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Franziska Frey

Henrik Christensen

Nicholas DiSantis

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Franziska S. Frey, Ph.D.
McGhee Distinguished Professor
School of Print Media
Rochester Institute of Technology

Henrik H. Christensen
Graduate Student, School of Print Media
Rochester Institute of Technology

Nicholas DiSantis
Graduate Student, School of Print Media
Rochester Institute of Technology

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Abstract

This study outlines the life cycle of digitally printed marketing and promotional materials, transactional and business communications, direct mail, and on-demand color books. For each of the stages of the life cycle, stresses that influence permanence are discussed. A methodology is laid out to test the key variables determining the life expectancy of digitally printed products.

Executive Summary

The purpose of this study is to understand the life expectancy of products printed with digital processes. As the technology advances, new markets and applications are developing, requiring improved document longevity and robustness. With more documents being printed digitally, it is important to understand how these documents fare in terms of permanence in various stages of their life cycle, and how they compare to conventionally printed offset documents.

This study is limited to four categories of digitally printed documents:

- marketing and promotional materials,
- transactional and business communications,
- direct mail, and
- on-demand color books.

Focusing on the stressors induced in each stage of the life cycle, the aim is to paint a clear picture of the specific aspects of digital print production, distribution and usage that are key to product longevity.

In the printing and finishing stages of the life cycle, little physical or chemical stress is induced by the actual printing, but scratching and cracking typically occur during finishing. During the mailing and fulfillment stages, additional scratching and cracking, and heat, light, and air contaminants were seen as stressors. Similarly, scratching, cracking, heat and moisture were problems in the distribution stage. In the usage stage, the printing is subjected to a wide variety of stresses. Finally, recycling digitally printed products presents obstacles not encountered in the processes used for offset printed materials.

A methodology is laid out to test the key variables that determine the life expectancy of digitally printed products. Several tests were investigated, and preliminary interviews were conducted to provide information on what problems printing companies, vendors, and consumers are facing in terms of permanence.

The continuation of this study will monitor the performance of actual permanence tests. Conclusions will be reached assessing permanence performance measures created for digital printing technologies and their particular use with regard to certain products. These will include comparisons between three main commercial digital presses, inkjet printers, and offset lithography.

Introduction

The purpose of this study is to understand the life expectancy of products printed with digital processes. As the technology advances, new markets and applications are developing, requiring improved document longevity and robustness. With more documents being printed digitally it is important to understand how these documents fare in terms of permanence in various stages of their life cycle, and how they compare to conventionally printed offset documents. The definition of permanence depends on the type of product and its purpose.

This investigation examines the permanence life cycle itself and each stage's contribution of physical and chemical stressors to the product. It also explores the key parameters that affect document longevity and ways to test these parameters.

This study looks at four categories of documents:

- marketing and promotional materials,
- direct mail,
- transactional and business communications, and
- on-demand color books.

What these four digital print categories have in common is that they have all been predicted to play a major role in the on-demand digital color print market by graphic communication providers, research organizations, and vendors of printing equipment alike. For example, NAPL's 2004–2005 State of the Industry Report revealed the following critical market trend: "Demand for color, design, and customization [is] growing as clients recognize power of timely, visually compelling, personalized printing" as Andrew Paparozzi mentioned while talking at RIT in October 2005 (Paparozzi, 2005, October). Marketing and promotional materials, direct mail, color books, and transactional and business communications are all document categories located within this critical market trend.

In a survey by Frey and Christensen (2005), printing companies were asked which job type their companies would most likely be required to offer to ensure their future growth. Twenty-two percent of the respondents chose marketing and promotional materials, 24% chose direct mail, 14% transactional and business communications, and 2% book production. This question, however, was not asked particularly with digital print in mind, which may explain the low percentage for book production. Had on-demand color books been an option, the percentage might have been significantly higher.

The *GATF World 2005 Technology Forecast* (Davis, 2005, February) adds some perspective to this matter by describing growing print niches:

> As discussed earlier, within all print market segments digital printing is growing faster than traditional ink on paper printing. Sales revenues from digital printing has been growing at two to four times the rate of growth of traditional ink-on-paper printing over the past couple of years and this trend should continue. (p. 7)

With regards to growth in digital printing, Paparozzi (2005, October) stated that 56.4% of the respondents of the NAPL survey expected the “digital printing: variable” category to be the fastest growing service over the next two years. Furthermore, the category “digital printing: static” was expected by 40.8% of the respondents to grow the fastest. In the diversification plans of the respondents, digital printing presses and systems are a priority of 60.2% of the NAPL survey respondents over the next five years, whereas in the previous five-year period, this had only been a priority for 24.3% of them.

