and paper companies responded with broader product offerings tailored specifically to digital press requirements. Over the last five years, the range of digital color production presses and the qualified papers specifically designed for the technology have increased significantly.

The overall digital printing market encompasses a significant proportion of business and transactional printing, estimated to be 91% (American Printer Staff, 2004). Although there has been steady growth in the commercial printing segment, the astronomic predictions of a few years ago were not realized (American Printer Staff, 2004). It appears that the caution exhibited by commercial printers was fueled not only by limited capital availability, but also by the per-sheet costs and the complexities of the newer digital technologies. Press manufactures such as Xerox and NexPress appear to be addressing these barriers by actively working to reduce the price per printed page, and working with business models and training packages which can move digital assets into traditional printing environments. Meanwhile, the perception of limited digital press speeds has been somewhat overcome by the expansion of the productivity concept, from sheets per hour on press, to finished documents delivered to the point of use. This has opened up the potential for short run, distributed on-demand printing and value-added pricing models. However, this progress has been struggling against the tide of the commodity pricing structures of the traditional long-run print market segments, which benefit from economies of scale and long-term procurement agreements for supplies. In this environment paper, along with print itself, is viewed as a commodity. One sheet is very much like another, as long as it arrives on time and fits the press. Into this paradigm digital printing has had to struggle to be viewed as a value proposition with unique capabilities, requiring specially-designed papers to reach its full potential.

The Challenges of Digital Printing

The challenges involved in developing a digital printing function include finding customers who understand the capabilities of the technology, understanding the competition, working with the current range of substrates, managing print capacity, educating the workforce in the technology, working within available finishing capabilities, and managing costs. With most production digital presses currently in operation, the per-impression cost is higher than traditional technologies beyond a certain "break even point" of a few thousand impressions. This cost comprises contributions from toner/

inks, paper, maintenance, press consumables, and amortization of the equipment capital investment. As run length increases, this differential also increases, rendering digital production no longer viable. In order to manage digital per-impression costs, suppliers use the benefits of just-in-time delivery to eliminate or reduce warehousing and transportation costs (Romano, 2003). This is consistent with the print-on-demand paradigm enabled by digital printing, in which turnarounds may be short, file submission may be entirely electronic, and print production may be carried out at point-of-use. These advantages of digital printing are becoming more widely understood within the marketplace as the technology becomes mainstream.

At the same time, the print quality of the new high-end digital presses is approaching offset levels in the judgment of many print experts, opening up a demand for new graphics applications. This is one driver of the demand for a wider range of substrates as full-color, high quality jobs migrate from offset to digital presses. The higher bar of acceptable digital print quality also puts pressure onto substrate suppliers, because defects, poor toner fusion, non-uniformities, poor charging characteristics and mottle are no longer tolerated as inevitable consequences of using digital. Runnability (see below) poses significant technical challenges for digital papers, and as press speeds increase (the Xerox iGen3 can now print 110 pages per minute), this becomes more of a challenge for papers. Duplexing (two-sided printing) and in-line finishing are more commonly used with the recent increase in booklet and finished document production, requiring mixed substrates to be run simultaneously, each with adequate runnability properties.

Trends in the Digital Printing Market

Printing industry growth in 2004 was driven primarily by digital printing and a range of auxiliary services. This trend is anticipated to continue and accelerate in 2005 (Lamparter, 2005). The market for digital printing is growing at a faster rate than that of the overall print market. However, the growth rate is slower than the rate predicted by many industry analysts a few years ago (Biscos, 2004). Many printing companies who have invested in digital equipment are using it alongside traditional technologies such as offset lithography. Concerns about digital quality, entry price, and the reliability of the technology have resulted in lower than expected investment in digital production presses. Offset is still producing the bulk of printed pages, and in many print operations, digital presses are used for special applications only. According to technology research and consulting firm InterQuest, the number of color digital production presses installed worldwide increased from about 2,500 units at the end of 1998 to approximately 3,600 at the end of 2003. This slow increase can be attributed to several factors: the economic downturn, the high equipment and software purchase price and operating cost, competition from the lower volume copier/printer segment with lower entry risk, and the slow implementation of color variable-data printing.

Nonetheless, a surge in print buyers' demands and system enhancements, and the decline in the total cost of operation have contributed to a recent market growth (Digital Dots, 2004). Those printers who have made the digital leap are generally satisfied with their new equipment; many are seeing a change in their businesses after crossing the digital line, and are finding innovative ways to make digital printing profitable (Bauer,

2004). Overall the market for digital printing has matured and strengthened within the last five years. According to *GATFWorld* (2005), "2004 was a very good year for digital color printing. Suppliers shipped 16,000 digital color printing systems worldwide, with about 9,000 in North America." Over the last few years, market share has increased relative to offset as the speed of digital presses has increased, and larger sheet sizes have been introduced, enabling documents to be designed in terms of signatures rather than printed pages. In 2005, 13% of the total printing industry revenue is expected to come from the digital segment, and by 2010 this is anticipated to grow to 19% (GATFWorld, 2005). A study conducted by the National Association of Printing Leadership (NAPL) reports that 48.6% of printers are including the purchase of digital printing presses/systems among their priorities for the next five years (NAPL, 2004). Although many digital presses currently installed do not achieve near-offset quality in full color, the capability to produce custom short-run color and black-and-white output will drive growth, and with most presses, digital color quality is acceptable for a range of applications. Digital print quality continues to improve, as press, paper, and ink/toner technologies advance (Cody, 2003).

The growth in digital printing requires the cooperation between equipment and materials suppliers, printing companies, print purchasers, and end users of print. The entire supply chain must work together, and elements of the chain must constantly upgrade their skills and knowledge to remain competitive (Frey, in press). Digital printing can offer high quality solutions to clients, but printers need to know how to sell the product (Joss, 2004). Digital printing allows printers to develop solutions-oriented relationships with customers, relationships which are structured differently than those currently in place, based on traditional technologies. The relationships between materials suppliers and print providers must also change to adequately address the different technological and logistical requirements of digital supplies. For example, papers for digital printing must be transported and stored in such a way as to preserve their required properties, adding an element of cost (Pope, 2002). Therefore the emerging trends in the digital market are not only centered on the new digital technologies, but also on business structures. To be successful in this market, effective marketing, training, and an understanding of the customers' business problems are critical (GATFWorld Staff, 2003).

Trends that have emerged in the digital printing market include:

- **Short run:** Short run lengths are the secret to success and financial viability in digital printing. The capability to bring run lengths down to just one impression differentiates digital from offset printing. A product can be customized, produced, and fulfilled immediately when requested (Romano, 2003). Digital printing can produce prints with no make-ready and no waste; therefore it's a cost effective process for very short runs (Romano, 2001).
- **Print-on-demand:** Quick turnaround and responsiveness to customer needs are the driving forces behind the success of on-demand printing. This is enabled by electronic file submission and low levels of make-ready. The first print out is often saleable. Inline finishing extends the capabilities to print complete products in one pass when, where, and how the customer demands.

- **Variable data printing (VDP):** Digital printing allows printed materials to include information elements (images, graphs, charts) that change for each impression. Dynamic fields are inserted amidst static regions that are the same for all impressions. The variable content may be a simple name, graphics may be linked to a database of information driving the selection, and in some cases the entire impression is uniquely tailored to the individual recipient. (Romano, 2001). The VDP concept was introduced in the late '90s and received an enthusiastic response. Putting the concept into practice, however, has proved to be difficult (Kita, 2003). Some print providers don't have the resources or technical expertise to engineer a complex VDP project (GATFWorld Staff, 2003). Additional expertise is required to sell and produce personalized marketing programs (Bauer, 2004). As technology for VDP improves and customers begin to perceive its value, the market for it is expected to grow (Bober, 2003).
- **Distribute and print:** Distribution of the electronic file and printing close to point of need reduces postal and other distribution costs by moving the point of production closer to the point of delivery (Romano, 2003). In traditional printing, the client purchases a quantity of printed material, which is generally printed centrally and delivered to a specified site. This is known as the "print and distribute" workflow. With digital printing, a file can be electronically distributed to a number of different digital printers at different locations. Using this "distribute and print" workflow, a file is printed and distributed locally, dramatically reducing the costs associated with shipping, warehousing and distribution. (Romano, 2001).
- **Online procurement:** The relationship between buyer, seller, and end user is facilitated by the Internet. In the printing industry, e-commerce capabilities are broadly defined as a "value-added service" rather than as product procurement (Goldberg & Romano, 2001). Today, e-commerce services in the printing industry entail anything from electronic file submission to remote printing, online job tracking, or simple electronic bill payment.
- **Customer relationship management (CRM):** Building customer loyalty or securing long term relationships with customers is key to the success of any business. An important aspect of CRM is its ability to personalize communications targeted to a specific audience. Digital printing provides the capability to personalize, which greatly increases the effectiveness of the marketing piece (GATFWorld, 2003).
- **Digital asset management (DAM):** Trends in the area of digital asset management include web-to-print, e-commerce marketing, versioning, and color print-on-demand. Understanding the value of asset management and setting up processes to manage this function is a current trend (Frey, Williams-Allen, Vogl, & Chandra, 2004).
- **Workflow:** Changes in digital workflows and industry standards such as job definition format (JDF) and CIP4 are essential to the flow of information. The industry is working with standards for integrating inline finishing systems into digital presses, opening up the market for specialized manufacturers.

The Digital Black and White Market

Most research and industry exposure in digital printing concerns full color, however the black-and-white production segment still represents the bulk of digital volumes produced in the last few years (Romano, 2004). Black-and-white production can be the main revenue generator in a digital operation, enabling investment into digital color technologies. The monochrome production segment includes financial and transactional printing (check printing, billing statements, insurance, banking, etc.), book publishing, healthcare documentation, retail, government documents, educational materials such as transcripts, and more. Today's black-and-white production printers have increased in speed, versatility, resolution, and quality. Also, their ability to handle a wide range of stocks and the integration with inline finishing solutions has widened output capabilities (Miley, 2005). The post-fuser insertion of pre-printed color pages, and the ability to print on hybrid offset and digital shells and forms allows variable components to be added to color documents cost effectively. While some commercial printers are still unsure of the economics and dynamics of color digital printing 10 years after its introduction, the monochrome sector long ago proved its worth in a pure manufacturing industry sense (Howard, 2003).

Digital Paper Market Trends

2004 was a year of significant digital press acquisitions (Romano, 2004). It was projected by InfoTrends/CAP Ventures (2003) that by 2006, more than 15,000 digital presses would be installed in the U.S. alone. Digital printing is projected to expand by 42% annually through 2006 (Cody, 2003). Mirroring the growth of digital presses is the concomitant development of papers that have been manufactured specifically to meet digital press requirements.

Digital paper is the fastest growing category in paper manufacturing (Clinkunbroomer, 2004). Although overall digital paper volumes are modest compared with other market segments (e.g., uncoated freesheet and web stock for newspapers), the volume for digital paper in the U.S. is projected to expand at a rapid rate, to reach more than 60,000 tons annually by 2006. Although coated and value-added grades offer higher profit potential, the bulk of this volume is expected to be uncoated. As a result, many paper manufacturers are experiencing a rise in business in the digital paper arena. Garth Geist, director of digital media at Smart Paper, reports that the company's digital business has been expanding at a rate of 30% per year (Cody, 2003). According to an InfoTrends/CAP Ventures survey (2005), over 70% of respondents indicated they are printing more documents in color than they were 2 years ago. Ninety-five percent of respondents are using the same amount or more paper than they have in the past, and most forecast a similar level of usage in the next two years In the early days of digital printing, paper performance, runnability, and limited paper choices were the concerns of print buyers and print services providers. Research and development into papers for digital printing has somewhat addressed these concerns.

In response to these market dynamics, paper manufacturers have been launching new digital paper lines and expanding existing lines with new product sizes, weights

(both higher and lower basis weights) and finishes (Hitchcock, 2005). Both printers and print specifiers are increasingly demanding a wider and more diverse selection of papers qualified for digital presses, and an expansion of other media for use with these technologies (for example, self-adhesive labels which function at high fusing temperatures, envelopes, identity cards, synthetics, etc.). Printers with multiple technologies and a variety of presses are calling for papers that are functional across both offset and digital equipments, an exacting requirement. Some manufacturers are redeveloping grades currently available for offset and qualifying them for digital applications (Hitchcock, 2003), often by managing the specifications and moisture levels more tightly (and increasing the price significantly!). New coated stocks, specialty substrates, recycled papers (e.g., to comply with state and local government requirements), wider size ranges, textured grades, carbonless, perforated and scored stocks, and new paper finishes have been launched in the last few years. Thomas Lapham, national sales manager at Finch Paper, states that "When customers talk to distributors and they tell us there's a need, we develop new products and stock new sizes" (Hitchcock, 2003). However, the perspective of print providers may be different, and it is this what the current study has been investigating.

End-user customer demands need to be balanced with the demands and restrictions imposed by digital presses. As many printer manufacturers introduce new equipment that accepts heavier stocks (e.g., 140 lb. cover) and new sizes and weights, paper suppliers have been developing new products for these devices. There is significant collaboration between paper suppliers and press manufacturers. Steve Simpson, vice president of the Xerox Paper Business Unit, states that the Xerox works closely with paper manufactures, creating a good product development pipeline for media (Hitchcock, 2003). Similarly, HP Indigo works closely with International Paper and Mohawk to develop a press-compatible digital paper line. Qualified paper lines reassure press operators when running an unfamiliar paper, and minimize on-site testing, a costly and time-consuming activity. These digital paper lines include pre-treated papers for specific equipment such as HP Indigo presses, Xeikon presses, etc. (American Printer Staff, 2004). Press manufacturers realize the need to design equipment that can handle a broader range of existing substrates (lighter than 20 lb. and heavier than 90 lb.), particularly in light of increased cost sensitivity. Qualified lower basis weight stocks can be used to reduce distribution and mailing costs, a growing need in light of projected postal rate increases. Magazine, book and manual distribution costs can be reduced by using lighter weight stocks with equivalent properties to current grades (American Printer Staff, 2004).

Pricing Trends

In order to market a range of digital paper grades effectively, the discussion needs to focus on value and attributes rather than cost, as the digital print market moves away from a commodity towards a value-added paradigm. A price focus may predominate for products marketed through value-added resellers (VARs) and distributors. Intermediate decision makers in the value chain may not have an understanding of paper attributes that differentiate digital papers from those grades designed for traditional technologies. A technical understanding of these issues is essential if print buyers are to appreciate the value offered by digital products. Thus the sales and distribution mechanisms commonly used in marketing printing papers may not be optimal for digital grades.

Overall, the pricing for uncoated freesheet grades has declined over the last few years (American Printer Staff, 2004), but coated papers and special grades offer opportunities for increased profit margins. However, these margins may be eroded by multiple steps in the supply chain, and may not enable research and development by paper manufacturers, who frequently realize the smallest profit margins in the chain.

The cost of digital papers remains high compared to offset papers, and this is a challenge for sales personnel selling both categories to a print provider. Equivalent grades qualified for digital and offset technologies may differ very significantly in price. For many print buyers, the decision to purchase digital papers is driven by end-user demands; in some cases the end-user and print specifier collaborate with the print provider on making an appropriate choice. Printers frequently negotiate with paper merchants on individual purchases, but may also have long-term procurement agreements to with structured pricing models. Anecdotal evidence suggests that to many printers the price per sheet is not as significant as the reliability of the supplier and the runnability of the paper. In some cases, more emphasis is placed on the supplier's ability to deliver on demand (e.g., next-day delivery) than on the actual properties or cost of the paper (Fraser, 2000). It is this relative importance of purchasing considerations that this study will explore.

Paper Purchasing Decision Criteria

With new technological developments in electrophotographic printing, more stringent demands are being placed on paper performance. With higher run speeds and higher image quality expectations, paper manufacturers are challenged to produce papers with the appropriate characteristics at acceptable price points. Print buyers have higher expectations than ever before, requiring "on-demand" print solutions with near photo-quality color output. The trend towards graphic-intense documents is fueled by both the developing sophistication of color electrographic print engines at the office level, and the growing popularity of accessible graphics software applications. Therefore, digital substrates must be able to handle higher levels of toner from four component colors while maintaining sharp line edge acuity and accurate dot placement. End users are demanding snappy colors, defect-free areas of solid color, and sharp text with high edge sharpness.

Paper performance for printing may be broken down into three functional areas: runnability, printability, and fitness for use.

Runnability is generally understood to encompass the performance of papers in press operation, such that sheets will run smoothly through the print engine without jamming, and webs will not break. Printability relates to the image quality and overall appearance of the printed piece (Levlin & Soderhjelm, 1999). Fitness for use or usability of the final printed piece is assessed in terms of grade-related properties such as color, texture, and basis weight, the ability to be finished and distributed in the required manner, and the ability of the image to meet permanence requirements for the specific use.

In order to discuss the technical requirements of digital papers and to understand the survey responses in which properties are ranked, it is useful to consider the paper-

related steps of the electrophotographic marking event. Two steps in this process are critically related to paper properties: toner transfer and fusing.

Inside an electrophotographic printer, the image is written using a laser or other light-based system to a photosensitive drum or belt known as the photoreceptor. Charged toner is attracted to the image areas of photoreceptor, which are charged differently than the background (or non-image) areas. The dielectric force that drives the toner transfer arises from a charge placed on the paper before it reaches the transfer "gap." The strength and uniformity of this force determines the efficiency of toner transfer.

Discontinuities and variation in this force result in mottle (uneven print density) and low image quality. Toner transfer efficiency is related to the distribution and density of fillers within the paper structure, and also is significantly affected by thickness variations (Provatas, Cassidy, & Inoue, 2004). Toner penetrates very little into the paper surface, and so mottle or print density variations are primarily due to the factors that control toner transfer. Other factors include surface roughness, and moisture non-uniformity, which even on a very localized level can affect the dielectric force strength sufficiently to produce a visible optical density fluctuation. Where toner transfer is inefficient, residual toner remains on the photoreceptor and may be transferred to the next image, increasing background speckle or producing "ghosting." Background speckle can reduce the apparent brightness of papers and can lead to lower relative contrast, reducing image quality (Tse, Forrest, & Wong, 1999).

Once on the paper, the toned image must be fused to become permanent, and this can be accomplished in various ways, including heat and pressure, cold pressure, radiation, or vapor methods (Hwang, 2000). A commonly-used method is hot roll fusing under applied pressure. In the fusing process, toner melts under heat and pressure exerted by the nip forming rollers. The degree of toner penetration into the paper voids and pores depends on process conditions, toner rheology, and paper properties. In plain papers, toner just penetrates the voids at the paper surface. In some systems toner penetration is minimal, and the bonding between the toner and paper may be inadequate for permanence and rub resistance. Paper permeability is a parameter that encompasses the shape, size, spacing and distribution of surface voids and pores, and this parameter is frequently related to fusing efficiency and toner penetration (Hwang, 2000). Other paper properties that influence fusing include the thermal properties of the sheet, moisture content, surface energy and roughness, and thickness (AL-Rubaiey & Oittinen 2004). Generally, fusing quality decreases as the surface roughness of the paper increases (Apel, Knott, Schleusener, & Petschik, 1995).

Liquid "inks" consisting of toner particles dispersed in a vehicle are used in the HP Indigo systems. Vehicle penetration into the paper pores and evaporation leave the toner particles on the substrate surface. The fusing step tends to require lower temperatures and pressures compared with powder toner technologies. Some substrate / liquid ink combinations require surface treatments to yield adequate vehicle wetting and colorant adhesion. However, new ink formulations and advances in substrate sizing are being developed to bypass this requirement (Mohawk, 2005).

Digital Substrate Range

In order to offer new and exciting applications for digital print and move the market perception away from a commodity service to a value-added manufacturing process, a wide range of substrates must be available to designers. To fully utilize the flexibility of digital printing, a full range of colors, textures, sizes, and basis weights is needed. Currently one paper manufacturer offers more than 1,000 offerings (different sizes, basis weights, finishes, etc.) in its digital lineup. Printing complex jobs using multiple stocks in one pass through a digital production press is a key advantage of digital printing. With one-pass document printing and finishing, the concept of "productivity" extends beyond press run speeds to the idea of finished pieces per unit time. This integrated capability is driving the need for wider and matched substrate ranges which can run concurrently in a print job.

A printing operation using both offset and digital technologies may prefer to work with the "same" paper grades on each press; this means purchasing technology-specific grades designed with a similar look and feel, e.g., color, finish, and basis weight (Rector, 2004a). The development of matching text weights and covers within a product range for both offset and digital printing increases the flexibility of making real-time decisions in the pressroom about which technology to use. The digital/offset cost breakeven point may be less important in making the decision about choice of press than schedule availability and other logistical factors. Such a decision may be made just before printing, so the stock range must be available. This may be a strong incentive to participate in single-source procurement. In order to manage costs, many industries are seeing sole-supplier agreements and long-term sourcing contracts become more predominant in larger companies. Grades designed for hybrid printing workflows, such as digital printing on offset shells, can combine the advantages of economies of scale with the value-add of variable data printing. However, carrying equivalent digital and offset grades in a paper inventory highlights any pricing difference. The higher digital paper price may be explained to some extent by the need for greater uniformity, tighter tolerances of physical properties, and the reduced level of moisture that can be tolerated in digital presses. Nevertheless, paper sales representatives may be challenged to explain to paper buyers why a digital grade is significantly more expensive than an equivalent offset grade. This market complexity can be addressed by communicating clearly why digital papers are different.

The wide range of paper sizes, finishes, basis weights and colors designed for each print technology results in a huge inventory problem for many print businesses where space and cash flow are at a premium. Where several print technologies are functioning within one print operation, a universal paper has significant economic advantages. However, the best runnability and image quality for digital printing is obtained from papers designed specifically for electrophotographic applications (Pope, 2002).

- **Web vs. cut-sheet papers:** The majority of digital presses are sheetfed, although roll-fed systems are being used for high-end financial and transactional printing. In this production segment, the concept of unattended operation is being promoted by many of the major press manufacturers as a productivity enabler

and cost-management strategy. Web presses generally enable longer runs to proceed with less stock replenishment activity. Some presses, such as those in the Kodak NexPress DigiMaster series, are able to cut sheets from a roll-fed stock to enable long runs without a break for stock replenishment. Web-fed Xeikon presses can sheet after printing to any length, enabling a range of product configurations including banners. Replenishment on-the-fly of most consumables is standard in the more recent high-end production presses.

- **Sizes:** The range of digital presses on the market vary considerably in the paper sizes they can accommodate. This means that digital paper manufactures must supply a very wide range of paper sizes. In order to fully exploit the flexibility of digital printing, stocks ranging from postcard-size to that of full signatures must be available, presenting a manufacturing challenge to the papermakers and an inventory challenge to the printers. Many dry toner systems require a print-free margin to prevent fused toner building up on press components. For full-bleed designs, larger stock sizes are used and then trimmed. This adds another sizing element to the product mix (and a production cost component).
- **Basis weight:** The basis weight of paper is the mass in pounds of 500 sheets of a specified size, this standard size being dependent upon the paper type or grade. This metric expresses the amount of material within a standard sheet. Outside the U.S., more metrically-inclined societies prefer the "grams per square meter" unit, which is fast becoming the universal standard and is independent of paper grade or type. In this study, basis weight was used in the survey, following U.S. industry conventions.

  Some digital presses are able to incorporate stock ranges from 18 to 140 pounds, which offers design flexibility breadth for mixed-stock documents such as software manuals and complex booklets. As the costs of shipping, mailing and distributing documents increase, there is a need to develop lighter-weight papers with adequate opacity for two-sided printing. Such papers must withstand the rigors of high fuser temperatures in digital printers while maintaining dimensional stability (no curl or shrinkage), and must have adequate stiffness to operate in high-speed paper transport mechanisms. A number of studies are being undertaken to understand fiber formation and component orientation in new lower basis weight materials, and the relationships of these new papers with the mechanical properties that digital presses require.

  Another factor in the development of low basis weight papers is the relative cost of wood-derived fibers compared with inorganic filler materials. New filler technologies allow the direct precipitation of inorganic fillers onto fibers in the early stages of papermaking, yielding a more uniform structure with desirable properties and lower fiber contents (Blixt, 2003). However, it is challenging to manufacture lighter stocks which have the properties required to run on mid-range and high-speed production digital printers in this segment. (American Printer Staff, 2004).

Higher basis weight stocks are also required as document covers and tab dividers. The fusing and transport mechanisms must be able to cope with very different materials running concurrently. Some presses need to slow down to adjust temperatures in the fusing station with different basis weight stocks. Newer presses claim that full speed is achievable with all stocks, and use sensing technologies to adjust fuser station dwell-time and other parameters to achieve this. For example, in the Xerox iGen3, intelligent sensing can adjust transport speeds, nip pressures, fusing dwell-times and temperatures, and adjust other press parameters according to detected basis weight, conductivity, and thickness, as different sheets move through the press.

- **Specialty grades:** As customers move into new markets with personalized applications, the need for synthetic substrates, ID tags, and value-added niche substrates grows. With a full range of substrate materials, designers can plan the development of a complete marketing kit, encompassing decals, labels, mailers, brochures, etc. The field of security printing is developing in sophistication, requiring new materials and inks/toners. HP Indigo and Xeikon presses offer unique features such as microtext and special inks that can be viewed only under certain conditions such as UV illumination. Carbonless papers are now available for some digital color printers to further open up the business forms, transactional, and healthcare markets to digital production (WhatTheyThink.com, 2005).

