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Adaptation and Countermeasures of Label Manufacturing Companies in the Face of the Growing Digital Printing Industry

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ADAPTATION AND COUNTERMEASURES OF LABEL MANUFACTURING COMPANIES IN THE FACE OF THE GROWING DIGITAL PRINTING INDUSTRY

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Abstract

In the constantly evolving landscape of the printing industry, the adoption rate of various technologies remains uneven, notably in digital printing. Although having existed for decades and increasingly matching the capacities of Flexography, label manufacturers have adopted digital printing within label manufacturing domains. This thesis delves deep into the history and operational mechanisms of Flexography and digital printing, shedding light on their innovative trends. By juxtaposing the capabilities of both methods through actual printed samples and comparing costs, we strive to discern the underlying reasons for companies either embracing or refraining from transitioning to digital printing. In conclusion, the research will provide insights into forthcoming industry trends, printing in developing nations, and the integration of printing techniques by packaging firms, providing a comprehensive overview of the industry's trajectory.

Acknowledgments

First, I want to acknowledge all the people who assisted me with the direction, help, and encouragement I received while attending the University of Clemson. Special thank you and acknowledgment to Doctor Carl Blue and Professor Michelle Fox, who allowed me to become a teaching assistant for their respective classes over the last year and a half and to learn about the printing processes in a classroom setting. If it were not for their direction and teaching practices, I would be where I am today in my ability to write this thesis and present this information confidently to Clemson University.

I also want to thank the Graphic Communication program, my teachers, colleagues, and the many students I taught during GC 2070 and 4061. Finally, I want to acknowledge my committee team members, Carl Blue, Duncan Darby, and Eric Weisenmiller, for helping me stay on track during my final semester here at Clemson.

Dedication

I want to dedicate this thesis to a few people. First and foremost, I plan to take my learning experiences from the Graphic Communications Program and apply them to the MR Label Co. and help grow the company that my grandfather and current family have been building since 1976. I dedicate my effort and this thesis to the MR Label Co. If it were not for the many summers working with the best twenty-three employees within the industry, I would need to find out where I would be today.

Most importantly, I dedicate this thesis to my family. First and foremost, my interest and knowledge of the printing industry would not have been created if not for my grandfather and grandmother, who gave up all their life savings to start a label manufacturing business in their basement. I dedicate this to my three siblings, Amanda, Mackenzie, and Ben. Finally, I want to dedicate this thesis to my father and mother. My father is one of the main reasons I am interested in this field of study, and he has shown me his passion for helping to grow the MR Label Co. My mother has always been my number one supporter and has encouraged me to take risks on things that I am passionate about. To all the people I have mentioned above and the others who helped me plan for this thesis, I dedicate my hard work to you.

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History of Flexography

The current printing process of Flexography is traceable and compared similarly to the creation of this process. However, many materials utilized in inks, plates, cylinders, and rollers have changed due to safety issues and the cost and result of using those quality materials. When tracing the start of the Flexographic process, the starting point of this print method occurred in 1853, when the creator of the first rubber plate designed a rotary press. Within the thesis A Historical Essay on the Development of Flexography by Ana Gomez, “the idea of printing with rubber plates originated in the U.S. some seventy years before its first commercial application” (Gomez, 2000, p. 9). At the time of the first rubber plates, this process was called aniline printing rather than Flexography. The aniline process was “the early name for rubber-plate printing using fast-drying aniline-based fluid inks” (Gomez, 2000, p. xi). The actual aniline dyes were “derivatives of coal-tar classified by chemical composition” (Gomez, 2000, p. xi). The name would later change to Flexography printing to help remove the wrong connotation of aniline printing due to the unsafe inks and materials used to print and a shift to using different types of ink.

There were a few attempts to create the first aniline printing presses from the 1890s to early 1900s, but all presses somewhat failed due to the type of ink used, specifically dyes and sugar dissolved in water. The first printing press that solved the ink issue at the time was in 1905 when the dyes were dissolved in alcohol, which made the ink applicable to printing on paper or bags. Figure 1 shows this was the first aniline printing press sold commercially in 1925.

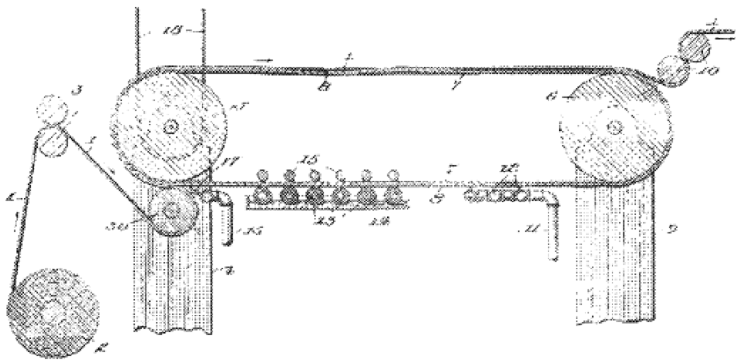


Figure 1: 1925 Flexible Printing Machine (Gomez, 2000, p. 10)

During this period, printing companies used stack presses or central impressions, the two leading Flexographic presses within the United States. A stack press (Figure 2) was built vertically, with each station above the other. In contrast, a central impression press (Figure 3) built each ink station onto one central impression drum where the substrate would wrap around the entire impression roller. Many United States companies were building their presses to replicate these two styles despite being manufactured initially in Europe. The problem with both style presses was "that working with them was extremely messy" and "since there were no accurate ink metering mechanisms, ink splashed all over the floor" (Gomez, 2000, p. 12).

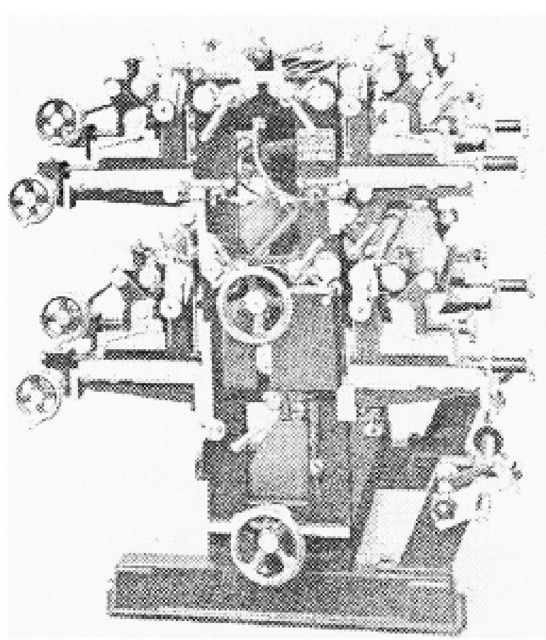


Figure 2: Stack Press (Gomez, 2000, p. 11)

A few of the issues during this period with aniline printing was that there was no ink metering, so running the press was messy; these aniline inks also had a short shelf life and were prone to smear, leaving the print illegible. Also, these inks were toxic, so the printed items could not be used for food products, and the inks were transparent. As seen from these issues, the printing process made sense and only needed a few changes to be what it is today. The type of ink used during this development stage was the main issue regarding what needed replacing (Gomez, 2000).

To help find more efficient and safer ways to use certain inks or substrates, the plate type and material needed to be changed to apply safer practices when printing with certain inks. The 1930s to the 1950s saw significant development in the Flexo printing industry with new non-absorbent substrates like cellophane, new inks with an opacity additive, water-based inks, and metallic inks. According to Gomez, the essential creation during this period was the design of "the first four-color aniline presses just duplicated this system and had two impression cylinders with four inking systems" (Gomez, 2000, p. 21).

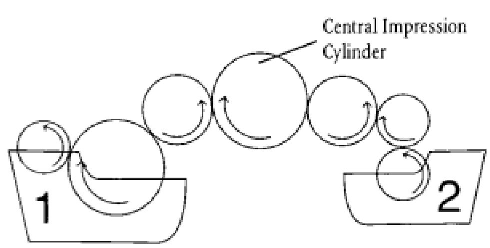


Figure 3: CI Cylinder Press with two Ink Stations (Gomez, 2000, p. 21)

Before this solution, companies could only print with two colors. Different curing or drying methods, like the gas flame in 1941, were created during this time. The industry saw the creation of anilox rollers, which helped transfer ink from roller to roller. These anilox rollers changed the industry forever since these rollers were the first of their kind that had a "mechanically engraved metering roll," which meant that it had excellent durability and "served to control the ink film thickness being deposited on the plate" (Gomez, 2000, p. 25). Figure 4 shows a system without the use of an anilox roller.

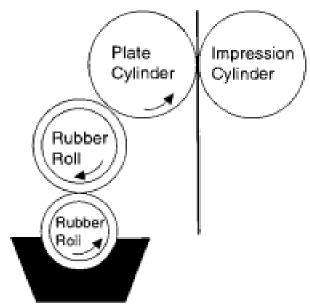


Figure 4: Press without Anilox Roll (Gomez, 2000, pp. 25-26)

Creating the sticky back and the mounter proofer machine helped register and mount the new rubber plates, which helped "provide a way of setting up and making ready the cylinders off the press" (Gomez, 2000, p. 27). A sticky back holds the plate onto the cylinder for press, while a mounting proofer machine allows the press operator to line up each plate within the center of the cylinder and apply it onto the sticky back. These innovations helped cut down on waste costs and time between runs. By the 1960s, companies adapted and created the first modern impression cylinder machine, which only used one center drum for all the stations. These new printing presses used new polyethylene (PE) substrates in addition to paper and cellophane. As these presses were expanding, so were the lines per inch capabilities. By 1959, "screens were already up to 110 lines per inch (lpi)" (Gomez, 2000, p. 33).

Die-cutting saw newer inventions attached to printing presses, and these new industry practices were taught in colleges and universities by the late 1950s. With more people becoming educated on this printing style, there was a development for process-color printing machines and photopolymer plates in the 1950s. Process-color printing entails printing with cyan, yellow, magenta, and black (CYMK). At the same time, a photopolymer plate is used as the material that holds the imaged item and is placed onto the plate cylinder during a press run. The process of imaging photopolymer plates, which uses UV light to expose the imaged area of a photopolymer plate and wash out the unused areas, is still used today, even at Clemson University within their Graphic Communications Program.