The four document categories in this study were traditionally printed as short run offset lithography, and a declining portion of these jobs will continue to be produced this way. But changing print buyer demands and the increasing capabilities of digital printing equipment have made “on-demand printing” more suitable for producing them. Whereas short-run work can be produced with either digital imaging (DI) presses, traditional offset, or digital presses, the requirements of on-demand printing dictate the use of pure digital presses without a fixed image carrier. In the 2005 *Seybold Report*, Fleming (2005, March) describes the difference between on-demand printing (referred to as “print-on-demand” or POD) and short-run printing:

> POD is production and distribution in quantities and cycle times based upon actual end-user demand. Most short-run printing is produced in quantities and cycle times ordered by the print buyer. For a multitude of reasons, the print buyer’s orders might have little if any relationship to the dynamics of the actual end-user demand. (p. 8)

Fleming (2005, March) further explains that digital printing is better at delivering the appropriate information to a selected market segment than conventional printing with a fixed image carrier. Thus short-run and POD both can have significant targeting value in personalized and other customized printing applications, but in POD the targeting value is even greater, because it is the end-user who triggers the print order, either individually or collectively. After the triggering event, the order is printed and fulfilled directly to the end-user. In short-run printing the print buyer, not the end-user, triggers the print order, and after delivery stores it in bulk for subsequent distribution. Furthermore, Fleming states:

> Pricing surveys by Strategies on Demand, L.L.C., have shown that 60% of the premium that customers pay for digital POD over conventional short-run production is directly attributed to the time value. Most of the premium comes from reducing cycle times in the distribution channel to the end user. (p. 8)

Fleming (2005, March) summarizes the three characteristics that are shared by POD applications as:

- targeted demand,
- time-critical delivery, and
- direct fulfillment.

All three characteristics are important to POD documents but in varying degrees according to the application. The most time-critical document categories are those equivalent to marketing and promotional materials, direct mail, transactional and business communications, and on-demand books, but these applications also rely on targeted demand and direct fulfillment. The value added by POD technology drives the demand for the four document categories of this study, and thereby increases the use of digital printing technologies in their production.

Specific research objectives for this extended study will be to:

- Investigate and describe the life cycle of various products produced with digital presses,
- Investigate finishing and handling parameters for digital products,
- Investigate archiving environments for digitally printed documents,
- Investigate and define key variables that determine life expectancy,
- Investigate and define tests for the above variables, and
- Build a foundation for defining quality metrics for various types of digital material in comparison with lithography.

Literature Review

The following literature review begins by describing the life cycle of digitally printed documents and then defines the various physical and chemical stressors that the printed document is subject to over the stages of its life cycle.

Life Cycle Terminology and Focus

The search for sources dealing with the life cycle of digital print or print in general did not reveal an actual, detailed description. This study therefore takes a step back and examines life cycle theory itself. Järvenpää (2004, Spring) explains that life cycle theory is a framework for describing a system in constant change. Change is described as the development that these systems undergo throughout the stages of their life cycle. A stage is therefore made up of a specific set of processes that impact the system during its development. Even though life cycle theory has its origin in biology it has spread into less organic sectors such as the software industry, the managerial field, electrical engineering, environmental research, and architecture and construction. Due to the diversification of these scientific and industrial areas, divergent life cycle terminologies have been created. Järvenpää (2004, Spring) explains, "Different sectors tend to define the concepts in their own words and use the same expressions in different ways. This causes problems on different levels of organizations" (p. 1).

The literature typically explains the life cycle of documents as the movement from an electronic form to some tangible form, such as print or microfilm. However it does not go into detail about the life cycle stages of this study's four digitally printed document types. Therefore, we have been compelled to define a life cycle appropriate to the scope of this study and then find sources that match the processes for one or more stages of this life cycle. According to Järvenpää (2004, Spring), the industrial sector works with approaches to life cycle theory that have this commonality:

The industrial cluster is working with very complex entities, which are associated with huge amounts of knowledge. The life cycle theory provides a mental framework for this environment. It claims the different stages of a product or service require different operations performed. The approach emphasizes the complexity of issues and provides an opportunity to define what is important in each stage of the development. (p. 6)

With this in mind, this study has been constrained to the section of the digitally printed document's life cycle between the printing process and recycling. The stages included are:

- printing and finishing,
- mailing and fulfillment (mail preparation and fulfillment processes not including the actual physical distribution),
- distribution (this includes all steps of the physical distribution),

- usage, and
- recycling.

In these five life cycle stages, physical and chemical stress is inflicted on the print. Since four categories of digital printed documents are dealt with, the processes within the stages of each category might differ slightly. An overview of processes in the life cycle stages of each category is therefore provided.

Stress Induction on Print

The determining factor in the choice of digital printing technology for producing the four document categories of this study is highly dependent upon costs as well as life cycle requirements. Costs are determined from the product specification, complimentary services, and pricing strategy of the producer. With this quantity of variables it is impossible to determine the exact distribution of preferred digital printing technologies within the four document categories of this study, or to accurately predict future developments in technology and the marketplace. Therefore, inkjet, dry toner, and liquid toner printing technologies are regarded as having equal importance for producing the four document categories.