Runnability

The trend towards short-run, variable data electrophotographic printing for targeted marketing applications requires robust paper runnability. Downtime is as expensive in a digital printing environment as anywhere else, but is a particular issue in variable data printing, where the loss of a single sheet can disrupt the integrity of the print run. Same-page recovery functionality within workflow solutions (e.g., the NexPress workflow solution for the DigiMaster presses) can go some way towards addressing this. Even so, the risks of printing the wrong address on secure financial transactional documents are high. Complex clustered and networked printer workflows also rely on robust runnability. The challenge for paper manufacturers is to design papers with appropriate runnability characteristics that can operate across the full range of digital print engines currently in use.

As labor costs increase and operational workflows are reconstructed to output more work with fewer people, digital technologies can offer improved throughput speeds, unattended printer operation, and in-line finishing operations, all of which can lead to lower levels of human involvement in a press run. Such functionality involves more complex paper paths and feed mechanisms, and hence requires tighter tolerances on dimensional stability and sheet uniformity. Runnability issues are common across all printing processes, but some are specific to digital printing. A leading cause of paper jams is out-of-plane deformation (such as curl or cockle), a problem that is exacerbated at the higher toner levels and fuser temperatures used in full color printing. Compared with many offset press requirements, sheet properties for digital printing must be more stringently controlled in terms of stiffness, moisture level, edge quality and dimensional integrity in order to meet the jam-free requirements of complex high-speed paper paths.

Strength Properties

Stiffness is the ability of a sheet to resist an applied bending force, and has a significant effect on runnability. It is closely related to formation, thickness, and moisture level (Thompson, 2004). High stiffness may be an end-use requirement (e.g., for cover stocks), but can also inhibit smooth transport around paper paths with tight curvature. Historically, digital printers evolving from the office copier segment have been designed with minimum footprints to address space constraints, but more recently in the production segment the space requirements have been seen as less significant than robust runnability. Some press manufacturers are now promoting a "straight paper path" as a runnability enabler in order to cope with the broadening range of digital papers. Low stiffness is one limiting factor for running low basis weight papers. Some press designs use bypass feed lines for stocks that are out of range in physical properties for the regular paper path (Pope, 2002).

Web presses can generally run substrates with a wider range of physical properties, and can print on materials with lower basis weights, lower stiffness, greater flexibility (useful for synthetics), and less dimensional stability than sheetfed presses. Some presses will cut a web of paper into sheets prior to printing, which can extend the unattended operation functional range. Others sheet the paper on exit, giving them the exact registration advantages offered by simultaneous two-sided printing (e.g., Xeikon engines). However, the range of stocks and the number of digital presses available for web printing is still somewhat limited.

The ability to absorb some stretch without breaking is an important paper property, particularly in web printing where sudden changes in longitudinal stress can occur. Tensile strength, stress/strain failure points, and creep behaviors are therefore key specifications and should be considered for both press performance and finishing requirements. In general, web breaks result more from point defects and localized non-uniformities rather than an overall strength deficit in the web (Levlin & Soderhjelm, 1999). Breaks are generally initiated at the point of weakness, such as a wrinkle, fiber flock, unusually large void, contaminant, area of uneven formation, etc. Eliminating localized variations is thus essential for runnability. Moisture non-uniformities can also result in areas of weakness. These requirements are similar for digital and traditional web presses.

Caliper (Thickness)

Automatic feed systems, high capacity stackers and inline finishing equipment function effectively only if paper caliper is sufficiently uniform. Some systems employ real-time inline thickness measurement to detect and compensate for variation. The stack thickness of a collated document or book can vary significantly with only a small variation in sheet thickness, which introduces complexity into inline finishing involving covers and binding. However, there is a more urgent reason to manage caliper in digital printing, because the magnitude of the electrostatic force which pulls toner towards the sheet surface in the toner transfer step depends on how much material is beneath the surface. Sheet thickness variation, or z-direction non-uniformity, has been shown to be a significant factor in the variation of surface charge density (Provatas et al., 2004). Additionally,

the distribution of fillers both close to the surface and within the body of the paper affects this dielectric force Thus, image density non-uniformities (print mottle) can result from thickness variations and non-uniformities in filler distribution within a sheet. Formation and thickness must therefore be controlled more tightly than in papers designed for non-electrostatic printing methods.

Grain Direction

The grain direction, or the direction in which most fibers lie in a sheet, determines the relative level of a range of physical properties that can vary between the width and length of a sheet. This is particularly true of stiffness, a key runnability factor. All print technologies require specific alignment of web and sheet grain direction in order to optimize the strength, stiffness and other performance characteristics on press. In digital presses, feeding sheets with the grain in the wrong direction can cause paper jams if the stiffness is not in the functional range.

Formation

Formation is the relative arrangement of fibers and other components in the sheet, and expresses the orientation and distribution of fibers, fillers, pores and voids. The performance of paper in digital printing has been shown to be very closely related to formation, or the distribution of mass density (Dodson, Oba, & Sampson, 2000). Ink penetration depends on the right size, depth, shape and distribution of voids and pores in the surface. Void and pore structures play a key role in the flow and subsequent bonding of molten toner to the paper surface in the fusing step, and is a factor in managing toner adhesion. Sheet formation non-uniformity contributes to mottle, or the unevenness of optical density in a solid-toned area. Strength and dimensional stability are also affected by formation since the degree of fiber-fiber contact and bonding dictates the strength properties, particularly stiffness. In general, a sheet with uneven formation containing large voids and fiber flocks will have a cloudy and uneven appearance, and will exhibit low strength. Such a sheet is generally regarded as lower quality, although specialty grades such as parchment feature designed unevenness in formation leading to desirable textural and mottle effects.

Surface Properties and Print Quality

Print quality is all about ink/paper interactions, and so the surface characteristics of paper must be matched to the specific ink or toner as much as to the press technology. Surface characteristics important to toner printing are uniformity, adhesion, strength, and smoothness.

Uniformity must be designed and managed carefully; localized non-uniformities such as pores and voids will dictate the degree of efficiency of the interaction mechanisms, such as for bonding and penetration. However on a macro scale, these localized non-uniformities must be reproduced equivalently across the sheet.

Fluctuations in paper surface composition can result in variations in surface resistivity, and hence toner density, degrading the print quality of graphic images. This use of

color graphics therefore puts new pressures on paper manufacturers for microstructural uniformity. This is not only important in the lateral dimension (in-plane with the surface) but also in the z-direction (perpendicular to the surface). The distribution of fillers within the body of the paper both laterally and perpendicularly to the surface will affect the charge density at the surface, and hence influence the toner transfer step.

Toner Adhesion

Toner adhesion is important not only for the long-term permanence of an image, but also for the general handling and processing involved in finishing and distribution. Adhesion is determined both by toner characteristics and the paper's surface energy, resistivity and moisture levels. Poor adhesion leads to rub-off, scuffing and scratching, and is especially an issue with mailed pieces and booklet covers.

In offset printing and liquid ink digital technologies, ink holdout (ink remaining on the surface) is balanced with vehicle penetration (non-colorant components moving into the sheet). The objective is immobilization of the colorant at the point it is placed, preferably without too much lateral spread (dot gain). Dry toners used in digital printing generally penetrate much less into the surface, even though there is a molten phase in which some liquid polymer or resin is able to penetrate pores and voids. Thus there is a higher concentration of colorant on the surface than with similar offset inking levels. Coated papers retain more toner on the surfaces, but do still rely on some pore penetration for effective adhesion.

Surface Strength

In the toner fusing stage, paper surface strength must be adequate to prevent delamination of coatings, or fiber-picking with uncoated papers. Either fuser oil or surface control agents on the toner particles themselves maybe used to enable release from fuser rolls.

Smoothness

The smoothness of the paper surface is often described in marketing terms as its "finish," and a wide range of finishes are available, from cast-coated gloss with an almost mirror finish, to low-gloss matte surfaces, to rough-textured surfaces such as vellum. Special embossed finishes with specific patterns can add interest, but these substrates are notoriously difficult to print on most dry toner systems.

Very smooth surfaces cause high levels of light reflection from the paper surface, or gloss. One disadvantage of powder toner systems is that the substrate finish is dominated by the toner gloss. In areas with differential toner coverage, or if fusing is non-uniform, differential gloss across solid tones can be distracting. Designers who select a high gloss paper finish may be disappointed that the level of gloss in printed areas is determined by the toner, not by the substrate. New toner systems with release additives on toner particles that eliminate the need for fuser oil allow gloss levels to be managed, and reduce the difference in gloss between toned areas and substrates (Yamana, 2004). Liquid toner systems such as the HP Indigo system allow the substrate gloss to be apparent through the image. Gloss coatings are achieved with base papers of high smooth-

ness and with highly uniform coatings (Song, John, Yang, & Spangler, 2003). The resulting uniformity in surface, thickness and formation yields a uniform dielectric force and uniform toner transfer. Gloss stock can blister if the underlying moisture is heated in the fusing step and the steam has nowhere to go. Therefore environmental conditioning and low, uniform moisture levels are particularly important with high-gloss digital papers.

Generally, smoother surfaces produce better quality images with improved sharper line edge acuity, dot integrity and the ability to render fine detail. A rough surface will show less continuity in dielectric force across a sheet, and therefore uneven toner transfer can result (Provatas et al., 2004). Smoothness is a more stringent requirement in color printing where the building of color separations determines registration accuracy, and hence overall image fidelity. Where toner particles are unable to penetrate the valleys of a rough surface, density variations will result, leading to mottled image areas. There is increasing demand for textured papers for special applications. Newer technologies use various mechanisms to encourage toner particles to enter valleys in uneven surfaces (e.g., the NexPress 2100 sonic assist mechanism). This is one reason why coated papers produce better quality images, but textures are increasingly being demanded by creative designers used to working with the full range of offset substrates. Paper texture may be part of an overall professional identity along with the logo and company colors (Rector, 2004).

Runnability can also be affected by smoothness in friction feed systems—some friction is necessary for grippers to function. This must be balanced with image quality.

Dimensional Stability

Dimensional stability refers to the change in shape or dimension of a sheet or web, and also can refer to the change in planarity. In a digital press, papers are subjected to heat, pressure and variety of forces, most of which are imposed in the fusing cycle. High temperatures can cause expansion, contraction, curl, cockle (an uneven wavy surface), and in some cases accelerated creep. Curl occurs when extreme temperatures and pressures are exerted differentially on the paper, so that one surface heats and contracts more than another. Some presses have anti-curl systems to compensate for this out-of-plane deformation. Curl is related to fiber orientation (formation) and previous drying and moisture history, and is a leading cause of poor runnability in digital presses (Levlin & Soderhjelm, 1999). This is one reason why the moisture level of digital papers must be maintained at a low, specified level, and must be uniform across a sheet. After fusing, even a non-curled sheet can experience dimensional instability if the moisture level in the environment is high, resulting in fast and uneven adsorption of the toner into the sheet. Cockle is related to uneven moisture levels, and non-uniform formation and fillers. Dimensional stability differences between sheet surfaces can also result in cockle, which is mostly an issue in two-sided copying. A cockled sheet will not experience efficient toner transfer on the second side due to the variation in transfer distance. Fusing pressure can also result in compression in the z-direction followed by some level of elastic recovery.

Papers must be able to maintain adequate dimensional stability in fusing cycles up to 400 degrees F to enable the accurate registration of images on both sides of the paper. In

duplex printing, sheets pass through the fuser system twice, so the toned sheet must also survive the second heat and charge exposure without cockling and curling. Some press technologies reduce the initial fusing cycle temperature to initiate minimal toner/paper bonding, in anticipation of a more stringent treatment for the second pass. This reduces the impact of the dual fusing exposure on paper.

Moisture

Of all digital paper properties, the moisture level and moisture history are arguably the most critical, and are often the only rigid paper specifications provided by a press manufacturer. The moisture level of most digital papers generally varies from 4 to just below 5 weight percent. Moisture affects resistivity, which in turn affects the magnitude of the dielectric force in toner transfer, and hence the resulting image quality. Non-uniformities in moisture level will result in variations in this dielectric force, leading to print mottle. Manufacturing specifications for both level and uniformity of moisture across the sheet are tight, and this is one reason why digital papers may cost more to produce. Some printer technologies such as Xeikon engines require on-press preconditioning of paper, to control temperature and relative humidity within specific ranges.

In the fusing cycle, the image side of a sheet may be exposed to high heat, driving off moisture unevenly. This can result in cockle if the paper's initial moisture level was inappropriate. Paper that is too dry may result in static discharge within the print engine, resulting in paper jams. Too much moisture causes print defects, curl, and again, jamming. Thus the runnability of paper is strongly dependent on its humidity and temperature. However, the moisture history is also a factor: paper "remembers" moisture and temperature exposures, and may not fully recover from an inappropriate environmental exposure.

Paper Conditioning

Dimensional stability on press requires sufficient paper conditioning time, and many press operations follow TAPPI standards for accomplishing this (TAPPI, 1999). This means allowing paper to come to equilibrium with the relative humidity and temperature in the press room or storage area, but at a specified rate of change. This makes true print-on-demand workflows difficult to accomplish with non-standard stocks. The range of paper sizes needed to operate a true print-on-demand environment means providing temperature and humidity controlled warehousing for papers.

Wrapping and packaging can be important in managing the challenge of significant variations in environmental conditions across climates and seasons. A recyclable ream wrap with a moisture barrier is used in some Xerox digital office papers. Xerox recommends storage in wrappers on pallets or shelves until the press run commences, under conditions of 68–76 degrees F and relative humidity of 35–55%. Conditioning should be a minimum of 24 hours, and with coated papers a minimum of 48 hours (Xerox Corporation, 2004). Stacking too many cartons can result in excessive forces that will compress and deform paper.

Charging Characteristics

Digital papers must be able to take and hold a charge in order to effect a clean and efficient image transfer. The characteristics that relate to efficient toner transfer include the paper's intrinsic conductivity (the product of the charge density and mobility) and also the charge injection and charge lifetimes (Tse et al., 1999). Thus the charging characteristics are a result of a number of interrelated complex phenomena. Due to the effects of temperature and humidity on this mechanism, in some high-end presses the print engine is enclosed in an environmentally-controlled unit. The charging characteristics of paper in electrophotographic print processes are related to moisture level. Retained or equilibrium moisture level is, in turn, related to the internal and surface fillers and sizing of the paper structure. Low humidity improves the charging characteristics of the paper, which enhances toner transfer to the paper surface. But low humidity also creates static buildup and runnability issues. In general, if the surface charge on the paper is too low, low toner adhesion results. Too high a charge may lead to static discharge and paper jamming. Highly charged sheets will adhere together and will not feed appropriately (Levlin & Soderhjelm, 1999).

Static properties of papers are generally expressed by the parameter resistivity, which expresses the time it takes for a static charge to decay. However, this parameter may not correlate fully with print quality performance, and other parameters such as electrostatic charge decay may be more useful (Tse et al., 1999). The maximum charge the paper can hold, and the rate of decay of that charge, will be related to the efficiency of toner transfer and the runnability on press.

Some level of electrostatic non-uniformity in paper is inevitable and can be tolerated. Image noise (related to uniformity of toner transfer) and optical density levels (related to transfer efficiency) have been correlated with a "characteristic length" which describes the typical scale of voltage variations experienced at the surface (Tse et al., 1999). In effect, the demands on paper are specific—that the paper be able to allow charge transfer to exactly the right extent, followed by limited decay and holding that charge for long enough for the transfer step to take place. This sophisticated balance is a critical property of substrates for digital printing.

Appearance Properties

Rendering near-continuous tone, photo-quality images requires high-integrity, sharp dot placement onto bright papers to provide the expected high contrast and image resolution. Overall the standard of acceptable image quality is increasing, putting pressure onto the optical and physical properties of the paper. With several presses the commonly-used CMYK gamut has been broadened with process colors such as orange and green, spot colors, clear toners, and special-effect toners. Printers are becoming more sophisticated at color management, and new presses offer internal and closed-loop color calibration. Early digital printers suffered from significant inconsistency of color and image density during print runs, and a common practice was to operate in several shorter runs to allow "recovery" to a normalized state. As print engine consistency and color management capability in the pressroom improves, more pressure is exerted

on not only the quality of appearance characteristics of papers, but also on within-lot consistency. Further, there is a requirement for consistency across multiple paper lots that may be manufactured on different paper machines under the same brand name. Therefore the stability requirements of papers for color rendering ability and brightness are tighter with the newer digital technologies.

There is a general tendency towards brighter paper shades to add apparent snap to color digital images; this is driven primarily by marketing initiatives, but there is no doubt that a high brightness paper offers print quality advantages. However, optical brighteners, or fluorescent whitening agents will degrade in time, limiting the shelf-life of high brightness papers.

Whiteness and brightness are frequently confused in the world of paper specifications, and recent marketing campaigns have capitalized on this confusion. Whiteness and shade refer to light reflection properties; a truly white paper reflects all colors of the visible spectrum evenly. Paper that absorbs some frequencies in the visible range may appear to have a color cast or hue to the human eye. A paper with a "cool" blue cast may appear to make blue and black printed colors snap more from the page. Paper with a neutral or warm white hue tend to bring out reds, yellows and oranges, and can be a suitable choice for rendering skin tones. Overall, high whiteness may be linked to the appearance of greater contrast. There are marked geographical preferences for paper shades: European grades of business and office bond grades generally have a more "blue" shade; U.S. grades frequently lean towards the warm red side of neutral; and grades for Asian markets may lean towards a greener shade.

Brightness, metrics express light reflection from paper surfaces under specified geometries. There are different standard methods for measuring brightness (Levlin & Soderhjelm, 1999) that give different numbers. Since a higher number generally indicates to the purchasing public a "better" grade, some paper manufacturers have switched measurement units to express a higher number. In some cases the word "bright" is used, and it is suspected by the researchers of this study that the whiteness measurement is the origin of the higher number. Overall, brightness affects the contrast, color values, and attractive appearance of a printed product.

Opacity describes the amount of light that can pass through a sheet (Thompson, 2004). Light is scattered and attenuated by fibers and fillers within the body of the sheet, and also reflected from the surface. These effects combine to prevent light passing through. However, opacity does not always correlate with caliper (thickness) or basis weight Additives with high light scattering properties can be used for a higher opacity but equivalent weight design. Opacity is an important consideration with duplex (two-sided) printing. Although toners do not penetrate as deeply as offset and inkjet inks into the structure of the paper, highly toned areas can lead to show-through in two-sided printing. This is more of a challenge to color printing in which toner levels in some systems may approach 400% coverage.

Hybrid Printing

Digital printing, with its variable data capability, may be used to print variable content onto shells or forms that have been printed using traditional, fixed-plate technologies. This means that a substrate is subjected to two sets of stresses, for example, high moisture levels from offset fountain solution exposure, followed by high heat and charging levels in a digital press. Dimensional instability is a key failure mode, often managed by controlled environmental conditioning between printing stages. Minimizing both ink density and fountain solution level may reduce dimensional instability in subsequent digital runs (Oller, 2001). Waterless offset processes therefore are advantageous if electrophotographic printing is to follow.

Printing toner onto offset-printed areas can result in poor toner adhesion, so designers need to be aware of the need to leave sufficient space between digital and offset printed areas to avoid overprinting. Coated papers printed digitally after an offset run can cause blistering if moisture is trapped beneath the surface. This moisture can boil in the fusing cycle and burst through the coating if it is unable to escape through pores. This also occurs in areas of high ink or toner coverage if fusing temperatures are too high. Some coated inkjet grades will exhibit blisters when exposed to high fusing temperatures, so specialty inkjet papers are generally not appropriate for electrophotography. Jamming and press-component contamination can also occur with inkjet grades.

Toners

The recent trend in toner technology is towards smaller, more tightly controlled particles with more sophisticated surface additives (Yamana, 2004). Smaller toner particles now available with lower resin-to-pigment ratios perform best on the smoothest papers. Lower toner resin levels are improving image quality, reducing differential gloss, enabling a more matte appearance, and resulting in lower toner coverage. This has resulted in per-impression cost savings and enhanced physical stability of the image.

Emulsion aggregation or chemically-prepared toners result in a more uniform and more precise shape and particle size distribution than toners prepared by extrusion/grinding methods (Yamana, 2004). This increased level of size control coupled with the use of sophisticated charge control agents and other surface additives has brought toners into a new age of functionality, and is largely responsible for the significant improvement in image quality in third generation digital systems. Cleaning, transfer and toner charging are now more efficient and image quality improvements are shown in halftone rendering and fine line reproduction. Digital papers with textures are now accessible to some systems with these new toners.

Liquid ink systems such as those used with HP Indigo technology are able to render images that allow the substrate finish to impact the overall image appearance. In powder toner systems, the image gloss is dominated by the toner layer properties (Oliver, 2003). Liquid inks can in some cases be placed more accurately than some powder toner marking systems, resulting in improved dot integrity and control. These liquid ink systems also use lower pressures and temperatures, and therefore exert lower stresses

on substrates. Synthetic substrates can be used for a wide range of applications (packaging, signage, labeling, security documents, etc.) if their surface energies are carefully balanced with qualified inks/toners.

Finishing

In-line finishing capabilities available with the high-end production digital presses challenge the runnability of papers, which may be subjected to multiple stresses. Both tighter sheet dimension tolerances and more uniform thicknesses are essential as more sophisticated finishing options become available. In some systems, pre-printed sheets are fed through sequential digital print cycles and must withstand the rigors of repeat fusing cycles at temperatures up to 400 degrees F. Inline perfect binding may involve additional temperature and pressure in the gluing step. Post-fusing inserters are available in some printers, useful for adding pre-printed color elements such as book covers, which are then assembled on a monochrome press with inline finishing equipment.

Systems with inline cutting and trimming need to manage dust in order to minimize static problems in the digital print engine (Pope, 2002). Dust can arise from front-end sheeting, and also from loose material such as fibers and fillers that become detached from paper surfaces, particularly at high production speeds and with friction feeds. If enough dust accumulates in the system's electronics, it can create an insulating effect that may cause the machine to overheat. Dust can also be attracted to the photoreceptor resulting in point image defects and discharging.

Some inline booklet finishing equipment may require folding across the paper grain, which is a problem for highly toned areas. Toned areas may crack when folded against the grain and this should be taken into account when designing documents. For such applications grain-short papers are available, but the stiffness may not be appropriate for high-speed transport and may require lower run speeds.

Recycled Papers in Digital Printing

There are many challenges in manufacturing high quality printing papers using recycled fibers (White, Peter, & Evans, 2005). This is a growing segment of the digital papers market, especially for transactional and business applications for which a company's environmental policy may dictate materials choices. "Stickies" and contaminants in recycled papers are a particular hazard for electrophotographic printing because non-uniformities in charging characteristics may interfere with toner transfer. Defects may be exaggerated by a surrounding charge field, and even small contaminants can result in deletion spots that are easily visible in highly toned areas. New technologies are developing to increase the efficiency of recycling, and to manage contamination levels, and it is anticipated that improved quality in uncoated recycled grades will open up the usage in digital printing. Recent product launches are reflecting this trend.

Summary of Technical Requirements

In order to produce high quality images and good on-press runnability, electrophotographic papers are required to have high levels of dimensional stability and surface

smoothness. They require small, evenly distributed additives and fillers, more tightly controlled uniform moisture levels, and uniform charging characteristics. As with all complex multi-phase materials, adjusting one property will inevitably affect others. Paper design is thus a matter of compromise and statistical optimization of properties. Unique to digital printing is the complexity of toner transfer efficiency, which results from the intrinsic charge density and is influenced by many factors. The chemical composition and spatial distribution of components and thickness uniformity of paper is therefore more critical than in traditional printing papers. Thus the design and production of high quality digital papers requires more thought than just turning up the dryer on an offset formulation to reduce moisture levels (Tse et al., 1999), or tightening the specification latitudes.

Within the paradigm of on-demand printing, there is a lower tolerance for waste (both of time and materials) and an increased need for productivity, which puts pressure onto paper manufacturers to produce more uniform products to higher specifications. In many cases the economic viability of a print job depends on the quality of the substrate; poor runnability and low image quality can differentiate between profit and loss in an industry with tight profit margins. The demands on paper manufacturers and the need for open research into digital papers have never been greater.

Research Objectives and Methodology

Research Objectives

The objective of this study is to identify constraints and potential solutions for improved performance and quality of digital printing papers. This was accomplished through a survey of printers using the network of printing companies currently engaged with the Printing Industry Center research activities. In order to understand the characteristics of the digital printing market segment in the U.S. in 2005, a demographic study of the respondent group was conducted. There was an emphasis on the role that paper characteristics requirements play in limiting efficiency and document quality.

The survey was designed to gain an overall impression of how and why different papers are selected for digital printing jobs. Specific research objectives included:

- identifying the paper grades commonly used for the market segment of production digital printing,
- identifying the number of brands used and the nature of printing companies' relationships to suppliers,
- determining the factors that affect brand and purchase decisions,
- discovering the relative importance of different paper properties and characteristics,
- assessing the deficiencies in currently-available paper grades, and

- determining what improvements are required by digital printers, and what limitations are currently imposed by press design.

Where possible, the demographics of the survey sample were related to question responses in these areas. Finally, the respondents were asked for their perceptions of the change in paper costs to the printer over the last two years (2002–2004), and to what extent if any changes in paper costs affected the prices charged to print buyers.

Research Methodology

A literature search on the business and technical aspects of papers for digital printing was conducted. Based on discussions with paper and printing industry experts, a survey was constructed to address the research questions outlined above.

A pilot survey was conducted with several paper manufacturers, individuals within press manufacturing companies, and printing technologists familiar with the range of digital papers available both on the market and in current development. On the basis of the pilot feedback, questions were adjusted and new content introduced to explore the research objectives.

