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Survey of digital press manufacturers: Critical paper requirements

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A Research Monograph of the
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R·I·T Printing Industry Center
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Executive Summary

The purpose of this study was to identify constraints and potential solutions for improved performance and quality of digitally printed papers. From a device manufacturer standpoint, this research sought to understand the characteristics that are important to successful printing and the various elements that make up the total value proposition presented to print customers.

Specific research objectives were:

- To understand paper properties that limit innovation in printing devices.
- To identify and rate critical paper property requirements which constrain digital printer performance and quality.
- To determine the decision factors that, along with paper price, make up the total value proposition presented to print customers.
- To evaluate current and future digital printing industry technological trends, including printer technologies, consumer needs, and new market opportunities.

Findings indicated that the only universally critical paper properties for digital presses were dimensional stability and uniformity of product. However, several other paper characteristics, such as sheet filler transfer to fuser rollers, sheet recycle content, moisture level, and toner adhesion, were considered important based on the application of the printed piece.

Elements that were considered universally important to the value proposition presented to customers when considering purchasing a digital press were variable data capability, ability to use different grades of paper, print quality, runnability of sheetfed devices, and runnability of the printed sheet through finishing equipment. Additionally, several other elements were highly rated by some respondents, such as ability to print the same stock across different technologies, higher image quality expectations, more automated finishing operations, and current presses imposing paper choice limitations. Those elements considered critical to the value proposition by most device manufacturers represent a set of customer expectations for all digital presses. On the other hand, elements that were considered important to the value proposition by only some manufacturers, yet still highly scaled, were considered strongly related to the market segment that the manufacturer serves.

Overall, it was found that there was no best set of paper characteristics for production digital presses. Likewise, there is no one best value proposition to present to customers. Instead, there are multiple paper property requirements and value propositions based on specific print applications and customer needs.

Introduction

The purpose of this study was to identify constraints and potential solutions for improved performance and quality of digitally printed papers. Input was obtained from digital press manufacturers about substrate properties that limit innovation in digital presses, and that limit the ability to address known customer needs through print engine innovation.

From a device manufacturer standpoint, this research sought to understand the characteristics that are important to successful printing and the various elements that make up the total value proposition presented to print customers. Specific research objectives were:

- To understand paper properties that limit innovation in printing devices.
- To identify and rate critical paper property requirements which constrain digital printer performance and quality.
- To determine the decision factors that, along with paper price, make up the total value proposition presented to print customers.
- To evaluate current and future digital printing industry technological trends, including printer technologies, consumer needs, and new market opportunities.

The scope of this research was limited to the high-end digital production market segment in North America. Research was limited to devices using electrophotographic technology. Inkjet technology, though rapidly growing in use, was considered to have different substrate challenges better addressed separately.

The findings indicated that there were few paper properties that all device manufacturers considered to be critically important for digital presses.

Recap of Phase One

The initial phase of research sought "to identify constraints and potential solutions for improved performance and quality of digitally printed papers" (Evans & LeMaire, 2005, p. 3). The source of information was print service providers who used what would be considered high-end electrophotographic printing devices. One hundred and three companies listed in the Rochester Institute of Technology Printing Industry Center database were surveyed. Included in the survey were both United States and Canadian organizations. The respondents represented a wide segment of the printing industry as measured by number of employees, total revenue, years in business, and types of work performed.

Digital papers were divided into several categories, and respondents were queried on their use by category. Overall, print service providers considered runnability and print quality to be the most important characteristics in paper selection. When queried about specific critically important paper characteristics, toner/ink adhesion, sheet uniformity, and accurate sheet dimensions were ranked most important. When asked which areas of digital papers needed improvement, the responses were more evenly matched. Product range, the need for multipurpose papers, runnability, appearance, and print quality were all considered important. However, when open-ended responses were considered, the need for increased product range and more multipurpose papers emerged. Vectors of product range limitation included basis weight, size, and caliper. Price was not considered a prime factor in digital paper selection (Evans & LeMaire, 2005, p. 64).

Respondents indicated that the most likely candidates for future growth were marketing and promotional materials, direct mail, and transactional printing (Evans & LeMaire, 2005, p. 36). Survey responses revealed that 5% of respondents produced 80% of all variable data jobs. Furthermore, 72% of respondents also owned sheetfed offset printing equipment. Leading into the second phase of research, print service providers were asked how the digital print engines they use limited their choice of paper. Inability to use a particular basis weight of paper, particularly heaver weights, was considered the most important limitation, closely followed by paper size and caliper.

Background

Technology

In the last two decades, electrophotography has developed to the point where it is a legitimate alternative to analog print production technologies such as offset lithography. Electrophotography's lack of a permanent image master provides unique advantages over analog printing methods, including reduced makeready and the ability to vary information from one page to the next. Several manufacturers have entered the production digital printing market because of these advantages.

The exact use of electrophotography varies from manufacturer to manufacturer, but the basic principle is the same. Initially, a photoconductive belt or roller is uniformly charged. Next, the image area is selectively discharged, usually by means of a laser. Subsequently, polymeric toner is brought into contact with the photoreceptor. Upon contact with the photoreceptor, toner particles attach to the discharged image areas of the photoreceptor. This toner image is then transferred to the substrate, where it is bonded using heat and pressure. Finally, the photoreceptor is cleaned of residual charges and toner in preparation for the next image.

Manufacturer-specific printing technology varies in several ways. First, toner can be attached to carrier beads by triboelectrification, or it can be suspended in a non-conductive liquid. Image development can be accomplished by a number of methods, including magnetic brushes, toner clouds, or flowing toner suspended in liquid across the surface of the photoreceptor. Another area of differentiation is the method used to transfer toner to the substrate. Toner can be transferred to the substrate using the photoreceptor belt or a separate roller. Additionally, the toner image can be transferred to the substrate one color at a time, or an entire toner image can be built on the intermediary belt prior to transfer. Also, each device manufacturer employs numerous proprietary electrostatic and physical mechanisms to ensure complete and uniform toner transfer to the substrate. Regardless of the method used, the goal is the same: superb image quality on a wide range of substrates.

The Relationship of Paper and Press

Both offset lithography and digital printing processes face substrate challenges. These challenges can be divided into four broad categories. First, the substrate must run through the press. Second, the substrate must accept the ink/toner, as well as the method of application, without undesirable effects. Third, the process must provide suitable image quality. Fourth, the printed piece must able to withstand the rigors it will be subjected to throughout its intended use.

A useful comparison may be drawn by briefly examining offset lithography. In offset, suction is used to remove a single sheet from the cut sheet stack. Subsequently, the sheet is passed from roller to roller by means of interconnected gripper fingers that maintain the sheet position relative to the printing units. Ink application is accomplished by taking advantage of differences in surface tension between the image and non-image areas of the printing plate. Once the application of ink has taken place, the substance used to carry the ink is either absorbed by the substrate or evaporated, leaving the colorant and vehicle bonded to the substrate.

Technical Considerations

Offset lithography faces numerous substrate challenges; however, there are unique differences in the role that substrates play in the digital printing processes. Since toner is deposited on the substrate primarily using electrostatic charges, both the design of the press and the conductivity of the substrate must be taken into account.

The moisture content of any substrate intended for digital printing is critical because moisture level affects the dielectric properties of the substrate. The moisture level must be low enough so that the substrate maintains its dielectric properties while holding a sufficient charge to enable toner transfer. However, substrate moisture level cannot be too low, as this will cause an excessive electrostatic charge that interferes with transport. On the other hand, if the moisture level is too high then the substrate will not be able to hold a sufficient charge, resulting in poor toner transfer (Xerox, 2004, p. 17). The substrate must also be able to hold the proper charge through the transfer phase (Johnson, 1998, p.71). Therefore, electrophotographic devices must be designed to preserve optimal paper conductivity throughout the entire printing process. Furthermore, factors such as the type of pulp, the orientation of substrate fibers, and the fillers used in the substrate have additional effects on conductivity. As Borch and Svendsen (1983) aptly point out, "[t]ransfer and fusing of toner particles require suitable electrical and chemical paper characteristics in addition to the possible adjustment of some of the more conventional (classical) paper properties" (p. 285).

After toner application, the toner is permanently bonded to the substrate. Typically, bonding takes place by fusing the toner to the substrate using heat and pressure. In the fusing process, polymeric toner is heated to its glass transition temperature T_g (Schuize-Hagenest & Rohde, 2004, p. 494). At glass transition temperature, solid toner changes to a liquid state and individual particles begin to coalesce. Above T_g, toner viscosity rapidly decreases. As liquefaction occurs, the toner penetrates and bonds to the substrate fibers. The strength of the bond is significantly dependent on the permeability of the substrate. Permeability is defined by Hwang (2000) as a set of conditions taking "into account the size, shape, spacing, and roughness of the paper as well as the physical properties of the fluid" (p. 26).

Physical properties of the substrate can also lead to printing difficulties in electrophotography. Dimensional stability of the substrate during the printing process is closely associated to changes in moisture content, which can often be related to the fusing process. Dimensional stability during transport becomes critical in duplexing, since the substrate is cycled through the printing system a second time. The surface finish of the substrate is also important. Unlike lithography, where a liquid ink penetrates the surface of the substrate, toner must be drawn into the substrate by electrostatic charge with the assistance of physical mechanisms.

Grain direction is another critical aspect of digital substrates because substrate stiffness has an affect on transport. It is a good printing practice to consider grain direction from the end use of the product back through any finishing steps, and then, to the print engine. However, at times the substrate grain will not be in the ideal direction for transport, and additional waste may be incurred to resolve the press and finishing conflicts.

One of the most important concepts of digital printing is to produce a complete document, and the production of a complete document for an end user typically involves some form of finishing. Due to the fusing process, digitally printed sheets have a lower moisture content than lithographically printed sheets. This can lead to increased static and sheet curl problems that interfere with finishing processes (Xerox, 2004, p. 37). Table 1 summarizes the relationship between several common substrate properties, conditions that affect those properties, and digital press performance.

Table 1. Relationship of paper conditions to press performance

Parameter	Cause	Result	Transport	Printing	Post-Processing
High moisture level	Environment, Manufacture	Increased conductivity, Change in dimensions, Wavy edges	Feed problems	Poor toner transfer, Misregistration	Jams in finishing
Low moisture level	Environment, Manufacture	Decreased conductivity, Change in dimensions, Static buildup, Tight edges	Jams	Misregistration	Jams in finishing
	Fusing	Change in dimensions		Misregistration	Jams in finishing
Grain direction	Substrate	Variance in stiffness	Transport		Toner cracking
Substrate dimensions	Environment, Moisture, Cutting accuracy, Fusing	Wrong or inconsistent dimensions	Feed problems		Feed problems in finishing
Surface smoothness: Too smooth	Manufacture		Feed problems		Feed problems in finishing
Surface smoothness: Too rough	Manufacture			Poor toner transfer	
Porosity	Manufacture		Vacuum feed problems	Toner penetration	Vacuum feed problems
Filler & Formation	Manufacture			Toner transfer & Even toner density, Filler buildup on fuser roller	
Paper dust	Cutting	Paper dust		Dust buildup on fuser roller	

Business Considerations

Regardless of the substrates used in digital printing, technical challenges are expressed through the business purpose of the print job. A primary business reason for using digital technology is the reduction of print cycle time. The ability to reduce makeready time by eliminating the permanent image master and subsequent preparatory work reduces both the materials and the time to the first good press sheet, enabling fast turn-around of short run jobs. However, reduced cycle time places unique demands on digital device manufacturers. The initial characteristics of the substrate must contribute to reliable transport as well as excellent print quality. Also, during the printing and fusing processes the substrate must maintain those conditions, as the substrate must not adversely change to a degree that interferes with finishing and distribution upon exit from the press. Furthermore, customized communication places even stricter demands on substrate runnability, since a uniquely printed piece must be accounted for and replaced if destroyed.