These three printing process technologies, the formulation of their colorants, and the characteristics of the substrates dedicated to them of course vary. The effect of the types of stress induced on them therefore varies as well. Inkjet is more vulnerable to certain types of stress than toner-based technologies. There is also a difference in the effects of stress between dry and liquid toner print, but due to the similarity of the technologies, the differences are smaller. According to Kitamura, Oki, Kanada, and Hayashi (2003, p. 415), efforts to improve inkjet print durability have been targeted in six main areas:

- lightfastness,
- humidity control,
- thermostability,
- "plasticizer-fastness,"
- "water-fastness,"
- and "gas-fastness."

A reasonable durability in the first five areas has been achieved but the sixth, "gas-fastness," still remains problematic. Gas fastness can be defined as a substrate's stability after prolonged exposure to open air. In order to compensate for these stressors of light, humidity, heat, chemicals, water and open air contaminants, both inks and substrates need to be improved. Fading of inkjet prints occurs rapidly, even though the lightfastness of the colorants has been tested to be adequate. This fading can be attributed mainly to poor performance in gas-fastness when the "primary agent" is ozone (Kitamura, Oki, Kanada, & Hayashi, 2003, p. 415).

Kitamura, Oki, Kanada, and Hayashi (2003) explain:

> For this reason, resistance to ozone is the most important area to explore in terms of gas-fastness. At the same time, the necessity of objectively comparing and verifying ozone-resistance capability also makes the establishment of evaluation technology highly significant. (p. 415)

Sastri and Sankaran (2003) investigated substrate/toner interactions in laser printing processes that use both dry and liquid toner, and discovered that in such printing processes, "Print evenness, toner adhesion, and good optical quality of the print is essential" (p. 619). They elaborate on this by stating, "The output should be free of mottled appearance, have uniform optical density, and should be smear-free. Any deviations from these requirements can cause unacceptable print quality and customer rejections" (Sastri & Sankaran, 2003, p. 619).

Sipi (2003) agrees. "In electrophotographic prints the most important quality parameters are considered to be print evenness (lack of mottle) and toner adhesion to the paper, in addition to normal optical quality parameters" (p. 145). The toner adhesion is determined by the combination of properties in the fuser systems, toner, and substrate. Sipi (2003) also explains that pigments in the toner do not have a "specific affinity" to the surface of the substrate, which makes the toner resin the "main factor" in the adhesion of toner to substrate. This issue is further described by Sipi (2003):

> There are a few main theories for explaining the principles of adhesion on polymeric materials, but they have not been directly structured for toner adhesion. The general theories entail both mechanical and chemical adhesion. When paper is the receiving layer, both types of adhesion are involved. (p. 145)

Deprez, Op de Beeck, and Rosenberger (2003) explain how toner images, after printing, have to withstand external factors applied in subsequent treatment processes. They are considering:

> The problems associated with multiple, superimposed layers of toner particles that are in one way or another fixed on a substrate are manifold, not only with respect to image quality but also with respect to image stability and with respect to mechanical issues. (p. 487)

Deprez, Op de Beeck, and Rosenberger (2003) give the example of a mechanical issue that produces a high impact on print as the "sorting of printed papers (e.g. direct mail applications)" (p. 487). Here the turning wheels of a sorting machine can result in temperatures that exceed the "glass transition temperature (Tg) of the resin used, which can cause contamination with pigmented toner resin on the next coming papers" (p. 487).

Based on these and several other sources, the following structure for investigating stressors throughout the life cycle of the four categories of documents has been selected:

Table 1. The main types of stressors that confront the four document categories

Stress	Type	Test	Testing Instrument
Scratching	Physical	Abrasion resistance Rub resistance	Taber Abrasion Tester Sutherland Rub Test
Cracking	Physical	Folding test	Fold tester
Solvent	Chemical	Solvent resistance test	
Light (UV)	Chemical	Lightfastness	Fluorescent / Xenon Light Chamber
Moisture	Chemical	Humidity-fastness Water resistance DIN-16524-1	
Heat	Chemical	Thermostability	
Air contaminants	Chemical	Gas-fastness, ozone test	Ozone Chamber

Each of the three digital processes (inkjet, dry toner and liquid toner) is dealt with individually throughout the stages of the life cycle in further analysis. Therefore, the stress types related to each particular process will be listed and described in the following sections.

Processes in the Printing and Finishing Stage

1.a) Printing: Toner-based printing technologies

Toner-based printing technologies can basically be divided into five steps (Kipphan, 2001, p. 60):

- imaging,
- inking,
- toner transfer,
- toner fixing, and
- cleaning.