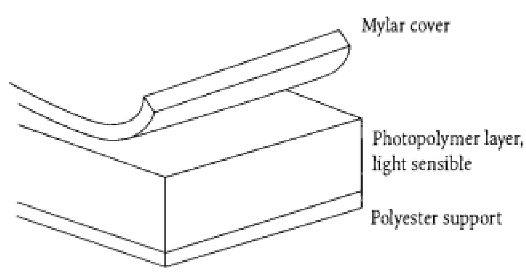


Figure 5: Photopolymer Plate (Gomez, 2000, p. 43)

According to Gomez, the 1960s had a few innovations that essentially created the transfer of ink that many companies still use today. One invention was the chambered reverse angle doctor blades. Newer rubber rollers were also installed into the printing press. The rubber roller's purpose was to pick the ink from the ink tray and transfer it to the anilox roller. The angle doctor blade helps meter ink transfer from the rubber roller to the anilox by scraping off the excess ink. These two new features allow for a more precise ink metering system today.

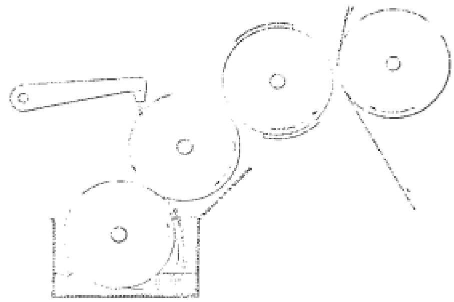


Figure 6: Press Configuration with Rubber Rolls and Doctor Blade (Gomez, 2000, p. 38)

Since then, new substrates and processes have been implemented within the printing process to help limit waste and become more efficient with longer and shorter press runs. These new capabilities include press width, press-enclosed ink chambers that help with "protecting the ink from coming in contact with air and moisture," in-line registration systems, cameras that replaced strobe lights, die-cutting stations using magnetic dies, ceramic replaced chrome anilox rolls, solvents being eliminated from plate making and from the inks, line screens that exceeded the prior 110 lines per inch, laser imaging and thermal curing of the photopolymer plates (direct to plate), and the use of different types of ink like water-based, solvent, UV, and LED (Gomez, 2000, p. 44). This list was not just for work and efficiency; quality and safety were also improved.

Flexographic Process

With all the new capabilities and features that have expanded for the current use within the Flexographic printing method, the interpretation of the Flexographic printing process will be with the present techniques and procedures used today within the printing industry. Despite having different types of presses or inks used, the premise of how ink transfers to the substrate remains relatively the same. According to *Dornans Printing*, Flexography was "originally used for corrugated cardboard," and due to the rough surface of the material, the printing plate has adapted to having a flexible and robust ink transfer (Dornans Printing, 2023, p.1).

Depending on whether the printing calls for four color processes (Cyan, Yellow, Magenta, and Black) or spot colors, transferring the ink onto the substrate remains the same. According to *Printing Processes and Their Potential for RFID Printing* by Anne Blayo, "Flexography is a direct printing process, using a relief flexible plate that applies a fluid ink to the substrate" (Blayo, 2005, p. 28).

The substrate is webbed throughout the press before any printing occurs. Before running the press, the forces from the unwind and rewind stations must be even so that the substrate has tension throughout the run. Sensors (web guide) ensure the webbed substrate gets pulled through the press without moving to the left or right. Some Flexographic presses have a corona treater built into the press that increases the surface tension of materials to help with ink adhesion. Some substrates needing to change their surface tension include "polypropylene, vinyl, foils, polyethylene, and metalized surfaces" (Tantec, 2023, p. 1). Plastic substrates like shrink and stretch film use a corona treater.

The Flexographic printing industry has three different types of Flexographic presses. The process is relatively the same, but each press has a few differences. The main differences between these presses are Central Impression, ink-chambered, and rubber rollers.

The press, with a rubber roller, starts with an ink tray. The rubber roller takes the ink and then transfers it to an anilox roller, where the ink is evenly metered throughout the roller using a doctor blade. A doctor blade helps scrap off excess ink and provides consistent transferring of ink. When deciding which anilox roller to use, Lines per Inch (lpi) on the roller help determine how much ink will be printed. The lower the lpi, the bigger the dot, which means it holds more ink within that area. The higher the lpi, the lower the dot, producing a more precise print and minor details. The anilox roller then transfers the ink to the plate cylinder. The plate cylinder picks up ink within the printing area using holding cells and transfers it to the substrate. The substrate can receive the ink in the printed area due to having an impression cylinder behind the substrate to help transfer and adhesion. This is shown in Figure 7.

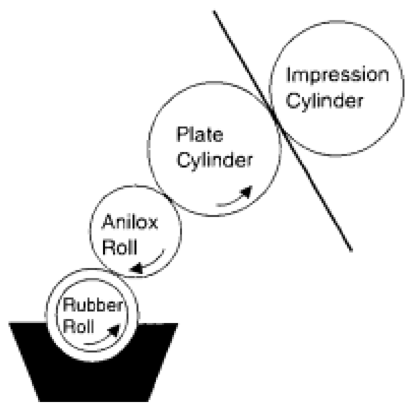


Figure 7: Flexographic Press with Rubber Roller (Gomez, 2000, pp. 25-26)

The only difference between this Flexographic press and one with an ink-chambered unit is that there is no rubber roller. Ink is pumped into the enclosed ink-chambered unit, where the chambered unit transfers ink onto the anilox roller. The ink chamber has a doctor blade and a containment blade on each side of the unit. The doctor blade helps remove excess ink and produce a consistent ink transfer throughout the press run, while the containment blade helps prevent the ink from being removed from the chamber and contamination. Transferring ink to the substrate remains the same as the other Flexographic press once the anilox roller picks up the ink from the ink chamber.

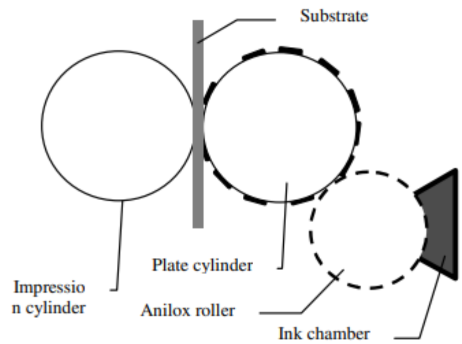


Figure 8: Ink-Chambered Flexographic Press (Blayo, 2005, p. 28)

The third type of Flexographic printing press can either use the rubber roller or ink-chambered process; the only difference is that a Central Impression Flexographic press uses only one impression cylinder for the entire process.

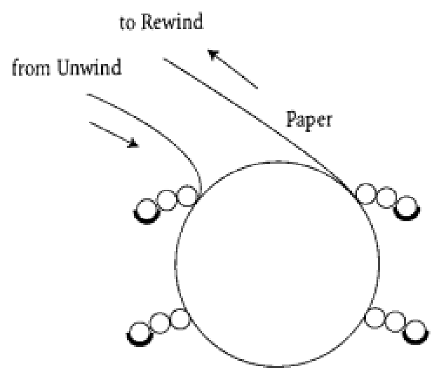


Figure 9: Modern CI Press (Gomez, 2000, p. 33)

Each color repeats the process for that specific press run. For each station to dry in time for the next color, chill rollers or different curing methods are used to dry each color printed. The curing method or chill roller is decided depending on the type of ink. For example, if a Flexographic press prints with UV-curable ink, each station will have a UV light to cure that ink. Most recently created presses feature in-line finishing, like adding foil to a print, embellishments, or magnetic dies. Magnetic dies allow labels to be peeled right off the substrate.

Many companies print with the Flexographic process because it can "print on various substrates: paper, board, corrugated cardboard, flexible and rigid polymers, metals, glass" and films (Blayo, 2005, p. 28). Also, this printing process uses quick-drying, semi-liquid inks and can be used for high-volume jobs (Dornans Printing, 2023, p. 1).

Innovative Trends

Clemson University, within the Graphic Communications Program, teaches Flexography printing to students learning about this specific printing method using machines like the Nilpeter and Comco. Assignments throughout different classes teach students how to prep their files, make photopolymer plates, mount their plates, set up print stations, and use the process of automation to create labels for their designs.

There are only a few current innovative trends that this process is currently offering. One of these trends is that many new presses, like the Nilpeter at Clemson University, provide the capability for in-line finishing options like foil and automation options using a touchscreen interface. Automation is also taking over the entire Flexography process. Many steps within the pre-press to plate-making process are implementing automation to reduce wait times and decrease the chances of human errors. Many presses have touchscreen interfaces and opportunities for the press operator to save prior runs to help reduce setup time.

Digital Printing

<u>History of Digital Printing</u>

According to "Emerging Applications for Inkjet Technology" by Carl Thomas Ashley, the author stated that the purpose of digital printing was "originally developed for office and data processing applications," but "is now finding use in virtually every field or printing" (Ashley, 2002, p. 540). Digital printing is any process that "allows all page, text, and image composition to take place on a computer and the creation of a printing plate directly from the digital file" (Hargrave, 2013, p. 230).

Before the introduction of electrophotography print, many scholars considered the transfer of print onto paper to occur in three different ways. These are direct contact, photography, and electrophotography. The third print development considered is electrophotography, which Chester Carlson created. The creation of liquid toners occurred in 1953. It took about eight years to build the first label machine to use liquid toners in manufacturing. Charles E. Case, who wrote the History of Liquid Toner Innovation, considers the A B Dick Video Graph 910 as the "1st liquid toner label printer" (Case, 1998, p. 226).

From the 1960s to the 1990s, many new companies created digital printing machinery to sell similar products to companies implementing digital printing. These processes may differ, but all were within the digital printing industry. These significant companies include Ricoh, Canon, Minolta, and Indigo. Innovations, such as platemakers, color-proofing systems, copiers, electro printers, inkjets, laser printers, and digital offset presses, entered the market to aid this new digital printing industry (Case, 1998).

As for inkjet printing, many consider the starting point of this process to have occurred during the 1970s. Inkjet printing executed new types of technology like oscillographs, which are "electrical signal recording devices," and character printers (Ashley, 2002, p. 540). Many original inkjet printing machines focused on printing simple things for companies and their offices. By the 1980s to the 1990s, inkjet printing speeds and quality took a significant step forward due to "the arrival of new printheads that increasingly offer the combination of speed with quality," as well as the offering "of a wide range of inks" (Ashley, 2002, p. 540).