Productivity

Previous challenges in digital printing centered on image quality. With current developments in digital printing technology, image quality has become a minor issue. It is now understood that digital devices will coexist with lithographic devices, with both producing high quality print jobs, and often in the same facility. Current issues center on the productivity of digital presses, the durability of digitally printed pieces, and increasing the range of applications for digital printing.

While the current generation of digital presses produce pages at a previously unheard of rate, they are still slow when compared to their lithographic counterparts. Print speed is important because of overhead. Typically, overhead consists of two components, variable overhead and fixed overhead. Variable overhead includes labor, materials, maintenance, click charges, and et cetera, and it is proportional to device output. Conversely, fixed overhead includes the costs of equipment, building space, and other fixed expenses, and it is inversely proportional to device output. Therefore, a significant component of reducing the cost of a digital print is increasing output per unit of time. However, increased productivity places additional strain on the substrate-device relationship. Transport speed must be increased while charging and toner transfer time is decreased. Additionally, as transport speed increases, fuser dwell time decreases, requiring increased fusing temperature. These criteria place additional demands on the both the substrate and how the press maintains the substrate at optimal condition.

Fulfillment and Mailing

Another important business consideration for digital device manufacturers is the ability of the press to handle substrates intended for mailing. As found by Evans and LeMaire (2005), direct mail and transactional documents comprised 38% of digitally printed pieces. Furthermore, marketing and promotional materials, many of which are mailed, consisted of an additional 24% of that total. Moreover, the reliance on the U.S. Postal Service to place the finished piece in the hands of the customer imposes several conditions. First, the digital press must be able to run the correct type and size of substrate for mail distribution. Second, cost control in mailing implies weight reduction. These constraints, coupled with short cycle times, often create the need to run partly formed pieces to reduce finishing time. Therefore, the stock and the digital press must be closely matched in capabilities to reduce waste.

Another challenge for digital devices is the durability of the printed piece. In electrophotography, toner particles coalesce and flow into the fibers of the substrate. A pressure roller coated with a release oil forces the liquefied toner into the surface of the substrate (Johnson, 1998, p. 121). However, liquefied toner penetrates the fibers of the substrate to a lesser degree than lithographic ink, making toner more susceptible to abrasion. With the importance of finishing operations and the use of the USPS for delivery, digitally printed pieces undergo significant handling prior to reaching their destination. As Frey, Christensen, and DiSantis (2006) comment, during the fulfillment and mailing stages a digitally printed document undergoes a number of physical and chemical stresses, including abrasion, folding, and exposure to light, heat, and air contaminants.

New Products

As Fryer (2007) comments, "Speedier market intelligence and production in smaller batches allows firms to match supply to changing conditions." The advantages of inventory reduction dovetail with digital printing because of its low makeready cost and ability to respond to actual demand. The packaging and label markets are two notable areas where the use of digital printing is being explored. On-demand printing and customization allow printers to explore new possibilities by coupling digital printing with databases.

One example is Merlin International, a digital printer founded in 1991 in Rochester, NY, that exploits the potential of customized label printing to its fullest. For one customer, Merlin creates price strips using a three-dimensional model. Strips are printed on large sheets approximately twenty inches wide by seventy-two inches long. Product names are printed along the length of the sheet. Along the width of the sheet, prices for each product are printed that vary according to the region a particular store occupies. Sheets are then printed and stacked so that, when a group of finished sheets is cut into strips, the strips represent the layout for all the products for an individual store within a unique price zone (Smith, D., personal communication, May 1, 2007).

Digital printing has also extended to the area of packaging, where ongoing research is being conducted on printing substrates previously reserved for analog printing processes, such as paperboard and synthetic materials. To facilitate printing these substrates, Sirviö (2003) explains that high-end digital presses use some form of intermediary transfer belt that reduces the need for optimal substrate dielectric properties (p. 603). The use of intermediate transfer devices enables printing of a wider range of substrates; nevertheless, there are additional challenges printing packaging substrates, and in particular synthetics. As Lahti (2005) comments, "Extrusion coatings in general have an impervious, chemically inert, non-porous surface with low surface energies that cause them to be non-receptive to bonding with toners" (p. 2). Therefore, similar to flexographic presses, nonporous synthetic substrates need a corona treatment that oxidizes the surface to reduce its surface tension below that of the toner.

Trends in Digital Printing

As pointed out by Evans and LeMaire (2005), runnability is currently the most significant substrate-related problem faced by production digital presses. However, substrate modification to improve runnability, although possible, often involves sacrificing other desirable substrate characteristics. For example, increased surface roughness improves feeding; however, it also reduces efficiency of toner transfer. Increasing substrate moisture content to resolve curling adversely affects the conductivity of the substrate, sacrificing toner transfer. Because of conflicting substrate requirements, some solutions lie outside the realm of substrate properties. One effective solution is to convert digital presses to webfed presses. Web technology has been used by lithography for decades, and it eliminates the problems encountered during sheet transport. Web feeding allows digital presses to run substrates of reduced basis weight, thereby lowering distribution costs. Obviously, webfed printing requires a sheeting process after printing. However, if it can be efficiently integrated into the workflow, web feeding offers a proven method of increasing runnability.

Digital printing relies on the successful placement and bonding of toner to the substrate. Traditionally, polymeric toner was manufactured by combining polymer, pigment, and additives (Mort, 1989, p. 131-134). The resulting mass was extruded and mechanically ground to produce toner particles small enough for use in electrophotography. Good results have been achieved through this process resulting in toner partials less than 10 microns in size. As Mort (1989) comments, a single period at the end of a sentence can contain over 100 toner particles. In spite of this success, mechanically ground toner has limitations. One limitation is minimum particle size. Mechanical milling limits the minimum particle size to about 7 microns (Galliford, 2004, p. 3). Particle size is important because it limits device resolution.

> "Grunlach's Law theoretically shows that there is an inverse exponential relationship between the mean toner particle size and addressed dot density in digital printing. Theoretically, for perfect reproduction of dots and print features at 600 dpi particle size of about 5 µ is required and at 1200 dpi you need toner of about 3 µ." (Galliford, 2004, p. 3)

In addition to limitation of mean particle size, mechanically milled toners exhibit a wide distribution of particle sizes and shapes that adversely affect image quality.

One solution is the use of chemically prepared toner (CPT). Unlike mechanical milling, CPT toner is synthesized from nanometer-sized particles by one of several chemical processes, such as suspension polymerization, emulsion aggregation, or chemical milling (Galliford, 2004, pp. 6-5). CPT toners have smaller particle sizes (3-5 µ), as well as more uniform mean particle size distribution. Furthermore, CPT allows a device to deposit a thinner layer of toner on the substrate. A thinner toner requires less fusing energy, which, in turn, allows faster printing speeds with reduced substrate distortion. Additionally, the smaller particle size permits better bonding of the toner to the substrate, thereby reducing the impact of abrasion. Frey, Christensen, and DiSantis (2006) comment, "[s]ince the strength of the mechanical adhesion is dependent upon the degree of "intermingling," smaller polymer molecules are preferable. They tend to mingle better in the locations of the voids between fibers, and therefore create stronger bonds in these areas" (p. 12). Nevertheless, there are substrate challenges using CPT toner. According to Sirviö (2003), "thinner [toner] layers would in principle mean also increased requirements [for smoothness] on paper surface" (p. 604).

Research Methodology

Introduction

The purpose of this study is to identify constraints and potential solutions for improved performance and quality of digitally printed papers used by the high-end digital production market in North America. In this phase of research, input was obtained from digital press manufacturers about substrate properties that limit innovation in digital presses, therefore limiting the ability to address known customer needs through print engine innovation.

Manufacturers of high-end electrophotographic devices were surveyed. From a device manufacturer standpoint, this research sought to understand the characteristics that are important to successful printing and the various elements that make up the total value proposition presented to print customers. Specific research objectives were:

- To understand paper properties that limit innovation in printing devices.
- To identify and rate critical paper property requirements which constrain digital printer performance and quality.
- To determine the decision factors that, along with paper price, make up the total value proposition presented to print customers.
- To evaluate current and future digital printing industry technological trends, including printer technologies, consumer needs, and new market opportunities.

Survey Design

Based on the stated objectives, a literature review was conducted to understand the substrate challenges faced by device manufacturers when designing production digital equipment.

The survey consisted of structured questions regarding various paper properties that were thought to limit current performance or future innovation in digital devices. Respondents were asked to rank the most important paper properties that limit performance and innovation. Also, from their perspective, device manufacturers were asked to indicate the paper properties that were part of the total value proposition presented to customers when making the decision to purchase a digital press. Furthermore, general information was requested on the type of print jobs each manufacturer's digital devices printed. Opportunity was provided for respondents to supply additional information not addressed by the survey questions. The survey was initially pilot tested at the RIT Printing Applications Laboratory because this lab has considerable experience with high-end electrophotographic devices. In addition, pilot tests were performed with the cooperation of several paper manufacturers.

Data Collection Plan

The survey was conducted by telephone with representatives from leading digital device manufacturers. These contacts were selected because they have had a prior relationship with the Printing Industry Center at RIT. Initially, a letter with the survey form was sent to these contacts. A follow-up phone call was made to set a date and time for a phone conference. During the phone conference, respondents were asked to answer the survey questions and to provide any additional information that they thought was important to the study.

The survey was divided into the following sections:

- Paper properties that limit current performance or future innovation,
- Important paper characteristics for optimal toner application,
- The decision factors that make up the total value proposition presented to printers who are evaluating production digital presses,
- Customer needs to be addressed by means of future print engine innovation,
- Specific types of print jobs that digital presses target,
- The color capability required for different types of print jobs, and
- Overall revenue related to electrophotography and the types of digital production presses offered.

These questions were presented along with a set of structured responses. Respondents were asked to rate each answer presented as critically important, quite important, somewhat important, or not important. They were then asked to rank the critically important responses in relation to the question. Respondents were encouraged to comment on any response where they felt it was necessary to elaborate on the available answers. Additionally, at the end of each section respondents were asked if they wanted to supply additional data or comments.

Data Analysis Plan

The importance of each response was determined using a Likert type scale. Responses were treated as interval data. The ranking of responses was structured as follows:

Critically Important	4
Quite Important	3
Somewhat Important	2
Not Important	1

Undoubtedly, as with any qualitative measurement, the assurance of a true interval scale could not be guaranteed. However, the lack of a true interval scale in Likert-style responses does not seriously affect a meaningful comparison of responses. As Jacquard and Wan (1996) assert, "for many statistical tests, rather severe departures [from intervalness] do not seem to affect Type I and Type II errors dramatically" (p. 4). However, it is likely that different respondents placed different emphasis on the terms critical, quite, somewhat, and not important. Therefore, it must be remembered that the differences between the level of importance attributed to the factors surveyed do not represent any form of ratio. Where applicable, the percentage of responses that indicated property importance was recorded. This was done to separate substrate requirements considered universally important to digital printing from substrate requirements that were considered to be application specific. Explanations for answers and open-ended responses were studied for trends as well as novel ideas. It is important to note that respondents represented a limited segment of the organization for which they worked. Therefore, this data may not represent the overall view of the organizations polled.