The toner fixing step is of particular interest to this study because the adhesion properties are to a great extent determined at this point. Kipphan (2001) describes this step:

> A fixing unit is required to anchor the particles of toner on the paper and create a stable print image. This is usually designed so that melting and consequent anchoring of the toner on the paper takes place by heat application and contact pressure. (p. 60)

Polyester toners are the most commonly used toners due to their low minimum fixing temperature and hot offset temperature (Sipi, 2003, p. 145). The surface structure of paper is popularly described as having "hills and valleys," products of the bonding of cellulose fibers that typically measure 1 to 3 mm in length and 30 to 50 microns in thickness. When fibers in this size range bond, voids will occur between the fibers, and even though these are filled with small particles of inorganic material, the paper surface will appear undulated. The degree of undulation of course varies with differences in coating.

In the toner transfer step, toner particles come in contact with the paper surface. Since the toner particles on average measure 7 to 12 microns, they come in contact with both fibers and voids and are expected to “anchor” there until the subsequent toner-fixing step (Sastri, Sankaran, 2003, p. 619).

The adhesion of the toner to the paper surface, which happens during toner fixing, is both a mechanical and chemical adhesion. The mechanical adhesion involves polymeric toner molecules penetrating into the voids of the paper surface and interlocking with the solid surface and each other. Since 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.

The “adhered-to” areas of the substrate consist of toner polymer chains on and between paper cellulose fibers.. The cellulose fiber polymer chains are longer and therefore weaker than the shorter toner polymer chains.

In chemical adhesion, the most applicable theory is absorption. This adhesion strength is determined primarily by the wetting of the paper from the toner’s resin. The strength of chemical adhesion is thus highly dependent on the paper’s surface energy properties for the chemical bonds to endure stress (Sipi, 2003, p. 145).

So toner adhesion is affected by both the mechanical and chemical properties of the paper. Sipi (2003) explains:

> On uncoated papers the unmelted toner particles in the voids do not adhere as well as particles on the peaks of the profile, so paper roughness contributes to the adhesion level. Porosity and swelling of the fibers also have a certain effect. On pigmented and coated papers the surface chemistry is believed to have a stronger effect (p. 146).

1.b) Printing: Inkjet printing

The inkjet printing process is distinct from other printing technologies because ink is applied directly onto the paper, without an intermediary transferring device (cylinder, blanket, etc.). Since the drying of the liquid ink is the key to image quality, the paper’s surface ability to carry ink is of great importance. Special papers are therefore often necessary although specially formulated inks in conjunction with drying process adaptations can increase the range of suitable papers significantly (Kipphan, 2001, p. 63–65).

Inkjet inks solidify on the substrate in a very different way than toner does. The drying process involves the ink being partially absorbed by the substrate and its carrier being partially evaporated when going from a liquid to solid state. With both water-based and solvent-based carriers, the remaining ink film thickness on the substrate surface is approximately 5 microns. Ultraviolet (UV)-curing inks solidify forming a slightly thicker ink film –approximately 15 microns (Kipphan, 2001, p. 687).

The absorption of ink into the paper in inkjet printing is the major difference between toner-based and inkjet printing technologies. It is also the reason why abrasion resistance and adhesion strength are, in most cases, less critical issues to investigate when looking at inkjet print permanence. However, substrate properties like media pH, surface coating nature and location of the colorant have a big impact on aging properties of inkjet materials. Blayo, Pineaux, and Medlege (2001) describe an example with inkjet printing on coated paper:

> [A]fter UV-light exposure, the color shifts for magenta ink were much larger than the corresponding degradation of the other colors, which is due to the intrinsic properties of this colorant, but was emphasized by the nature of the coated media. This suggests that the molecules of the coating layer, and their degradation, promote the photo-degradation of the magenta pigments and dyes used in the ink formulation. (p. 238)

2.) Finishing

The amount of stress applied to substrates in the various printing processes is minimal compared to the physical stress applied in all phases of finishing. Table 2 summarizes the stress types and categories that can occur in the printing and finishing stage. Kipphan (2001) explains the folding process as “the sharp-edged bending of paper webs or sheets under pressure at a prepared or unprepared bending point along a straight line according to specified dimensions and folding layouts” (p. 796). “Wire-stitching,” Kipphan says, “is a form-fit jointing method. With wire-stitching binding, wire staples are pushed through the sheets of a block and closed on the underside” (p. 839). Wire comb binding can be either plastic binding, Wire-O® binding, or spiral binding. They all function according to the same principle: a plastic or metal wire is inserted into the pre-punched or predrilled openings of a book block (Kipphan, 2001, p. 827). Perfect binding has two variants applicable to this study, notch binding and flexo-stable binding. Trimming is also explained by Kipphan:

> Blocks for hard covers and brochures are cut on one, three (or four) sides to the final format, whereby the closed fold edges on the head, foot, and front side of the block are eliminated, if this is intended for the product. (p. 842)

Table 2. Summary of processes in the printing and finishing stage and their contribution of stress to printed products

Process	Document Category	Stress Category	Stress Type
Printing	All	None	None
Folding	All	Physical	Cracking
Stitching	Marketing and promotional materials	Physical	Cracking
Wire comb binding	On-demand color books	Physical	Scratching, cracking
Tape binding	On-demand color books	Physical	Scratching
Perfect binding	On-demand color books	Physical	Scratching, cracking
Trimming	All	Physical	Scratching

Processes in the Mailing (Mail Preparation) and Fulfillment Stage

This stage of the life cycle was defined to include mail preparation and various fulfillment processes not including the actual physical distribution of the process. The following therefore might not all apply to this life cycle stage as defined for this study.