The survey was conducted by telephone with individuals who had been contacted previously by letter, with an explanation of the key research goals. Some questions involved structured responses, and others enabled free responses to be recorded. In some cases, dual-approach questions enabled similar information to be obtained in different ways. Open-ended questions were asked about the limitations imposed by digital presses on paper choices and other aspects of paper purchasing.

The survey was structured into the following areas:

- **Company demographics:**
  Company size and growth rate were selected as demographic characteristics which could potentially indicate both the level of success in implementing digital printing, and the availability of resources to invest in new technologies. These growth rates were related to the year of entry into digital printing. The types of printing jobs performed were surveyed along with the proportion of variable data printing. Respondents were asked to identify a job type that they viewed as being a key contributor to future growth. The types and numbers of digital presses and the acquisition years were requested along with types of other printing technologies used in their operations.
- **Paper grades for digital printing applications:**
  Paper grades used in digital paper applications were surveyed using a ranked scale of usage. Where recycled papers were used, the recycled fiber content was requested. The proportion of web and sheet grades was explored. This information is of interest to paper manufacturers who are looking to either expand or rationalize the range of grades and sizes offered.

Respondents were also asked to provide information on who selects paper grades, the print buyer or a person within the print operation. In a 2003 survey, InfoTrends/CAP Ventures found that customers usually specify papers in terms of the physical attributes, but often do not specify the brand (InfoTrends/CAP Ventures, 2003). In the study, larger customers were found to be more likely to specify actual brands, but print providers may play an advisory role.

- **Paper selection criteria:**
  In order to explore the effect of contractual procurement agreements on paper choices, respondents were asked for information on the extent and advantages of such relationships. The factors which printers might consider when evaluating papers for purchase were explored; these factors were price, runnability, print quality, appearance characteristics, product range (basis weight, sizes, finish, etc.), availability of grade (turnaround time on delivery), and whether multipurpose papers were available for different technologies. Respondents were then asked to consider these parameters in terms of differences between brands or manufacturers.

- **Acceptability of current paper grades and market trends:**
  A listing of paper properties and characteristics was presented and respondents were asked to judge the importance of each. An overall ranking was constructed which will be related to fiber characteristics in a future phase of the research. The limitations of currently available papers were explored by requesting a ranking of purchase decision factors (as above) in terms of desired improvements. Open questions were asked on which specific improvements respondents would like to see in digital papers, and what limitations their existing presses currently impose. Due to the stringent storage and conditioning requirements of digital papers, respondents were asked whether it was necessary to modify storage facilities to handle digital papers. Finally, the respondents' perceptions of market trends on the cost of digital papers and how any cost changes may have been passed on to print buyers were explored.

Sample of Respondents

A total of 103 printing companies listed in the RIT Printing Industry Center (PIC) database responded to the telephone survey. This database includes companies across the U.S. and Canada. Market segmentation for participating companies includes commercial printers, label/packaging printers, large format printers, book/magazine publishers, full service digital printers and in-plant quick print shops. The research was conducted in conjunction with a concurrent Printing Industry Center at RIT study addressing the training needs for digital printers, which used the same demographic survey. Respondents were asked to confirm that they had the necessary knowledge and information to answer questions in either one or both of the areas of demographics and paper selection. In some cases, two different respondents within a company answered questions in these two areas. For purposes of confidentiality, company names are not disclosed nor is any information that would indicate the identity of the participating companies. Open-ended question information was recorded verbatim and is available for detailed study.

It is important to note that this analysis is based on a sample of 103 printing companies that offer digital printing services. Some of the responses and inferences may not be representative of the digital printing market segment as a whole (see Research Limitations section). Refer to the Appendices for a complete summary of research responses.

Data Analysis

Data was analyzed using SPSS software (www.spss.com), using standard parametric and non-parametric statistical techniques (Fink, 2003). Unless otherwise stated, statistical inferences and hypothesis testing were calculated at the 95% confidence level.

Survey Results

The responses to the survey questions from 103 respondents are summarized below. First the company demographics are explored, and then the responses to questions relating to digital paper selection and usage are discussed and related to the demographic findings where possible.

All participants offer digital printing in some shape or form, but are not necessarily basing their business solely on digital printing technology. It transpires that there is some ambiguity in the definition of "digital printing," evident from the press brands and technologies reported by respondents (see Appendix C). Evidently some computer-to-plate and direct-to-press technologies have been regarded as "digital" by respondents.

Company Demographics

The size of the respondent firms was measured using both the number of employees and the companies' 2004 annual revenue. The changes in both metrics over the last few

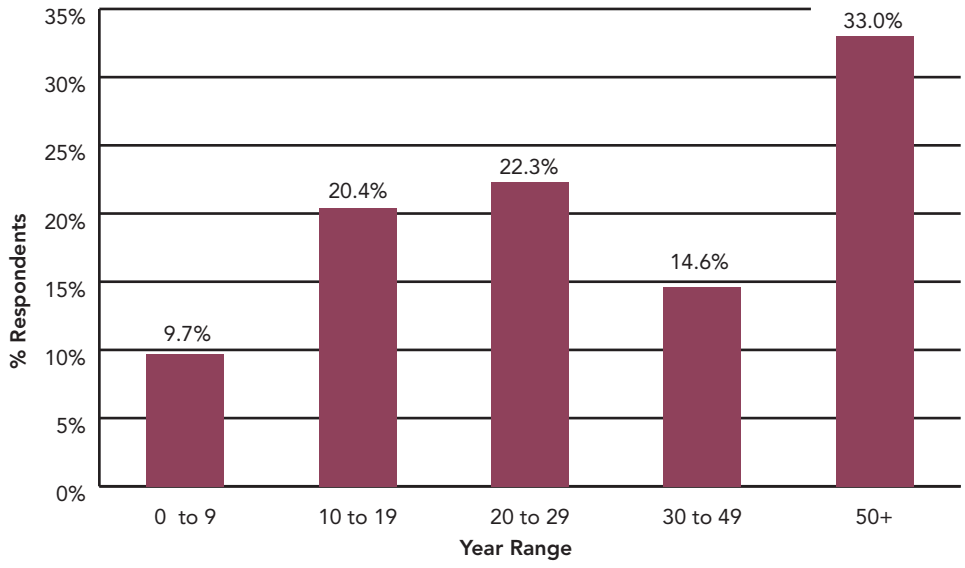

Figure 1. Number of years the respondent firms have been in business.

years were explored. The number of years participating companies have been in business ranges broadly, from 3 to 197 years, with a median of 28 years (Figure 1). More than 30% of respondents have been in business for over 50 years, and 6 firms have been in business for more than 100 years. This skews the mean of 40; the 5% trimmed mean is approximately 37 years.

Figure 2 shows the 5-year change in distribution of number of employees from 1999 to 2004. In 1999, 6.3% of our participants had over 200 employees, which decreased to 4.9% in 2004. However, there is a more significant change in the 50 to 99 employee range, with 18.4% of companies in this size range in 2004 compared to only 11.5% in 1999.

The relative changes in number of employees can be seen more clearly in Figure 3, which uses the same data as Figure 2. Overall there is no significant difference in the mean number of employees between 1999 and 2004 at the 95% confidence level. However, within certain size categories there is some significant change; Figure 3 shows the decrease in number of employees in the 10–19 and 20–49 size ranges, and a slight decrease in the 200+ category. The increase in the 50–99 category is significant. A detailed research study examining demographics in the printing industry was published by the Printing Industry Center. This research, entitled *An Investigation into Printing Industry Trends,* explains the development in the number of employees within the 50–99 category (Romano, 2004).

There was no significant correlation between the number of employees and number of years in business, indicating that company size depends on factors other than age.

Figure 4 shows the mean distribution of employees over five functions in our participants' companies. The functions are print production, prepress, information technol-

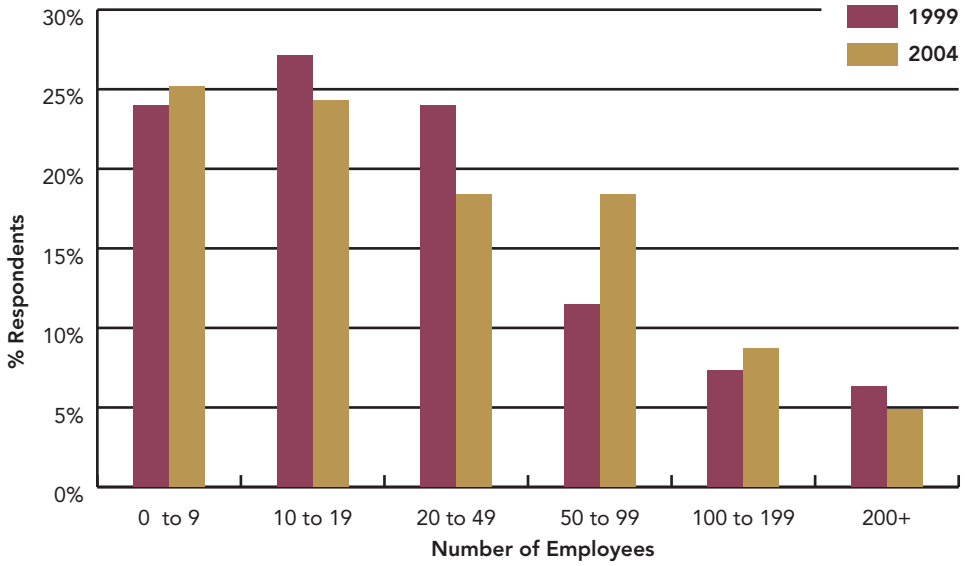

Figure 2. The distribution of the number of employees in the respondent firms over a five-year period.

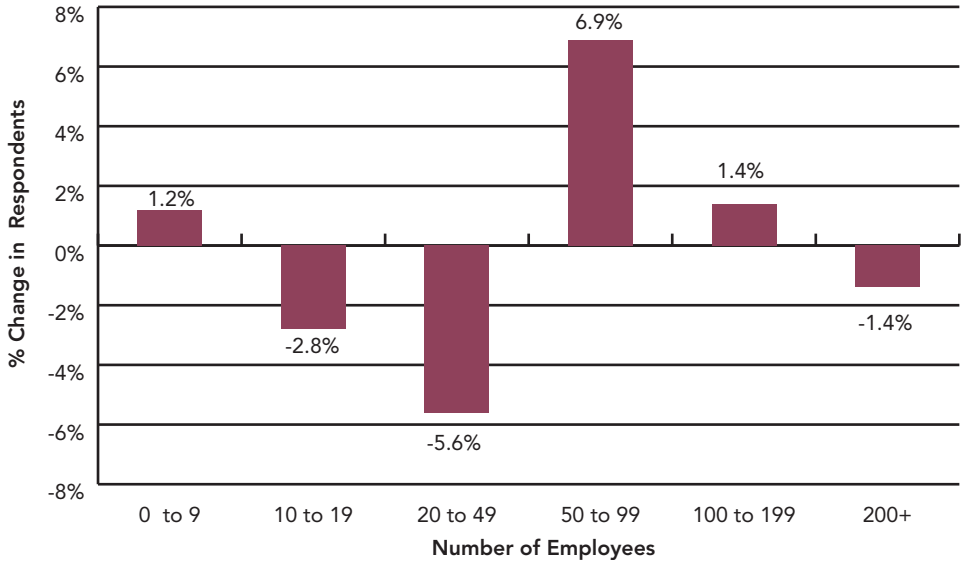

Figure 3. The percent change in the number of employees from 1999 to 2004 by category of employee number.

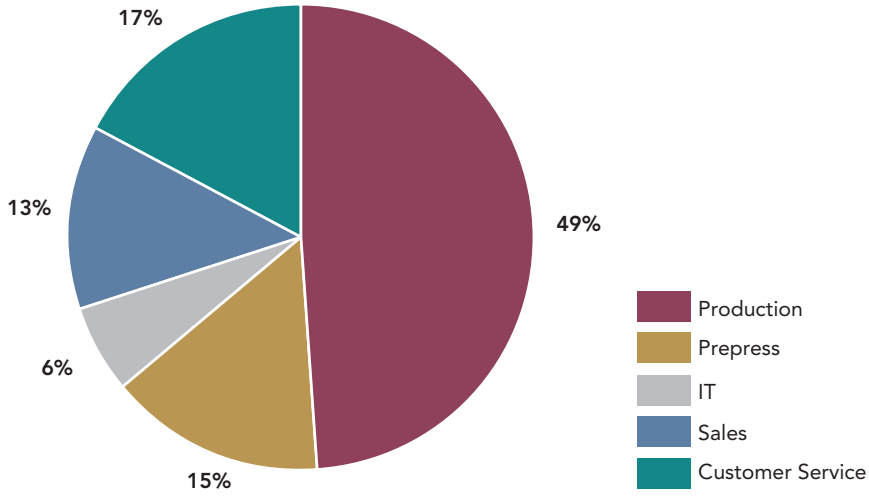

Figure 4. The distribution of employees over five job functions.

ogy (IT), sales, and customer service. An overview of the minimum and maximum values for the five functions can be found in Appendix B. Forty-nine percent of our respondents have most of their employees in production, followed by customer service (17%), prepress (15%), sales (13%), and IT (6%). The choices that were presented to the participants did not include post-press operations, and it is possible that some printers rolled this category (which may have included binding, finishing, and distribution) into production. The balance of different functions is also different over the size ranges; the company with the most employees has a lower proportion of employees in the production segment than smaller companies.

The second measure of respondent company size is the reported 2004 annual revenue, shown by category in Figure 5. The distribution is far from normal, which limited potential correlations with other response statistics using parametric methods. The median annual revenue is approximately $1M, with 68% of participants in the less than $3M category, which confirms the predominance of small- and medium-sized enterprises (SMEs) in the printing industry.

The respondent firms were asked to reveal qualitatively how their revenues have changed over the last 12 months, with the option to select whether they had grown, decreased, or stayed the same. The distribution of the response to this question is shown in Figure

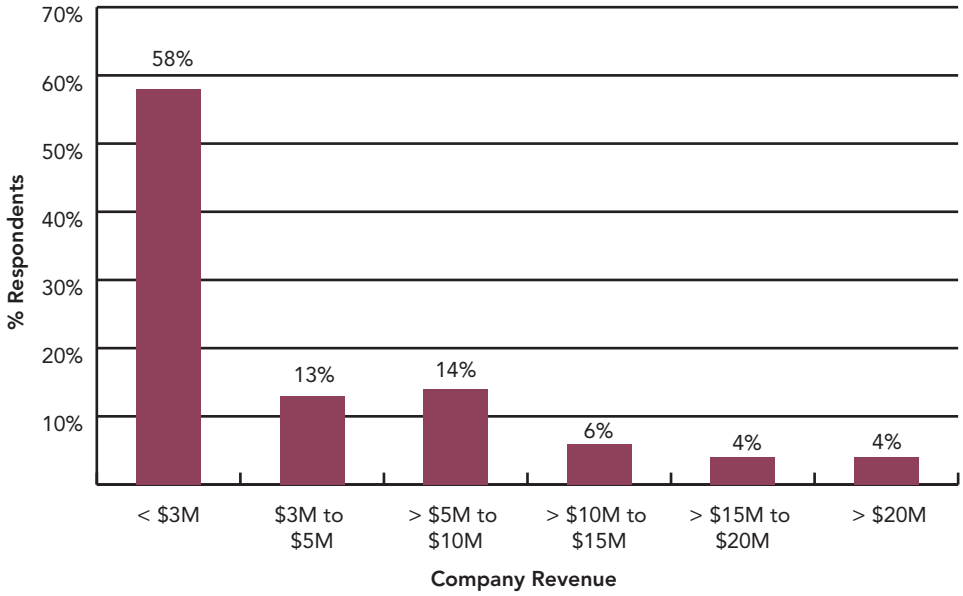

Figure 5. Printing companies' reported annual 2004 revenues, by size category.

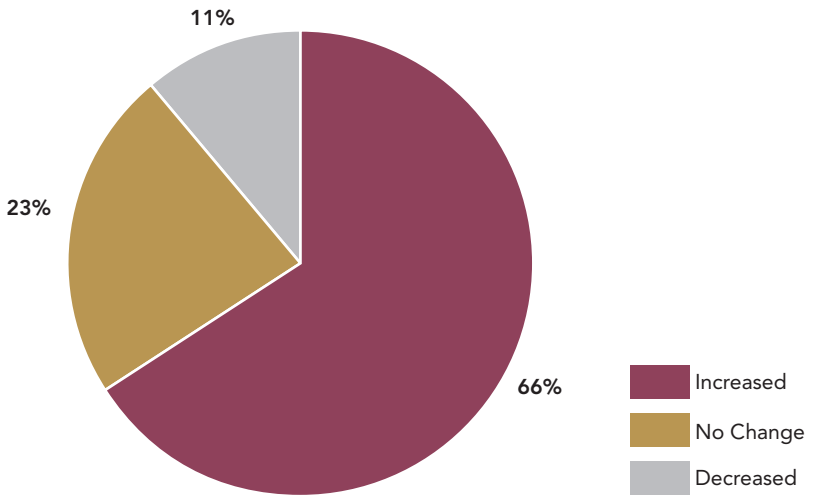

Figure 6. The change in annual revenues for 2004 compared with 2003.

6, and broken out into company size groupings in Figure 7. The majority of respondents (66%) experienced an increase in annual revenue in 2004 compared with 2003, while 11% decreased in revenue and 23% reported no change over this time period.

Respondents reporting revenue growth were asked to give the approximate percentage of change over the 2003–2004 time period. Figure 7 shows the change in revenues grouped by overall revenue levels. The segment with the strongest revenue growth is the over $15 to $20 million category, although only four companies fall within this revenue range. In the greater than $20 million category there are again only four companies, three of whom reported growth. Within the $3 to $5 million and the over $5 to $10 million categories were 13 and 14 companies respectively, with more than 70% of respondents reporting growth. Looking at this data in a different way, Figure 8 shows the mean percent of annual growth within each 2004 revenues range category. (Note that this figure includes data only for those companies reporting growth.) The over $5 to $10 million range shows the highest growth rate of about 25%. Interestingly, the larger companies with over $20 million in revenues are reporting a relatively low level of growth.

In Figure 9, the respondents' revenue distribution is related to number of years in business. In the $10–15 million category (a segment with relatively low revenue growth) the mean number of years in business was 53. The least time in business was reported by the largest company revenues category, over $20 million. There is no clear correlation between company age and level of revenues, indicating once again that age is not necessarily a driver of prosperity.

Figure 10 shows digital printing applications, and identifies whether respondents considered these job-types a major portion of the business, a minor portion, rarely performed, or never performed. The leading categories when ranked by "major portion" are marketing and promotional materials, quick printing applications, and direct mail.

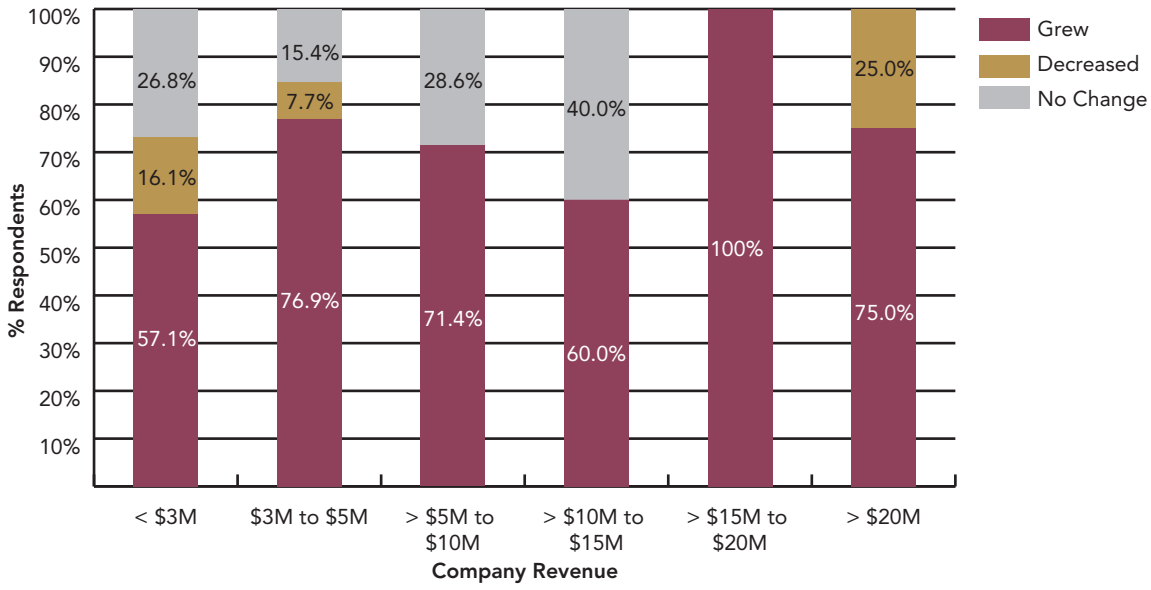

Figure 7. The change in annual revenues for 2004 compared with 2003, by size category.

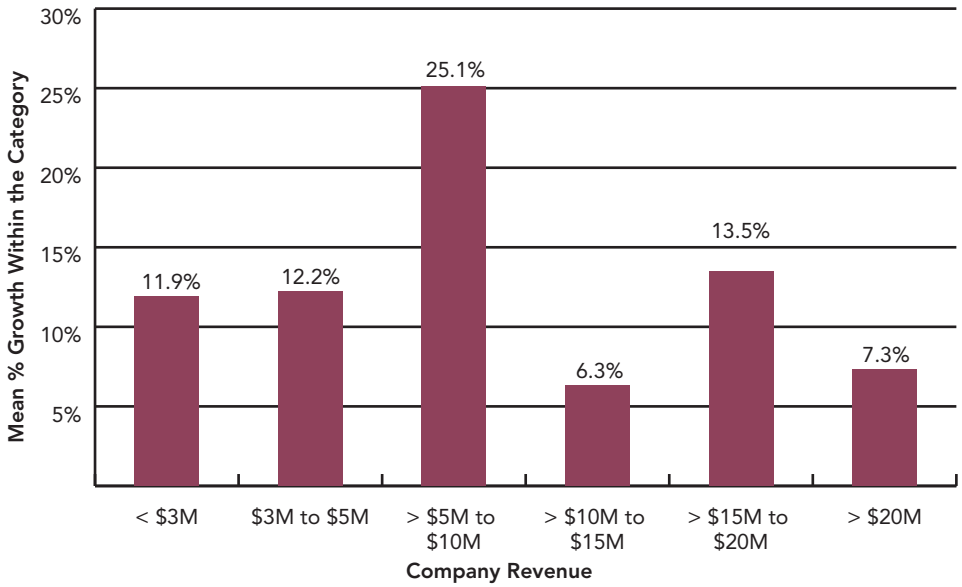

Figure 8. 2004 revenue versus percent of growth.

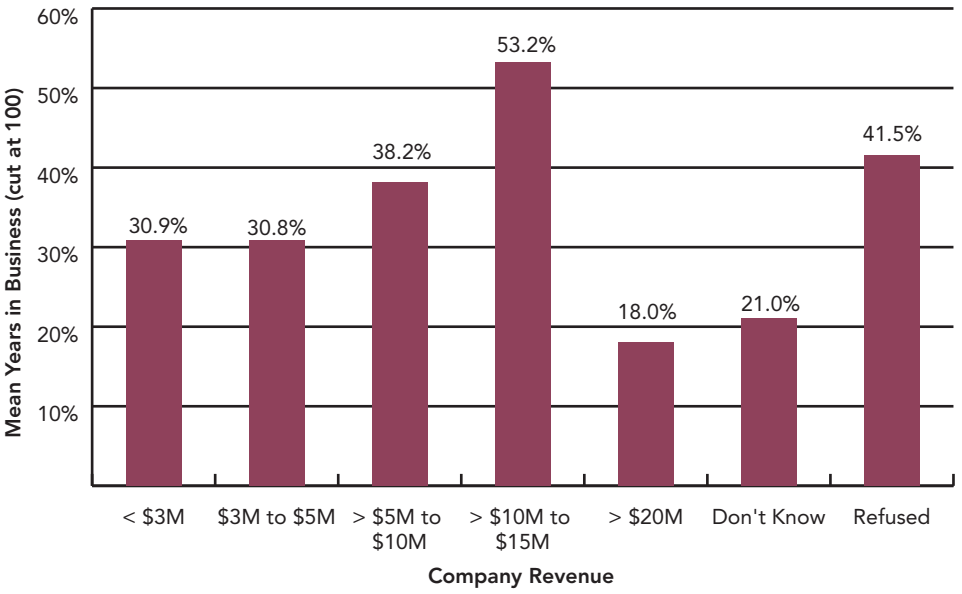

Figure 9. Years in business versus 2004 revenue.