Summary of Findings

The responses to the survey questions and any additional information supplied are summarized below. Responses are shown as individual questions, with any additional information following.

Question 1: Which paper properties limit current performance/ future innovation in production digital (electrophotographic) presses?

Note: Information capacity was defined as the inclusion of content other than text and images on the printed sheet, such as RFID tags.

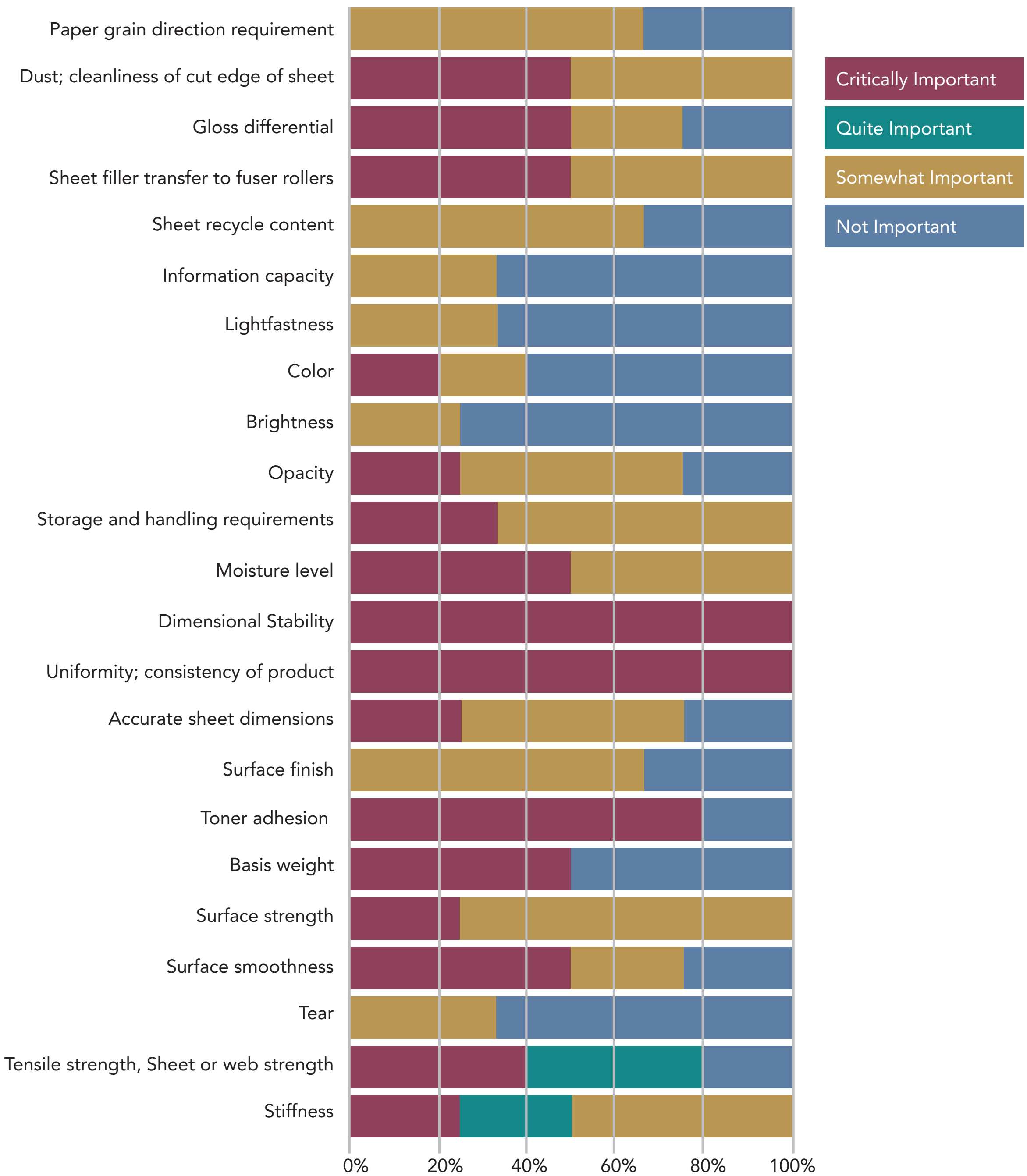

Figure 1. Percent of respondents indicating degree of importance of specific paper characteristics

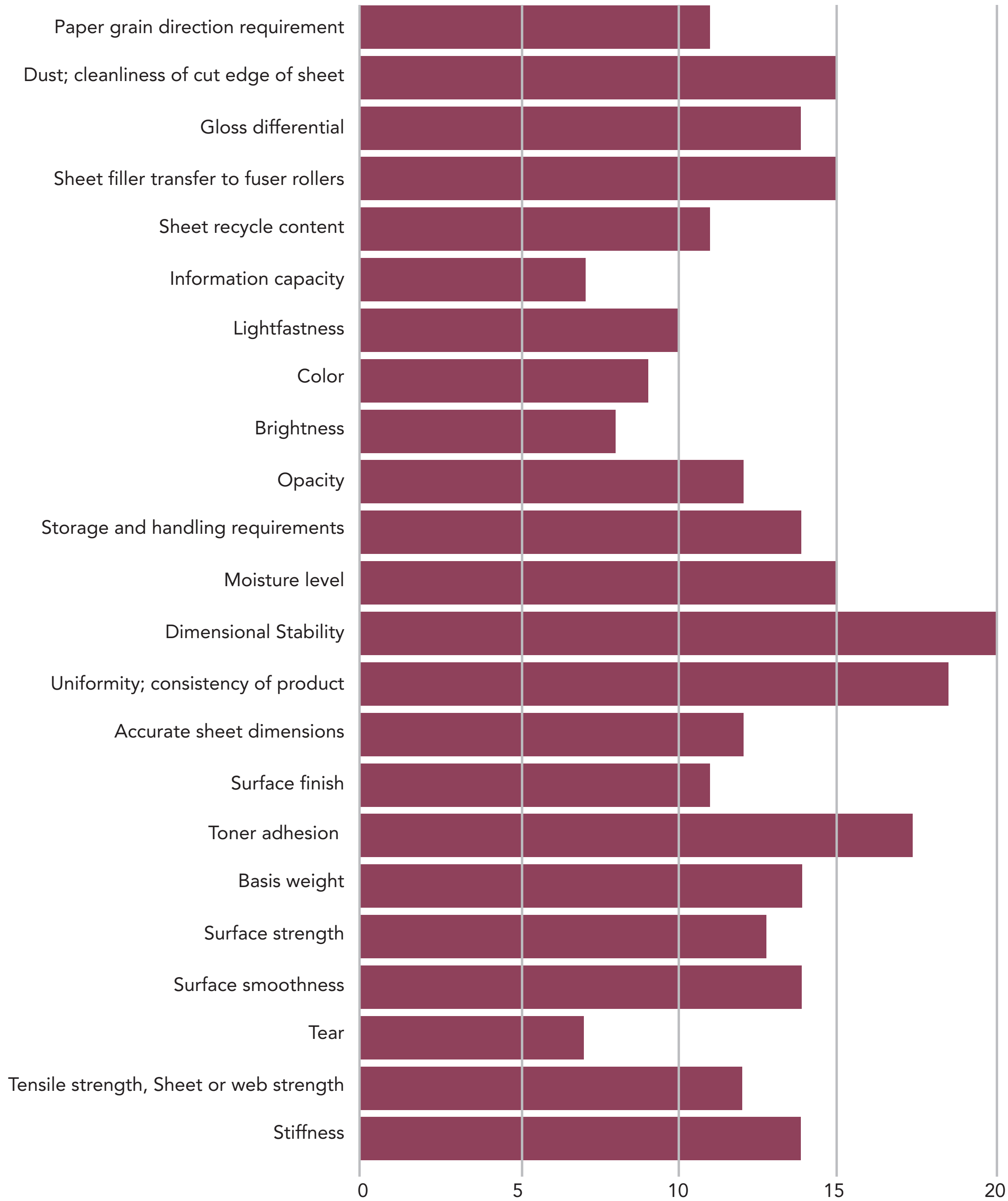

Figure 2. Totals of respondents indicating degree of importance of specific paper characteristics

Figure 1 shows that the paper properties dimensional stability and uniformity of product were critically important to all device manufacturers. One respondent declared that dimensional stability, while critically important, was especially important in printing applications where the substrate was put through the fuser more than once. Another respondent commented that it was important to consider stiffness in both machine and cross machine directions. Cross machine stiffness of paper had more of an effect in the feed section of the device, while machine direction stiffness had more importance in the transport system of the device.

On the other hand, information capacity, lightfastness, brightness, and tear were considered the least important paper characteristics. Several respondents commented that appearance qualities such as brightness were mostly aesthetic and more important to designers than device manufacturers. Another respondent remarked that attributes such as opacity, color, light fastness, and brightness were very application-focused. For example, the lightfastness of a direct mail piece was unimportant because of its short useful life.

Several respondents indicated that the importance of specific paper characteristics was dependent on the application as well as the intended market of the digitally printed piece. One respondent commented that if someone prints a set of presentation notes, then toner adhesion is not as important as it is to someone who is creating a piece for direct mail that will go through the U.S. Postal Service.

While only dimensional stability and uniformity of product were considered universally important, several other paper characteristics rated highly as shown by the Likert scale ratings in Figure 2. Characteristics also rating highly were sheet filler transfer to fuser rollers, sheet recycle content, moisture level, and toner adhesion. It was noted by one respondent that paper manufacturers need to eliminate contaminates that increase service calls.

These additional paper characteristics should be considered important. Also, since these specific paper characteristics rated highly, but were not considered universally important, it would be reasonable to say that they were dependent on the final application of the printed piece.

Most respondents did not specifically separate current needs from future requirements. However, some did indicate that sheet uniformity, dimensional stability, and handling requirements were important to current performance as well as to future innovation.

Question 1a: Out of the critically important characteristics (from Question 1), which one is most important and which is second most important?