According to a survey by Andrew Paparozzi of NAPL, mailing and fulfillment are both expected to increase by approximately 45% from 2005–2007. Printers are focusing their priorities on mailing and fulfillment capabilities almost twice as much now and for the next four years as opposed to the last four years (Paparozzi, 2005).

Fulfillment

Mailing and fulfillment are usually tied together because fulfillment can include mailing. Fulfillment is viewed as a value-added service which an increasing number of print services providers are offering. Cummings and Chhita's Industry Trends in Fulfillment, Finishing and Distribution (2004) defines fulfillment as "the storing and distribution of products directly to end users, after the initial job has been printed and mailed" (p. 10).

Cummings and Chhita define three types of fulfillment:

- literature fulfillment,
- product fulfillment, and
- Internet fulfillment or e-fulfillment.

Table 3 summarizes key processes in the mailing and fulfillment stage and their contribution of stress to the printed product.

Table 3. Summary of the processes in the mailing and fulfillment stage and their contribution of stress to printed products

Process	Document Category	Stress Category	Stress Type
Collecting	Direct mail Marketing and promotional materials Transactional and business communications	Physical	Scratching, cracking
Inserting	Direct mail Marketing and promotional materials Transactional and business communications	Physical	Scratching, cracking
Wrapping/packing	All	Physical/chemical	Scratching, heat
Addressing	Direct mail Marketing and promotional materials Transactional and business communications	Physical/chemical	Scratching, light, heat
Pre-postage sorting	Direct mail Marketing and promotional materials Transactional and business communications	Physical/chemical	Scratching, cracking, heat
Postage application	Direct mail Marketing and promotional materials Transactional and business communications	Physical/chemical	Scratching, heat
Ware-housing/storage	All	Physical/chemical	Scratching, air contaminants

Processes in the Physical Distribution Stage

Distribution normally takes place after finishing, and involves a printed product being sent directly to the customer, end user, a distributor, a warehouse, or a database (Kipphan, 2001, p. 971). For print services providers or third parties that offer distribution services, costs, handling procedures, storage, and safety are of the utmost concern. Distribution is a key part of the digital print life cycle because, in most cases, it is the final stage before the end user.

Mailing as Part of the Physical Distribution

The mailing process is hard on all printed pieces, however, direct mailers that are printed by digital processes typically sustain more damage than mailers produced by any other printing technology. According to C. Clint Bolte, reporting on the PIA/GATF Tech Alert 2005 Conference, "It seems that the various USPS (United States Postal Service) high speed sorting equipment scrap, scuff, scratch and rub the digital toners leaving streaks, smears and unsightly crinkles at a frustratingly high proportion of the total project run" (p. 4). Press vendors have provided coatings to combat this problem and although they have helped, coatings have definitely not eliminated the problem (Bolte, 2005, p.4).

Companies dealing with direct mailings are usually not concerned with light and UV radiation fading the prints. Because direct mailings are not typically archived, the shelf life of these documents does not need to be very long. However image quality and the overall look of the final document when it reaches the end user are extremely important. Therefore, humidity, water exposure, temperature, smearing, handling procedures, and scratching are all concerns to the commercial printer needs when printing bulk mailers (Johnson, 2003, p. 157–173).

Humidity, temperature and water exposure not only affect the substrate but can also distort the inked image on the substrate. This is a much bigger problem in the summer and in the South where humidity and temperatures are high. High humidity coupled with high temperatures will curl paper and speed up chemical decomposition of the printed piece. During the winter months in the colder regions, humidity is not a big factor, but water exposure is of huge concern in all climates. Bulk mailers are frequently exposed to water. Mail that travels long distances can cover a wide variety of climates in a short period of time and be exposed to rain, snow, UV exposure and high humidity. Bulk mailers must be able to withstand this exposure and still look presentable when they reach the end user (Johnson, 2003, p. 157-173).

All these factors are important to printing press vendors, print services providers, mail services, and end users. For this reason the Printing Industries of America / Graphic Arts Technical Foundation (PIA/GATF) teamed up with the USPS, printing press vendors, print services providers, and digital paper mills to identify and study common problems the industry is having with digital mailers. The primary objective was to see how measures like UV coatings, aqueous coatings and varnishes affected the performance and permanence of digitally-printed materials through the mailing process. The researchers soon discovered that the problem was larger than they had anticipated (Bolte, 2005, p. 4).