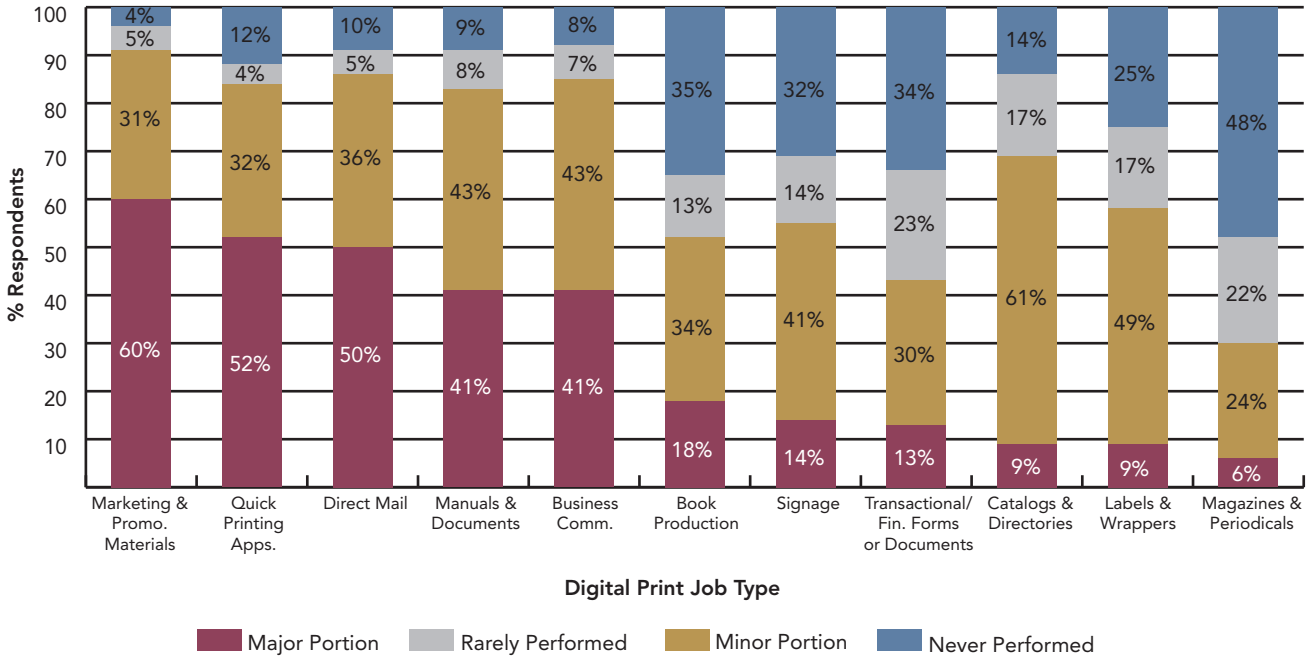

Figure 10. The relative importance of different digital printing job types (applications).

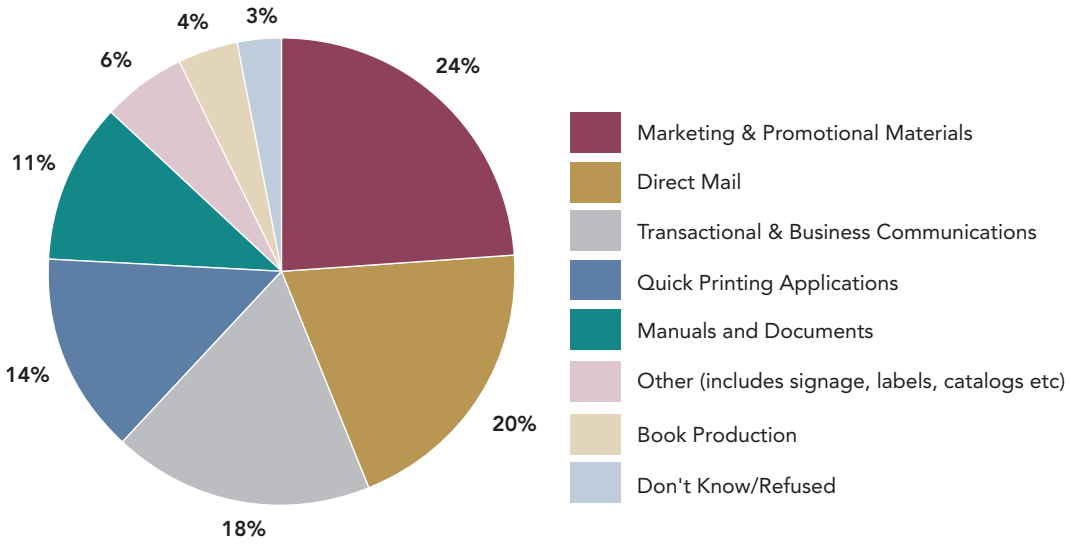

Figure 11. Digital printing applications identified as predominant job type.

When asked in a separate question to indicate only one job type as predominantly performed in the company, the leading application is again marketing and promotional materials (24%), followed by direct mail (21%), manuals and documents (19%), and quick printing applications (14%). These job types generate the greatest revenues for digital printing businesses. The low percentage for book production can be attributed to our sample demographics; most of our participants are commercial printers and not book publishers.

Respondents were asked whether there was another job type that was not listed in the structured responses of the question presented above, and to identify this if it was considered a major portion, minor portion, rarely performed, or never performed in their business. Only 10% identified other job types, and these were mostly niche markets such as fine art, personal invitations, statistical/surveys, imprints, etc. Forty percent of these respondents indicated that these other job types constituted a major portion of their business, indicating that these firms are highly specialized in specific, and in some cases, niche markets.

The approximate percentage of revenue growth in 2004 was linked with the job type generating the greatest revenues. Figure 12 shows that the percent of growth for the main job categories from Figure 11 is as follows:

- marketing and promotional, about 16%,
- business communications, 13%,
- direct mail, about 12%,
- manuals and documents at 8%, and
- quick printing, the lowest growth rate, at only 7%.

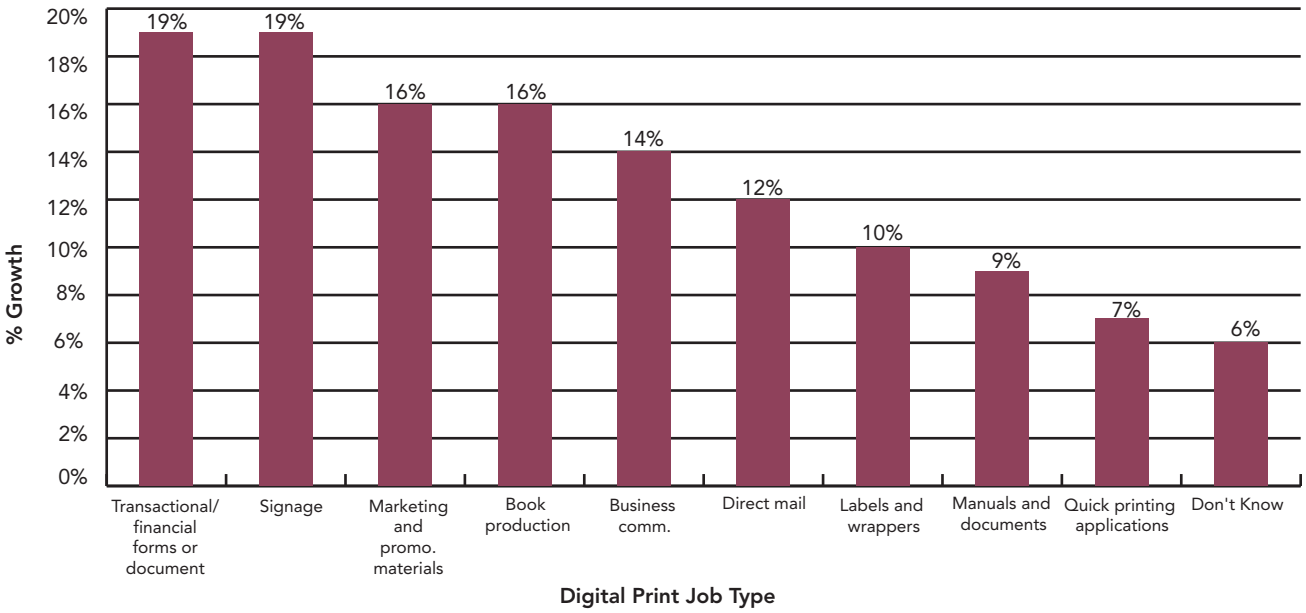

Figure 12. Job type versus percent growth in revenue.

The greatest revenue growth, however, was in the categories of transactional/financial, and signage (19% each). It is possible that some signage involves inkjet graphic arts printers, a segment with considerable growth and profitability potential.

When asked which types of jobs printers need to be successful at to ensure future growth, 24% of our respondents said direct mail, 22% mentioned marketing and promotional materials, 14% mentioned transactional and business communications, and 10% mentioned quick printing applications. Figure 13 shows a distribution of what job types respondents thought would ensure future growth.

The categories of manuals, documents, and quick printing applications are not anticipated by our respondents to be major revenue generators in the future as they are now. The marked decrease in the outlook for revenue potential for these applications may be related to the increased use of e-forms of software manuals and the use of PDF document formats. The change in outlooked revenues with marketing material jobs may not be significant within this data set. Direct mail and transactional and business communications jobs are projected to show an increase in potential revenue generation in the future (see Figure 14).

The question concerning the percentage of variable data jobs performed on digital presses yielded some interesting answers. Only 5% of participants have produced 80% or more variable data printing jobs in the last 12 months, 80% do less than half variable data, and 56% reported less than 10% of their output was variable data (see Figure 15).

When asked what percent of the company's variable data printing jobs involved color, 45.5% of respondents reported that more than 60% of their VDP jobs involved color; about 31% reported that less than 30% of these involved color; and 23% reported that

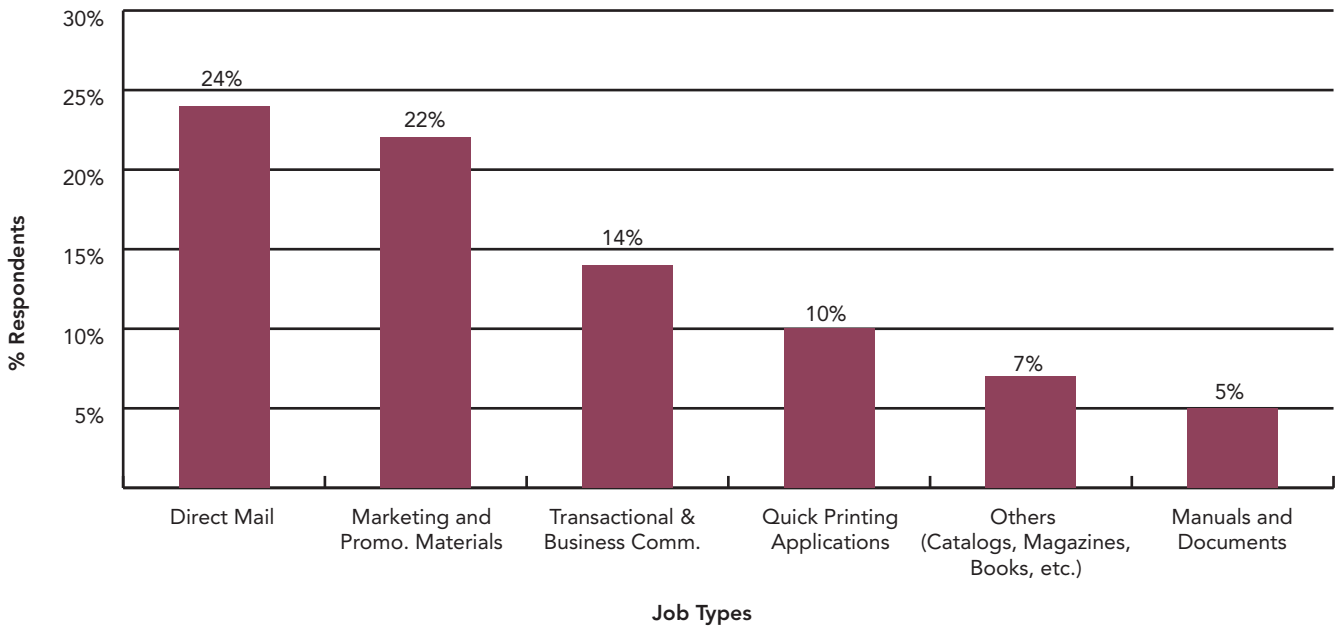

Figure 13. Job types that are expected to be key to success and to ensure future growth.

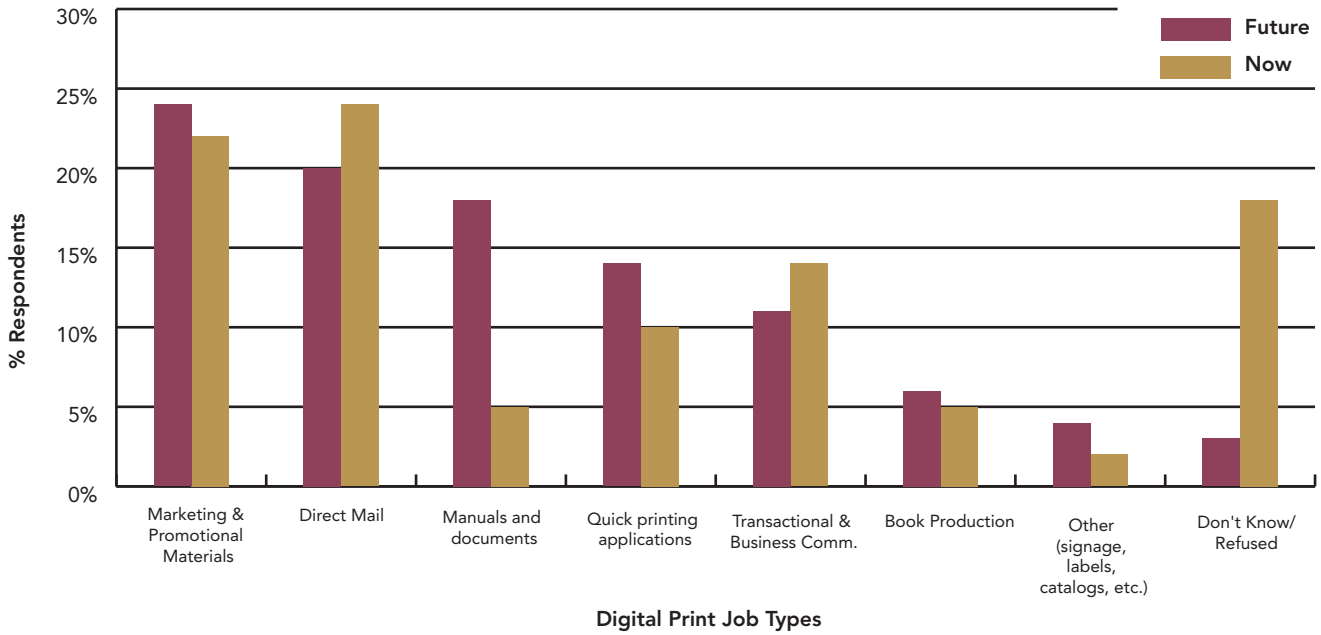

Figure 14. Predicted revenue generating jobs now and in the future.

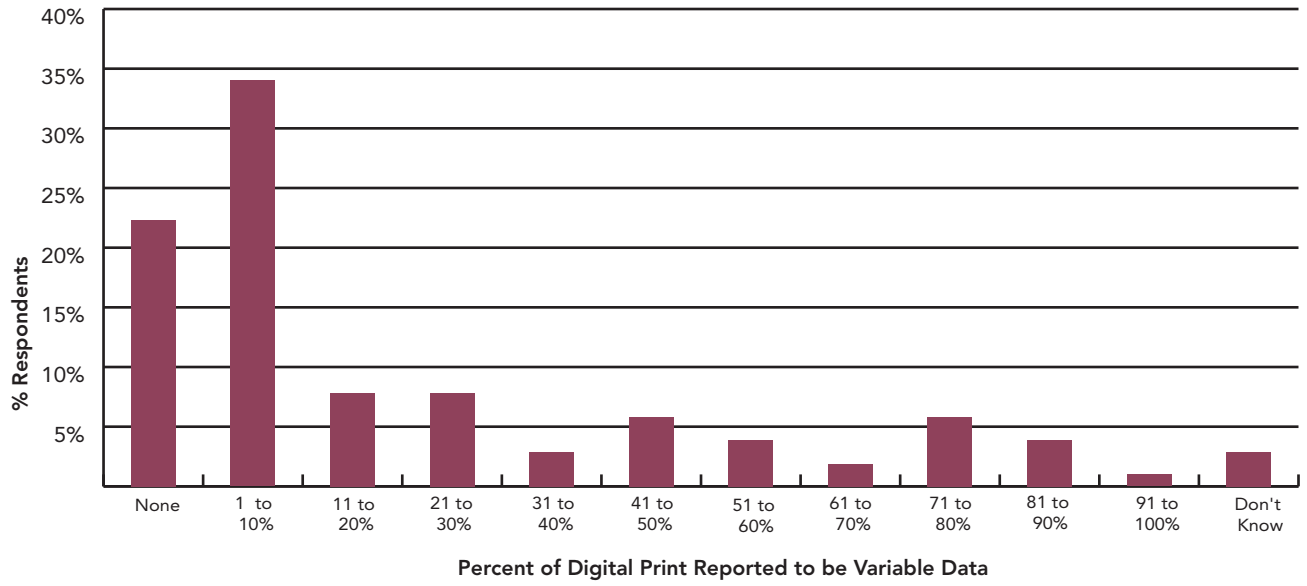

Figure 15. Percentage of digital print jobs reported to be variable data, over the last 12 months.

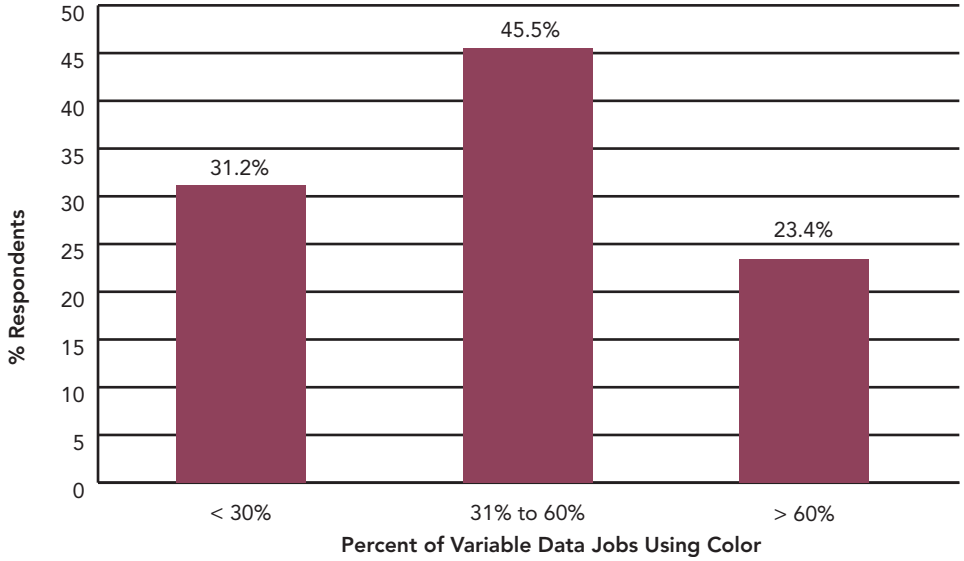

Figure 16. Percent of variable data printing jobs in color.

between 30–60% of their VDP jobs involved color (see Figure 16). There was no significant linear correlation between the percent of VDP jobs using color and the percent of variable data jobs as a whole.

Relating the percent of variable data printing to job type in Figure 17, the clear leader is in the business communications category, with about 62% variable. Labels and wrappers are second with about 43% and direct mail was 33% variable. Interestingly, no variable data printing was associated with the either the catalogs and directories or the magazines and periodicals categories, and the percentage was very low in the book production and quick printing categories. The transactional and financial category was low at 21%, which indicated a low proportion of bills, statements and individually-targeted communications normally included within this job category. The percent of variable data jobs was found not to correlate with either the number of employees in a company, or with years in business.

The various brands and models of digital printing equipment that our respondents utilize in their businesses are shown in Figure 18. This distribution of press types, as judged by the researchers, is not necessarily representative of the production digital printing market segment nationally. A wide range of printer brands and models was reported (38% in the "other" category), some not necessarily digital in the sense of a "no fixed plate" technology. A complete list of these "other" presses can be found in Figure 18 and Appendix D.

When asked to specify the year of entry into digital production, about 15% of the respondents reported purchasing their first digital presses in 1995. This may correspond to the market introduction of the Indigo and Xeikon digital color presses. As the bar graph shows, these were the early adopters, and subsequent investment levels were

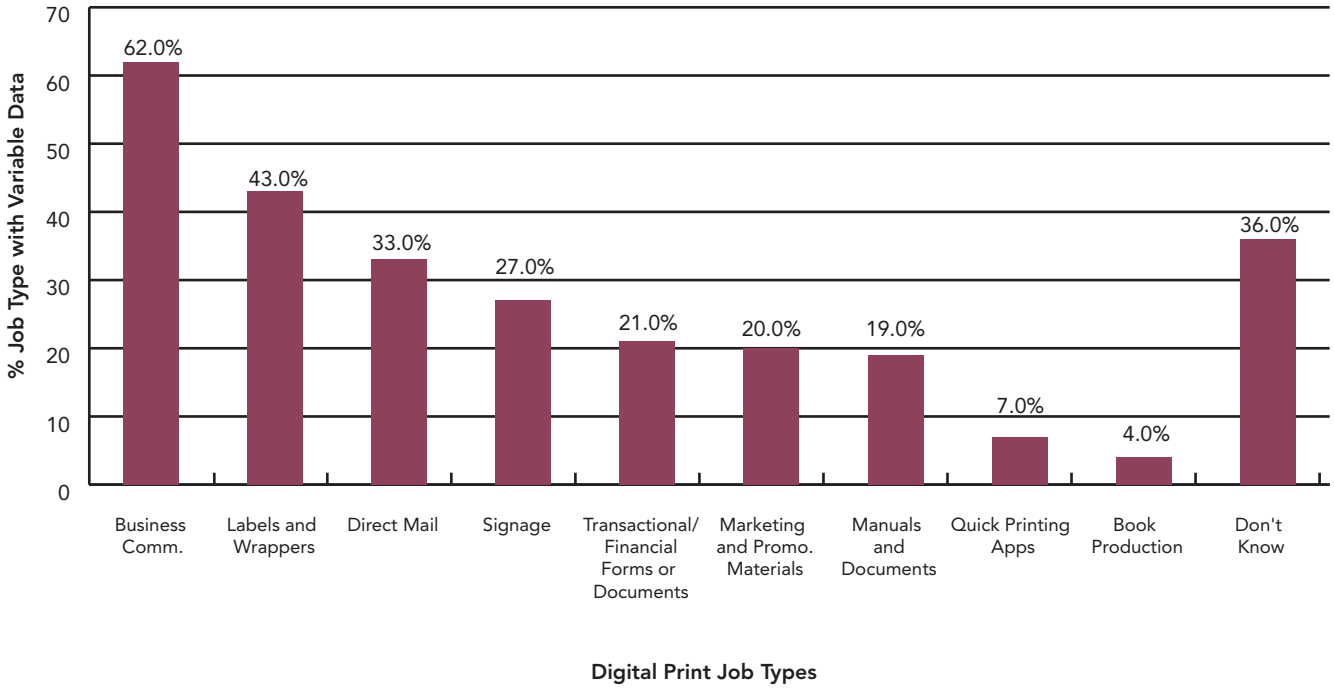

Figure 17. Percentage of variable data jobs within each product category.