As computers and technology get smarter with communication, inkjet printing and electrophotographic (toner) printers will continue to be used within households and companies worldwide. This computer-to-print style has allowed label manufacturers to use this style of printing because it is one of the most cost-effective options for "print-on-demand and short-run digital printing" (Hargrave, 2013, p. 230). In today's climate, digital printing continues to influence the printing industry by being a direct competitor or aid to other printing processes. It even offers the same capabilities and features as other printing processes.

Digital Printing Process

Electrophotography (Figure 10) is the process that "forms its images by electrostatic force on charged particles" (Cousoulis, 2015, p. 7). When digital printers use the process of electrophotography, it is essential to note that some steps co-occur with one another. According to a research article titled *Electrophotography,* this process has six main steps. These six steps are charging, exposure, development, transfer, fixing, and cleaning (Cousoulis, 2015).

The first step in this process is to charge the photoconductive drum or insulator. A charge is placed on the photoconductor drum. The insulator holds the conducted energy until the exposure step. Once charged, the second step of the process occurs, which is exposure.

As the drum rotates, a laser places the latent image on the drum and removes the charge within that area. Through these optical lenses, the light from the laser is dispersed and discharges the light areas of the sheet, while the dark areas stay charged. This occurs because the insulator "is photoconductive, so that any area exposed to light becomes conducting, removes the charge from the surface, and neutralizes it" (Cousoulis, 2015, p. 720).

Once exposed, the third step occurs, which is called the development stage. The development stage helps form the actual image of the print. Dry colored toner gets dispersed onto the insulator, where the colored toner has "a charge opposite in sign to the photoreceptor charge so that they stick to the photoreceptor in the areas that are charged and form a visible image" (Cousoulis, 2015, p. 720). The toner does not stick to the areas of the insulator where the charge was.

As the drum rotates past the development and placement of the toner, an opposite-charged transfer roller is placed behind the substrate. As the image passes this transfer roller, the toner is attracted and transferred to the substrate. This action is the transfer part of the process, which is the fourth step.

The fifth step, fusing or fixing, must be performed to protect the image when transferred to the paper. The fusing process involves "heating the toner to soften it and applying pressure so that it flows into the paper fibers" (Cousoulis, 2015, p. 720). The final cleaning step occurs to help remove the toner, paper, and charge left behind to help prevent the insulator from having the image permanently placed onto it. The leftover toner is scraped off using a cleaning blade. This process repeats itself for every printed piece. As technology has improved, many of these steps are fully automated within these newer presses (Cousoulis, 2015).

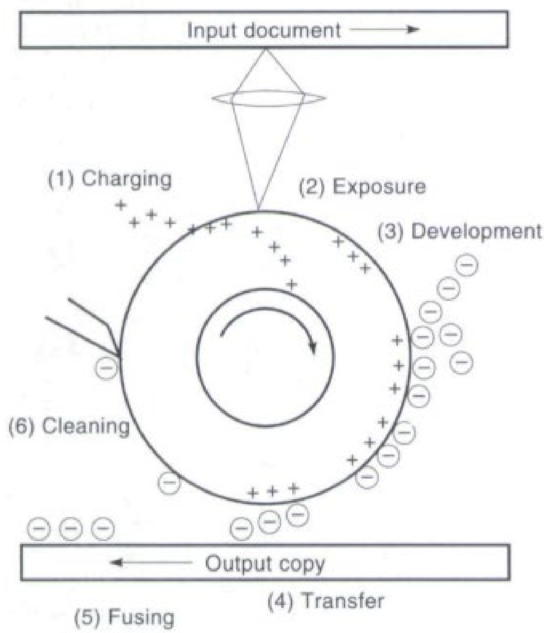


Figure 10: Electrophotography Process (Cousoulis, 2015, p. 721)

This electrophotographic process can also use liquid toner. HP developed an Indigo printing press, which “has earned a reputation for its exceptional print quality, versatility, and efficiency” (Columbine, 2023, p. 1). Producing a label with the Indigo remains relatively the same as if printed with dry toner.

There are six steps when printing with HP Indigo. The first charging step remains the same, except the negatively placed charge goes onto the Photo Imaging Plate (PIP). The second occurs when a laser “removes charge from the image area” (HP, 2023, p. 1). The Binary Ink Developers, or BID, releases the liquid toner onto the plate, which is the development stage of this printing process. The printed image is transferred onto a heated blanket, which "melts the resin particles within" the liquid toner (HP, 2023, p. 1). The heated blanket then transfers the image onto the substrate. This process can either be completed by repeating the process for each color or printed with HP's one-shot process, which has "all color separations accumulate on the blanket" at one time (HP, 2023, p. 1).

Inkjet has two printing styles. These two types of printing are either continuous or drop-on-demand. Continuous and Drop-on-demand inkjet printing follow similar processes, but a few differences exist. In the continuous inkjet printing process, "a constant flow of droplets is generated, but only part of the droplet flow is transferred to the substrate" (Sellars, 2011, p.6).

When printing with inkjet, ink droplets disperse onto the passing substrate. These droplets remain on the substrate until an electrical plate comes into contact with the ink. The electrical plates help differentiate the different types of droplets. The charged droplets stick within the imaged area, while the uncharged ones are placed into the process for a future print recycle. The uncharged droplets do not cover part of the imaged area, which will be recycled as they pass through the printhead. The positives of using continuous inkjet printing are that it offers a "high velocity of each ink droplet and the high drop release frequency" (Sellars, 2011, p. 6). These two positives of continuous inkjet printing allow for a wide range of substrates, their thicknesses, and the quickness of print for different jobs. One primary capability that continuous printing has over drop-on-demand is that "the nozzles do not have problems clogging" (Sellars, 2011, p. 6).

Drop-on-demand inkjet printing has multiple methods subcategories in piezo (Figure 11), thermal (Figure 12), or other rare types. For the inkjet printing process of drop-on-demand, "one single ink droplet can be jetted from the reservoir through the nozzle" (Blayo, 2005, p. 29).

These ink droplets are moved from the reservoir to the substrate by either "the vibration of the piezo element (piezo) or to a bubble resulting from the rapid evaporation (thermal)" (Blayo, 2005, p. 29).

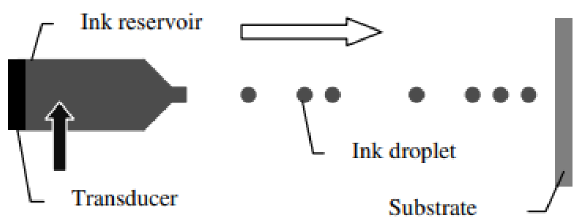


Figure 11: Piezo Inkjet (Blayo, 2005, p. 29)

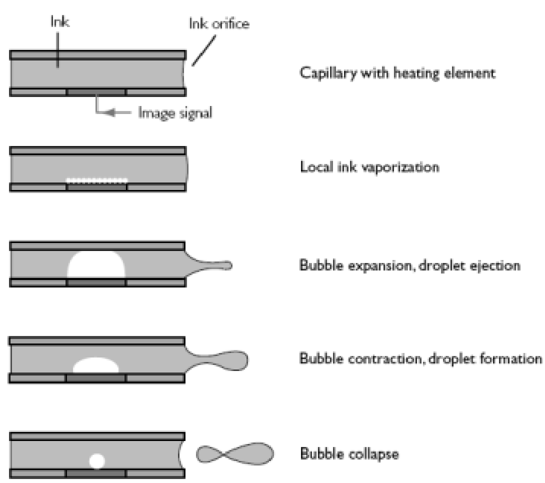


Figure 12: Thermal Inkjet (Sellars, 2011, p. 7)

Piezo and thermal inkjet methods of drop-on-demand printing have different strengths and weaknesses (Figure 13). If a company decides to use thermal technology for the droplets, this "allows for smaller drop sizes and higher densities for each nozzle," which means that companies can print smaller dot sizes and spend less on the drops (Sellars, 2011, p. 7). The disadvantage of using only thermal technology is that the company can only utilize water-based inks.

Piezo technology offers “a wider range of ink choices” like UV, solvent, or water-based inks (Sellars, 2011, p. 8). Even though this technology is significantly more expensive than continuous or thermal drop-on-demand, “the print heads usually last longer with this option, and this technology is usually more reliable” (Sellars, 2011, p. 8).

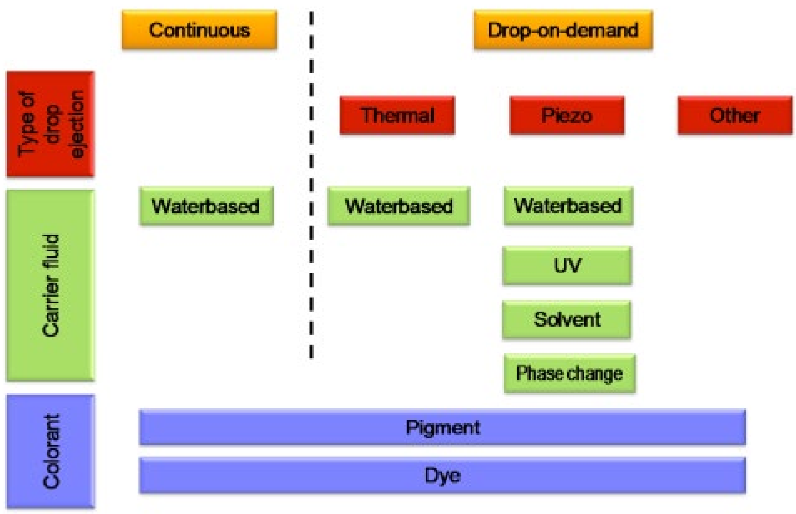


Figure 13: Comparison of Process Between Inkjet Printing (Sellars, 2011, p. 6)

<u>Innovative Trends</u>

Although toner-based and inkjet digital printing are considered competitors, the digital printing industry is growing and finding new technologies for each process that are either adopted by the industry or considered possible improvements as the industry continues to grow. With inkjet and electrophotography being newer than other print methods, tests are being completed for newer technologies and trends to help expand the already growing industry. These tests are printed with flexible crystal polymer substrates and use environmentally friendly toners (Cho, 2017) (Ataeefard, 2015).