The post office's sorting equipment was designed to handle standard-sized envelopes. But digital mailers are not typically designed to be standard-sized because savvy designers realize that creativity in size will draw attention to their pieces. In the 2005 PIA/GATF mailing study, more than one-quarter of the pieces arriving at their final destination were damaged. This problem is undoubtedly a high priority for direct marketers.

Irradiation of mail that started in parts of the country to destroy anthrax poses another stress that has to be studied for the various print processes.

A shift in distribution trends in the past few years has addressed the concerns of distributors. Historically, printers followed a "print and distribute" business model, that is, physically printing the product in one location and then delivering it to a remote end user. In the newer "distribute and print" business model, electronic files are distributed close to the ultimate product destination and then printed. This workflow reduces distribution stresses and is a breakthrough in cost efficiency as well as storage and safety (Cummings & Chhita, 2004).

Both models entail stresses on the printed product, including scratching, cracking, moisture, heat, and air contaminants. These stresses are outlined in Table 4.

Table 4. Summary of the processes in the distribution stage and their contribution of stress to printed products

Process	Document Category	Stress Category	Stress Type
Sorting	All	Physical/Chemical	Scratching, cracking, heat
Packing	All	Physical	Scratching, heat
Transportation	All	Physical/Chemical	Scratching, moisture, heat
Delivery	All	Physical/Chemical	Scratching, cracking, moisture, heat

Processes in the Usage Stage

Although literature concerning the user stage of the product life cycle in digital printing is scarce, permanence issues, quality, and archivability are most critical at this stage. The definition of permanence depends on the type of product and its purpose.

The principal documents focused on in this study include: marketing and promotional materials, direct mail, transactional and business communications, and on-demand color books. Based on the materials and processes used, these products vary widely in terms of user expectations about permanence.

Normally, marketing and promotional materials do not have a long shelf life. However, they are expected to be immaculate when they get to the end user. Because of their potentially short shelf life, marketing materials need not excel in archival qualities but must last long enough to survive the printing, finishing, and distribution processes, all the while maintaining superior quality. The shelf life of direct mail is also short, and it also must survive the stages of printing, finishing and distribution and look great when it reaches the end user.

Transactional and business documents, on the other hand, have different requirements. They usually contain legal or contractual qualities and are therefore expected to last. These types of documents may be filed and kept for years, so in addition to withstanding the aforementioned processes, they must be permanent.

Lastly, expectations for on-demand color books are similar to transactional and business documents. Books are meant to be read and used but are also viewed as keepsakes. They must survive the printing, finishing, and distribution stages as well as continuous use and prolonged exposure to the elements. This may be the only type of product discussed in this research that is exposed to every type of stress mentioned.

Table 5 summarizes the processes in the usage stage and their contribution of stress to the prints.

Table 5. Summary of the processes in the usage stage and their contribution of stress to printed products

Process	Document Category	Stress Category	Stress Type
Usage	Marketing & promotional	Physical/chemical	Scratching, cracking, moisture, heat
	Direct mail	Physical/chemical	Scratching, cracking, moisture, heat
	Transactional/Business communications	Physical/chemical	All but solvents
	On-demand color books	Physical/chemical	All

Processes in the Recycling Stage

The last stage in a digitally-printed product's life cycle is recycling, the breaking down of ink and paper to be reused. Recycling digitally printed materials is more complex than recycling offset lithographic materials.

Traditionally, the recycling process began with a process to de-ink the printed sheets. To improve ink release, chemicals such as caustic soda, sodium silicate, hydrogen peroxide, and soap were introduced during the repulping stage of paper, making a slurry of paper fibers (Carre, Magnin, & Ayala, n.d., p. 12). In the slurry, air bubbles rose up, carrying ink particles from the paper to the top of the slurry. Once the ink particles had risen, due to the hydrophobic properties of the ink, they were easily targeted and removed.

However, most digitally printed products are very difficult to process this way. According to Bolanca, Agic, and Bauer, "unlike conventional printing inks, [toners] contain synthetic binders based on polyester or polymers of styrene with acrylates, methacrylates or butadiene. The toners contain 90–95% resin, 3–5% colorant, 1–3% charge control agents and other technical additives" (Bolanca, Agic, & Bauer, n.d., p. 2). These binders make it very difficult to complete the recycling process. During the first stage of the process, the toner tends to break up into very large particles, some of which are too large to be removed, unlike conventional printing ink particles (Bolanca, Agic, & Bauer, n.d., p. 1).

Other recycling techniques include screening, cleaning, washing, and dispersion. In the screening process the pulp is pushed through openings in a fine web to remove large contaminants. Washing also removes unwanted contaminants through a screen, with the addition of water. Cleaning removes large or small contaminants in somewhat of a washing machine approach. As Carre, Magnin, and Ayala describe cleaning, it "is based on particle separation in a centrifugal flow field. A swirling motion is created by the tangential inlet flow. The vortex motion creates centrifugal force which causes the particles heavier than the stock to migrate to the outside of the cleaner, while the light-weight particles migrate toward the vortex core" (Carre, Magnin, & Ayala, n.d., p. 2). Finally, dispersion is used to reduce residual contaminants. With the addition of heat, this process can rid the old product of adhesives, varnishes, toners, or coatings that may have been left over from previous recycling procedures (Carre, Magnin, & Ayala, n.d., p. 2).