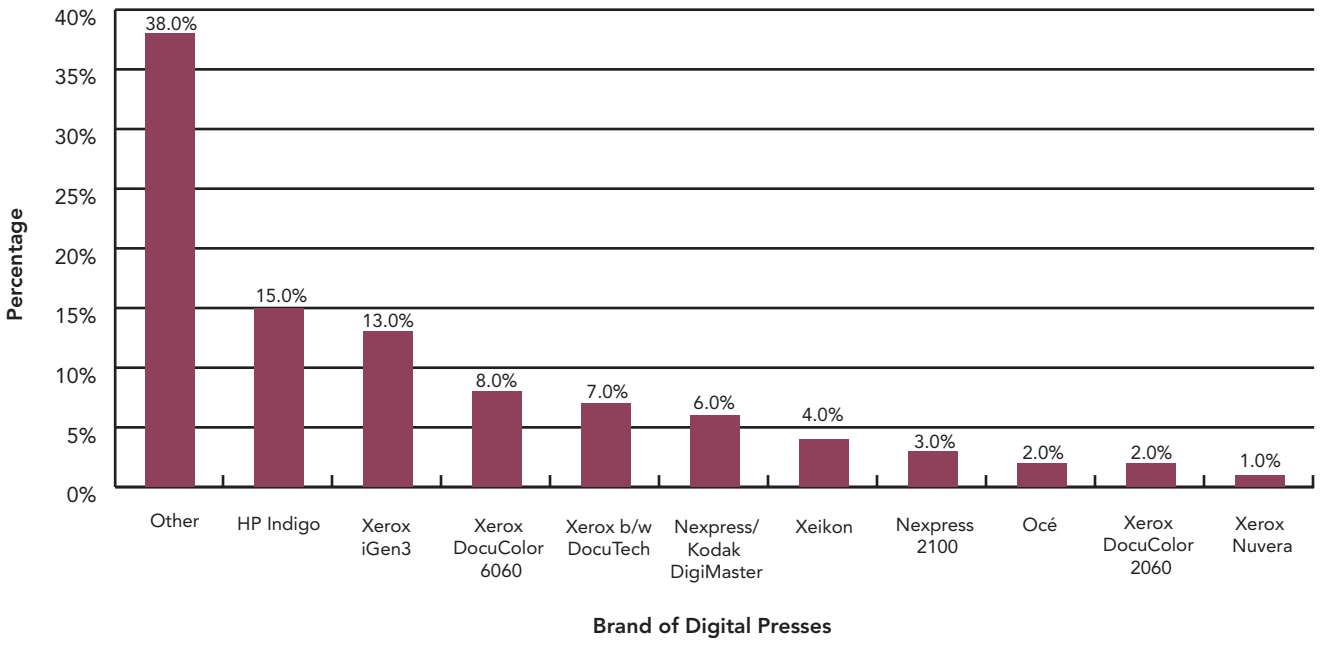

Figure 18. Brands and models of production digital equipment. (More details available in Appendix C.)

mixed year by year. There was a significant boom in 2002, when 12% purchased their first digital presses, closely followed by a decrease in 2003 when only 6% entered the market. Subsequent years have shown a slight decline in new entrants with only 5% of respondents purchased digital presses in 2004 and the same number projected for 2005. The year of entry was found not to correlate significantly with the percentage of variable data jobs, or with the overall 2004 company revenues, although for those companies entering the market in 2001 (4% of respondents), the revenues were higher than reported in other years. This may be a case of stepping into the market void left by print

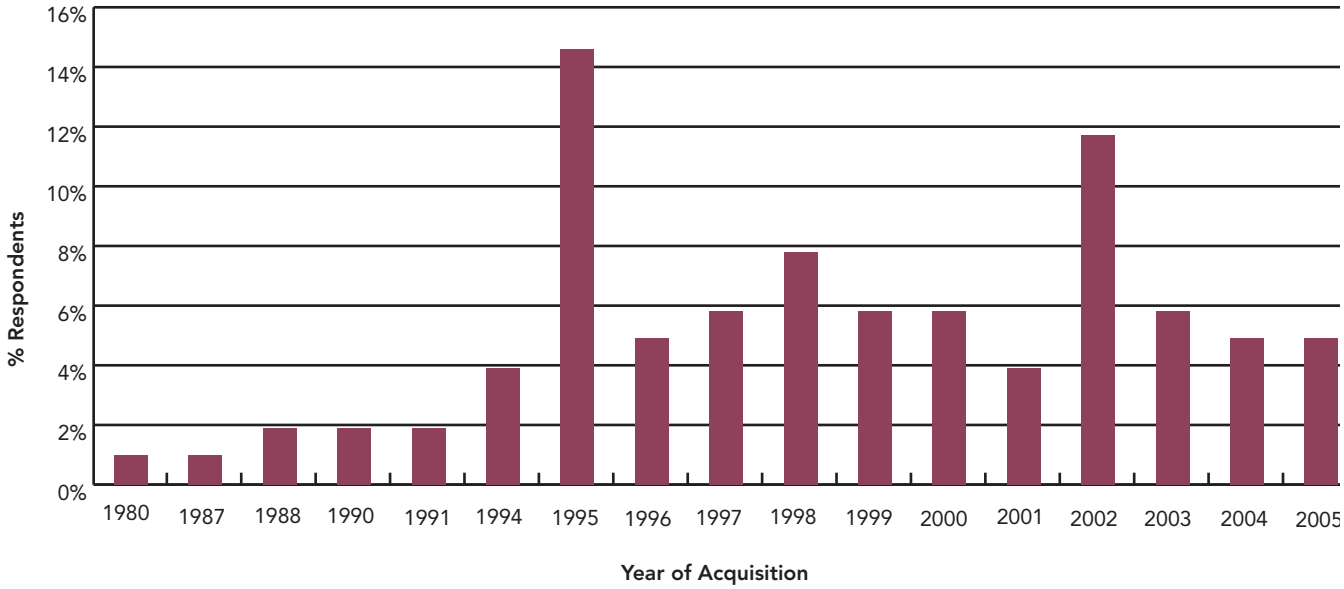

Figure 19. Year of market entry into digital production, indicated by acquisition of the first digital press.

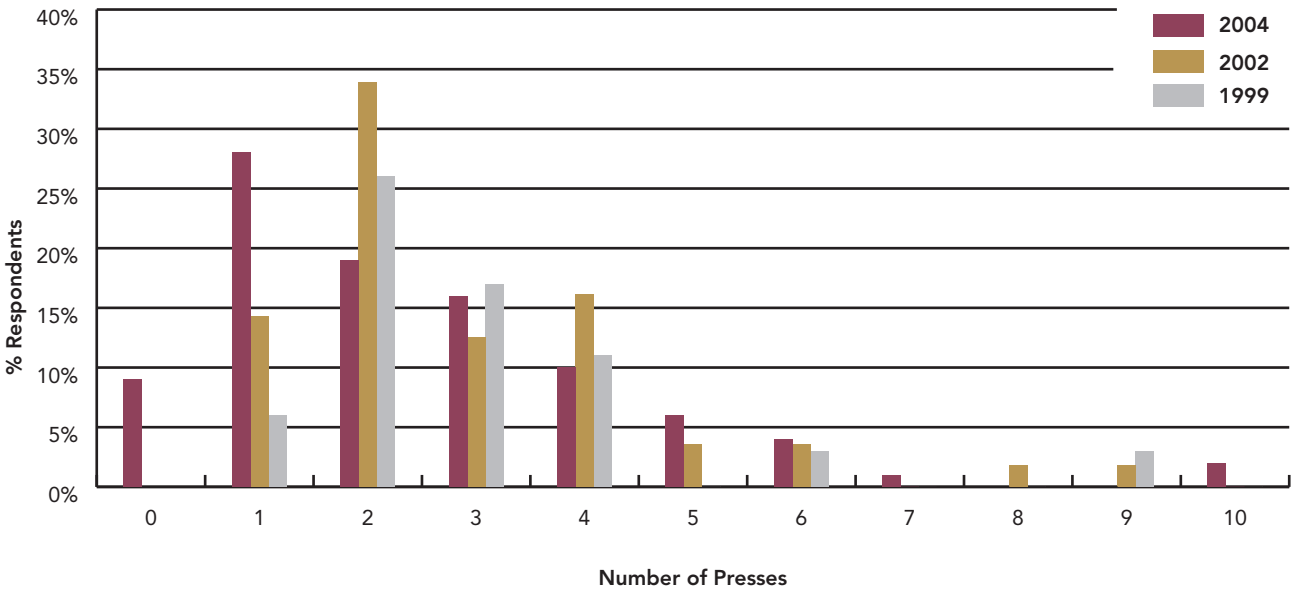

Figure 20. The digital printing equipment owned at the end of 1999, 2002, and 2004.

Table 1. Number of digital printers owned at year end.

# of Presses	1999	2000	2001	2002	2003	2004
0						9%[1]
1	6%	7.5%	15%	14.3%	12.3%	28%
2	26%	30.0%	28%	33.9%	29.2%	19%
3	17%	22.5%	21%	12.5%	21.5%	16%
4	11%	10.0%	11%	16.1%	15.4%	10%
5	0%	0.0%	2%	3.6%	3.1%	6%
6	3%	5.0%	6%	3.6%	6.2%	4%
7	0%	0.0%	0%	0.0%	0.0%	1%
8	0%	0.0%	0%	1.8%	1.5%	0%
9	3%	2.5%	2%	1.8%	0.0%	0%
10	0%	0.0%	0%	0.0%	1.5%	2%
Don't know	23%	12.5%	6%	5.4%	3.1%	2%
Refused	11%	10.0%	9%	7.1%	6.2%	4%
Total	100	100	100	100	100	100
Median	3	3	2	2	3	2
Maximum	9	9	9	9	10	10

[1] Some of the printers in the sample no longer owned any digital printing equipment by the end of 2004. See Digital Color—Where is the Market? (PICRM-2002-02) for an explanation of the development of the color digital print market.

providers closing during the recession, or to new product and technology opportunities. However, the number of respondents entering the digital market in 2001 is small.

The number of digital presses owned by companies was tracked over the period 1999–2004. By the end of 2004, 28% owned one digital press, 19% had two presses and 16% had three presses. The distribution is shown for 1999, 2002, and 2004.

Overall there are no consistent trends over time in number of presses in each size category. However the mean number of presses year by year increased slightly between 2002 and 2003, and then decreased between 2003 and 2004 (significant at 95% confidence). Other differences were either not significant or had close to borderline significance at this level. Looking at the yearly distributions by number of presses, the data is mixed, showing no clear trend in any size grouping; however there does seem to be an increase in the number of companies with just one digital press over the years 1999 to 2004.

The participants in our survey are not solely digital printers. In fact, most are commercial printers with some digital presses. Only 20% have all digital printing technology (see Figure 21). Of the 103 respondents, 72 have sheetfed offset presses, 14 have web offset presses, 13 have inkjet equipment, 3 have flexographic presses, and one participant has a gravure press. Included in the 13 "Other" category responses are engraving/letterpress equipment, screen printing presses, and Risograph.

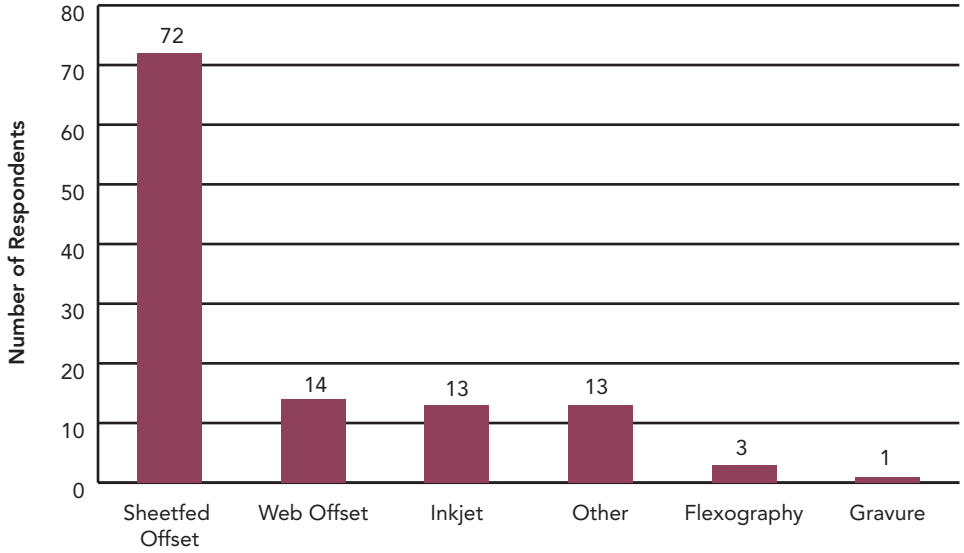

Figure 21. The non-digital printing equipment owned by the respondents.

Table 2. Non-digital printing equipment owned by survey participants.

Number of Other Presses	Number of Respondents
Web Offset	14
Sheetfed Offset	72
Flexography	3
Gravure	1
Inkjet	13
Other	13

Digital Paper Survey Results

Questions in this section of the survey were asked to understand how and why different papers are selected for digital printing jobs. The following categories were explored:

- Paper grades commonly used for digital printing jobs
- Number of brands used and companies' relationships with suppliers
- Factors which affect brand decisions
- Relative importance of different paper properties and characteristics
- Paper characteristics needing improvement
- Limitations imposed by digital press design
- Paper cost changes in recent years

Paper Grades For Digital Printing Applications

A structured response question explored the different paper grade categories that respondents used for digital printing, and their frequency of use. The grade descriptions were designed to avoid resemblance to brand names or product ranges, and were constructed based on feedback from the pilot survey and input from paper manufacturers and experienced digital print providers. Table 3 shows the paper grade categories by frequency of use.

Figure 22a shows the very frequently and somewhat frequently categories. Coated gloss is the leading grade. The other grades in the top five are premium uncoated, uncoated calendered, coated matte, uncoated uncalendered, and premium bond. Individual respondents identifying the "other" category mentioned card stock, pressure-sensitive media, cast coated, folding cartons, cotton bond, index, board, and carbonless. Each of these grades was identified by only one respondent.

In a separate question, respondents were asked to identify the grade they used most frequently for their digital printing applications, and to make only one selection. Their answers appear in Figure 22b and the last two columns in Table 3. The top grade is again coated gloss, identified by 32% of respondents. About 15% selected premium bond, and about 12% selected uncoated uncalendered. The top three grades in this question accounted for 58% of the "most often used" responses, and the top six grades accounted for 80%.

Table 3. Frequency of use of paper grades for digital printing.

Grade	Very Frequently	Somewhat Frequently	Very and Somewhat Frequently**	Most Used*	% Most Used*
Coated gloss	62	20	82	31	32.29
Premium uncoated	36	35	71	7	7.29
Uncoated calendered	30	38	68	6	6.25
Coated matte	30	36	66	8	8.33
Uncoated uncalendered	28	35	63	11	11.46
Premium bond	35	25	60	14	14.58
Coated high-gloss	24	35	59	5	5.21
Coated satin	21	28	49	3	3.13
Tinted/colored	15	31	46	3	3.13
Coated enamel	14	24	38	3	3.13
Recycled	8	28	36	2	2.08
Uncoated supercalendered	12	18	30	2	2.08
Textured	4	18	22	0	0.00
Synthetic grades	4	12	16	1	1.04

* The "most used" ranking was constructed from separate questions which allowed only one grade selection.

** The "very and somewhat frequently" category is a summation of the previous two categories.

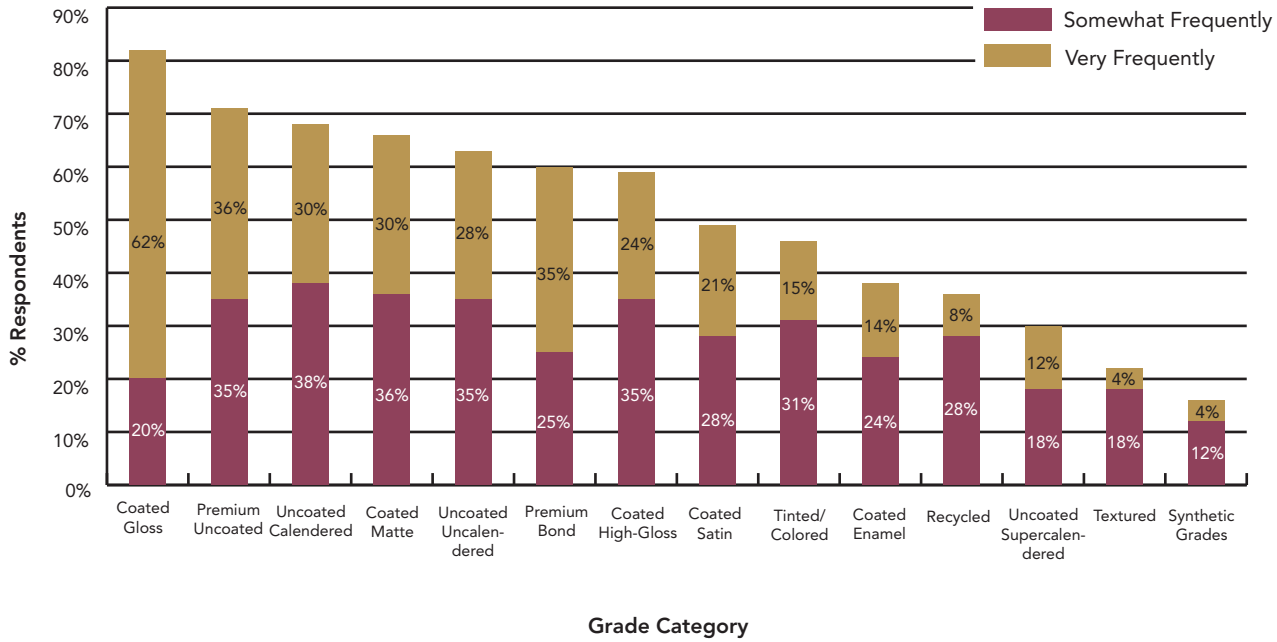

Figure 22a. Frequency of use of paper grades for digital printing.

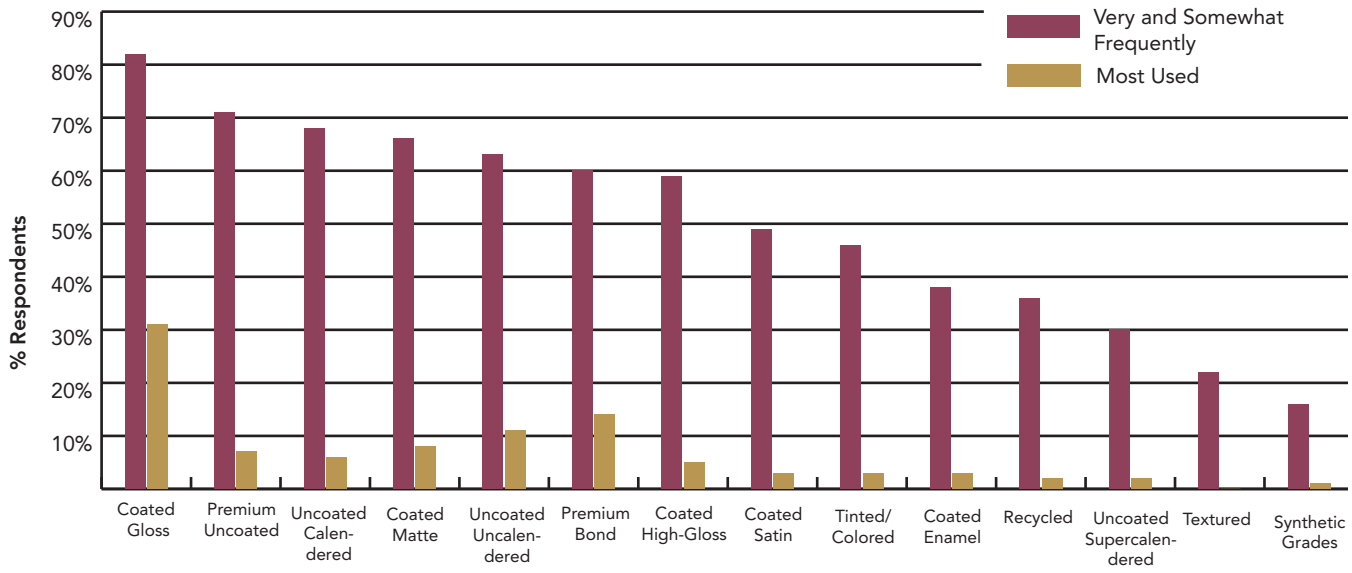

Figure 22b. Papers used very and somewhat frequently for digital printing applications, and the percentage of grades used most often.

It is evident that there is a wide range of substrates used within the research sample for digital printing. Discussions with printers and anecdotal evidence validate the rankings of the most commonly used grades. It is interesting that the relative usage rates seem to be slightly different based on the two questions. The first question asked for frequency of use, and allowed multiple grades to be selected. The second question asked for one grade only to be identified as the most often used. The differentiation between the leading grades is further explained with this "most often" question.

The combination of gloss grades (coated and coated high-gloss) accounts for about 38% of grades used most frequently. The coated and high-gloss grades were used either very or somewhat frequently by 82% and 59% respectively. This heavy usage correlates with the identification of marketing and promotional materials as a leading job type in this sample. Coated matte paper was used by 66% of respondents either very or somewhat frequently. Uncoated uncalendered is an economical grade with a wide range of uses, which is reflected in its position within the top six grades used for digital printing. Premium bond is more costly but nevertheless widely used, and can produce excellent print quality with few substrate-related disadvantages in digital presses. Tinted and colored papers were used most often by only 3% of the respondents, although 46% responded that they use these papers very or somewhat frequently. Textured grades are used very or somewhat frequently by only 22%, and none of the survey respondents claimed this grade as most often used. Synthetics are not used widely by our research participants.

Recycled paper is used most often by only 2% of respondents, although 36% stated that they used recycled paper very or somewhat frequently. A follow-up question (Figure 23) asked for the percentage of recycled content: the distribution has a median of 25%, and only 2% use 90–100% recycled content papers. Most recycled grades avail-

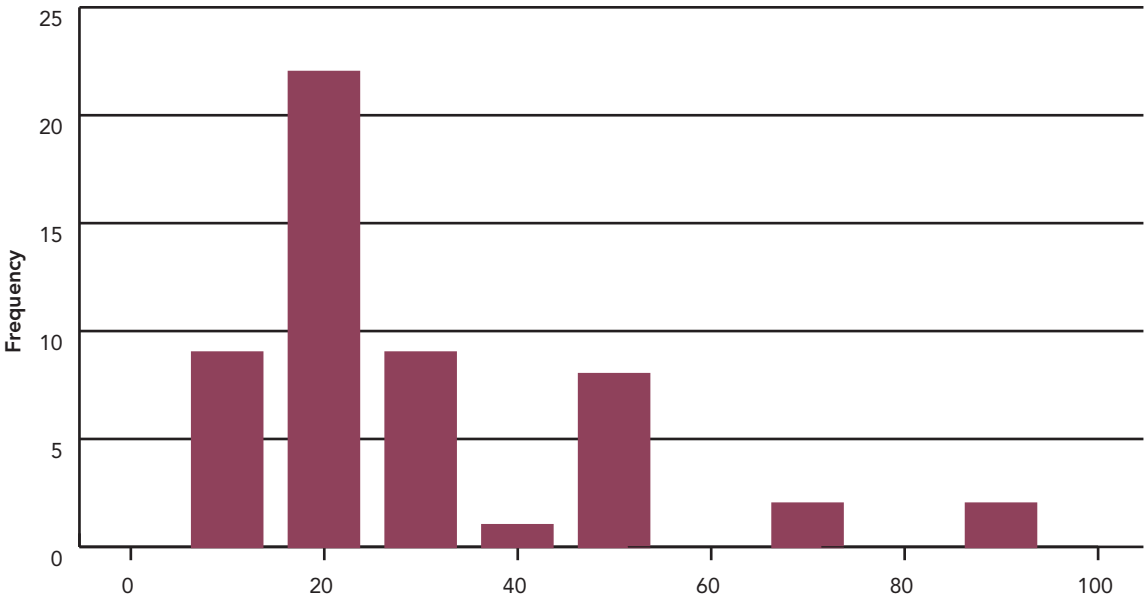

Figure 23. Histogram of recycled paper content for non-zero data, for papers used in digital printing applications.

able on the market today generally contain 20–30% and 50–60% recycled fiber content. These commonly available product categories are reflected in the peaks in the response distribution in Figure 23. Of the digital job types surveyed, which may be linked with recycled paper usage in the marketplace, business communications, transactional, and magazines and periodicals were not common. Only 6%, 5% and 1% respectively responded that these jobs generated the greatest revenues. Evidently within this sample, marketing and promotional materials, direct mail, manuals and documents, and quick printing applications are not using a significant amount of recycled papers.

As reported in the demographics section of this report, most of the digital presses used by respondents are evidently sheetfed. Eighty-five percent of survey respondents do not use webfed media at all, and only 5% use all webfed media. There was a low response across other webfed usage ranges (Table 4).

The Paper Purchase and Selection Decision

Respondents were asked how the paper selection decision is made: by an individual within the printing company, by the customer (print purchaser), or jointly, by both parties (Figure 24a). This is important for paper producers to understand, because it affects the manufacturers' advertising and marketing strategies for new paper brands.

Generally, there seems to be a tendency to collaborate on the selection of paper grades. About 46% of respondents are collaborating with customers to make paper decisions. However, the distribution of responses indicates mixed selection practices.

The 95% confidence interval plot (Figure 24b) indicates that there is no significant correlation between the means of the three variables shown, since the means overlap the other variable distributions. However, there is a borderline significant difference between the means of "both" and "customer." Respondents indicated that in 22% of the cases, all decisions were made jointly, but in 13% of the cases, there was no collaboration. In 38% of cases the decision does not involve the print buyer, and in 35% of cases the printing company is not involved. The survey results do not give an entirely consistent picture, because only 8% identified the company as always responsible and 4% identified the customer as always responsible.

Table 4. Webfed versus sheetfed usage by participants.

Usage	% of Respondents
Webfed only	5
Sheetfed only	85
Less than 50% web	6
More than 50% web	3
Refused	1

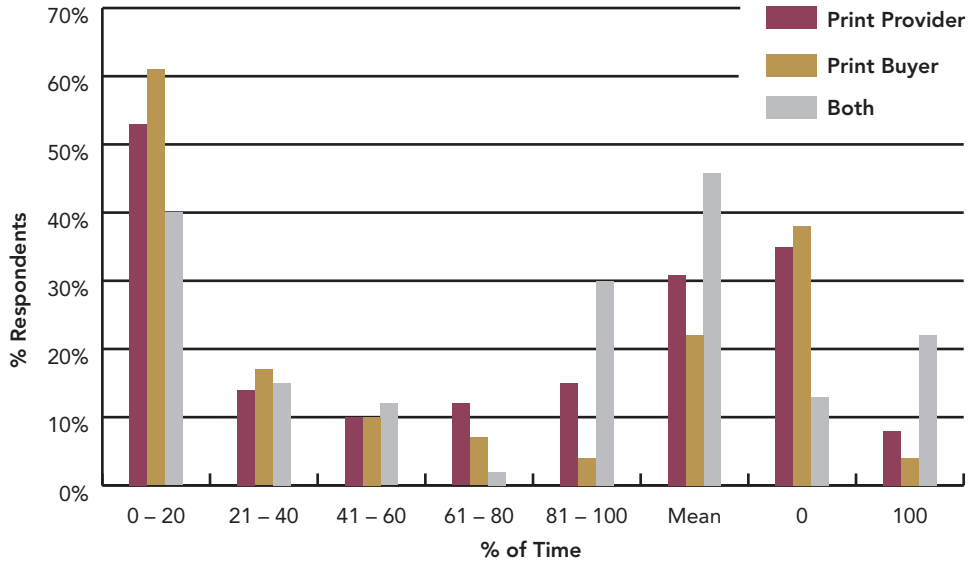

Figure 24a. The paper grade selection decision. "Print Provider" refers to an individual within the printing company making the paper grade selection alone; "Print Buyer" means the print buyer alone makes the decision; and "Both "refers to a joint decision between the print buyer and provider.