One study in 2016 wanted to test how inkjet would react to printing onto a flexible crystal polymer substrate. The survey conducted by Cheng-Lin Cho et al. wanted to use metallic inkjet printing to help create layers but wanted to test the capabilities and structure of inkjet printing. The study's results proved that "full inkjet-printing multilayer technology has high potential as a flexible, cost-efficient, fast, and environmentally friendly approach to fabricating 3D laminate structures" (Cho, 2017, p. 5). This study may be an attractive finding as 3D printing continues to be a part of everyday life.

Also, a recent study was on producing environmentally friendly toners for printing with an electrophotographic process. To help create a more environmentally friendly option to replace the toner, a group of scientists used a toner created from an emulsion aggregation chemical process. Emulsion aggregation "is inherently a unique, environmentally friendly process that gives the provider the benefits of an accurate and efficient printing" process (Ataeefard, 2015, p. 121). The process of this aggregation is that it "can produce toner particles with uniformly dispersed pigment particles," which helps create the toner for the electrophotographic printing process (Ataeefard, 2015, p. 824). By testing the reactions and usage of this toner, they concluded that their tests should be used when studying or looking at the manufacturing process of toner (Ataeefard, 2015).

As the printing industry and the world advance, similar analyses and tests continue to create solutions and provide more environmental practices and processes, which will help preserve the materials used on Planet Earth. One common complaint used throughout the printing industry is the number of materials and lack of recyclable options offered throughout the printing process. This printing technology and trend will help create a more environmentally friendly option for electrophotography printing (Ataeefard, 2015).

Comparison Between Digital and Flexography

Similarities Between the Processes

Even though digital and Flexography printing differ by process, the production of these processes produces similar labels. Many within the printing industry say that digital was lagging behind Flexography ten to fifteen years ago when it came to actual label production. However, digital printing has shown that it can offer the same capabilities and abilities as Flexography (Hurley, 2015).

One example of how both processes produce similar labels occurred during an examination by Rupert Hurley and his colleagues at the Pack Expo in Chicago in 2014 (Figure 14). Hurley wanted to see if the consumer preferred or could tell the difference between a product printed either by digital or a Flexographic process. This study was conducted by having the same label on a grocery store shelf, the only difference being how it was printed.

For this consumer study, they observed 248 participants as consumers and wanted to see if the printing process changed consumer purchasing habits. 61.3% of the test subjects deemed no preference for the label type. The study showed "that consumers cannot significantly determine a difference between the two printing methods tested" (Hurley, 2015, p. 149).

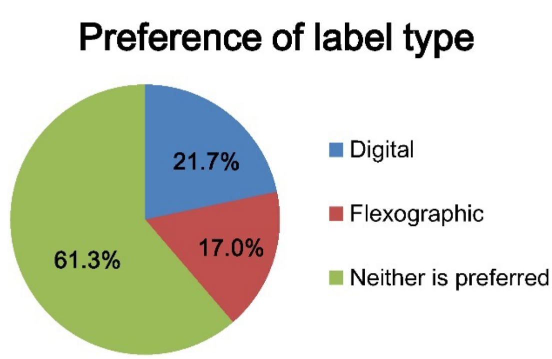


Figure 14: Preference of Label Type (Hurley, 2015, p. 154)

From the data and study done by Pack Expo, one can conclude that both processes can print similar labels and that there must be other reasons why companies prioritize one method over another. The data can also argue that digital printing has surpassed print quality and capability over Flexography due to consumers having a 4% preference for the digital sample over the Flexographic printed product.

Differences Between the Processes

Previous sections of this paper mentioned how the digital and Flexography processes work. This section will compare the differences in each process's capabilities. The main differences separating these processes are the capabilities offered by the two processes (Lee, 2017).

One of the appealing aspects of using a digital press is that the majority of the process of creating an image to printing a design is streamlined on a computer. Customers can order a label online, which directly communicates to a digital printing press and is ready to be created into an actual product. It takes little to no time to switch to different jobs or versions of a copy within seconds. This contrasts with Flexography, where printing plates must be made and mounted. Due to this capability, digital printing exhibits advantages for "smaller print volumes and variable information options for packaging and label printing" (Lee, 2017, p. 1). As digital printing excels in shorter runs, Flexography "is still more cost-effective for large quantities or long processing cycles" (Lee, 2017, p. 1). Other capabilities of digital printing include variable data printing and extended gamut printing.

Variable Data Printing (VDP) is a digital printing capability that "allows users to create customized printed media by changing and replacing particular elements such as image, text, name, color, or headline by using a database or an external file" (Cook, 2021, p. 1). This capability allows companies to print many order revisions using a database or spreadsheet during one press run. During Flexography runs, plates must be remounted and changed for different versions. Variable data and the ability to print many versions during one press run are two reasons the digital process is better for shorter and different version press runs (Cook, 2021).

Extended Color Gamut is a digital capability that allows printers to "reach more than 90% of Pantone Matching System (PMS) colors with greater accuracy than the conventional four-color process" (Oliver, Inc. 2022, p. 1). Extended Gamut can replicate spot colors through printing with Cyan, Magenta, Yellow, Black, Orange, Green, and Violet, better known as CMYKOGV. Using an extended color gamut saves companies money and time on mixing inks and creates opportunities for combination runs. The downside of using Extended Gamut is that if a company must use its brand colors for a label, it is nearly impossible to match those color specifications precisely (Oliver, Inc., 2022). The inks are costly compared to Flexographic inks, which using Extended Gamut causes companies to spend more money on already expensive inks.

Which Process Should a Company Choose?

Why Are Companies Switching to Digital?

As mentioned in the Similarities Between the Processes section, digital printing has matched Flexography's printing capabilities and results. Digital printing has provided the same opportunities and capabilities for print as the Flexography processes. With the opportunity to print more versions or switch jobs in seconds, companies are willing to substitute CMYK for spot colors to ensure these short prints happen quickly. One thing that digital printing has been able to provide that Flexography is still trying to replicate is that specific digital labels can provide "traceability and anti-counterfeiting" measures through unique barcodes when offering the product to the public market (Cheng, 2020, p. 1).

According to Brian Moran of Meridian Imaging Solutions, the industrial printing industry has nine different trends influencing the label-making business. These tendencies in no ranked order are: (Moran, 2023)

1. "Continued shift to digital printing
2. Focus on sustainability
3. Variable data printing capabilities
4. Digital label printers
5. Expanded product offerings
6. Special effects and finishings
7. Printing on new substrates
8. Streamlining workflows and moving in-house
9. Short-run printing focus."

(Moran, 2023, p. 1)

The printing industry continues to expand and create new capabilities for the digital and Flexographic printing process, so companies must make necessary changes to stay ahead of these movements. Some of the trends mentioned by Brian Moran, like the continuing shift to digital printing, variable data, digital label printers, and limited quantity orders, can only be achieved using a digital printing press (Moran, 2023).

A shorter-run printing focus has become one of the most significant trends on this list, if not the most significant. Since the creation of the internet and purchasing products from the comfort of a laptop at home, many consumers have prioritized personalization and items associated with the consumer. Many consumers want to purchase personalized labels or products and want those orders to reach their front door quickly. Digital printing can match the demand and offer reasonable prices to the consumer since every order can be produced with "no need for printing plates" (Mejtoft, 2015, p. 54).

A web-to-print method, which customizes labels directly from manufacturing websites to printing right after a customer orders a product, allows digital printing companies to keep up with the personalization and print on demand. Many companies are willing to expand their product offerings because "the printing industry is fragmented, as approximately 90% of the printing companies worldwide employ less than 20 people" (Mejtoft, 2015, p. 55). Through studies done over the past ten years, companies can create cost-saving opportunities when "print runs of less than approximately one thousand copies" (Hargrave, 2013, p. 231). Using a web-to-print method allows companies to create an opportunity to make money in a congested industry and have fewer costs (Mejtoft, 2015).

An example in the industry is how a digital printing press would benefit the label manufacturer, and the client would be printing for a large candle company. This candle company has many scents bottled in different sizes or variations, like the number of wicks used. These quantities can be changed to adhere to the different seasons or holidays like Christmas or Thanksgiving. If an order has many stock-keeping units (SKU), digital printing can print more efficiently than Flexography because of variable data printing and the quick changeover between jobs. In contrast, the Flexo process may only print two to three versions during an eight-hour shift. These types of businesses would be an adequate market for digital printing.

Having this mindset has caused the digital printing industry to expand. From Brian Moran's research, he concluded that "digital printing now has a 19.3% share of the entire $821 billion global printing market, an increase from 15.7% in 2017", which would have a monetary value of 158.5 billion dollars (Moran, 2023, p. 1). Other statistics (Figure 15) even project the digital printing industry "to grow at a CAGR of 6.45 from 2021 to 2026" (Saumya, 2021, p. 1). These statistics show that many companies know these trends and have started buying digital presses or are preparing to enter the industry.

Figure 15: Digital Printing Industry Compound Annual Growth Rate Projection (Saumya, 2021, p. 1)

Why Are Companies Remaining with Flexography?

The digital printing industry continues to expand and significantly impact the print market, but many companies still need to dip their foot into this printing method. As mentioned in the section within the Flexography Process, Flexography specializes and is most cost-effective during large press runs, which brings opportunity for companies looking for large consumer orders.

The inability of digital presses to be cost-effective on large press runs is one of many reasons companies are remaining with just using a Flexography process when printing labels. Despite progress and innovative trends in the use of different types of ink and substrates to print on, “very few digital presses can print with PMS inks,” metallic or fluorescent ink, and “the variety of paper and substrate options just does not compare to those offered via traditional processes” (Phoenix Group, 2017, p. 1).

As the digital industry is relatively new, more technology and printing capabilities continue to arise for this method. However, it still needs to catch up in some areas compared to other traditional print methods. Luckily, an extended gamut allows digital printing to match some PMS colors. If a customer needs a specific PMS color for their brand, digital printing can only sometimes fulfill them. A digital printing press must complement a Flexography operation, creating cost-effective short- and long-term estimations (Mejtoft, 2015).