Recycling is particularly problematic when the paper has been printed with UV inks, liquid toner, hotmelt inkjet inks, home or office inkjet processes using water-based inks, or when the paper has a UV coating. These cases create problems such as speck contamination, sticky deposits, low brightness, and pronounced color shade (Carre, Magnin, & Ayala, n.d., p. 2).

For the recycling process to be economical as well as able to produce quality recycled papers, toners must be almost completely removed from the pulp. With digital printing taking more of the market share from traditional offset lithography, this could pose a serious problem in the future. However, testing has indicated that recycled paper produced from digital printing is comparable to recycled paper produced from offset printing. Recycled papers in general show a "deterioration of properties such as burst strength, tensile strength, stretching and double folds" (Bolanca, Agic, & Bauer, n.d., p. 71). However, "the use of recycled fibres leads to an improvement in properties such as stiffness, tear resistance, porosity, opacity and light scattering coefficient, because of the loss of swelling ability and fibre bending," say Bolanca, Agic, and Bauer (Bolanca, Agic, & Bauer, n.d., p. 71). New methods of efficiently recycling digitally printed products need to be explored.

Life Cycle Overview

The four document categories in this study encounter similar problems in their life cycle stages. Their situations differ, however, in the printing and finishing stage and in the mailing and fulfillment stage. Figures 1 through 4 depict the processes in the life cycle stages of each category. Note that the mailing and fulfillment stage includes mail preparation and fulfillment tasks not including the actual physical distribution. The distribution phase includes the physical distribution steps. The color coding refers to the types of stressors induced as described in Table 1.