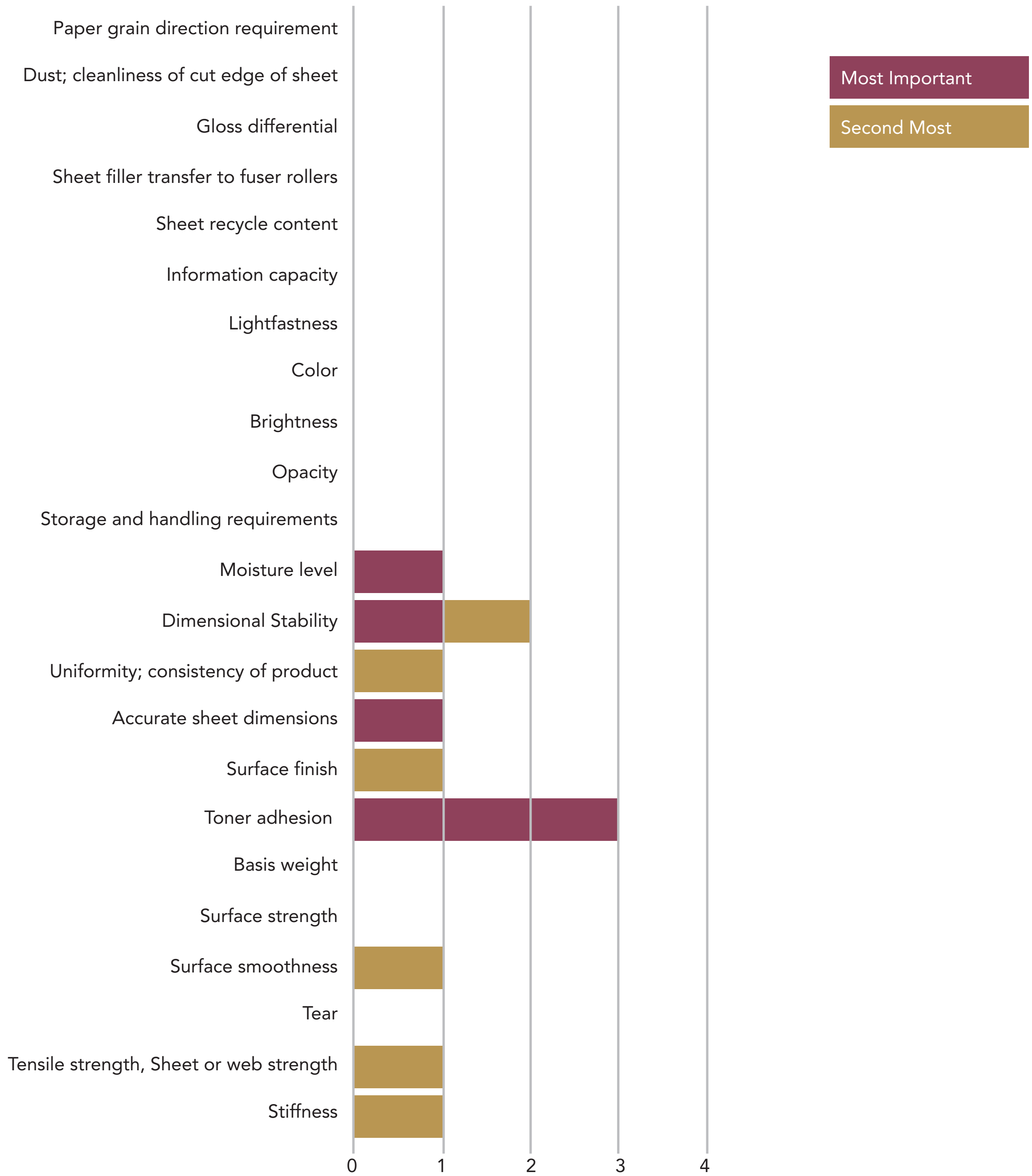

Figure 3. Ranking of critically important paper characteristics

This question asked respondents to select the most and second most important paper characteristic out of the characteristics that they considered critical.

This data was tallied as a count because many respondents were unable to rank any one characteristic as most important. Nevertheless, toner adhesion was most frequently cited because of abrasion in post-production processes.

Question 1b: How important are each of the following to optimal toner application?

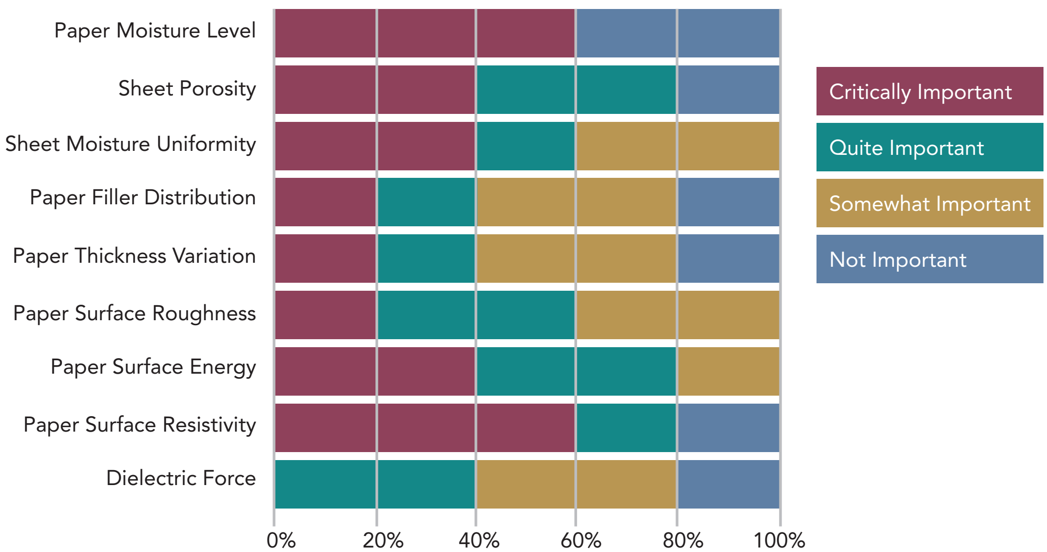

Figure 4. Percent of respondents indicating degree of importance of specific paper characteristics

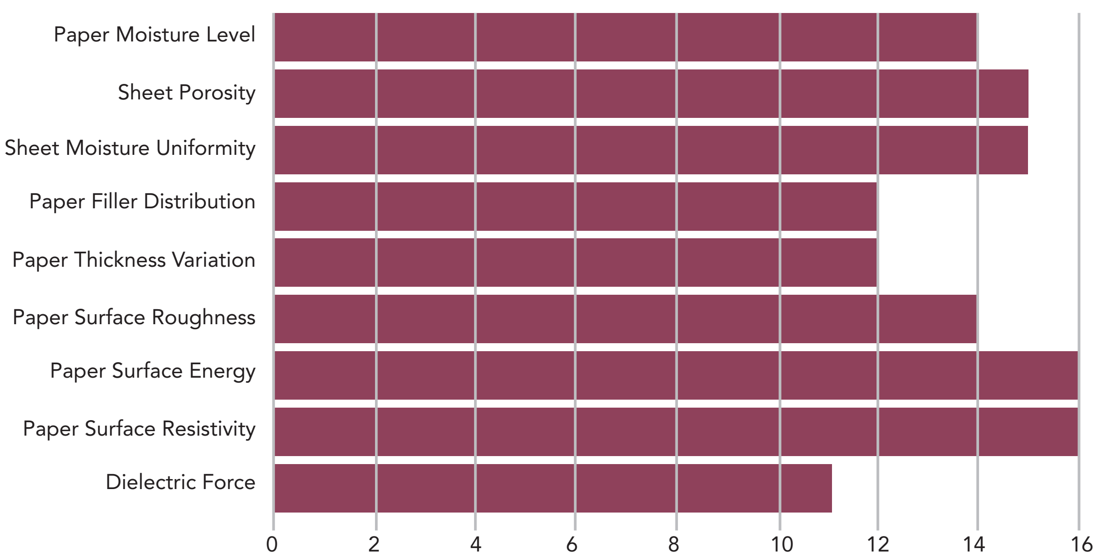

Figure 5. Totals of respondents indicating degree of importance of specific paper characteristics

Optimal toner application was considered essential to high-quality printing. Therefore, two substrate properties that contribute to optimal toner application—paper moisture and paper surface resistivity—were rated as critical by the highest percentage of respondents. Surface resistivity affects charge density at the surface of the substrate, which is related to even toner density. Since resistivity is greatly affected by formation and filler distribution within the sheet this response gives additional meaning to the importance of uniformity and consistency of product. One respondent commented that bulk resistivity was also important. Surface resistivity is the resistivity across two different points on the surface, while bulk resistivity is the resistivity from the top to the bottom of the sheet. Another respondent considered uniformity as print density across the sheet rather than a characteristic of the sheet itself. Dielectric force—which determines the efficiency of toner transfer—was considered least important.

Scaled results in Figure 5 confirmed the importance of surface resistivity and surface energy. In addition, sheet porosity, uniformity of moisture level, paper surface roughness, and paper surface energy ranked highly. The difference between the percentage of respondents indicating the importance of a characteristic to optimal toner application and the scaled importance of these characteristics can be attributed to the application as well as the device used for printing.

Evenness of toner density was considered critical in commercial printing, and in particular if the device is used for proofing. However, evenness of toner density was only considered somewhat important in in-plant printing, and even less important in direct mail applications. Also, respondents indicated that the larger the sheet size, the more the variance of print density. This was considered to be more of a device variance than a lack of substrate uniformity.

Question 1c: Are there specific sheet property metrics established for each of your production presses? If so, which properties?

Table 2. Established sheet property metrics for production presses

Company	Properties
Kodak NexPress	None indicated
Ricoh	None indicated
Océ	Basis Weight Range
HP	Basis Weight
Canon	Shrink ratio, Grain Direction, Finish, Basis Weight, Size, Curl

Question 1d: Are there specific paper grades recommended for use on your specific production presses: If so, which grades (on which press)?

Table 3. Recommended grades of paper for specific digital presses

Paper Grade	NexPress 2100 & 2100P	Ricoh	Océ VS9000 & VS7000	Océ VP6000	Océ CS650	HP Indigo 5000, 4050, 3250, 3500	Canon imagePress C7000VP
Groundwood - Uncoated	X	X	X	X	X	X	X
Freesheet - Uncoated Uncalendered	X		X	X	X	X	X
Freesheet - Uncoated Calendered	X		X	X	X	X	X
Freesheet - Uncoated Supercalendered	X		X	X	X	X	X
Freesheet - Premium Uncoated	X	X	X	X	X	X	X
Freesheet - Premium Bond	X	X	X	X	X	X	X
Groundwood - Coated	X	X	X	X	X	X	X
Freesheet - Coated Matte	X	X	X	X	X	X	X
Freesheet - Coated Satin	X	X	X	X	X	X	X
Freesheet - Coated Gloss	X	X	X	X	X	X	X
Freesheet - Coated High-Gloss	X	X			X	X	X
Freesheet - Coated Enamel	X					X	X
Freesheet - Coated, for Photo Reproduction	X					X	X
Recycled	X	X	X	X	X	X	X
Synthetic Grades				X		X	X
Textured	X			X		X	X
Tinted or Colored	X	X	X	X	X	X	X
Art Papers	X					X	X
Other (please define)							

Question 2: Besides press cost, what are the decision factors that make up the total value proposition presented to printers who are evaluating production digital (electrophotographic) press options?