According to Werner Zapka and his book titled *Handbook of Industrial Inkjet Printing: A Full System Approach, Volume 1*, some cons of inkjet technology include:

- Expensive inks
- Sensitive interaction between the ink and the substrate
- Single-pass printing has a limited layer thickness
- Fluid viscosity is lower than other methods
- Inkjet is still a young technique with limited experience compared to other printing methods
- No availability for low-migration UV inks
- Lost and expensive nozzles
- It is hard to train operators because the method is intensive on software

(Zapka, 2018, p. 4)

A few concerns arose when directly discussing digital printing capabilities with the manufacturers of digital presses. These parties mentioned that any inks or replacement parts a label company needed must be purchased from the digital manufacturer supplying the press. The yearly service or maintenance contracts can cover some of these expenses. However, these contracts will become void if consumables, like ink or other parts, are not purchased directly from the printing press supplier. Digital printing press suppliers require maintenance contracts because companies need the technical expertise to fix and work on digital printers when necessary. From listening to these digital printing suppliers, one can say that the power and control of these digital printing suppliers create a mini monopoly over these label manufacturing companies.

One takeaway from the conversation with a Flexo printing manufacturer was that label companies are encouraged to contact the press supplier or third-party companies when needing technical expertise to fix and work on these Flexographic presses in-house. This company also encourages label manufacturers to order inks anywhere available.

Flexographic presses have an extended shelf-life and are considered adequate even after fifteen to twenty years, while digital printers are considered obsolete after a few years due to the constant change in technology and newer digital presses continually hitting the printing market. With the constant adaptation and offerings of new digital presses, it becomes costly when companies have already invested in an expensive printing process.

In a questionnaire and survey by Trevor Schroeder, over 260 commercial label manufacturing companies still needed to implement digital printing were asked questions about their thoughts on digital printing. From the results, companies listed positive and negative things about implementing the changes to the corporation. Of all the responses, one of the most common adverse responses on implementing digital printing was that “those in charge of the decision are concerned about budget within the next 12 months” due to the high costs of purchasing one of these presses (Schroeder, 2014, p. 50). Many of these companies had budgetary concerns about buying a new digital press (Schroeder, 2014).

If many of a label manufacturing company’s clients order large quantities of the same label, it is best to print these labels using Flexo printing. When a company receives multiple orders asking for many different variations of a label or needs different sizes, the press run will need to be with a digital printer. With huge labels, manufacturers should consider using a hybrid printing process that accounts for large, medium, and small label orders. Due to the extreme price tag, hybrid printing is typically only available to large-label manufacturers. A hybrid press’s starting price is roughly 1.5 million dollars (RLG, 2023).

Hybrid Printers

Hybrid printers combine the printing processes of both digital and Flexography. According to the Resource Label Group, the hybrid printing process both “have Flexographic printing stations, which can be used for CMYK printing, spot colors, varnishes, and more, as well as a digital printing module which can be used for variable data printing” (RLG, 2023, p. 1). These hybrid printers also accomplish extended gamut printing. Essentially, this hybrid printer combines the best features and capabilities offered by the two processes of Flexo and digital printing (RLG, 2023).

As mentioned in the section on the Differences Between the Processes, the main difference between digital and Flexo printing depends on the size of the press run. The reasoning and design for the hybrid printing process is to bridge digital and Flexo printing regarding the size of the press run. These hybrid printers can print any press run size but specialize in more medium-sized orders (RLG, 2023).

Between digital, Flexo, and hybrid printers, each printing process is more effective than the others regarding the cost of materials and the time spent setting up for different lengths of press runs. Figure 16 compares the three processes and how much each costs depending on the run length (RLG, 2023). This graph implies that digital printing has expensive consumables like ink, so this process specializes in shorter press runs. Flexography cost and run length do not change much over time, but this graph does not consider the press setup times and plate costs. As for hybrid printing, the pricing is within the ranges for Flexography and digital printing, which makes it a reasonable choice for medium-sized runs.

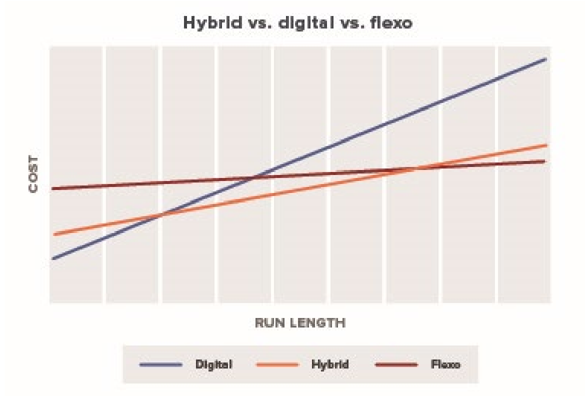


Figure 16: Hybrid, Flexo, and Digital Crossover Value (RLG, 2023, p. 1)

David Lee, who writes for Focus Label Machinery, mentions that hybrid printing creates five significant benefits for label manufacturers who purchase a hybrid printer:

1. Greater Flexibility
2. Increased Productivity
3. Strong Construction
4. Make Complex Jobs Easier
5. Advanced Features
    a. Touch Screen User Interface
    b. Remote Operation
    c. UV Drying
    d. Converting and Finishing
    e. Web Width Variety

(Lee, 2017, p. 1)

These are all reasons why hybrid printing is an enticing tool companies can use to strengthen their customer offerings. The print range is endless when a company can combine digital, hybrid, and Flexography printing processes. Many companies implementing the hybrid printing process are pleased with the results since these machines provide “quality and flexibility, and faster running speed than a pure digital press” (Coombes, 2021, p. 1).

Hybrid printing configurations can create a press with digital and Flexographic capabilities; why is there a lack of interest and usage in the label industry?

One of the main reasons why printing companies are staying away from hybrid printing presses is that many companies have found a niche within the label manufacturing industry. Many companies find it easier and more comfortable to focus on their specific printing process and cater to the customers that fit their needs. Another reason why these machines need help to gain traction is due to an underdeveloped market. This printing process is relatively new, and many decision-makers within their companies are afraid to change (Coombes, 2021).

In an interview hosted by Nick Coombes, who works for Label and Narrow Web, they asked questions of a manager from Mark Andy. During the interview, the Mark Andy manager stated that one of the reasons why hybrid printing has not been embraced by the printing industry yet is because many of the printers had “a degree of suspicion because it was an unknown and unproven concept” (Coombes, 2021, p. 1).

Companies are not using hybrid printing presses because of these machines’ extreme price tag and the unproven benefit of these machines. Only the largest printing companies can afford this machinery to keep up with their customers, creating jobs requiring digital, Flexography, and hybrid processing (Coombes, 2021) (RLG, 2023).

Future of the Printing Industry

Future Trends

One of the main discussion topics between industry leaders, label manufacturing companies, material suppliers, and consumers is the urgency and adaptation to implementing safer and more environmentally friendly practices. As mentioned in the Digital and Flexography Innovative Trends sections, scientists, companies, and R&D teams are creating and studying new trends within the printing industry, like printing on flexible crystal polymer substrates and using environmentally friendly toner.

As in any industry, many new techniques and studies implement more recyclable and safe practices within everyday life and the environment. The printing industry uses many resources to create labels for packages and other products, so new development methods help create a greener environmental footprint. Some other topics not previously mentioned are testing different recyclable materials and creating new methods to reduce waste (Dumea, 2009) (Lipiak, 2017).

In an experimental study by Nela Dumea of the Technical University of Iasi in Romania, the research group wanted to test and find a valuable way to de-ink Flexographic and digital ink off materials to create a reusable substrate for a future print. There were two ways of testing the de-inking process: slushing the print under alkaline or neutral conditions. The alkaline method consisted of four different chemicals. These were surfactant, sodium silicate, sodium hydroxide, and hydrogen peroxide (Dumea, 2009). The process of de-inking is shown in Figure 17.

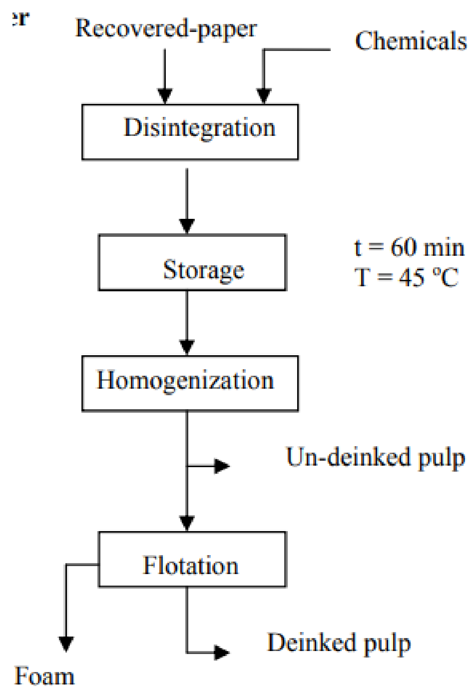


Figure 17: De-Inking Test (Dumea, 2009, p. 59)

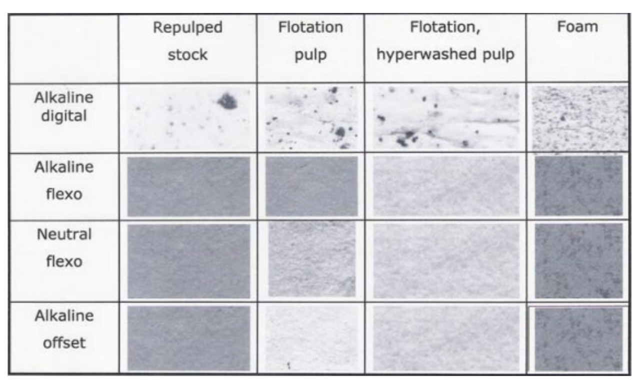


Figure 18: Results of the De-Inking Test During Each Stage (Dumea, 2009, p. 62)

Conclusions (Figure 18) drawn from this study included that “Flexographic prints should not be processed by the alkaline method” but instead using a neutral method, “digital prints need a complex – chemical enzymatic and mechanical – de-inking treatment,” and the de-inked substrates should not be reprinted with a different type of ink or reprinting method (Dumea, 2009, p. 63). Some methods succeeded over 90% when removing the ink from the substrate (Dumea, 2009).

Another example of how researchers are developing new ways to help reduce waste and create sustainable practices was a method studied by Warsaw University and spearheaded by Jan Lipiak. The study was designed to evaluate a current label manufacturing company and test different production methods to help with quality control efficiency in press runs and to help reduce waste (Lipiak, 2017).