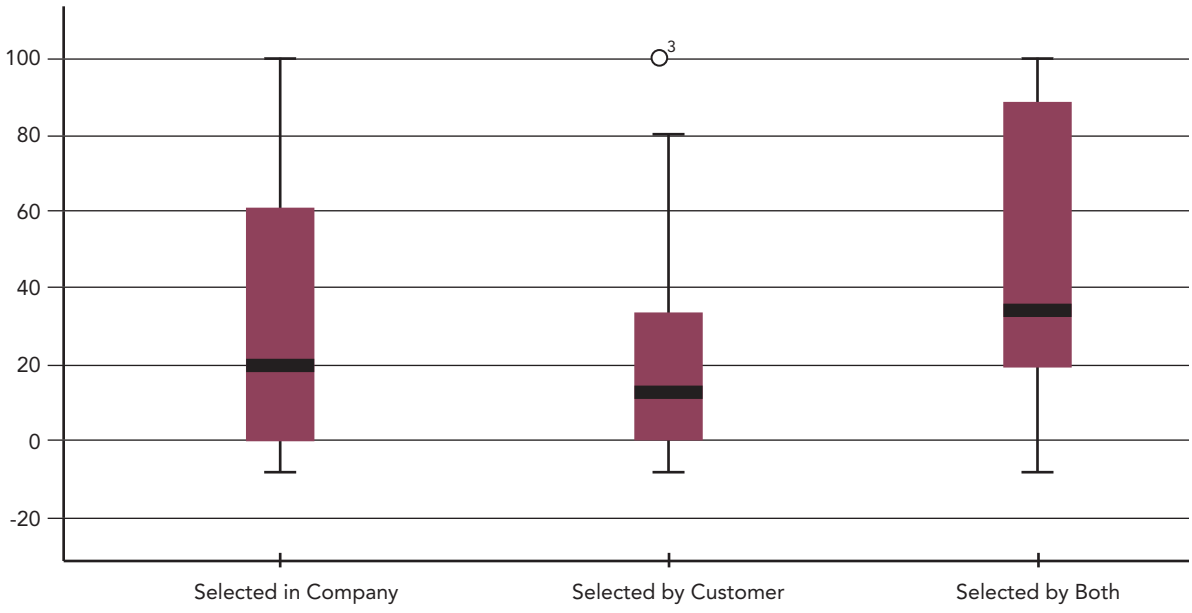

Figure 24b. Confidence intervals for paper grade selection decision.

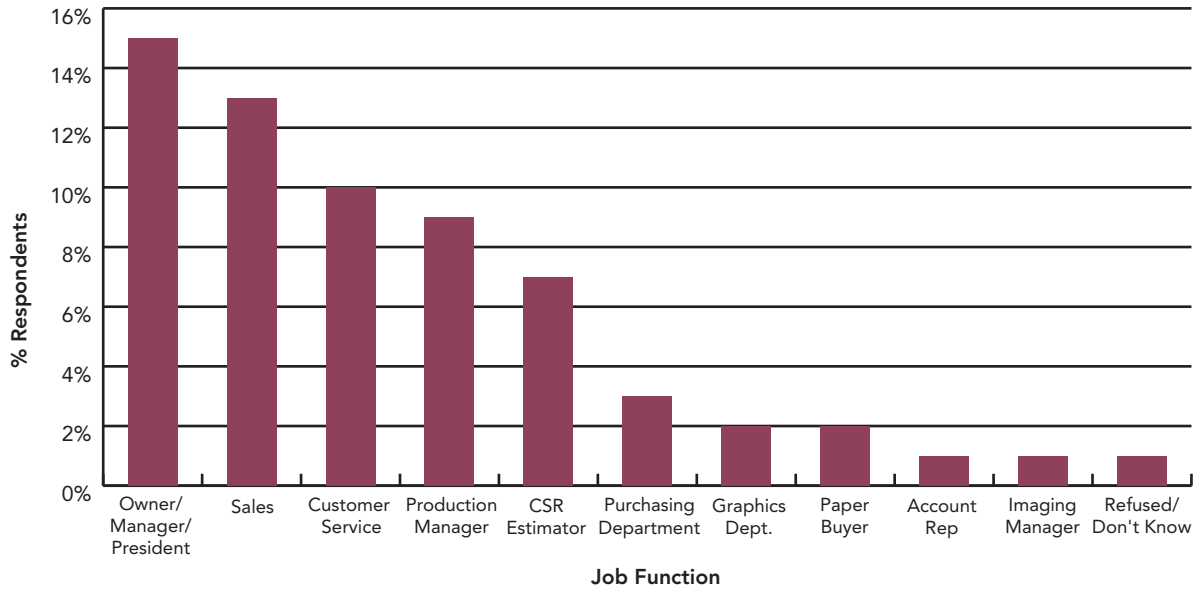

Figure 25. Job function or title of person selecting paper grade within the printing company.

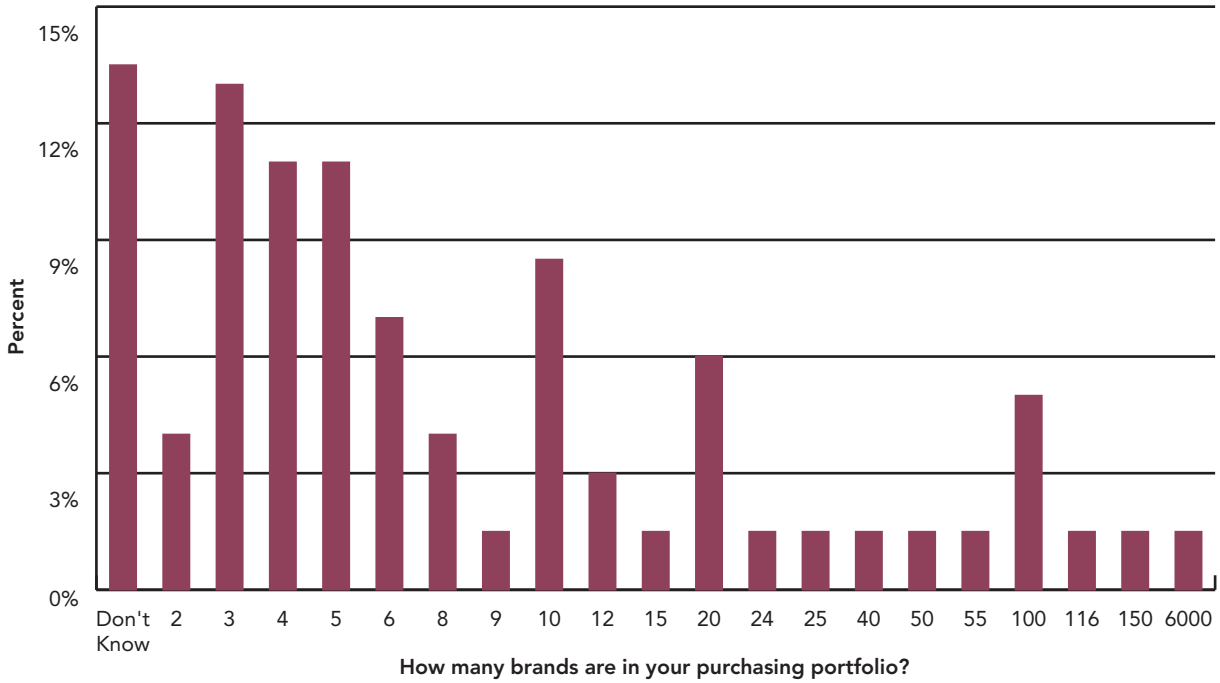

Figure 26. Number of brands in a printing company's purchasing portfolio.

In an open-ended question, respondents were asked who within their organization makes the paper grade selection. The responses were recorded and categorized, and are shown in Figure 25. In nearly 15% of cases, the owner/manager was responsible, correlating with the observation that the sample holds a significant proportion of small enterprises (25% have fewer than 10 employees). The sales function accounts for 13%, and customer service 10%. When customer service is combined with the category "Customer Service Estimator," this increases to 17%. Only 5% use the purchasing department or paper buyer. Production at 9% could be combined with the graphics and imaging functions to give a 12% "technical production" grouping, compared with a 51% "front office" grouping.

Brand Selection

In exploring brand and paper supplier relationships, the definition of the term "brand" was not made clear to respondents. It appears that in some cases "brand" was interpreted as a manufacturer such as International Paper, which carries a range of different paper grades within each categorized product portfolio. In other cases, "brand" was interpreted as a specific paper grade, characterized by size, basis weight, finish, etc. One respondent indicated 6,000 brands within the portfolio (there are not this many paper producers in the world!). See Figure 26.

Removing the outlier, the 5% trimmed mean is about 10 brands, with a median of 5 brands. Fifty percent of respondents indicated 5 or fewer brands in their portfolios. This indicates a degree of brand loyalty, which was further explored.

Figure 27a shows that 28% of respondents would be limited to one brand of paper, and 71% would not. Of those who are limited, 3% reported that there is a contractual relationship that requires the purchase of one particular brand, and 82% mentioned that this brand represents the best value in terms of price. One respondent reported that the brand offers the best quality (Figure 27b).

An open-ended question explored the advantages and disadvantages of a contractual relationship, and few respondents commented. Only two mentioned that cost savings were an advantage, and one identified availability of grade as an issue. Conversely, one respondent identified price as a disadvantage of a contractual relationship, perhaps referring to less flexibility than shopping in the open market. One respondent indicated that the contract was not under the control of the person specifying the paper grade, and that changing a contract is difficult.

Factors that impact the evaluation of different sources or brands of paper for a digital press were also investigated. For this, respondents were asked to rank factors on an importance scale. Runnability was described as no misfeeds or web breaks. Appearance characteristics included brightness, whiteness, finish type, etc. Product range included weight, size, finish, etc. Availability of grade referred to short turnaround on ordering, a factor which by anecdotal evidence and personal experience of the researchers can eliminate primary grade choices. Multipurpose application across different printing technologies was included as a factor introduced on the recommendations from the pilot

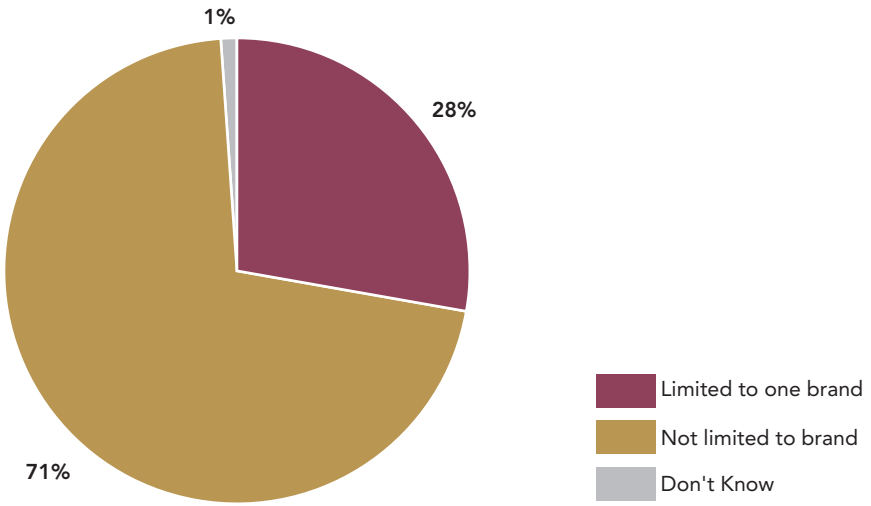

Figure 27a. Decision to purchase a particular brand of digital paper, with respondents limited to the choice of only one brand.

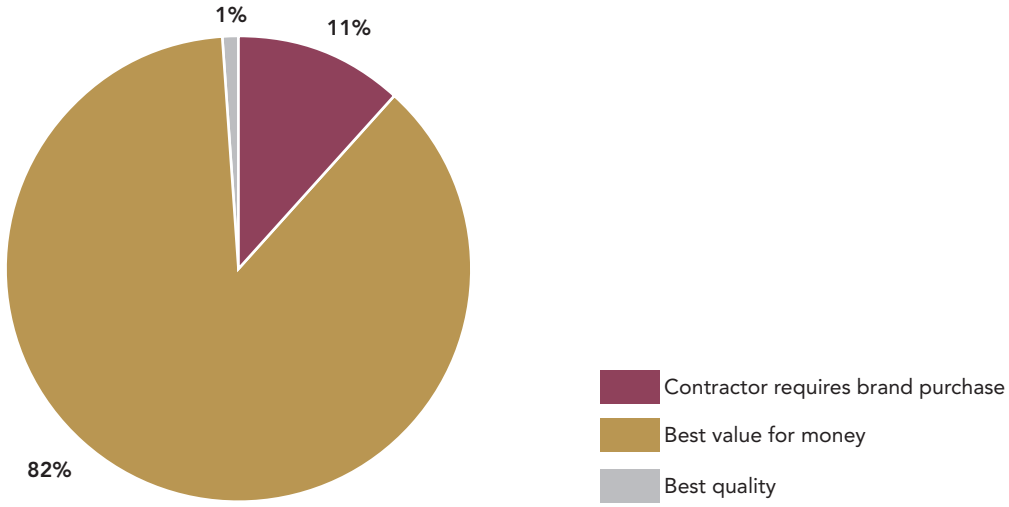

Figure 27b. Opinion of a brand to which respondents are limited.

survey. Pairwise comparisons were made for significance at the 95% confidence level (see Table 5).

Runnability and print quality (Figure 28) were the factors with the most importance, but there was no significant difference between them. The data suggests that runnability is significantly more important than availability, appearance, price, multipurpose and product range. Print quality is also significantly more important than other factors, with the exception of runnability. Availability of grade was less important than runnability and print quality, but more important than price, multipurpose application and product range. Appearance was more important than the two lowest-ranking factors, multipurpose and product range. Price and appearance characteristics were not significantly

Table 5. Relative importance of factors in determining the sources or brands of papers for digital printing.

	Importance of Factor in Selection of Brand or Manufacturer					
Factor	5	4	3	2	1	Don't Know
Runnability	75	21	2	1	0	1
Print quality	68	26	4	1	0	1
Availability of grade (short turnaround on ordering)	45	35	12	5	1	2
Appearance (brightness, whiteness, finish)	32	44	19	4	0	1
Price	29	30	34	5	1	1
Multipurpose applications across different printing technologies	19	20	22	22	15	2
Product range (weight, size, finish)	15	23	35	20	5	2

(Critical = 5; Not at all important = 1)

different, but price came out significantly lower in importance than runnability, print quality, and availability.

When grouping the categories relating to grade availability (multipurpose application, product range, turnaround time), and comparing them with the two factors linked with visual appearance (print quality and appearance), the appearance of the final document was found to be more important than the availability-related factors. Due to the increased error in combining these data sets, price shows no significant difference to these two grouped factors.

Using the same factors for selecting a brand, the difference between brands or paper manufacturers for each of these factors was investigated (major, minor or no difference). Figure 29 shows that the responses are close and clustered with the majority of responses, indicating a minor difference for each factor. About one third of respondents indicated that different brands showed a major difference in runnability, availability, and print quality. Only 27% indicated a major difference in price, with 62% indicating a minor difference. This may explain the relative low importance of price in the purchase decision.

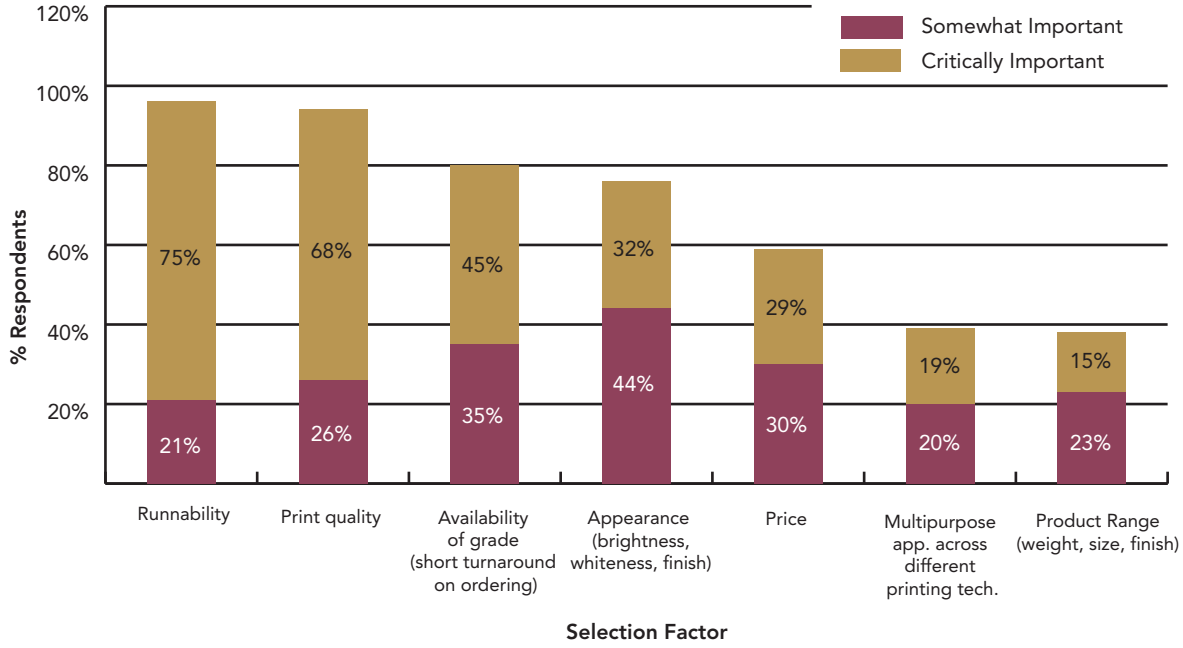

Figure 28. The relative importance of factors used to determine brand or source of paper.

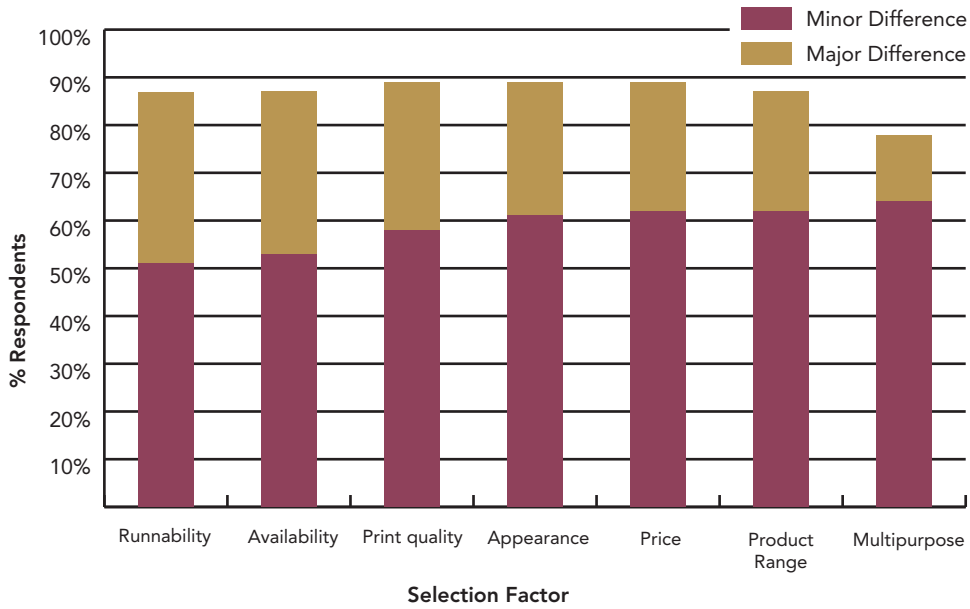

Figure 29. Perceived level of difference between factors used to determine brand or source of paper.

Paper Properties

The properties and characteristics of papers that may be considered when selecting a grade were investigated for relative importance. First, respondents were asked to identify whether given characteristics were critically, quite important, or somewhat important, or not important. The rankings for the critically and quite important categories are shown in Figure 30. The leading characteristics are toner/ink adhesion, accurate sheet dimensions, dimensional stability, and moisture level.

The previous question was rephrased to ask for just one characteristic to be identified as the most important. The top three characteristics are the same from both questions; 52 % of respondents identified toner/ink adhesion as most important when given the option to select only one factor (shown in the right columns of Table 6). Ten percent selected accurate sheet dimensions, and 7% uniformity. Other factors are shown in Table 6. When asked for the second most important characteristic, the same three factors and dimensional stability and brightness were chosen. No respondents identified brightness as the most important characteristic, and the overall relative ranking of brightness was well down the list.

Separating these factors into two groups, including those related to the performance of the sheet on press (uniformity, accurate sheet dimensions, dimensional stability, moisture level, basis weight, storage and handling, stiffness, and sheet/web strength) and appearance-related factors, there is a significantly greater importance attached to performance parameters (33% of respondents identified them as critically important, on average) than to appearance-related factors (22%).

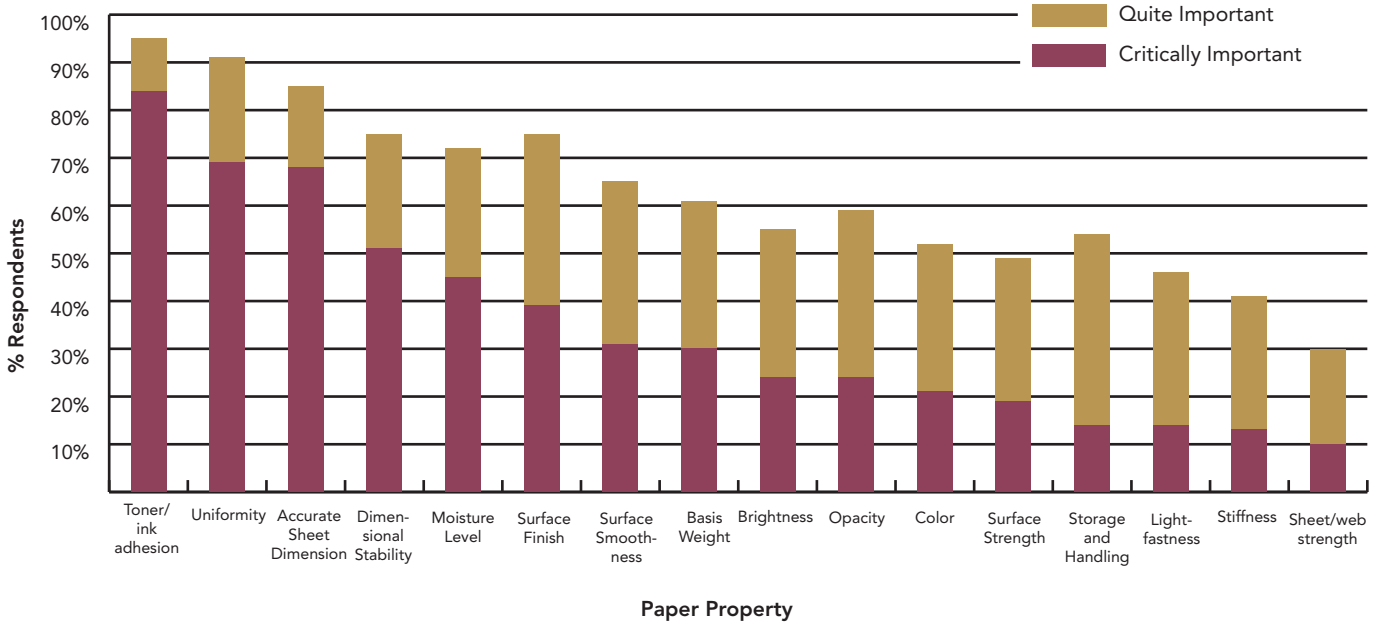

Figure 30. The relative importance of paper characteristics and properties in selecting a grade.

Table 6. Relative Importance of Paper Characteristics in Selecting a Grade

	Percent Respondents						
Property	Critically Important	Quite Important	Somewhat Important	Not Important	Don't Know	Most Important*	Second Most Important
Toner/Ink Adhesion	84	11	4	0	1	52	17
Uniformity	69	22	4	1	4	7	10
Accurate Sheet Dimensions	68	17	10	2	3	10	12
Dimensional Stability	51	24	19	5	1	4	13
Moisture Level	45	27	21	6	1	4	6
Surface Finish	39	36	21	2	2	3	5
Surface Smoothness	31	34	25	7	3	4	7
Basis Weight	30	31	29	5	5	2	1
Brightness	24	31	41	3	1	0	10
Opacity	24	35	36	1	4	3	0
Color	21	31	37	10	1	0	0
Surface Strength	19	30	35	11	5	0	2
Storage and Handling	14	40	32	13	1	1	1
Lightfastness	14	32	29	19	6	0	0
Stiffness	13	28	38	14	7	2	0
Sheetweb Strength	10	20	37	28	5	0	4

* Separate question

These paper characteristics may be related to the job type identified as generating the most revenues. Of those respondents identifying direct mail as generating the most revenue, only 2 of the 19 respondents did not identify toner/ink adhesion as either critically or quite important. When asked to identify the most important paper characteristic, 58% (11 of 19) identified adhesion. Similarly, of 23 respondents identifying marketing and promotional materials as most important, only 3 did not identify adhesion as critical, and all identified this characteristic as either critical or quite important. With quick printing, (14 respondents) only 2 did not identify adhesion as critical, and with manuals and documents (17 respondents), only 2 did not. Thus across a wide range of applications, and for all the most important job types in terms of revenue generation with digital printing, ink/toner adhesion is the most important factor for this sample of print providers.

Adhesion concerns correlate with the identification of coated gloss as the most commonly used paper grade (37% of respondents citing adhesion as the primary issue also identified this grade). This may be due to the lower bonding energies associated with very smooth surfaces, which provide fewer surface-active sites for bonding to toner or colorant particles. Seventeen percent of respondents in this "adhesion" group use mostly uncoated uncalendered, and 9% use mostly premium bond. No other grade was predominant for this group.