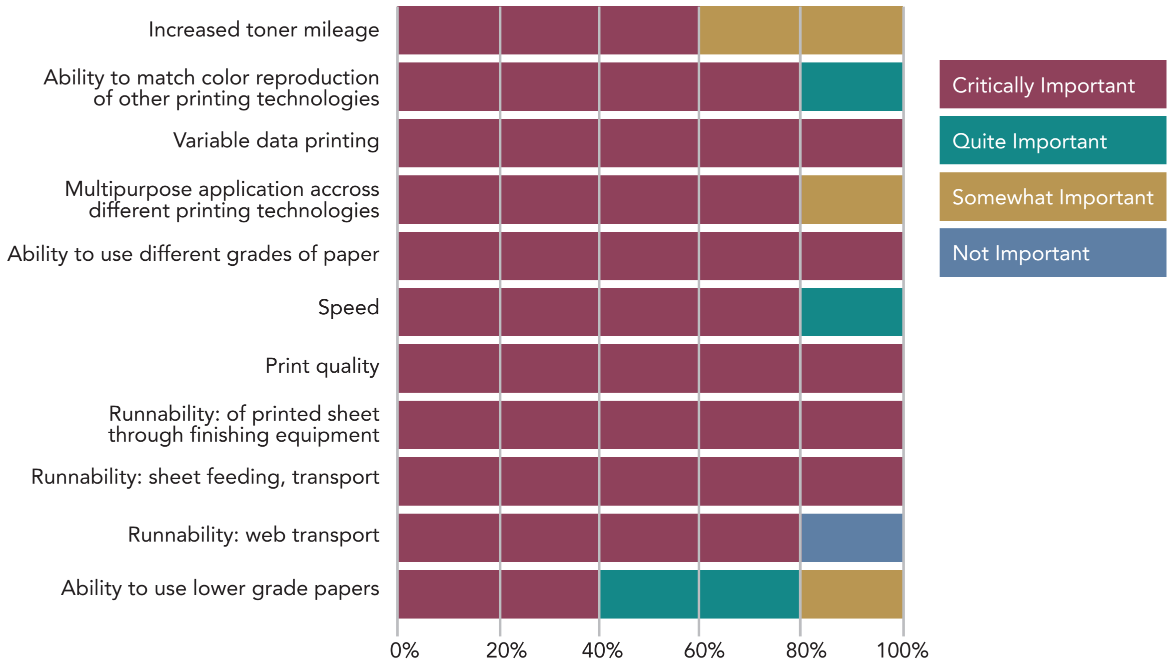

Figure 6. Decision factors that make up the total value proposition presented to printers who are evaluating production digital (electrophotographic) press options by percentage

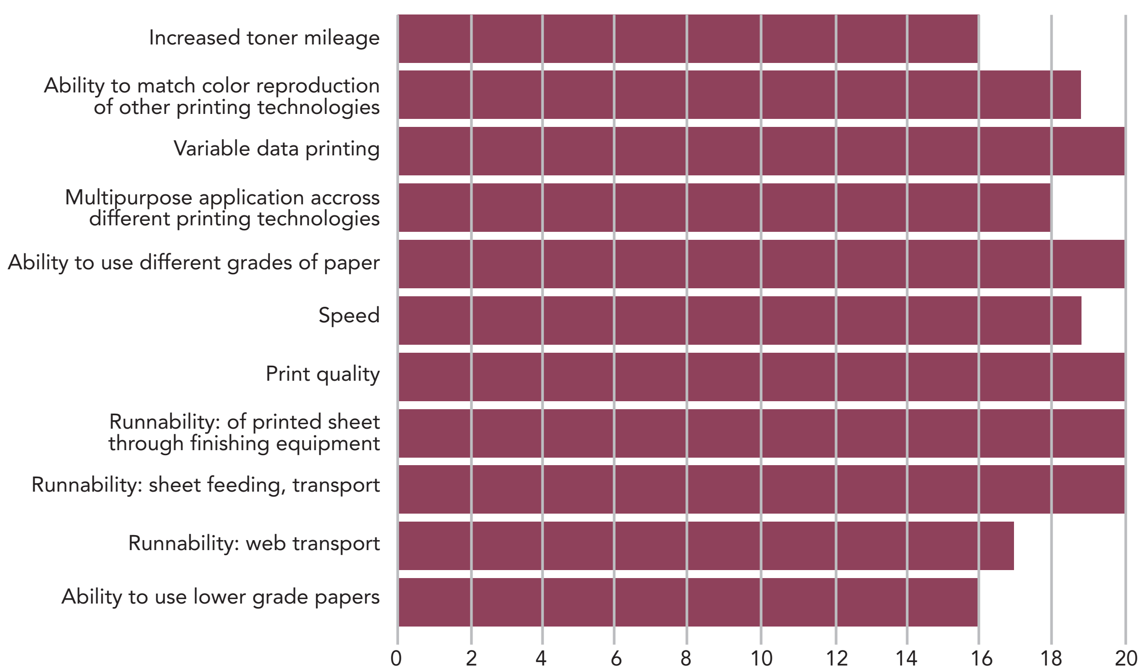

Figure 7. Decision factors that make up the total value proposition presented to printers who are evaluating production digital (electrophotographic) press options

Figure 6 shows that the decision to purchase a digital press involves a complex set of variables, the least of which is the ability to use lower grades of paper. Scaled results in Figure 7 again demonstrate the array of variables that make up the total value proposition presented to printers considering the purchase of a digital press.

Elements that were considered universally important to the value proposition presented were variable data printing, ability to use different grades of paper, print quality, runnability of printed sheet through finishing equipment, and runnability of sheetfed devices. The scaled results in Figure 7 confirm the importance of these elements, but the variance between elements is somewhat less. This may be attributed to the different market segments that each manufacturer serves.

The capability to print variable data was considered among the most important factors that make up the value proposition presented to customers. One respondent commented that the technology for variable data publishing was already here, that VDP was currently in an incubation phase, and that it will eventually explode. What was needed was finding the right customers, understanding how to train sales personnel how to market variable data printing, and how to train production staff to run variable data jobs.

Question 2a: Out of the critically important characteristics (from Question 2), which one is most important and which is second most important?

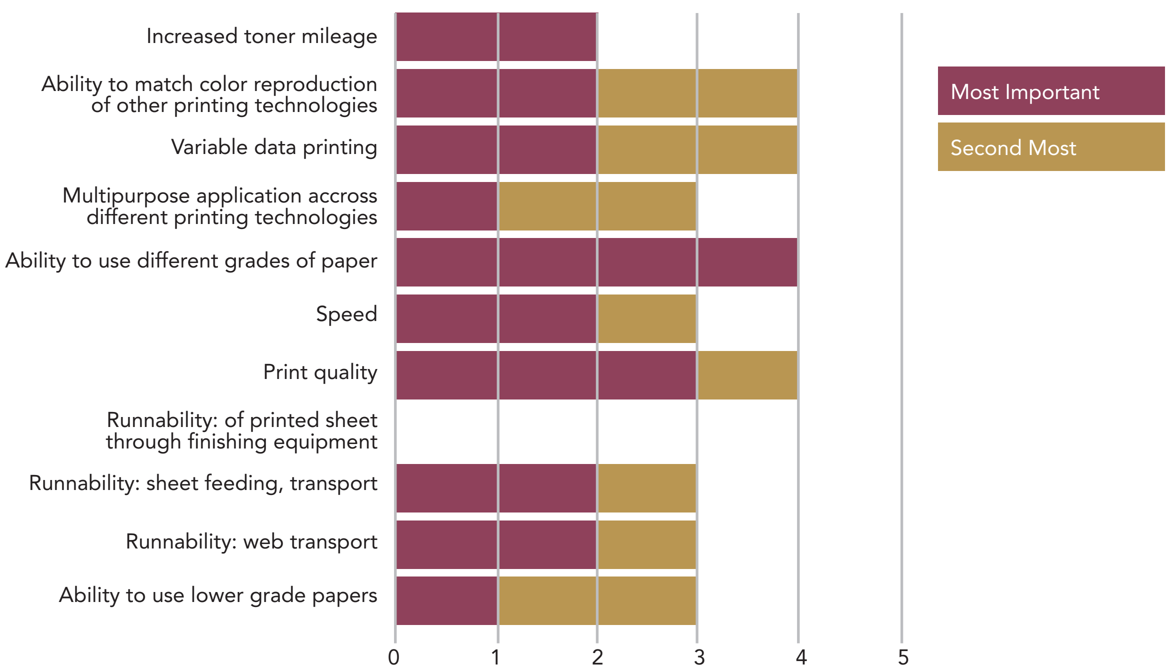

Figure 8. Ranking of the critically important decision factors of printers when evaluating the purchase of a digital production press

Some respondents chose more than one most critical characteristic; therefore a direct count of responses is more representative of the importance of a decision factor than a percentage. The most noticeable aspect in Figure 8 is the absence of responses regarding the runnability of the printed sheet through finishing equipment. All manufacturers considered it critical to the value proposition presented to customers that printed sheets run well through finishing equipment. However, when asked to rank the critical characteristics, none indicated runnability of the sheet through finishing equipment as the first or even the second most important characteristic.

One respondent noted that it was not only important to match technologies such as lithography, but that it was also important to match other digital technologies that customers have in place. Multipurpose application of substrates across different technologies was also considered important because customer's freedom to change paper brands was limited by existing contracts with paper manufacturers.

Question 3: How important is it to address each of the following customer needs by means of future print engine innovation?

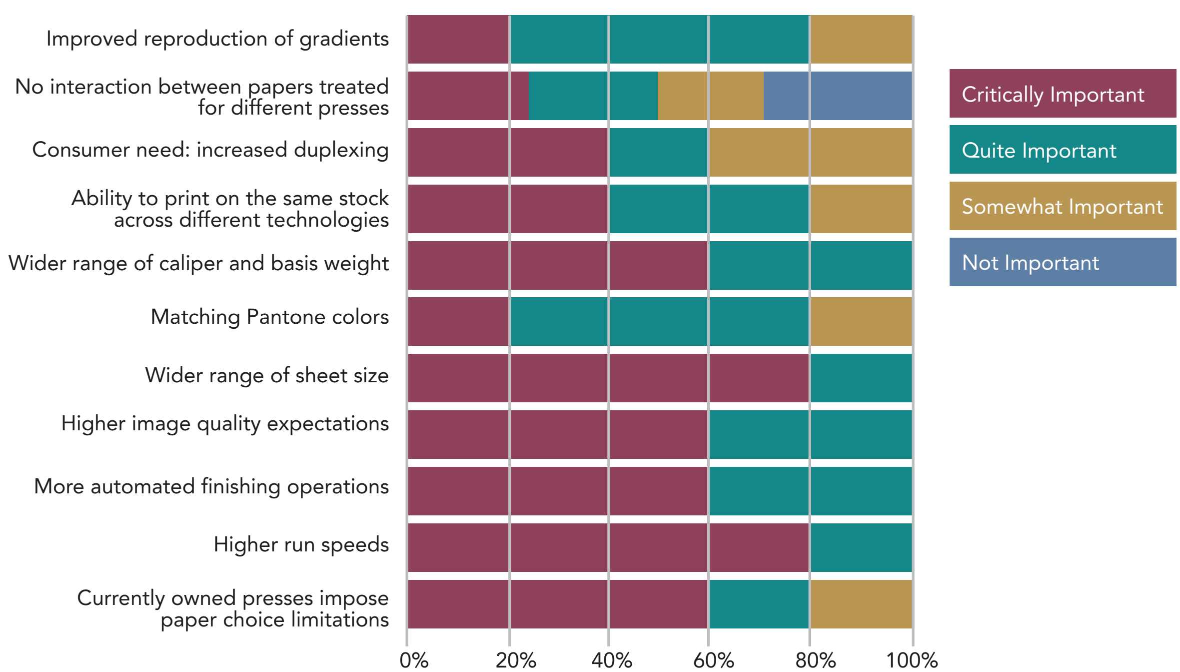

Figure 9. Percentage of responses indicating the importance of addressing customer needs by future print engine innovation