While compiling data about the company (Figure 19), the researchers found “that waste arising from changeovers made over 60% of total waste” (Lipiak, 2017, p. 404). To reduce this number, the company implemented the process of the Single Minute Exchange of Die (SMED), which “is a technique used in machine and appliance changeovers at a time based on a minute unit” (Lipiak, 2017, p. 405). There are two different ways to complete an SMED, which are external and internal changeovers. An external changeover occurs when it “can be performed at a work time of the machine,” while an internal changeover occurs when it “must be performed at a machine standstill” (Lipiak, 2017, p. 405). The results of this implementation helped the company save 193 work hours and lowered the materials wasted when printing (Lipiak, 2017).

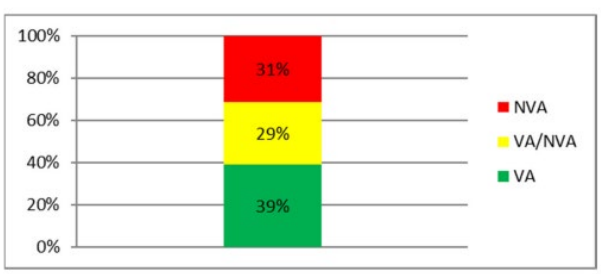


Figure 19: Value Chart of SMED (Lipiak, 2017, p. 407)

Another method tested in this study was the implementation of the Overall Equipment Effectiveness (OEE), which is a strategy that shows the "part of work the machines perform regarding a theoretically maximum value" (Lipiak, 2017, p. 407). This process and calculation allow companies to see where they create unnecessary costs and waste materials, inks, and time (Lipiak, 2017).

The final method used to help track the company's operations was Quality Function Deployment (QFD), which allows the evaluation of what the customer wants when ordering labels. This article concluded that these three methods "may bring positive economic effects in almost every production organization," including preventing waste and saving money (Lipiak, 2017, p. 410).

Researchers and companies are finding ways to create a more sustainable and eco-friendly process for manufacturing and printing labels (Dumea, 2009) (Lipiak, 2017).

Packaging Industry

The packaging and printing industries have a significant relationship with one another. Labels or some print on packaging allows companies, consumers, and shippers "to obtain information of the goods, such as origin, raw materials," the creation of the package and where the package is when being handled (Peng, 2021, p. 2480).

As can be seen in Figure 20, printing on packaging "covers nearly 50% of all printing today" (Stanislav, 2015, p. 27). Due to how the process works for Flexography and digital, both can print on various substrates and types of packages (Stanislav, 2015).

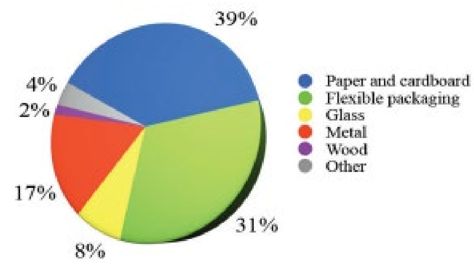


Figure 20: Print Substrate for Packaging (Stanislav, 2015, p. 28)

Just as it is for the label manufacturing industry, the packaging industry uses the Flexographic printing process for medium to large runs when printing on packages. In contrast, digital printing specializes in smaller orders or packages with multiple versions. If packages need metallic ink, Flexography is used to obtain the needed print (Stanislav, 2015).

As inkjet and electrophotography continue to grow and expand within the printing industry, more packaging companies will adopt the process of digital printing for their products. Some companies are using these two different types of digital printing because of the "low printing cost, fast printing speed, and good printing quality," which "perfectly meets the needs of flexible packaging" (Peng, 2021, p. 2479).

With the ever-growing demand for quick shipping and the creation of packaging when a consumer orders a product, digital printing has become an effective tool to help with this process because plates are not needed to create the image. Using only digital files to help create and print the image on a digital press "not only effectively simplifies the printing process, but also improves the printing efficiency" (Cheng, 2020, p. 1).

Currently, one of the most common types of printing for the packaging industry is the digital printing process of direct and indirect thermal printing, which specializes "to print prices and bar codes" (Stanislav, 2015, p. 28). Large packaging companies that print in-house are even implementing hybrid printing presses to handle the many packages that need printing (Stanislav, 2015).

One way packaging companies use the print process of Flexography is by printing spot colors rather than the standard four-color process printing of Cyan, Magenta, Yellow, and Black. As companies place more importance on branding colors within their packaging, using spot colors is the only accurate way to match the color exactly. For example, Coca-Cola Red can only be created and remain consistent if printed using a spot color (Min, 2023).

In the book titled *Innovative Technologies for Printing and Packaging*, tests ensued to see if spot colors can be a more effective way to print on product packaging than using a four-color process. The conclusion stated that "spot color printing has a good effect in color presentation and relatively stable color" (Min, 2023, p. 69). It was also concluded that "spot color printing can not only solve the problems of overprint and ink-water balance in four-color printing but also has the characteristics of ink saving, stable color, and wide color gamut" (Min, 2023, p. 62). For these reasons, spot colors used in packaging have already been and will continue to be used within the industry (Min, 2023).

Even within the food packaging industry, new trends and partnerships between the printing and packaging industries have helped create a safer and more protective process when packaging food and transferring it to the consumer. Many different labels help check the freshness of products, including if food has been tampered with or if there has been water, gas, or other condition damage to the product and its packaging. One type of QR label printed onto food packages helps companies create and have the opportunity "to acquire information about the food's quality, store that information and transfer it to the stakeholders" (Ruiz Garcia, 2018, p. 861).

As the printing industry continues to develop, keeping an eye on the new capabilities and opportunities created for the packaging industry is essential. The packaging industry will continue to use the new technology created by the print industry, which will be executed in the packages of all kinds of products.

Developing Countries

One of the best ways to track and find new trends within the printing industry is to look at what developing countries are doing to get ahead of other countries regarding print development and creating new jobs in these areas. With the increase in short-run production and the customer interest in printing on demand, many developing countries are attempting to build and create digital printing companies (Azly, 2019) (Saumya, 2021).

A research article by Noor Azly discussed how Malaysia is shifting its focus on creating digital printing companies. Countries developing their economy are switching to this printing process to get ahead of the new technology and wave within the printing industry. When the article came out in 2019, it projected that "the total digital market would reach a 225% increase in 2024" (Azly, 2019, p. 19).

Malaysia is one of many developing countries attempting to implement digital printing into its operating system. North America ranks only second in digital printing per region, while "the Asia Pacific region accounts for 35% of the digital print market" (Figure 21) (Saumya, 2021, p. 1).

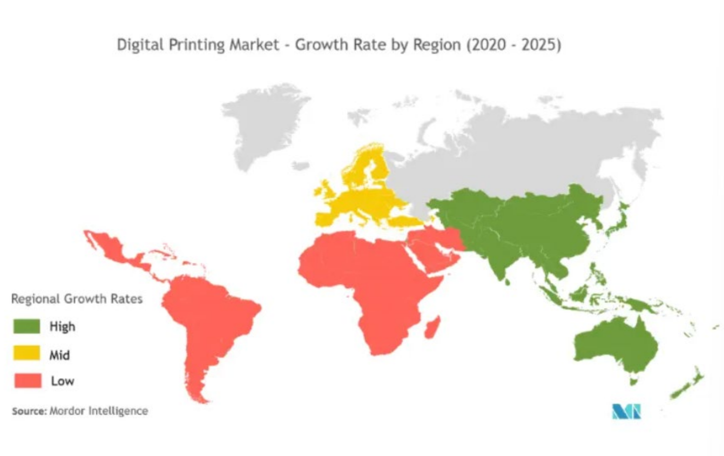


Figure 21: Digital Printing Market by Region (Saumya, 2021, p. 1)

It is crucial to keep an eye on how developing countries use the digital printing process and industry as an opportunity to grow the country, create jobs for their people, and provide valuable exports to other countries worldwide. As more technologies penetrate this industry, it will be interesting to see how these developing countries adapt to these changes (Azly, 2019) (Saumya, 2021).

Findings

<u>Samples</u>

A 5.75 by 11.875-inch label was sent from each printing process to help compare what actual samples would look like from a digital press versus a Flexographic press. This piece was duplicated eight times between seven digital presses and one Flexographic printing press. Five of those six digital presses came from different digital press manufacturing companies that market UV inkjet presses. A sample was also sent from a digital printing company that uses electrophotography and toner ink, while the final sample was from a UV Flexographic label company. There will be a comparison between eight examples during this test.

To help compare the digital and Flexographic samples exactly, the same artwork was sent out to all of these companies. The substrate used for all runs was on a paper stock with laminate. Of the six digital UV inkjet submissions, five used four-color process printing: Cyan, Yellow, Magenta, and Black (CMYK), while one used an extended gamut process: Cyan, Magenta, Yellow, Black, Orange, Green, and Violet (CMYKOGV). The electrophotography toner label used a four-color printing process, while the Flexo sample used a four-color printing process with a spot color.

There are many ways to compare the printing processes between one sample; the first primary test used to lead this comparison is the ability to match the needed color from the artwork. To help match the needed color from the artwork, a 2021 Pantone Formula Solid Coated Guide and an Exact X-Rite Pantone Spectrophotometer will be used to match the printed color to the pre-press artwork.

A Pantone Formula Solid Coated Guide is a “tool for designers, printers and color decision makers for specifying and approving spot colors in graphic projects, especially logos, branded designs and packaging” (Neurtek, 2023, p. 1). Companies use these books by placing their printed color on the booklet and comparing the two colors. The purpose of these books is to help printing companies match spot colors from their print directly to the customer’s brand colors. Each coated or uncoated book has “1341 solid colors and ink formulations” for these printing companies to color match while printing (Neurtek, 2023, p. 1).

Figure 22: Pantone Solid Coated Formula Guide

This specific sample was a prior job for an actual customer, which used a four-color process with a spot color. The spot color of 368 Pantone Green within the label is needed to match the brand of the product.

Figure 23: Sample Used for Comparison

As mentioned in the section Why are Companies Remaining with Flexography, Flexographic printing can print with a four-color process and spot color to match a company's brand colors onto a label. The Flexographic company matched the pre-press artwork and printed the green area with the closest spot color to 368 Pantone Green, which created a close match from the pre-press artwork when using a Pantone Book.

Figure 24: Flexographic Sample with Pantone 368C

As for the six UV inkjet samples and the one electrophotography toner-based ink sample, all six total samples cannot use a spot color when printing, which causes these printers to only use a four-color process or extended Gamut. The inability to use a spot color causes the label manufacturer to have longer setup times to perfect the brand or specific Pantone colors needed for the press run.