Acceptability of Current Paper Grades

Using the same paper characteristics as above, respondents were asked to identify the extent of improvement they would like to see (major, minor, or none). The need for product range improvement was ranked significantly higher at the 0.05 level than runnability, appearance and print quality, but was not significantly different than the need for brands which function across different printing technologies (multipurpose). (Figure 31 and Table 7). Runnability, a key factor in determining brand, was ranked significantly less in need of improvement than product range, but was not otherwise significantly different than other factors. Overall, the greatest need for improvement is in product range and the availability of multipurpose brands.

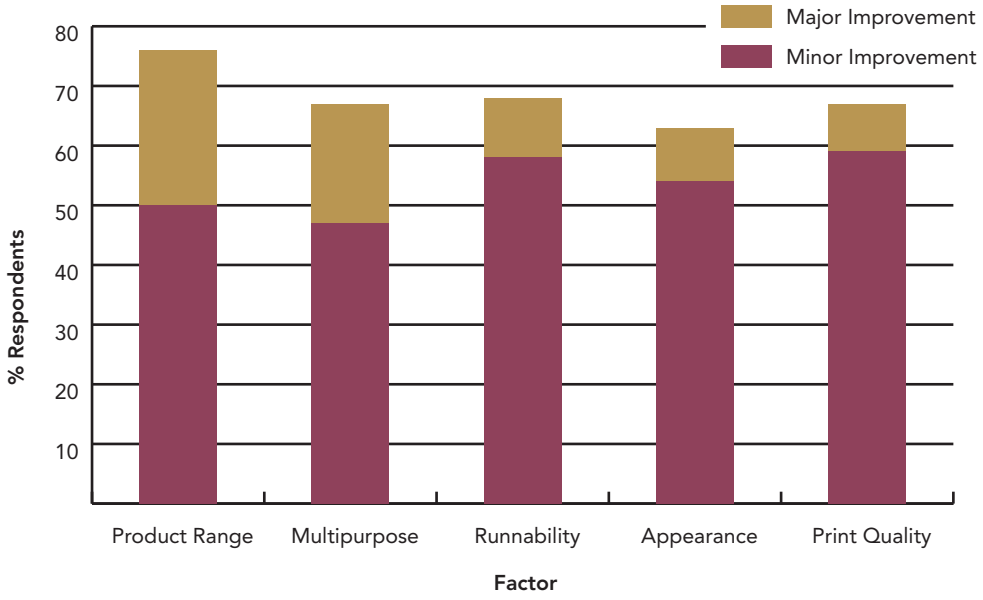

Figure 31. Factors needing improvement in digital papers.

Table 7. Relative pairwise comparisons for improvement factors.

Factor	Product Range	Multipurpose	Runnability	Appearance	Print Quality
Product Range	–	NS	S	S	S
Multipurpose		–	NS	S	NS
Runnability				NS	NS
Appearance				–	NS
Print Quality					–

S = Significant differences in the means; NS = Not significant at the 0.05 level.

Open-ended comments were invited in response to a question concerning other specific improvements printers would like to see; these are collated and shown in Table 8.

Of the 81 respondents who elected to outline improvements they wish to see in digital papers, seven stated that no improvements were necessary in their view. One respondent indicated the potential to "print on anything."

Price

Only eight respondents indicated that they would like to see a lowering of paper price, indicating that profit on a specific job is not governed primarily by the paper price, but by other factors such as finishing, distribution, value-added services, etc. This is consistent with the observation from earlier questions that price is not a leading driver in the brand selection and purchase decision. One respondent called for pricing to be brought into line with that of related non-digital grades (anecdotal evidence from conversations

Table 8. Response categories for the question: "What specific improvements would you most like to see in new digital paper product offerings?" and "What limitations on your choice of papers does your digital press impose?"

Response Category	Number of respondents commenting in the category (Total 81 respondents)
No improvements needed	7
Adhesion	10
Price	8
Consistency and uniformity	6
Runnability	6
Brightness	4
Logistics/inventory	3
Product Range	44*
General product range (no detail specified)	10
Wider range of sizes	9
Wider range of caliper/thickness	6
More colors	5
Ability to print on textured stock	5
Product range across all press technologies	5
Higher basis weights	3
Wider range of finishes	3
Ability to print on synthetics	2
Grain orientation (for folding)	2
Label stocks	2
Lower basis weights	1

* 44 comments related to the product range available; some respondents called out more than one sub-category in this group of responses.

with paper manufacturer sales representatives confirms that this is a concern with printers familiar with non-digital paper cost structures).

Consistency and Uniformity

Eight comments related to consistency and uniformity of properties: three in terms of brightness (see below); one looking for "consistency of weights across different paper companies;" and four concerned with uniformity of quality, citing "accuracy of dimensions," "size varies in the cartons," and "cleaner sheets."

Runnability

Six respondents specifically called out the term "runnability" as an area for improvement, three mentioning the need for grades that run across different printers. One indicated difficulty in running prints with "heavy layout," presumably referring to high ink coverage levels.

Brightness

Of the four respondents requiring improvements in brightness, three referred specifically to the consistency of brightness rather than the level, either ream-to-ream, or across brands. Only one called for a "brighter white," which is interesting in light of the new product offerings in the major digital ranges launched in 2004–2005.

Product Range

It is clear from the comments of 44 respondents that current product ranges are not sufficient at this time to meet all needs for digital document production. Ten respondents left the comment as general, but many indicated more than one area in which product offerings are not available. The primary areas are: wider range of sizes (10), more colors, a wider range of caliper/thickness and basis weights, and the ability to print on the same stock across different technologies (Table 7). Five respondents would like to be able to print on textured stocks (this is possible on some digital printers only). Only one identified the need for lower basis weight stocks, which is surprising in light of the trend towards increased mailing and shipment costs. One respondent requires "more exotic" products, which poses an interesting challenge to product designers.

Inventory and Logistics

Three inventory and logistics related comments brought out a concern with the shortening turnaround times associated with print-on-demand. "We have to plan way ahead to get some papers just because it is so hard to know when they'll be available." Another would like reassurance that an identified grade will "continue to be available," and one indicated that it may be necessary to "wait a few weeks" for shipment.

Adhesion

A range of comments related to the adhesion of toner or ink onto the substrate. Several respondents mentioned paper cracking at fold lines, a common problem in digital book-

let-making. One specifically requires paper that transfers heat better in order to get better toner fusion. Several mentioned that specific surface treatment is required for adequate adhesion and print quality—a limitation imposed on available grades, and also on shelf-life. Fifteen percent of the respondents in this sample own liquid-ink technology digital presses which have until recently required most stocks to be pre-treated with a receptive coating.

Other needed improvements identified by the respondents included more opacity, better "image retention," improved heat stability (the paper "shrinks" when printed on both sides), and the ability to print on letterheads, possibly referring to the limitations in using offset-printed forms and shells in digital presses with high fusing temperatures.

Limitations Imposed by the Digital Press

A further open question asked, "What limitations on your choice of papers does your digital press impose?" The response categories in general were similar to those addressing areas of improvement (Table 9).

The leading limiting factors relate to product range: basis weight, size and thickness. Twenty respondents commented that they are limited in basis weight, but only one

Table 9. Responses to: "What limitations on your choice of papers does your digital press impose?"

Response Category	Number of respondents commenting in the category (Total 81 respondents)
Basis weight	20
General comment	7
Not high enough	12
Not low enough	1
Size	15
Thickness	10
Adhesion	8
Pre-treatment of receptive coating	7
Moisture control requirements	4
Paper / ink compatibility	4
Smoothness requirement	4
Can't run high gloss	3
Runnability	2
Dimensional stability	2
Don't have roll feed	1
Stiffness	1
Ability to handle heat	1
Grain direction requirements	1

Total 83 respondents.

at the low end. Fifteen are limited to sizes imposed by the press, and 10 are limited by thickness. The adhesion category included comments related to the pre-treatment requirement. This restriction could be linked with the "paper/ink compatibility" comments. The smoothness limitations may also link with adhesion. Only one respondent was limited by a stiffness requirement, although this may have been reported by others in terms of basis weight or thickness since these properties are closely related. Interestingly, three respondents reported that they have to perform tests themselves to pre-qualify media before running it on press.

Storage Facilities

When asked if respondents had to modify their storage facilities to accommodate digital papers, the responses were as follows: storage facilities were modified only by 16% of respondents to deal with digital paper grades. Apparently 84% already had adequate facilities for other printing technologies, or were able to use the existing pressroom or storage environments. This links with the observation that only four respondents mentioned moisture control requirements as a limitation imposed by the digital press. It is possible that the press environment is generally environmentally-controlled, providing integrated facilities press-side for paper conditioning.

Paper Cost

In order to understand the perception of paper cost changes from the print providers' viewpoint, the relative level of change was investigated. Seventy percent of respondents (Figure 32) stated that paper costs have increased either significantly or somewhat over the last two years (2002–2004), 7% reported that paper costs had decreased somewhat, and 18% reported no change in paper costs. Of those 70% reporting cost increases, 49% pass these costs onto their customers. Twenty-five percent of these pass the cost on in its entirety, and 10% pass on only 50% of the cost increase. Beyond these two levels of 100% and 50%, no other levels were predominant.

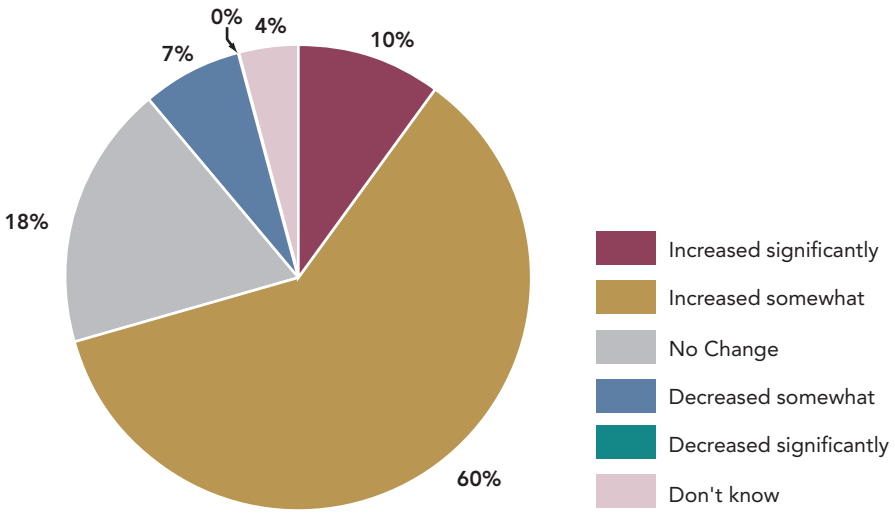

Figure 32. Perceived paper cost change in the period 2002 – 2004.

Summary of Findings

Company Demographics

No significant effects relating to company size and paper-related factors were found for this sample. There was no significant correlation between the number of employees and number of years in business, indicating that company size depends on factors other than age. There was no correlation between current levels of digital investment or revenues and the factors explored relating to digital paper usage.

The balance of different job functions was found to differ with company size range; the larger companies have a lower proportion of production employees compared with "front office" and support functions. This may indicate the implementation of efficient technologies and processes in the larger companies, requiring initial financial investments inaccessible to smaller firms. For the overall sample, the "front office" and IT categories together accounted for 36% of employees, with the hands-on "productive" categories (including prepress and production) amounting to 64%. A "functional ratio" relating these two metrics can be used to gauge efficiency and lean structure within a company or an industry. As technology advances and printers enter new and diverse markets, the distribution of employees can change. New functional areas will inevitably be incorporated into company structures, and this distribution (and the functional ratio) will change over time.

This sample is dominated by smaller companies, with 68% of participants generating 2004 revenues of less than $3M. This confirms the predominance of small- and medium-size enterprises (SMEs) in the printing industry. This finding correlates with the survey observation that for a significant proportion of respondents the "owner-manager" makes the paper selection decision, indicating a small company with hands-on multi-tasking management. It is particularly encouraging that 66% of firms experienced an increase in annual revenues in 2004 compared with 2003. Since so many of the firms in this sample are relatively small, they may not have the financial robustness and asset structure to weather significant year-over-year revenue decreases.

The job categories which are predicted to experience the greatest revenue growth potential (in dollar terms) are marketing and promotional materials, direct mail, transactional and business communications. The greatest revenue growth in percentage terms was projected to be in the categories of transactional/financial, and signage (which grew significantly from 2003–2004, although it was still a relatively minor category). This signage category could include inkjet wide-format and other non-toner technologies, a segment with considerable growth and profitability potential. Interestingly, manuals and documents and quick printing applications are predicted by respondents to generate a lower proportion of revenues compared with current levels. This may be related to the increased use of electronic forms and software manuals and the use of PDF document formats.

The use of variable data was relatively low in this sample (80% do less than half variable data, and 56% reported less than 10%) compared with the study conducted by Sorce and

Pletka (2004). No monotonic relationship between the use of color and level of variable data content was found. Business communications was the leading variable data category (62%), labels and wrappers came second (43%), and direct mail was third (33%). The transactional and financial category was surprisingly low at 21%, which is interesting in light of the nature of bills, statements and individually targeted communications normally included within this job category. Evidently this sample is not capturing the in-plant check, billing and statement production segment. The percent of variable data was found not to correlate with either the number of employees or with years in business.

There was a wide range of digital printing equipment utilized in respondents' businesses, and some equipment was not fully digital in the sense of having no fixed plate, and no capability to produce different impressions and do variable data. It should be noted that the survey sample may not necessarily be representative of the production digital printing market segment nationally. In addition to digital technologies, the majority of respondents have other non-digital presses, with the majority owning sheetfed offset presses. A few had flexographic or gravure presses. Only 20% have exclusively digital printing technology.

The year of entry into digital print production, indicated by the year of the first digital press acquisition, was found not to correlate significantly with the percentage of variable data jobs, or with the overall 2004 company revenues. There was a spike in 1995 and again in 2002, which may relate to the introduction of new technologies and capabilities (particularly in 1995). The 2002 spike may relate to both recession-driven aggressive price positioning and new market opportunities.

Paper Grades For Digital Printing Applications

Coated gloss is the leading grade for digital printing. The other grades in the top six are (in descending order):

- premium uncoated,
- uncoated calendered,
- coated matte,
- uncoated uncalendered, and
- premium bond.

When asked to identify only one predominant grade, 58% of our respondents identified the first three listed above, and 80% the top six. Other than these leading grades a wide range of substrate usage within the research sample was found.

The combination of gloss grades (coated and coated high-gloss) accounts for about 38% of grades used most frequently. This heavy usage correlates with the identification of marketing and promotional materials as a leading job type in this sample. Many direct mail pieces also use glossy stocks. The use of matte covers for brochures and high-end promotional pieces is growing (particularly in Europe), since a highly-colored matte finish can differentiate a piece from the crowd with striking effect.

Synthetics are not used widely by this sample, indicating a potential growth area as fusing technology develops. Fifteen percent of respondents use systems with liquid ink technology, which have well-established application to synthetic materials for packaging and document production; however, it appears that this usage was not primary among this sample group.

Colored and tinted stocks are used frequently by 46% of respondents. Textured grades are used frequently by only 22%, and none of the survey respondents claimed this grade as most often used. This may very well change as technology develops to enable toner particles to cover and adhere to rough surfaces. The Xerox iGen3 and NexPress 2100 have demonstrated significant progress in fusing and print quality on textured stocks, and have implemented technologies to enable toner particles to reach the recesses in uneven surfaces.

Recycled paper is used most often by only 2% of respondents, although 36% stated that their usage of recycled paper was very or somewhat frequent. For this sample, the digital production of marketing and promotional materials, direct mail, manuals and documents, and quick printing applications are not using significant proportions of recycled papers.

Eighty-five percent of the respondents use only digital sheetfed presses, and only 5% have only digital web capabilities. Once again this is an indicator that the survey sample is not capturing the web-fed high-speed transactional segment that is responsible for a significant proportion of digital production volume.

The Paper Purchase and Selection Decision

When making the paper purchase decision, there is a tendency for print providers and print purchasers to collaborate on the selection of paper grades. About 46% of print provider respondents are collaborating with customers to make paper decisions. However, the distribution of responses indicates mixed selection practices. It appears that in 51% of cases, "front office" functions such as owner/manager, sales, customer service, etc. make the decision. The responses are interesting, as technical requirements for digital papers may not be fully comprehended by individuals that specialize in sales, marketing and finance. However, in smaller companies, there is little to no distinction between business front-office and the technical production functions, and many customer service representatives spend time in the press-room and are aware of technical considerations.

In the exploration of how many brands of paper are used within a printing company, there was some ambiguity in the definition of the term "brand," which complicated the data interpretation. The 5% trimmed mean is about 10 brands, with a median of 5 brands. Fifty percent of respondents indicated 5 or fewer brands in their portfolio. This indicates a degree of brand loyalty, but 71% of respondents reported that they are not limited to a specific brand choice.

Factors affecting the purchase decision were identified in order of importance. Runnability and print quality were the factors with the most importance, followed by availability, appearance, price, multipurpose functionality and product range (see the

Results section for definitions of these terms, and significances of the rank ordering). Price and appearance characteristics were not significantly different, but price was found to be significantly lower in importance than runnability, print quality, and availability. Appearance-related factors were found to be more important in the purchase decision than availability-related factors. Considering how different these purchase decision factors are across different paper brands, about one third of respondents indicated that different brands show a major difference in runnability, availability, and print quality. Only 27% indicated a major difference in price, with 62% indicating a minor difference. This may explain the relative low importance of price in the purchase decision.

Characteristics and properties of digital papers were investigated for relative importance. The leading characteristics were found to be toner/ink adhesion, accurate sheet dimensions, dimensional stability, and moisture level. The adhesion issue was the clear lead, with 84% of respondents identified toner/ink adhesion as being critically important. Across a wide range of applications, and for all the most important job types in terms of revenue generation with digital printing, ink/toner adhesion is the most important factor for this sample of print providers. Adhesion concerns correlated with the use of coated gloss stocks; this is intuitive, as a very smooth surface may provide fewer surface-active sites for bonding to toner or colorant particles. Additionally, glossy stocks are frequently selected for photo-quality images and high-color graphics, and these associated high ink/toner coverage images result in problematic toner-on-toner laydown, cracking, flaking and other adhesion issues.

Overall, performance-and runnability-related factors were found to be more important than appearance-related factors in the purchase decision. This makes sense in profitability terms; a press which does not run due to paper misfeeds leads to costly downtime and wasted materials. Quality issues related to appearance and end-document quality are judged subjectively, and may have a lower impact on the bottom line.

Acceptability of Current Paper Grades

The areas in need of greatest improvement are related to the range of products available for digital printing, and the availability of multipurpose brands. This result came from both structured responses and from open ended questions. These two factors ranked significantly higher than runnability, appearance and print quality. Relatively few respondents identified lowering of paper price as an important need; it seems that the digital printing markets served by this sample offer markup potential for services and finishing, etc., and that this is not a commodity segment. This is consistent with the observation that price is not a key driver in selecting brand or grade type.

The limiting factors on paper choice imposed by a printer's current digital press were found to be product range in terms of basis weight, size and thickness. Another significant limitation was related to adhesion, and the need to have some substrates pre-treated prior to printing.

Few respondents (16%) had to modify existing storage facilities in order to manage the pre-conditioning requirements of digital papers.

Paper costs to printers were reported by 70% of respondents to have increased either significantly or somewhat over the last two years (2002–2004). Nearly half experiencing cost increases pass these on to their customers, either entirely or in part.

Limitations of the Study

The sample was evidently not inclusive of in-plant print providers performing transactional and business documentation with roll-fed high-speed monochrome printers—a segment with significant volumes and a consumer of specific paper grades. The wide range of company sizes and technologies involved in this digital segment render representative sampling difficult.

The use of open-ended questions had the advantage of allowing free comments, but the meaning and intent of the respondent was not always clear. However, structured questions can emphasize certain responses that would otherwise not arise, which could lead to misunderstandings. This may have been the case in our use of the terms "grades" and "brand." It is likely that some respondents identified "brand" as equivalent to one specific paper type, size, finish, etc., rather than the intended meaning of an integrated product line produced by a single manufacturer (e.g., Mohawk's Navajo). Overall, a balance of open-ended and structured response questions may be the best approach.

There was also some inconsistency in identifying the perception of key issues. For example, adhesion was called out as a primary concern in some questions, but was not emphasized to the same extent in the open ended responses. It was useful to ask similar questions in different ways (for example, allowing multiple selections of factors, followed by a separate question with only one primary factor allowed).

In order to fully comprehend the technical aspects of digital papers, the survey respondents were identified as having expertise in this area. It is possible that in larger companies with separate procurement functions, the exact nature and relative importance of pricing structures and complex long-term sourcing agreements with paper manufacturers were not weighted equivalently to the technical factors by these individuals. A case study approach may reveal the relative weightings of these factors more closely.

Conclusions

Paper grades commonly used for the production digital market segment have been explored, and a ranking produced. The leading grades are coated gloss, premium uncoated, uncoated calendered, coated matte, uncoated uncalendered, and premium bond.

The median number of paper brands used is five, with a wide range reported across the sample. When making the paper purchase decision, almost half of the time print providers and print purchasers collaborate on the selection of paper grades.

Factors affecting the paper purchase decision were identified, in order of importance, as:

- runnability and print quality (two separate factors that were given equal weight by respondents),
- availability of grade,
- appearance properties,
- price,
- multipurpose functionality across different printing technologies,
- and product range.

The leading paper characteristics considered when making a purchase decision were found to be, in order of importance:

- toner/ink adhesion,
- accurate sheet dimensions,
- dimensional stability, and
- moisture level.

Overall, performance- and runnability-related factors were found to be more important than appearance-related factors in the purchase decision.

In general the price of papers charged by manufacturers to print producers seems not to be a leading factor in making the paper selection decision. Price is not a key driver in selecting brand or grade type, even though most printers have experienced paper cost increases in the last few years.

The area of improvement that printers want to see most is an extended product range, with more sizes, finishes and basis weights available for their digital presses. The presses currently owned impose paper choice limitations on size, basis weight, thickness, and surface treatment requirements.

Overall, it appears that there is room for product development to meet the developing potential for production digital printing applications. This imposes a significant inventory and product planning challenge to paper manufacturers since there are currently many different press technologies with a wide range of required sheet and roll sizes. This challenge becomes more acute in light of the print-on-demand paradigm coupled with just-in-time inventory and lean manufacturing practices. Carrying a wide range of substrates to meet most customers' needs not only uses up storage space, but also puts restrictions on cash flow.

This year (2005) a variety of new digital papers and new product lines have been introduced into the marketplace with more color options, a wider range of basis weights and sizes, and new textures and finishes. These new products are designed to meet the

growing potential for production digital print applications. Certainly paper manufacturers are rising to the challenge, but technical issues remain, and printers will continue to look for papers with improved runnability, printability and fitness for use in the new generation of production digital presses.

Agenda for Future Research

On the basis of the findings of this survey phase, a case-study investigation will be constructed to explore in greater depth the current state of digital paper usage among digital printers.

Additionally, printer device manufacturers will be surveyed to understand the limitations that available paper grades impose on digital press design, and conversely the limitations that digital press design impose on the use of currently-available papers. The future trends in digital papers enabled by technology developments will also be investigated.

The importance of price in the purchasing decision will be explored in the context of other decision factors. Emphasis will be placed on the total value proposition to digital print customers, and the role of paper in producing a value-added product that extends the traditional concept of print as a commodity.

Based on these future findings in conjunction with the current survey analysis, potential solutions for digital paper manufacturers will be identified in terms of printing technology trends and paper substrate requirements.

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Appendix A

Summary of demographics survey results.