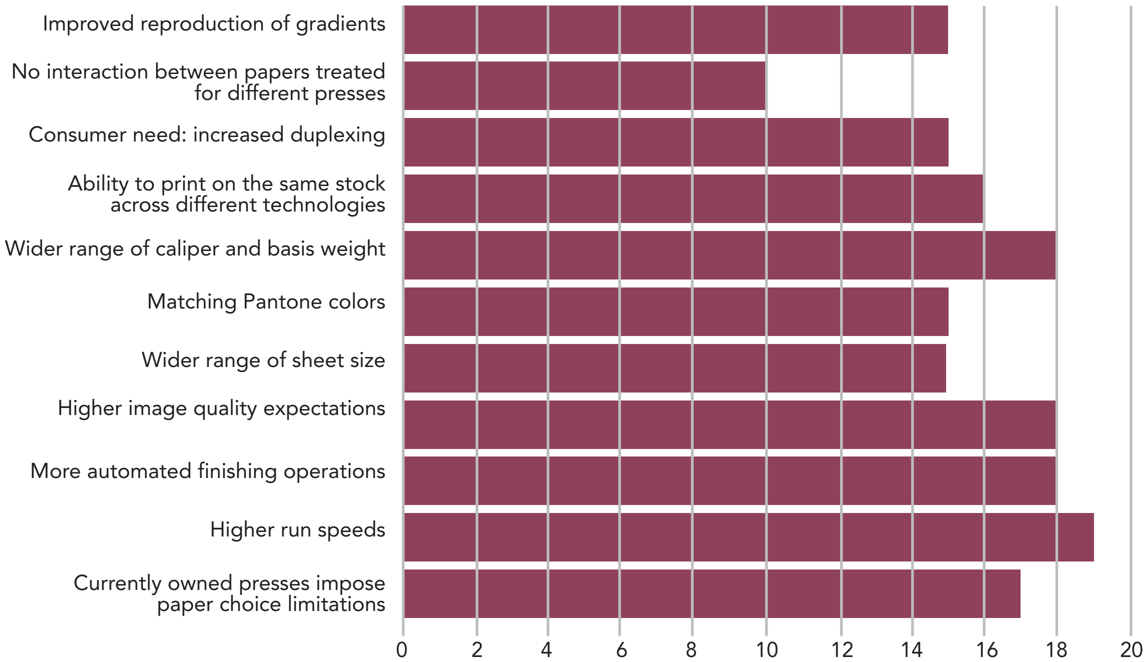

Figure 10. Importance of addressing customer needs by future print engine innovation

Figure 9 shows that the ability to run a wider range of sheet sizes and higher run speeds as the most critical needs to be addressed by future print engine innovation. Additional results are mixed, with the ability to match Pantone colors and improved reproduction of gradients being least important.

As the scaled results in Figure 10 demonstrate, attaining higher run speeds was slightly more important than running a wider range of sheet sizes. In addition, several other elements gained importance, such as ability to print the same stock across different technologies, higher image quality expectations, more automated finishing operations, and current presses imposing paper choice limitations. Again, this difference demonstrated the diversity of the markets that device manufacturers serve.

Question 3a: Out of the critically important characteristics (from Question 3), which one is most important and which is second most important?

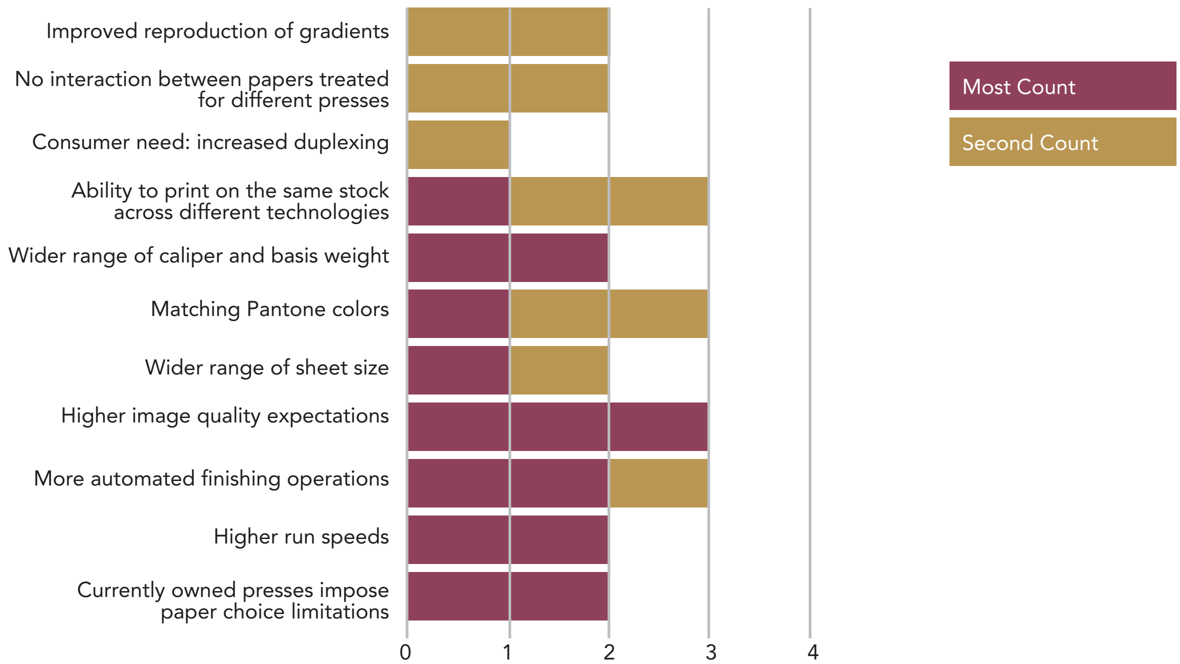

Figure 11. Ranking of critically important needs to consider in future print engine innovation

When asked to select the most important and second most important element of the value proposition presented to customers, higher image quality expectations was selected as most important as shown in Figure 11. This result conflicts with that shown in Figures 9 and 10. However, if second most important responses are added, ability to print stocks across different technologies, matching Pantone colors, and more automated finishing operations are equally important, bringing the responses in line with those from Question 3. Based on these results, it could be said that the higher image quality expectation represented a binary characteristic that could not be compromised, and that other elements of the value proposition, while important, could be improved incrementally.

Question 4: Which of the following best describes your company's 2006 revenues related to production digital (electrophotographic) presses?

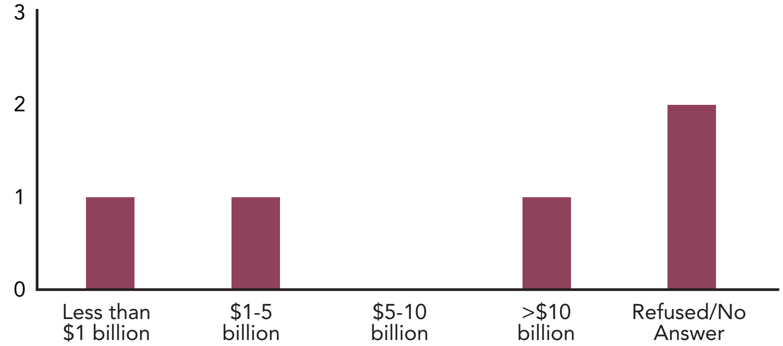

Figure 12. Organization's total revenue from electrophotographic production digital printing devices

Question 5: What is the brand and model number of the production digital (electrophotographic) presses (up to five) offered by your company?

Table 4. Brand and model of digital presses offered

Kodak	Ricoh	Océ	HP	Canon
NexPress 2100	Aficio MP 9000, 1100, 1350	Océ VS9000	Indigo 5000	imagePress C700VP
NexPress 2100P	DDP 92, 184	Océ VS7000	Indigo 4050	imagePress C1
NexPress 2500	EMP 156	Océ VP6000	Indigo 3250	imageRunner7125
NexPress S3000		Océ CS650	Indigo 3500	imageRunner7138
NexPress M700			Indigo 5500	imageRunner7150

Question 6: Are there specific production digital (electrophotographic) printing jobs that your individual presses target? Choose from the following:

- Marketing and promotional materials
- Manuals and documents
- Catalogs and directories
- Magazines and periodicals
- Transactional / financial forms or documents; other business communications
- Book production
- Direct mail
- Signage, labels, wrappers

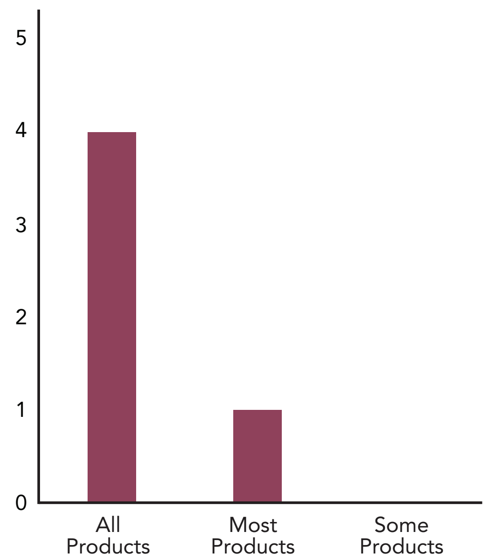

Figure 13. Types of digital print jobs organization's presses target

Question 7: Are there other types of digital printing jobs that your presses target which are not included above?

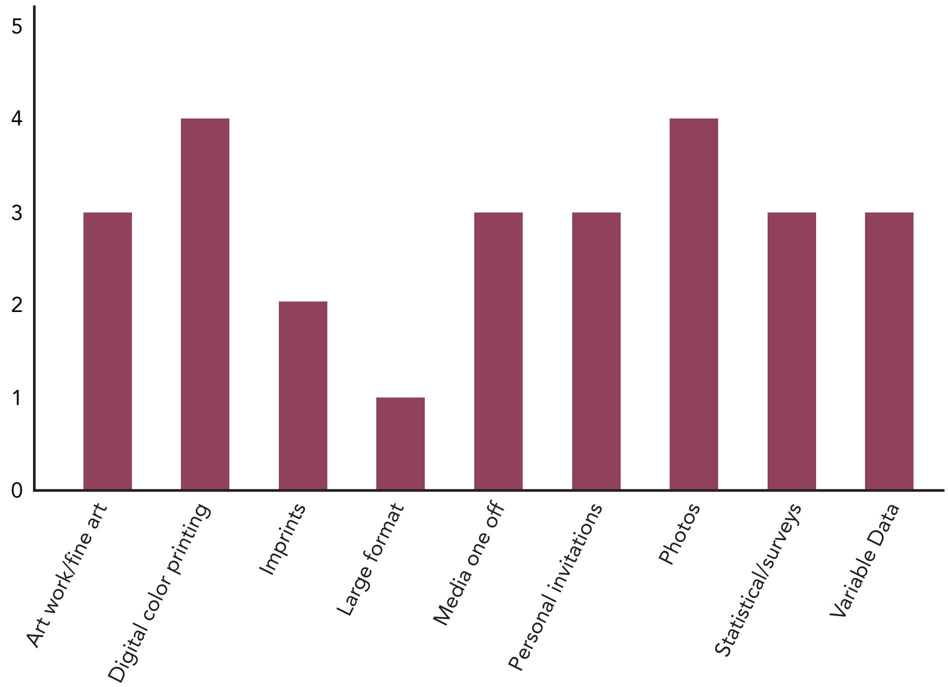

Figure 14. Other types of printing jobs organization's presses target

Question 8: This other type: is that a major, minor portion, rarely performed, or never performed job that your presses target?