Figure 25: Digital Sample with Color Match

Color Print Sample	Match Pantone #
Toner 1	2294
UV 1	7738
UV 2	2301
UV 3	360
UV 4	369
UV 5	2464
UV 6 (EG)	7489
Flexo 1	368

Table 1: Pantone Book Color Matches

When using the Pantone Book, a light room, and the naked eye, all the digitally printed samples were close to 368 Pantone Green from the pre-press artwork. Even though none of the digitally printed samples matched directly to the 368 Pantone Green, many of these colors matched to a spot color similar to the brand color from the pre-press artwork.

The more exact and specific color-matching tool companies use to match their printed color to the pre-press artwork is a spectrophotometer. When measuring the printed area of a label, companies use a spectrophotometer, which "is an essential device for formulators to quantify spectral data reflected by process, spot the colors on printed samples, and learn coordinates in the CIE L*a*b* color space" (Altay, 2019, p. 911). The easiest way to convert the printed values into Pantone numbers is to find the CIE L*a*b* values, which is a "color space" that "is globally preferred numerical method to describe colors," as well as Delta E (Altay, 2019, p. 911).

The measurement of "Delta E (the total color difference) is based on delta L*, delta a*, and delta b* color values," in which Delta E is "the difference between displayed color and the original color standard" (Work, 2021, p. 1). According to Zachary Schuessler, the scale for this measurement is:

"<= 1.0: Not perceptible by the human eye

1-2: Perceptible through close observation.

2-10: Perceptible at a glance.

11-49: Colors are more similar than opposite.

100: Colors are exact opposite."

(Schuessler, 2019, p. 1)

Figure 26: Exact X-Rite Spectrophotometer

The spectrophotometer has a feature where a sample can be compared to a Pantone solid-coated color. By selecting Pantone 368 C and measuring the piece, the spectrophotometer records the L*a*b* of the sample, the delta L*a*b*, and a total Delta E value. By using the Delta E scale, it can be determined how close the sample is to the original standard color.

Figure 27: Spectrophotometer and its L*a*b* and Delta E Values of a Sample

The results of each L*a*b* and Delta E are listed below in Table 2:

Print Sample	L*a*b* Values	Delta E	Scale
Toner 1	65.29, -33.53, 57.70	4.72	Detectable difference at a glance
UV 1	65.92, -42.49, 59.72	4.15	Detectable difference at a glance
UV 2	70.60, -30.42, 56.09	3.64	Detectable difference at a glance
UV 3	67.37, -41.06, 61.21	2.48	Detectable difference at a glance
UV 4	66.39, -38.07, 58.46	3.16	Detectable difference at a glance
UV 5	68.32, -37.41, 51.99	3.48	Detectable difference at a glance
UV 6 (EG)	64.54, -32.50, 47.17	6.89	Detectable difference at a glance
Flexo 1	64.24, -43.26, 60.51	5.54	Detectable difference at a glance

Table 2: Spectrophotometer Color Matches

Using a spectrophotometer eliminates human error and the naked eye to judge the printed color comparison between the label manufacturer print and the pre-press artwork. As can be seen from comparing the data from Tables 1 and 2, it is not always best to use the naked eye and a Pantone Book to compare the printed samples to the pre-press artwork. Also, from the data collected from Table 2, all the digitally and Flexographic printed labels were within the third tier of the scale, a detectable difference at a glance. All these samples differed from the original standard color, which makes it disappointing that the difference in print could be spotted.

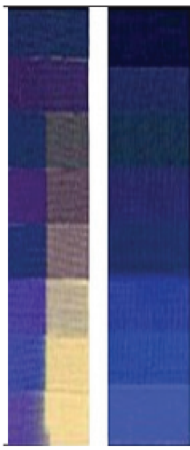
Through the use of profiling and color management, it can be brought to within an acceptable tolerance. It can become indisputable to a conventionally printed spot color.

As for the Flexographic results, it was likely that the company mixed their inks rather than buy ink that is 368 Pantone Green. A similar mistake happened when using a Pantone Book, as seen in Table 1; this company most likely did not use a spectrophotometer to color match their printed samples to the pre-press artwork but instead used a Pantone Book. Despite the color matching by using the naked eye, and the book may look like a color match, the actual print may be off when using a spectrophotometer. Despite this issue, Flexographic companies can still purchase the customer's brand colors in a spot color form and avoid the issue of printing the wrong color.

This example of color matching shows how digital companies can counter the issue of not being able to print with a spot color and create a color close enough. If a company is particular about its brand color and needs a 100% match, the Flexographic process would make the most sense because it can print with the brand's spot color.

Another comparison completed between the Flexographic and digital samples was comparing the durability of the print. When obtaining information from both digital and Flexographic companies, they all mentioned that using the Blue Wool Scale is one way to test the durability of ink and how it can withstand sunlight if placed outside. The Blue Wool Scale helps printing companies and manufacturers determine if their inks are durable and have light fastness, which is "the resistance of a color to fading under the sunlight" (Aydemir, 2018, p. 37).

This "scale was originally developed to characterize the light fastness of textile dyes" but "was later accepted as a reference point for testing a variety of color materials such including paint" since it was used for this work, the "fading of an ink is caused by light" (Aydemir, 2018, pp. 37, 39). Printing companies and ink manufacturers test the durability and light fastness by using a Xenon lamp tester and placing their printed inks under the lamp. The scale ranges from one to eight, where one stands for very poor, while eight means that the ink has outstanding durability and light fastness (Aydemir, 2018).



Blue wool scale	A	Comments
	8	Outstanding
	7	Excellent
	6	Very Good
	5	Good
	4	Moderate
	3	Fair
	2	Poor
	1	Very Poor

Figure 28: Blue Wool Scale (Aydemir, 2018, p. 39)

These inks are graded depending on how long the ink will fade under the Xenon lamp. By doing this study repetitively, the Xenon Arc Lamp has predicted the amount of sunlight needed to fade depending on the grading of the ink. This scale is one of the most influential rankings companies and ink manufacturers use when testing the durability of their ink, especially when the label or product is outside. (Aydemir, 2018).

BWS	Xenon Arc Lamp	Sunlight
1	0,5- 2 Hour	5 Hour
2	2- 4 Hour	12 Hour
3	1 Day	2 Day
4	3 Day	5 Day
5	6 Day	12 Day
6	8 Day	1 Month
7	12 Day	2 Month
8	> 30 Day	> 3 Month

Figure 29: Blue Wool Scale Times (Aydemir, 2018, p. 39)

When collecting data for the eight samples, each company provided its Blue Wool Scale ratings for their four-process colors. These are listed below in Table 3:

*DNS= Did Not Specify

BWS Scores	Cyan	Magenta	Yellow	Black	Average
Toner 1	DNS	DNS	DNS	DNS	DNS
UV 1	DNS	DNS	DNS	DNS	DNS
UV 2	7	7	7	7	7
UV 3	7	7	7	7	7
UV 4	8	8	8	8	8
UV 5	8	8	8	8	8
UV 6 (EG)	8	8	8	8	8
Flexo 1	7	6	6	8	6.75

Table 3: Blue Wool Scale for Each Sample

From evaluating the data above, the companies that provided data on their Blue Wool Scale values all had a durability and last fastness score ranging from very good to outstanding quality within their UV inks; regardless of which process used for printing, all process colors from any of these samples would withstand at least one month outdoors when being exposed to the sunlight.

These tests, color matching and the Blue Wool Scale proved that both printing processes shared similar results and offered similar qualities when printing outdoor samples using a paper and laminate substrate.

Price Comparison

To understand when Flexographic companies should implement a digital printing press in their operations, digital and Flexographic printing costs should be compared. The comparisons will be based on initial press costs, maintenance, job costs, and consumables like price per gallon of ink or photopolymer plate costs. The data will show a pricing comparison between the initial Flexography and digital printing press and a job estimation and crossover point of the Mole Eliminator sample, run by both UV inkjet and Flexographic print processes.

To have non-skewed data, six different UV inkjet digital presses from four companies were evaluated to create an average price for a company to purchase one of these digital presses and offer Flexo UV printing press pricing.

The first part of this section will review some of the features and capabilities of these six digital printing presses. There is pricing on the initial press, which includes the in-line finishing of a die-cut, registration, and foil stations. Only two of the digital presses offered finishing and foil stations. The other digital presses will have an additional 200,000 dollars added to the initial cost of the press. This pricing was the average amount of the finishing, which came from the other companies that did not initially include this.

Most digital presses come with initial consumables like printhead wipes, web cleaner adhesive rolls, flush, UV bulbs, and air filters. Also, manufacturers of digital presses offer warranties that last anywhere from one to four years, as well as remote support, training, and roughly one week of installation. All six of these presses shared similar capabilities and had few differences.

As for the technology of these six UV inkjet digital roll presses, all presses had an LED final cure, inter-color pinning, print head height adjustments, an average white opacity of 86%, a splice detector, and upgradable options within the field. Three presses had only ONE extra slot to add one of the three colors (orange, green, and violet) used to achieve extended gamut printing. In contrast, two presses offered the ability to add all three, while one press provided no extra slots. On average, adding one color would cost an additional $69,000.

Each of these six digital presses offered a touchscreen interface, an average of ten minutes to change the substrate, pre-installed color profiles that the label manufacturer can also create, compatibility with standard substrates like precoating, an ink cost calculator, and an average ink blue wool value of seven to eight for the typical process colors and the extended Gamut. Each press was either proven in or in testing to prove compliance with UL and CSA certification.

As for the actual productivity of these presses, the average top print speed for all four companies that manufacture these digital printers for standard process color (CMYK) with white was 212 feet per minute (fpm). The average substrate print width minimum was 5.25 inches, while the print width maximum was 13.75 inches. The printing area can be anywhere from zero to thirteen inches. Two companies had an actual resolution of 600 x 600 dots per inch (dpi), and the other two offered an actual resolution of 1200 x 1200 dots per inch (dpi). The dot size ranged from 2 to 3 picolitres (pl). All presses had corona treatment, pre-register printing and variable data.

For the other station options, companies could either create a hybrid press configuration or add a separate finishing unit to their digital presses so that these digital printers could offer a Flexo station, lamination, die station, edge trim and slitting, fully integrated customizable finishing, and embellishments. Pricing for this in-line finishing was kept within these digital printing suppliers except for the die station and foil application station due to being part of the initial purchase of some of the presses.