A1	How many years has your firm been in business?	Count	Mean	Median	Min	Max
		103	40	28	3	197
A2	**How many employees are currently in your company?**	**Count**	**Mean**	**Min**	**Max**	**SD**
		103	79	1	2500	265
A3	**How many employees were in your company five years ago?**	**Count**	**Mean**	**Min**	**Max**	**SD**
		101	83	1	2700	295
A4	**How many employees do you have in each of the following functions?**	**Count**	**Mean**	**Min**	**Max**	**SD**
	Production	103	49	5	95	20
	Prepress	103	15	0	40	9
	IT	103	6	0	33	7
	Sales	103	13	0	50	10
	Customer service	103	17	0	61	12
A5	**Which of the following best describes your company's 2004 revenues?**	**Count**	**Percent**			
	Less than $3 million	70	68.0			
	$3 million to $5 million	20	19.4			
	More than $5M to $10 M	8	7.8			
	More than $10 M to $15 M	0	0.0			
	More than $15 to $20 M	0	0.0			
	More than $20 M	5	4.9			
	Don't know					
	Refused					
	Total	103	100			
A6	**Did your revenues grow, decrease, or stay the same over the past 12 months?**	**Count**	**Percent**			
	Grew	67	65.0			
	Decreased	11	10.7			
	No change	24	23.3			
	Don't know	1	1.0			
	Refused	0	0.0			
	Total	103	100			

	What was the approximate percent of growth?	Count	Mean	Min	Max	SD
		67	13.9	1	75	11.6
	What was the approximate percent of decline?\	Count	Mean	Min	Max	SD
		24	10.7	2	25	8.3
A7	In the last 12 months, which of these 11 types of digital printing jobs have been part of your business?	Count	Percent			
	Marketing and promotional materials	**103**	**100**			
	Major Portion	62	60			
	Minor Portion	32	31			
	Rarely Performed	5	5			
	Never Performed	4	4			
	Don't know	0	0			
	Refused	0	0			
	Manuals and documents	**103**	**100**			
	Major Portion	42	41			
	Minor Portion	44	43			
	Rarely Performed	8	8			
	Never Performed	9	9			
	Don't know	0	0			
	Refused	0	0			
	Catalogs and directories	**103**	**100**			
	Major Portion	9	9			
	Minor Portion	63	61			
	Rarely Performed	17	17			
	Never Performed	14	14			
	Don't know	0	0			
	Refused	0	0			
	Magazines and periodicals	**103**	**100**			
	Major Portion	6	6			
	Minor Portion	25	24			
	Rarely Performed	23	22			
	Never Performed	49	48			
	Don't know	0	0			
	Refused	0	0			
	Transactional / financial forms or documents	**103**	**100**			
	Major Portion	13	13			
	Minor Portion	31	30			
	Rarely Performed	24	23			
	Never Performed	35	34			

	Don't know	0	0			
	Refused	0	0			
	Book production	**103**	**100**			
	Major Portion	19	18			
	Minor Portion	35	34			
	Rarely Performed	13	13			
	Never Performed	36	35			
	Don't know	0	0			
	Refused	0	0			
	Direct mail	**103**	**100**			
	Major Portion	51	50			
	Minor Portion	37	36			
	Rarely Performed	5	5			
	Never Performed	10	10			
	Don't know	0	0			
	Refused	0	0			
	Signage	**103**	**100**			
	Major Portion	14	14			
	Minor Portion	42	41			
	Rarely Performed	14	14			
	Never Performed	33	32			
	Don't know	0	0			
	Refused	0	0			
	Labels and wrappers	**103**	**100**			
	Major Portion	9	9			
	Minor Portion	50	49			
	Rarely Performed	18	17			
	Never Performed	26	25			
	Don't know	0	0			
	Refused	0	0			
	Quick printing applications	**103**	**100**			
	Major Portion	54	52			
	Minor Portion	33	32			
	Rarely Performed	4	4			
	Never Performed	12	12			
	Don't know	0	0			
	Refused	0	0			
	Business communications	**103**	**100**			
	Major Portion	42	41			
	Minor Portion	44	43			
	Rarely Performed	7	7			
	Never Performed	8	8			
	Don't know	2	2			
	Refused	0	0			

A8	Is there another type of digital printing job that you do that is not included?	Count	Percent			
	No	89	86			
	Don't know	0	0			
	Refused	4	4			
	Yes					
	Art work/fine art	2	2			
	Digital color printing	1	1			
	Imprints	1	1			
	Large format	1	1			
	Media one off	1	1			
	Personal invitations	1	1			
	Statistical/surveys	1	1			
	Variable	2	2			
	Total	103	100			
	Is this other type a major portion of your business, a minor portion, rarely performed, or never performed?	Count	Percent			
	Major portion	4	40			
	Minor portion	6	60			
	Rarely performed	0	0			
	Never performed	0	0			
	Don't know	0	0			
	Refused	0	0			
	Total	10	100			
A9	Of the jobs the represent the major portions of your digital printing business, which one generates the greatest revenue?	Count	Percent			
	Marketing and promotional materials	23	24			
	Manuals and documents	17	18			
	Catalogs and directories	1	1			
	Magazines and periodicals	1	1			
	Transactional / financial forms or documents	5	5			
	Book production	4	4			
	Direct mail	19	20			
	Signage	2	2			
	Labels and wrappers	2	2			
	Quick printing applications	14	14			
	Business communications	6	6			
	Other	0	0			
	Don't know	3	3			
	Refused	0	0			

	Total	97	100			
A10	Which one of these job types do you really have to be successful at to ensure your future growth?	Count	Percent			
	Marketing and promotional materials	23	22			
	Manuals and documents	5	5			
	Catalogs and directories	2	2			
	Magazines and periodicals	1	1			
	Transactional / financial forms or documents	5	5			
	Book production	2	2			
	Direct mail	25	24			
	Signage	1	1			
	Labels and wrappers	1	1			
	Quick printing applications	10	10			
	Business communications	9	9			
	Other	0	0			
	Don't know	14	14			
	Refused	4	4			
	0ther Category	1	1			
	Total	103	100			
A11	Of the digital printing jobs that you did over the past 12 months, what percent of these jobs were variable data print jobs?	Count	Percent			
	0	23	22			
	1	3	3			
	2	2	2			
	3	2	2			
	4	1	1			
	5	15	15			
	9	1	1			
	10	11	11			
	15	5	5			
	20	3	3			
	25	4	4			
	30	4	4			
	35	1	1			
	40	2	2			
	45	1	1			
	50	5	5			
	60	4	4			
	70	2	2			
	75	1	1			

	80	5	5			
	85	1	1			
	90	3	3			
	97	1	1			
	Don't know	3	3			
	Refused	0	0			
	Total	103	100			
	What percent of those jobs involved color?	Count	Percent			
	0	5	6			
	1	1	1			
	2	4	5			
	5	3	4			
	10	5	6			
	15	1	1			
	18	1	1			
	20	2	3			
	30	2	3			
	40	2	3			
	50	9	12			
	60	7	9			
	80	3	4			
	85	1	1			
	90	4	5			
	95	2	3			
	96	1	1			
	98	1	1			
	100	23	30			
	Don't know	0	0			
	Refused	0	0			
	Total	77	100			
A12	What is the brand and model number of each digital press used in your company?	Count	Percent			
	HP Indigo	20	15			
	IBM	0	0			
	NexPress 2100	2	2			
	NexPress/Kodak DigiMaster	5	4			
	Océ	3	2			
	Xerox 200 series	0	0			
	Xerox black and white DocuTech	8	6			
	Xerox DocuColor 2060	2	2			
	Xerox DocuColor 6060	9	7			
	Xerox DocuColor 8000	0	0			

	Xerox iGen3	10	8			
	Xerox Nuvera	1	1			
	Xeikon	4	3			
	Other	49	38			
	Don't know	12	9			
	Refused	5	4			
	Total	130	100			
	Specify the brand and model number for your first press under other to question 1.12	Count	Percent			
	AB Dick	1	2			
	Akiyama	1	2			
	CAC 3900	1	2			
	Canon (other)	11	23			
	Canon 7200	0	0			
	CLC 4000	1	2			
	DocuTech	3	6			
	Heidelberg	2	4			
	Hewlett Packard/HP	3	6			
	Karat	1	2			
	Konica	5	10			
	NCAD	1	2			
	Quick Master	1	2			
	Ricoh	1	2			
	Ryobi	1	2			
	Toshiba	2	4			
	Viewtech	1	2			
	Xerox (other)	3	6			
	Xerox 2045	4	8			
	Xerox 6135	3	6			
	DocuColor 12	2	4			
	Lanier	0	0			
	MP 8500	0	0			
	Savin	0	0			
	Sakurai	0	0			
	Other	0	0			
	Don't know	0	0			
	Refused	0	0			
	Total	48	100			

	Specify the brand and model number for your second press under other to question 1.12	Count	Percent			
	AB Dick	0	0			
	Akiyama	0	0			
	CAC 3900	0	0			
	Canon (other)	6	12			
	Canon 7200	2	4			
	CLC 4000	0	0			
	DocuTech	1	2			
	Heidelberg	1	2			
	Hewlett Packard/HP	0	0			
	Karat	0	0			
	Konica	1	2			
	NCAD	0	0			
	Quick Master	0	0			
	Ricoh	1	2			
	Ryobi	1	2			
	Toshiba	1	2			
	Viewtech	0	0			
	Xerox (other)	4	8			
	Xerox 2045	0	0			
	Xerox 6135	0	0			
	DocuColor 12	3	6			
	Lanier	1	2			
	MP 8500	1	2			
	Savin	0	0			
	Sakurai	0	0			
	Other	1	2			
	Don't know	0	0			
	Refused	0	0			
	No other	25	51			
	Total	49	100			

	Specify the brand and model number for your third press under other to question 1.12	Count	Percent			
	AB Dick	0	0			
	Akiyama	0	0			
	CAC 3900	0	0			
	Canon (other)	3	13			
	Canon 7200	1	4			
	CLC 4000	0	0			

	DocuTech	0	0			
	Heidelberg	0	0			
	Hewlett Packard/HP	1	4			
	Karat	0	0			
	Konica	0	0			
	NCAD	0	0			
	Quick Master	0	0			
	Ricoh	1	4			
	Ryobi	0	0			
	Toshiba	0	0			
	Viewtech	0	0			
	Xerox (other)	1	4			
	Xerox 2045	0	0			
	Xerox 6135	0	0			
	DocuColor 12	0	0			
	Lanier	0	0			
	MP 8500	0	0			
	Savin	0	0			
	Sakurai	1	4			
	Other	0	0			
	Don't know	0	0			
	Refused	0	0			
	No other	16	67			
	Specify the brand and model number for your fourth press under other to question 1.12	Count	Percent			
	AB Dick	0	0			
	Akiyama	0	0			
	CAC 3900	0	0			
	Canon (other)	1	12.5			
	Canon 7200	0	0			
	CLC 4000	0	0			
	DocuTech	0	0			
	Heidelberg	0	0			
	Hewlett Packard/HP	0	0			
	Karat	0	0			
	Konica	0	0			
	NCAD	0	0			
	Quick Master	0	0			
	Ricoh	0	0			
	Ryobi	0	0			
	Toshiba	1	12.5			
	Viewtech	0	0			

	Xerox (other)	0	0			
	Xerox 2045	0	0			
	Xerox 6135	0	0			
	DocuColor 12	0	0			
	Lanier	0	0			
	MP 8500	0	0			
	Savin	0	0			
	Sakurai	0	0			
	Other	0	0			
	Don't know	0	0			
	Refused	0	0			
	No other	6	75			
	Total	8	100			
	Specify the brand and model number for your fifth press under other to question 1.12	Count	Percent			
	AB Dick	0	0			
	Akiyama	0	0			
	CAC 3900	0	0			
	Canon (other)	0	0			
	Canon 7200	0	0			
	CLC 4000	0	0			
	DocuTech	0	0			
	Heidelberg	0	0			
	Hewlett Packard/HP	0	0			
	Karat	0	0			
	Konica	0	0			
	NCAD	0	0			
	Quick Master	0	0			
	Ricoh	0	0			
	Ryobi	0	0			
	Toshiba	0	0			
	Viewtech	0	0			
	Xerox (other)	0	0			
	Xerox 2045	0	0			
	Xerox 6135	0	0			
	DocuColor 12	0	0			
	Lanier	0	0			
	MP 8500	0	0			
	Savin	0	0			
	Sakurai	0	0			
	Other	0	0			
	Don't know	0	0			

	Refused	0	0			
	No other	2	100			
	Total	2	100			
A13	In what year did you get your first digital press?	Count	Percent			
	2005	5	5			
	2004	5	5			
	2003	6	6			
	2002	12	12			
	2001	4	4			
	2000	6	6			
	1999	6	6			
	1998	8	8			
	1997	6	6			
	1996	5	5			
	1995	15	15			
	1994	4	4			
	1991	2	2			
	1990	2	2			
	1988	2	2			
	1987	1	1			
	1980	1	1			
	Don't know	10	10			
	Refused	3	3			
	Total	103	100			
A14	And how many digital presses did you have at the end of these following years?	Count	Percent			
	2004					
	0	9	8.7			
	1	29	28.2			
	2	20	19.4			
	3	16	15.5			
	4	10	9.7			
	5	6	5.8			
	6	4	3.9			
	7	1	1.0			
	10	2	1.9			
	Don't know	2	1.9			
	Refused	4	3.9			
	Total	103	100			

	2003					
	1	8	12.3			
	2	19	29.2			
	3	14	21.5			
	4	10	15.4			
	5	2	3.1			
	6	4	6.2			
	8	1	1.5			
	10	1	1.5			
	Don't know	2	3.1			
	Refused	4	6.2			
	Total	65	100			
	2002					
	1	8	14.3			
	2	19	33.9			
	3	7	12.5			
	4	9	16.1			
	5	2	3.6			
	6	2	3.6			
	8	1	1.8			
	9	1	1.8			
	Don't know	3	5.4			
	Refused	4	7.1			
	Total	56	100			
	2001					
	1	7	15			
	2	13	28			
	3	10	21			
	4	5	11			
	5	1	2			
	6	3	6			
	9	1	2			
	Don't know	3	6			
	Refused	4	9			
	Total	47	100			
	2000					
	1	3	7.5			
	2	12	30.0			
	3	9	22.5			
	4	4	10.0			
	6	2	5.0			
	9	1	2.5			
	Don't know	5	12.5			

	Refused	4	10.0			
	Total	40	100			
	1999					
	1	2	6			
	2	9	26			
	3	6	17			
	4	4	11			
	6	1	3			
	9	1	3			
	Don't know	8	23			
	Refused	4	11			
	Total	35	100			
	In what year did you you acquire each additional press?	Count	Percent			
	2004					
	-1	3	3			
	0	58	56			
	1	27	26			
	2	5	5			
	Don't know/refused	10	10			
	Total	103	100			
	2003					
	-1	1	1			
	0	64	62			
	1	22	21			
	2	4	4			
	3	1	1			
	Don't know/refused	11	11			
	Total	103	100			
	2002					
	-1	4	4			
	0	60	58			
	1	24	23			
	2	3	3			
	4	1	1			
	Don't know/refused	11	11			
	Total	103	100			
	2001					
	0	78	76			
	1	11	11			
	2	1	1			
	Don't know/refused	13	13			

	Total	103	100			
	2000					
	-1	1	1			
	0	75	73			
	1	8	8			
	2	3	3			
	Don't know/refused	16	16			
	Total	103	100			
	Before 2000					
	0	38	37			
	1	28	27			
	2	9	9			
	3	6	6			
	4	4	4			
	6	1	1			
	9	1	1			
	Don't know/refused	16	16			
	Total	103	100			
A15	How many other non-digital presses do you have in your company?	Count	Mean	Min	Max	SD
	Web Offset presses	14	0.4	0	13	1.6
	Sheetfed Offset presses	72	3.0	0	20	3.2
	Flexography presses	3	0.1	0	6	0.8
	Gravure presses	1	0.0	0	1	0.1
	Inkjet presses	13	0.2	0	4	0.7
	Other	13	0.5	0	20	2.6
	What kinds of other presses do you have?	Count	Percent			
	Engraving press/letter press	7	54			
	Cisograph	0	0			
	Screen printing	2	15			
	Water press	1	8			
	Risograph	2	15			
	Don't know	1	8			
	Refused	0	0			
	Total	13	100			

Appendix B

Summary of digital paper survey results.

A1	How frequently do you use the following grades of paper?	Count(100)	Very Frequently	Somewhat Frequently	Rarely	Never
a	Uncoated Uncalendered		28	35	24	13
b	Uncoated Calendered		30	38	23	8
c	Uncoated Supercalendered		12	18	32	31
d	Premium Uncoated		36	35	18	9
e	Premium Bond		35	25	25	13
f	Coated Matte		30	36	23	10
g	Coated Satin		21	28	29	20
h	Coated Gloss		62	20	11	6
i	Coated High-Gloss		24	35	22	17
j	Coated Enamel		14	24	19	41
k	Recycled		8	28	38	23
l	Synthetic Grades		4	12	35	45
m	Textured		4	18	46	30
n	Tinted or Colored		15	31	33	19
A2	Is there another grade that you use that wasn't included?	Count	Yes	No	Very Frequently	Somewhat Frequently
		100	10	90	6	4
A3	What percentage of fiber content is the recycled paper?	Count (74)	Percentage			
	0 - 9%	9	12%			
	20 - 30%	30	40%			
	40 - 49%	1	1%			
	> 50%	12	16%			
A4	Out of the grades used "Very Frequently" which one do you use the most?	Count (100)	Percentage			
a	Uncoated Uncalendered		11			
b	Uncoated Calendered		6			
c	Uncoated Supercalendered		2			
d	Premium Uncoated		7			

e	Premium Bond		14			
f	Coated Matte		8			
g	Coated Satin		3			
h	Coated Gloss		31			
i	Coated High-Gloss		5			
j	Coated Enamel		3			
k	Recycled		2			
l	Synthetic Grades		1			
m	Textured		0			
n	Tinted or Colored		3			
A5	What percentage of paper grades used are:	Count (100)	Percentage			
	Web-fed (roll)	5	5%			
	Sheet-fed	85	85%			
A6	How is the paper grade for a digital print job selected?	Count (100)	Percentage			
	By company only	8	8%			
	Who in the company make paper selections	Count (64)	Percentage			
	Owner/President/Management	15	23%			
	Sales	13	20%			
	Customer Service	10	16%			
	Production Manager	9	14%			
	Estimating	6	9%			
	Others	11	18%			
	By Customer/Print Buyer only	4	4%			
	Collaboration of Printer and Customer	22	22%			
A7	Is your purchasing process limited to a particular brand from the outset?	Count (100)				
	Yes	28				
	No	71				
	Don't Know	1				

		Count (28)	Percentage			
a	Contractual Agreement	3	11%			
b	Brand is best value for the money	23	82%			
c	Both contractual and money	0	0%			
d	Others (quality and availability	2	7%			
	Total		100%			
	How many brands are in your purchasing portfolio?	Count	5% Trimmed Mean	Min	Max	Standard Deviation
		71	18	2	150	31
A8	Which factors are critical when evaluating brands of paper for your digital press?	Count (100)	5 "Critically Important"	1"Not at all Important"		
a	Price		29	1		
b	Runnability		75	0		
c	Print Quality		68	0		
d	Appearance such as brightness, whiteness finish		32	0		
e	Product range (weight, size, finish)		15	5		
f	Availability of grade (short turn-around on ordering)		45	1		
g	Multipurpose application across different printing technologies		19	15		
A9	How big a difference do you see among the brands available with regard to the following factors?	Count (100)	Major Difference	Minor Difference	No Difference	
a	Price		27	62	6	
b	Runnability		36	51	8	
c	Print Quality		31	58	7	
d	Appearance such as brightness, whiteness finish		28	61	7	
e	Product range (weight, size, finish)		25	62	8	
f	Availability of grade (short turnaround on ordering)		34	53	9	
g	Multipurpose application across different printing technologies		14	64	18	

A10	When evaluating paper for your digital printing business, how important is each of the following paper characteristics?	Count (100)	Critically Important	Quite Important	Somewhat Important	Not Important
a	Stiffness		13	28	38	14
b	Sheet or web strength		10	20	37	28
c	Surface smoothness		31	34	25	7
d	Surface strength		19	30	35	11
e	Surface finish (e.g., matte, gloss)		39	36	21	2
f	Accurate sheet dimensions		68	17	10	2
g	Dimensional Stability (Change with moisture and heat e.g., curl)		51	24	19	5
h	Moisture level		45	27	21	6
i	Storage and handling requirements		14	40	32	13
h	Brightness		24	31	41	3
k	Color		21	31	37	10
l	Lightfastness		14	32	29	19
m	Toner/Ink adhesion		84	11	4	0
n	Opacity		24	35	36	1
o	Uniformity		69	22	4	1
p	Basis Weight		30	31	29	5
A11	Out of the Critically Important characteristics, which one is most important and second most important?	Count	Most Important	Second Most mportant		
			92	83		
a	Stiffness		2	0		
b	Sheet or web strength		0	3		
c	Surface smoothness		4	6		
d	Surface strength		0	2		
e	Surface finish (e.g., matte, gloss)		3	4		
f	Accurate sheet dimensions		9	10		
g	Dimensional Stability (Change with moisture and heat e.g., curl)		4	11		
h	Moisture level		4	5		
i	Storage and handling requirements		1	1		
h	Brightness		0	8		
k	Color		0	0		

l	Lightfastness		0	0		
m	Toner/Ink adhesion		48	14		
n	Opacity		6	8		
o	Uniformity		3	0		
p	Basis Weight		2	1		
A12	Based on your experience, which of the following factors needs major improvement, minor improvement or no improvement?	Count(100)	Major Improvement	Minor Improvement	No Improvement	
a	Runnability		10	58	26	
b	Print Quality		8	59	28	
c	Appearance such as brightness, whiteness finish		9	54	32	
d	Product range (weight, size, finish)		26	50	20	
e	Availability of grade (short turnaround on ordering)		20	47	28	
A13	What specific improvements would you most like to see in new digital paper product offerings?	Count	List of Responses			
		100	Stable/Consistency, brighter, accuracy of dimensions, adhesion, lower price, less chemicals, availability, accept toner better, runnability, variety of papers/ sizes			
A14	What limitations on your choice of papers does your digital press impose?	Count (100)	List of Responses			
			Cut size, Coating, Weight, Toner Problems, Runnability, Limited textures, Cracking/ Smoothness, Moisture control, etc			
A15	Did you have to modify storage facility to handle digital papers?	Count (100)				
	Yes	16				
	No	84				
A16	Would you say the cost of paper for digital printing over the last 2 years has:	Count (100)				
	Increased significantly	10				
	Increased somewhat	60				
	Stayed the same	18				

	Decreased somewhat	7				
	Decreased significantly	0				
A17	If the price of paper changes significantly either up or down, do you pass on the savings or additional cost to the customer?	Count(77)	Percentage			
	Yes, pass on savings	1	1%			
	Entire savings	1	100%			
	Some percentage	0	0%			
	Yes, pass on the costs	49	100%			
	Entire cost	25	51%			
	Some percentage	24	49%			
	No	26	34%			

Appendix C

Digital Press Brand and Model as Reported by Survey Respondents

Brand	Percent
HP Indigo	15%
IBM	0%
NexPress 2100	2%
NexPress/Kodak DigiMaster	4%
Océ	2%
Xerox 200 series	0%
Xerox black and white DocuTech	6%
Xerox DocuColor 2060	2%
Xerox DocuColor 6060	7%
Xerox DocuColor 8000	0%
Xerox iGen3	8%
Xerox Nuvera	1%
Xeikon	3%
Other	38%
Don't know	9%
Refused	4%
Total	100%

Appendix D

Other Types of Digital Presses as Reported by Research Participants

Specification of the brand and model number of digital presses in the "other" category.

Brand and Model Number	Percentage
Canon (other)	23%
Konica	10%
Xerox 2045	8%
Xerox (other)	6%
Xerox 6135	6%
Hewlett Packard/HP	6%
DocuTech	6%
DocuColor 12	4%
Heidelberg	4%
Toshiba	4%
AB Dick	2%
Akiyama	2%
CAC 3900	2%
NCAD	2%
Quick Master	2%
Ricoh	2%
Ryobi	2%
CLC 4000	2%
Karat	2%
Viewtech	2%
Canon 7200	0%
Lanier	0%
MP 8500	0%
Savin	0%
Sakurai	0%
Other	0%
Don't know	0%
Refused	0%
Total	100%

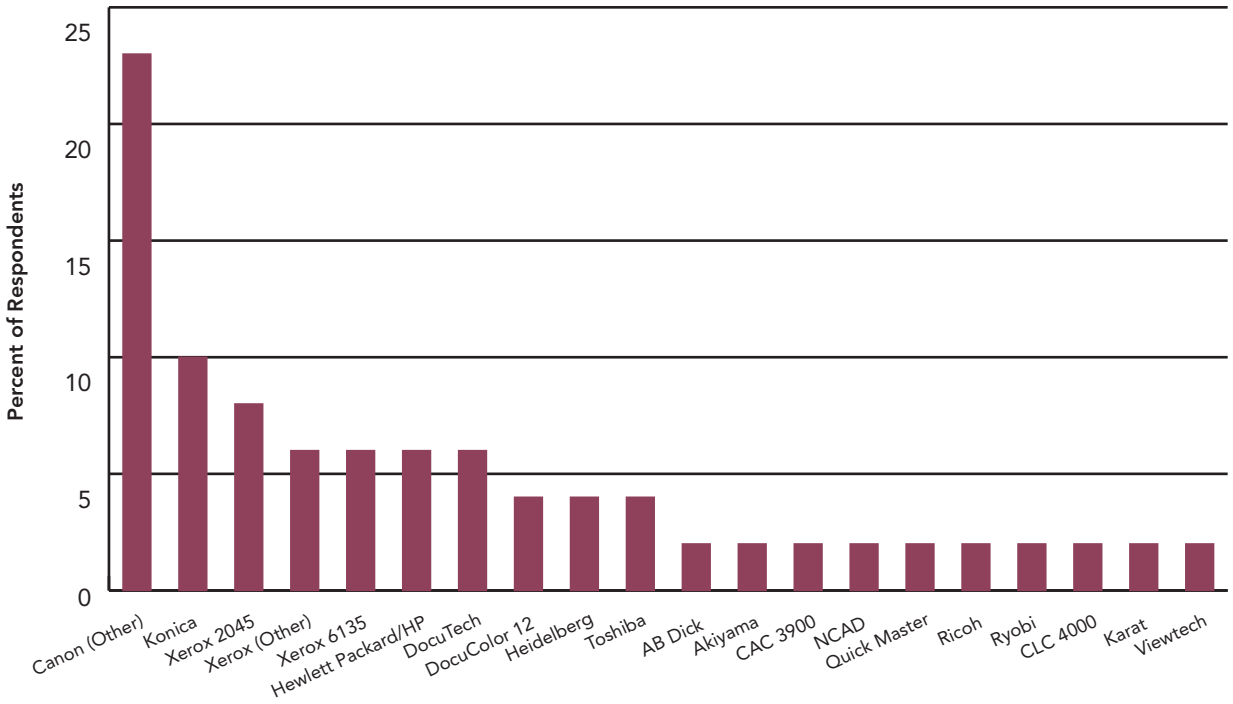

Figure A1. Specification of the brand and model number of other digital presses.

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