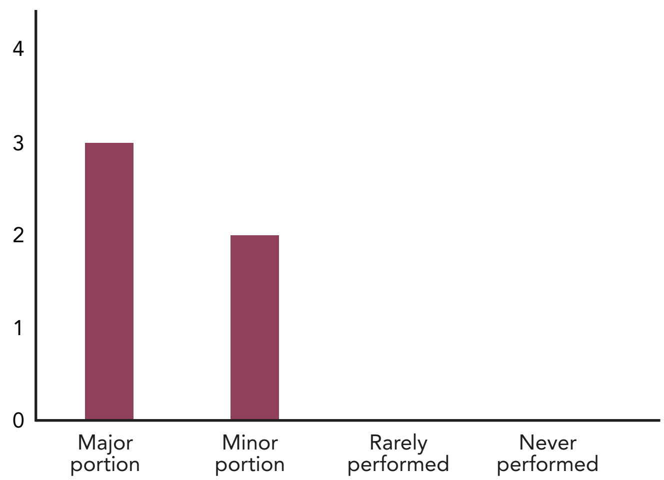

Figure 15. Portion of other jobs organization's digital presses target

Question 9: For which of these job types is it important to provide the capability to print variable data?

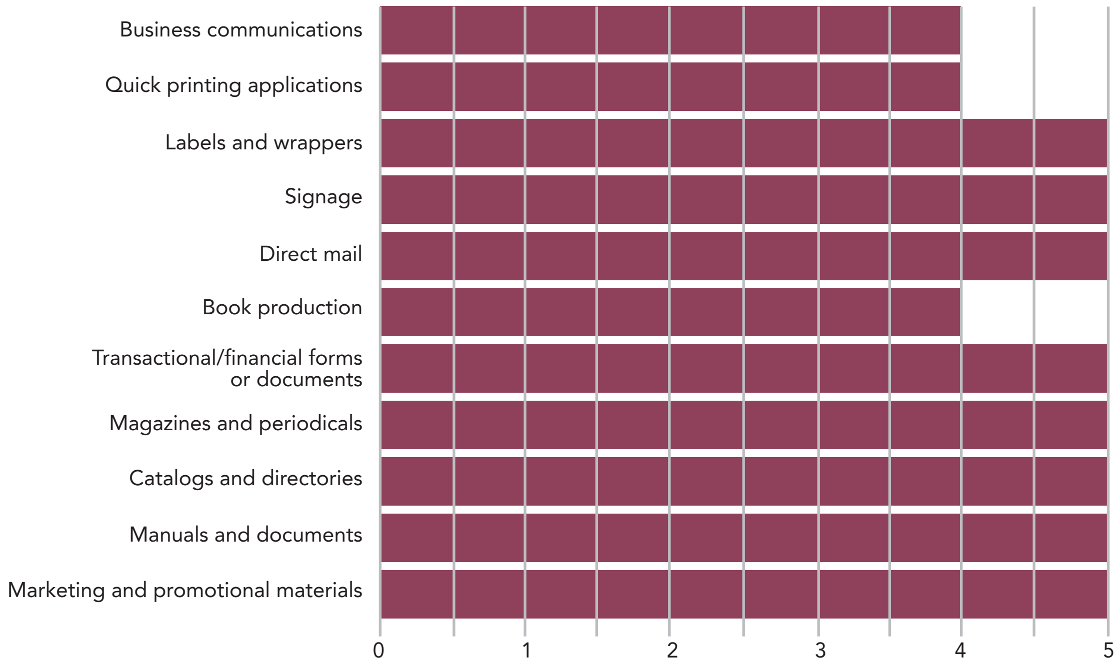

Figure 16. Percentage of respondents indicating importance of providing variable data capability by job type

Question 10: What type of color capability is required for the following job types?

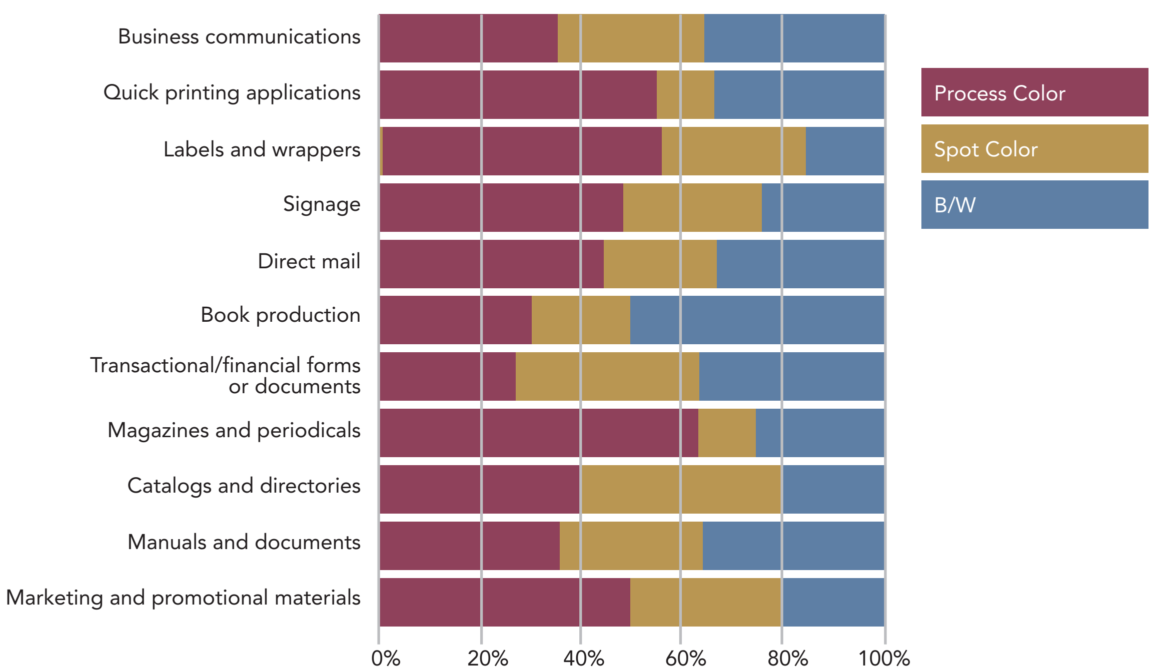

Figure 17. Percentage of respondents indicating the type of color capability that is required for different types of jobs

Analysis of Findings

Universal Characteristics

All device manufacturers considered dimensional stability and uniformity of product to be substrate conditions that limit current device performance. Increased uniformity of product must come from paper manufacturers. However, the question arises as to whether paper manufacturers can realistically increase uniformity of product with current papermaking technology. Also, the desire of printers for substrates that work across different technologies complicates the situation from both a technical and an economic standpoint.

Filler transfer to fuser rollers is another area that paper manufacturers need to address in order to increase the mean time between service calls. On the other hand, dimensional stability is a property that can, in part, be addressed by device manufacturers themselves. This is so because the fusing process—in particular when duplexing— plays a prominent role in dimensional stability.

Toner adhesion, while not universal in importance, was ranked as the most important paper property limiting performance. Lack of universality can be explained by considering applications where good toner adhesion was not important. Based on the importance of toner adhesion, it was obvious that device manufacturers extend their definition of performance to include finishing and distribution because these steps are known to be abrasive to the printed substrate. Papers could be manufactured to improve toner bonding, but this would not improve abrasion to the image surface. It is more likely that the practical answer to abrasion in post-production processes lies in coating the printed sheet.

When asked about paper characteristics important to optimal toner application, paper surface resistivity and moisture level were almost universally important. Surface resistivity and moisture level play an important role in toner density and evenness. Since fusing energy is evenly distributed on the substrate surface, unexpected variations in toner density result in less than optimal fusing of toner to substrate. Therefore, optimal toner fusing is, in part, based on substrate uniformity.

Application-Specific Characteristics

Dimensional stability, product uniformity, and toner adhesion were considered critically important by all respondents. However, after these considerations the importance of specific paper characteristics quickly diverged. This divergence can in part be attributed to differences in the technology that specific device manufacturers use. Nevertheless, the basic assumption can be made that an owner of a production digital printer will select the device that is best suited for the market they wish to serve. Therefore, the primary factor for the diversity of critical paper characteristics can be attributed to the specific print application.

Value Expectations

Considering the number of elements considered important when presenting a value proposition to customers who purchase digital devices, it can be said that elements considered by most device manufacturers as critical represent a set of customer expectations for all digital presses. On the other hand, elements that were not considered universally important to the value proposition but which were highly scaled could be considered expectations for devices intended for specific print applications.

Variable Data Printing

As most research has indicated, there is great interest in variable data printing. However, the problems encountered with variable data goes beyond technical considerations, and involve those of presenting a compelling value proposition to print buyers and training staff to sell and produce variable data products. Therefore, the importance of variable data capability might be based on customers' future, rather then current, needs.

Post Production

While sheet runnability through finishing equipment was considered a critical factor of the value proposition presented to customers, it was overshadowed by considerations such as runnability, print quality, print speed, ability to use different paper grades, and matching Pantone colors. This apparent lack of importance attributed to finishing runnability could be due to the background of those interviewed, or it could indicate that device manufacturers consider runnability through finishing equipment to be an area outside their responsibility.

This rated lack of importance, when considered in light of the relatively high importance of more automated finishing operations, may indicate a desire on the part of device manufacturers to add automated finishing to digital devices.

Conclusion

Possibly the most significant finding is that there is no best set of paper characteristics for production digital presses. With the exceptions of dimensional stability and uniformity of product, there are many 'right kinds' of digital paper based on the application being run.

Likewise, there is no one best value proposition to present to customers. Instead, there are multiple value propositions based on specific print applications. For example, a customer that intends to use a digital printer to compete with short-run commercial offset printing might consider matching Pantone colors as critical to the value proposition, while a customer who intends to print variable data direct mail pieces may consider sheet transport to be the most critical variable. Therefore, both the paper characteristics and the value proposition presented to customers who purchase production digital presses must be tailored to their specific needs.

Limitations of the Study

The small sample size caused exaggerations in data ranges. For example, if a single respondent considered a particular attribute unimportant, it significantly downgraded the entire results for that category.

As with any set of questions requiring structured responses, each respondent is left to their own interpretation of meaning. One respondent might consider sheet uniformity based on the even application of toner on the sheet, while another might consider uniformity as measured surface resistivity.

Also, respondents were considered to have expertise in the areas addressed by the survey. However, due to the range of questions, it is likely that some questions were answered by individuals with limited knowledge in a particular area.