A few service and maintenance requirements were needed to keep the presses running. These requirements are critical since all these digital printing presses charge the label manufacturer regardless of whether the press is running or not. It is recommended to wipe printheads daily and purge them if they need to be replaced. The average cost of a new printhead was $5,910 each. These printheads are typically replaced three to every five years. This timeframe dramatically depends on the press usage (one, two, and three shifts). For instance, a shop that only runs one shift will get a longer life from its printheads than a shop that runs three shifts. Preventive maintenance would occur at least once a year to ensure the press meets its standards.

The initial cost of the six different presses is listed in Table 4. Note that anything listed as DNS means the company did not specify that information when asked about the press.

Digital Costs	Digital Press 1	Digital Press 2	Digital Press 3	Digital Press 4	Digital Press 5	Digital Press 6	Average Cost
Initial Press Costs	$ 450,000	$ 725,000	$ 850,000	$ 889,000	$ 795,000	$ 922,560	$ 836,312

Table 4: Digital UV Inkjet Press Pricing

Digital Press 1 did not test as well for resolution and color matching. It is only a 10-inch-wide press, costing only $450,000. This press is separate from the initial cost calculation. A comparison between digital and Flexography is needed to help understand how expensive each press is. When getting pricing from a Flexo press manufacturer, a press would cost roughly 745,000 dollars for the initial cost of a press.

Despite costing $745,000, this Flexo press offers many capabilities like five different printing stations, a vision system, initial anilox rolls, die cutting with magnetic dies, opportunities for finishing included with a foil station, and a touchscreen interface. Some features of this press allow quicker setup times, including enclosed ink chambers and a plate sleeve mounting process.

Even though the digital printing press average was $836,312 and the Flexo printing press cost $745,000, both have consumable costs as the press runs and uses materials. Inks are the initial consumable that does not come with purchasing these presses, and photopolymer sheets are required for the Flexographic presses.

Digital printing presses have service contracts. There are different tiers of service contracts. The higher the tier of a service contract, the more expensive it will be, but the more features and consumables are offered. Some companies offer a package that includes consumables like printheads or maintenance when the highest tier of the service contract is purchased.

When retrieving data from these four companies, some did not specify the pricing of the many tiers of service contracts or did not provide prices for any service contract at all. Only the essential CMYK Service Contract will keep the average service contract price consistent (Table 5). Typically, the service or maintenance agreement kicks in in year two or three of the contract.

Digital Costs	Digital Press 1	Digital Press 2	Digital Press 3	Digital Press 4	Digital Press 5	Digital Press 6	Average Yearly Cost
Service Contract	DNS	DNS	DNS	$ 52,080	$ 49,860	DNS	$ 50,970

Table 5: Digital UV Inkjet Yearly CMYK Basic Service Contract Pricing

No service contracts need to be selected when purchasing a Flexo printing press. So, there is no additional cost for service or maintenance fees for a Flexographic printing press unless the company needs to hire a technician for a part to be fixed or replaced.

As for consumables, both presses typically need parts replaced over time, mainly when running forty+ hours a week. Some press-run consumables include substrate costs, magnetic dies, and UV inks. Flexography has the same consumables as Digital with the addition of photopolymer plates. Remember that once the photopolymer plate is created, it can be reused when the job is re-ordered and needs to be printed.

A crossover point was created as if the Flexographic and digital press printed the Mole Eliminator label, the same sample used for the color matching and durability tests, to help compare consumables usage and run costs. The quantities selected for the crossover point are 10,000, 25,000, 30,000, 35,000, 40,000, 50,000, 75,000, and 100,000. The process for printing the Mole Eliminator label on a digital press was with the four-color process (CMYK), while the Flexographic process used CMYK and a spot color of Pantone 368 Green.

The consumables included within this press run would be material costs (paper stock and laminate), UV ink, a mag die for die-cutting, and photopolymer plates. To help form a cost estimate for this press run, these consumables and other job costs like make ready, wash up, material setup, and running costs were also included. The companies that sent samples also sent the ink pricing of a single-label cost and a 100,000-quantity price to print a Mole Eliminator label (Table 6).

Press	Single Label Cost	100,000 Label Cost
UV 1	$ 0.02256	$ 2,256
UV 2	$ 0.02343	$ 2,343
UV 3	DNS	DNS
UV 4	$ 0.01900	$ 1,900
UV 5	$ 0.01932	$ 1,932
UV 6	$ 0.01932	$ 1,932
Flexo 1	$ 0.00420	$ 420

Table 6: Single Label and 100,000 Label Ink Cost

As a point of interest, the average digital cost for ink was $0.0209. The digital ink costs are 4.9 times more than the Flexo ink costs. To calculate the ink costs for each order, multiply the single-label cost by the number of labels produced. The magnetic die pricing for the digital and Flexographic press costs 230 dollars. As for the photopolymer plates, five plates will need to be created for each color separating on the Flexographic press, which came out to 539 dollars. The last things that need to be calculated are the material setup, material cost, make ready, wash up, and run cost.

When discussing the press runs with the Flexographic company that sent samples, it took roughly eighty minutes of setup time to run this job, as well as thirty minutes to wash up. Over six hundred feet of material was used to set up the press before suitable labels were produced, and the press speed during the run was 200 feet per minute. As for the digital companies, the average setup time was ten minutes, and it took an additional five minutes to wash up. Only forty feet was used for the material setup. The press speed was 100 feet per minute. With all this information gathered, these numbers were added to the formulas for each calculation. The formulas of how these were calculated are listed below: *Anything in bold means that this number changes depending on the quantity*

Ink Cost

Ink Cost = Single Label Cost * **Quantity of Labels**

Make Ready & Wash up

150 = The hourly billing for the new press

Flexo Make Ready = (80 min. set up/60 min.) *150

Flexo Wash Up = (30 min. wash up/60 min.) *150

Digital Make Ready = (10 min. set up/60 min.) *150

Digital Wash Up = (5 min. wash up/60 min.) *150

Material Setup and Cost

Flexo Material Setup = ((12.5-inch material*600 ft. of setup*12 in.)/1,000) *.60 price per material

Digital Material Setup = ((12.5-inch material*40 ft. of setup*12 in.)/1,000) *.60 price per material

Digital and Flexo Material Cost = ((((12.5 inch * 11-inch repeat)/2 up) ***Quantity of labels**)/1,000) *.6 material cost

***1,000 is to convert the price per thousand to square inches (1,000 square inches = msi) (Conversion Influenced by Ink Pricing) ***

Run Cost

Digital Run Cost = (((((11 repeat inch. /Two up) ***Quantity of labels**)/12 inch)/100 ft per min.)/60 min.) *150

Flexo Run Cost = (((((11 repeat inch. /Two up) ***Quantity of Labels**)/12 inch)/200 ft per min.)/60 min.) *150

Once all the parts of the consumables are calculated, they are all added up. Different quantities were calculated to help establish a crossover point (Table 7). A crossover point is useful within the industry because it allows companies to determine which type of printing process is best for each quantity for a specific job order.

	Cost Estimate	
Label Quantity	Digital Cost	Flexo Cost
10,000	$ 1,005.44	$ 1,609.79
25,000	$ 2,106.96	$ 2,377.48
30,000	$ 2,474.13	$ 2,633.38
35,000	$ 2,841.30	$ 2,889.27
40,000	$ 3,208.47	$ 3,145.17
50,000	$ 3,942.82	$ 3,656.96
75,000	$ 5,778.67	$ 4,936.44
100,000	$ 7,614.53	$ 6,215.92

Table 7: Crossover Point

The crossover point for this specific job is between 35,000 and 40,000 Mole Eliminator Labels. The crossover point exemplifies how digital printing excels in smaller to medium run volumes, while Flexographic printing is efficient in medium to large run volumes. This data proves the purpose of this thesis.

The Digital press costs more initially but will also have more consumables like yearly service contracts, replacement printheads, and ink costs start to build up in price over time, especially since the UV inks for digital cost way more to refill by the gallon. Also, once the initial free contract is up from the purchase of the digital press, companies will have to pay at least, on average, $50,970 for the primary service contract to keep the press up and running.

Conclusion

This thesis aimed to see the main differences between digital and Flexography printing processes. There has been a shift and an emphasis on the new technology and trend of digital printing. The research aims to test whether digital printing has impacted the Flexographic printing industry and how these companies adapt to the changes.

The research within this thesis can be extended and create an even more precise conclusion if the crossover points and pricing comparison are more in-depth than previously conducted. The pricing could implement ink coverage, labor costs, return on investment over five years, and plate-making and mounting machinery costs. As for the color-matching test, more precise data could have been established if multiple people had done the color-matching activity and more replication with the spectrophotometer.

As the actual printing processes between the two print methods are relatively straightforward and definite, the main question was why some companies remain with Flexography, switch entirely to digital, combine both capabilities using a hybrid configuration, or use both print methods within their offerings.

By comparing the strengths and weaknesses of both print methods, completing tests on light fastness and color matching between printed samples of both processes, analyzing developing countries with print, and identifying current trends within the print and packaging industry, it allowed for a more robust understanding on how both print methods line up to one another.

The takeaway from this thesis is that it is not a matter of "if" but of "when" these Flexographic companies will implement digital printing capabilities into their company's print offerings. As mentioned in the Developing Countries section, many countries with the opportunity to expand have invested in digital printing. With the tests of color matching and light fastness, digital printing has created a press and product that offers the same capabilities as Flexographic printing. As mentioned within the section of Similarities Between the Processes, it has been proven through studies conducted by Rupert Hurley that the consumer has no preference between digitally or Flexographic printed labels for their products.

Digital and Flexographic printing processes will always play a role within the industry, as some capabilities or abilities can only be achieved using one printing method. However, label manufacturing companies should add both methods of print into their processes so these companies can create the ability to print different jobs depending on the size of the run. When customers are ordering different sizes of label quantities, having both print methods will allow companies to save money and become efficient on their press runs.

To highlight some of the points that were mentioned previously, please see below for the main takeaways from writing this thesis:

- Shift in Digital Printing
- Matter of when Flexography implements Digital
- Consumers have no preference
- No method is replaceable
- Digital printing is not a competitor but a complimentary piece for Flexographic printing

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