Recommendations for Further Research

Many paper properties that limited current device performance were application-specific. Further research should be conducted to determine current and emerging digital print applications and the paper properties that will be critical to those applications. Specific applications could be analyzed for the formation of clusters of substrate requirements that suggest new value propositions for device manufacturers.

In addition, it would be beneficial to compare the range of jobs printed on digital presses to the range of jobs printed on conventional offset presses. A significant difference in range of work may signal that the value proposition presented to digital printers is fundamentally narrower than that presented to customers purchasing conventional offset equipment.

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Appendix: Survey Results in Tabular Format

Please note: Where applicable, the highest-ranking answer(s) in each table are shown in red.

Q1: Which paper properties limit current performance/ future innovation in production digital (electrophotographic) presses? *Indicate if response relates to current performance or future innovation or both.*	Likert Scale Totals	Critically Important (value=4)	Quite Important (value=3)	Somewhat Important (value=2)	Not Important (value=1)
Stiffness	14	1	2	2	--
Tensile strength, Sheet or web strength	12	2	1	--	1
Tear	7	--	1	1	2
Surface smoothness	14	2	1	1	1
Surface strength (delamination)	13	1	1	3	--
Basis weight	14	1	3	--	1
Toner adhesion	17	4	--	--	1
Surface finish (e.g. matte, gloss)	11	--	2	2	1
Accurate sheet dimensions	12	1	1	2	1
Uniformity; consistency of product	18	3	2	--	--
Dimensional Stability (Change with moisture and heat; e.g., curl)	20	5	--	--	--
Moisture level	15	2	1	2	--
Storage and handling requirements	14	1	2	2	--
Opacity (show through)	12	1	1	2	1
Brightness	8	--	1	1	3
Color	9	--	--	1	3
Lightfastness	10	--	2	1	2
Information capacity	7	--	1	1	2
Sheet recycle content	11	--	2	2	1
Sheet filler transfer to fuser rollers	15	1	3	1	--
Gloss differential between printed and non-printed surfaces	14	2	1	1	1
Dust; cleanliness of cut edge of sheet	15	2	1	2	--
Paper grain direction requirement	11	--	2	2	1

Q1a: Out of the Critically Important characteristics (from Q1), which one is most important and which is second most important? *Current performance – could relate to most common customer service problem directly related to paper. Future innovation-could be different properties*	Most Important	Second Most Important
Stiffness	--	1
Tensile strength, Sheet or web strength	--	1
Tear	--	--
Surface smoothness	--	1
Surface strength (delamination)	--	--
Basis weight	--	--
Toner adhesion	3	--
Surface finish (e.g. matte, gloss)	--	1
Accurate sheet dimensions	1	--
Uniformity; consistency of product	--	1
Dimensional Stability (Change with moisture and heat; e.g., curl)	1	1
Moisture level	1	--
Storage and handling requirements	--	--
Opacity (show through)	--	--
Brightness	--	--
Color	--	--
Lightfastness	--	--
Information capacity	--	--
Sheet recycle content	--	--
Sheet filler transfer to fuser rollers	--	--
Gloss differential between printed and non-printed surfaces	--	--
Dust; cleanliness of cut edge of sheet	--	--
Paper grain direction requirement	--	--

Q1b: How important are each of the following to optimal toner application?	Likert Scale Totals	Critically Important (value=4)	Quite Important (value=3)	Somewhat Important (value=2)	Not Important (value=1)
Dielectric force	11	--	2	2	1
Paper surface resistivity	16	3	1	--	1
Paper surface energy (contact angle)	16	2	2	1	--
Paper surface roughness	14	1	2	2	--
Paper thickness variation	12	1	1	2	1
Paper filler distribution	12	1	1	2	1
Sheet moisture uniformity	15	2	1	2	--
Sheet Porosity	15	2	2	--	1
Paper moisture level	14	3	--	--	2
Other (please list)	4	1	--	--	--

Q1c: Are there specific sheet property metrics established for each of your production presses: If so, which properties?	Properties
Kodak NexPress	None indicated
Ricoh	None indicated
Océ	Basis Weight Range
HP	Basis Weight
Canon	Shrink Ratio, Grain Direction, Finish, Basis Weight, Size, Curl

Q1d: Are there specific paper grades recommended (√) for use on your specific production presses: If so, which grades (on which presses)?	NexPress 2100 & 2100P	Ricoh	Océ VS9000 & VS7000	Océ VP6000	Océ CS650	HP Indigo 5000, 4050, 3250, 3500	Canon imagePress C7000VP
Groundwood - Uncoated	√	√	√	√	√	√	√
Freesheet - Uncoated Uncalendered	√		√	√	√	√	√
Freesheet - Uncoated Calendered	√		√	√	√	√	√
Freesheet - Uncoated Supercalendered	√		√	√	√	√	√
Freesheet - Premium Uncoated	√	√	√	√	√	√	√
Freesheet - Premium Bond	√	√	√	√	√	√	√
Groundwood - Coated	√	√	√	√	√	√	√
Freesheet - Coated Matte	√	√	√	√	√	√	√
Freesheet - Coated Satin	√	√	√	√	√	√	√
Freesheet - Coated Gloss	√	√	√	√	√	√	√
Freesheet - Coated High-Gloss	√	√			√	√	√
Freesheet - Coated Enamel	√					√	√
Freesheet - Coated, for Photo Reproduction	√					√	√
Recycled	√	√	√	√	√	√	√
Synthetic Grades				√		√	√
Textured	√			√		√	√
Tinted or Colored	√	√	√	√	√	√	√
Art Papers	√					√	√
Other (please define)							

Q2: Besides press cost, what are the decision factors that make up the total value proposition presented to printers who are evaluating production digital (electrophotographic) press options?	Likert Scale Totals	Critically Important (value=4)	Quite Important (value=3)	Somewhat Important (value=2)	Not Important (value=1)
Ability to use lower grade (price) papers Dielectric force	16	2	2	1	--
Runnability: Web transport	17	4	--	--	1
Runnability: Sheet feeding, transport	20	5	--	--	--
Runnability: Of printed sheet through finishing equipment	20	5	--	--	--
Print quality	20	5	--	--	--
Speed (sheets/minute)	19	4	1	--	--
Ability to use different grades of paper (product range- weight, size, finish)	20	5	--	--	--
Multipurpose application across different printing technologies	18	4	--	1	--
Variable data printing	20	5	--	--	--
Ability to match color reproduction of other printing technologies.	19	4	1	2	--
Increased toner mileage	16	3	--	--	--

Q2a: Out of the Critically Important characteristics (from Question 2), which one is most important and which is second most important?	Most Important	Second Most Important
Ability to use lower grade (price) papers Dielectric force	1	2
Runnability: Web transport	2	1
Runnability: Sheet feeding, transport	2	1
Runnability: Of printed sheet through finishing equipment	--	--
Print quality	3	1
Speed (sheets/minute)	2	1
Ability to use different grades of paper (product range- weight, size, finish)	4	--
Multipurpose application across different printing technologies	1	2
Variable data printing	2	2
Ability to match color reproduction of other printing technologies.	2	2
Increased toner mileage	2	--

Q3: How important is it to address each of the following customer needs by means of future print engine innovation?	Likert Scale Totals	Critically Important (value=4)	Quite Important (value=3)	Somewhat Important (value=2)	Not Important (value=1)
Currently owned presses impose paper choice limitations by size, basis weight, thickness, and surface treatment requirements	17	3	1	1	--
Higher run speeds	19	4	1	--	--
More automated finishing operations	18	3	2	--	--
Higher image quality expectations	18	3	2	--	--
Wider range of sheet size	15	4	1	--	--
Matching Pantone colors	15	1	3	1	--
Wider range of caliper/thickness and basis weights	18	3	2	--	--
Ability to print on the same stock across different technologies (dual purpose papers)	16	2	2	1	--
Increased duplexing	15	2	1	2	--
No interaction between papers treated for different presses	10	1	1	1	1
Increased toner mileage	15	1	3	1	--
Other	4	1	--	--	--

Q3a: Out of the Critically Important characteristics (from Q3), which one is most important and which is second most important?	Most Important	Second Most Important
Currently owned presses impose paper choice limitations by size, basis weight, thickness, and surface treatment requirements	2	--
Higher run speeds	2	--
More automated finishing operations	2	1
Higher image quality expectations	3	--
Wider range of sheet size	1	1
Matching Pantone colors	1	2
Wider range of caliper/thickness and basis weights	2	--
Ability to print on the same stock across different technologies (dual purpose papers)	1	2
Increased duplexing	--	1
No interaction between papers treated for different presses	--	2
Increased toner mileage	--	2
Other	--	--

Q4: Which of the following best describes your company's 2006 revenues related to production digital (Electrophotographic) presses?	Count
Less than $1 billion	1
$1-5 billion	1
$5-10 billion	1
> $10 billion	2

Q5: What is the brand and model number of the production digital (Electrophotographic) presses (up to five) offered by your company?	
Company	Press Brand and Model Number
Kodak	NexPress 2100, NexPress 2100P, NexPress 2500, NexPress S3000, NexPress M700
Ricoh	Aficio MP 9000, 1100, 1350; DDP 92, 184; EMP 156
Océ	Océ VS9000, Océ VS7000, Océ VP6000, Océ CS650
HP	Indigo 5000, Indigo 4050, Indigo 3250, Indigo 3500, Indigo 5500
Canon	imagePress C7000VP, imagePress C1, imageRunner7125, imageRunner7138, imageRunner7150

Q6: Are there specific production digital (electrophotographic) printing jobs that your individual presses target? Choose from the following: • Marketing and promotional materials • Manuals and documents • Direct mail • Catalogs and directories • Magazines and periodicals • Signage, labels, wrappers • Book production • Transactional / financial forms or documents; other business communications	Count
All products	4
Most products	1
Some products	0

Q7: Are there other types of digital printing jobs that your presses target not included above?	Count
Art work/fine art	3
Digital color printing	4
Imprints	2
Large format	1
Media one-off	3
Personal invitations	3
Photos	4
Statistical/surveys	3
Variable	3

Q8: This other type: is that a Major, Minor portion, Rarely Performed, or Never Performed job that your presses target?	Count
Major portion	3
Minor portion	2
Rarely performed	--
Never performed	--
Don't know	--
Refused	--

Q9: For which of these job types is it important to provide the capability to print variable data?	Count
Marketing and promotional materials	5
Manuals and documents	5
Catalogs and directories	5
Magazines and periodicals	5
Transactional / financial forms or documents	5
Book production	4
Direct mail	5
Signage	5
Labels and wrappers	5
Quick printing applications	4
Business communications	4
Other	--
Don't know	--
Refused	--
Other Category	--

Q10: What type of color capability is required for the following job types?	Process Color	Spot Color	B/W
Marketing and promotional materials	5	3	2
Manuals and documents	3	2	3
Catalogs and directories	4	4	2
Magazines and periodicals	5	1	2
Transactional / financial forms or documents	3	4	4
Book production	3	2	5
Direct mail	4	2	3
Signage	4	2	2
Labels and wrappers	4	2	1
Quick printing applications	5	1	3
Business communications	4	3	4
Other	--	--	--
Don't know	--	--	--
Refused	--	--	--
Other Category	--	--	--

R·I·T

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