Figure 1. The processes in the life cycle of marketing and promotional materials

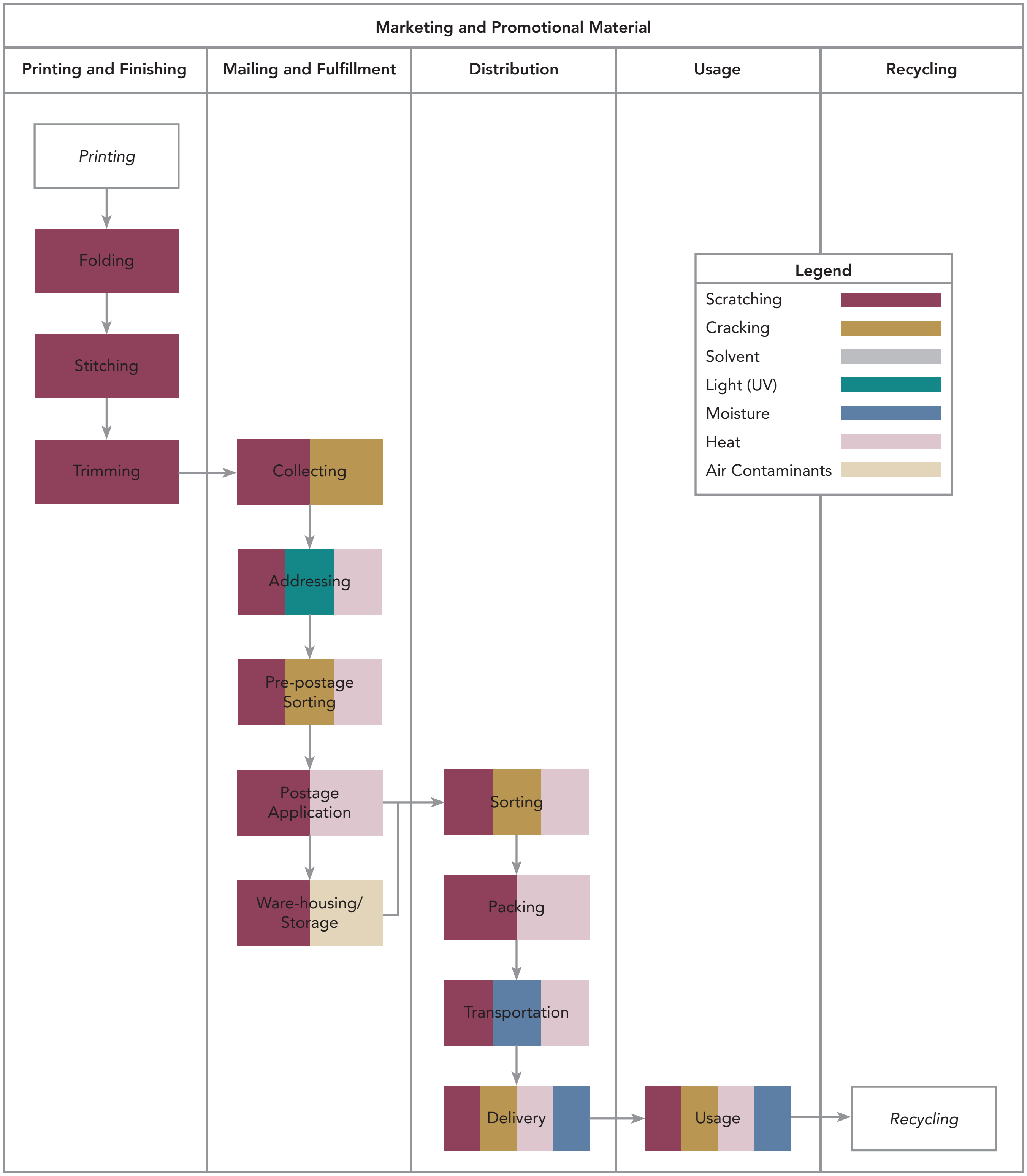


Figure 2. The processes in the life cycle of direct mail

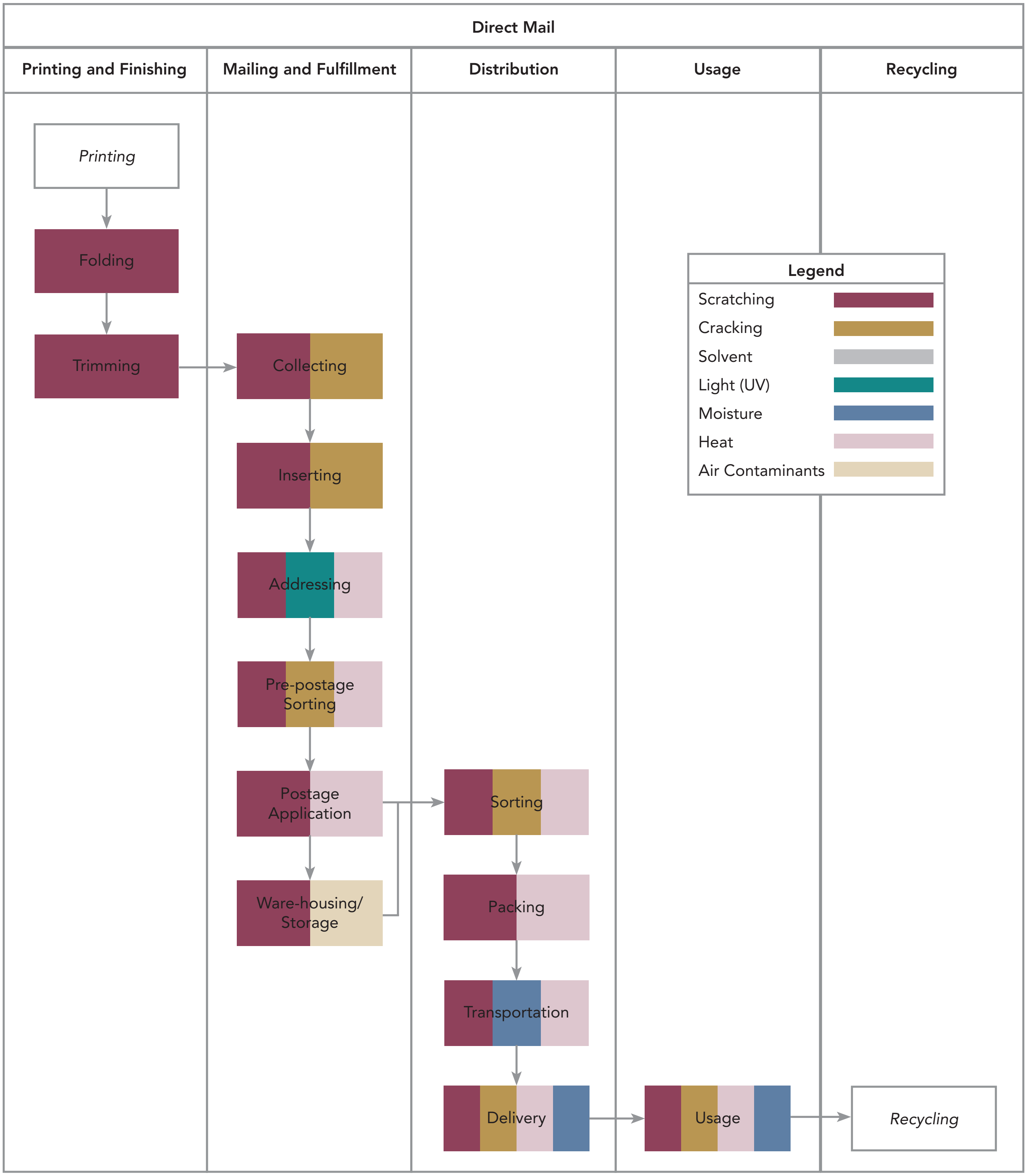


Figure 3. The processes in the life cycle of transactional and business communications

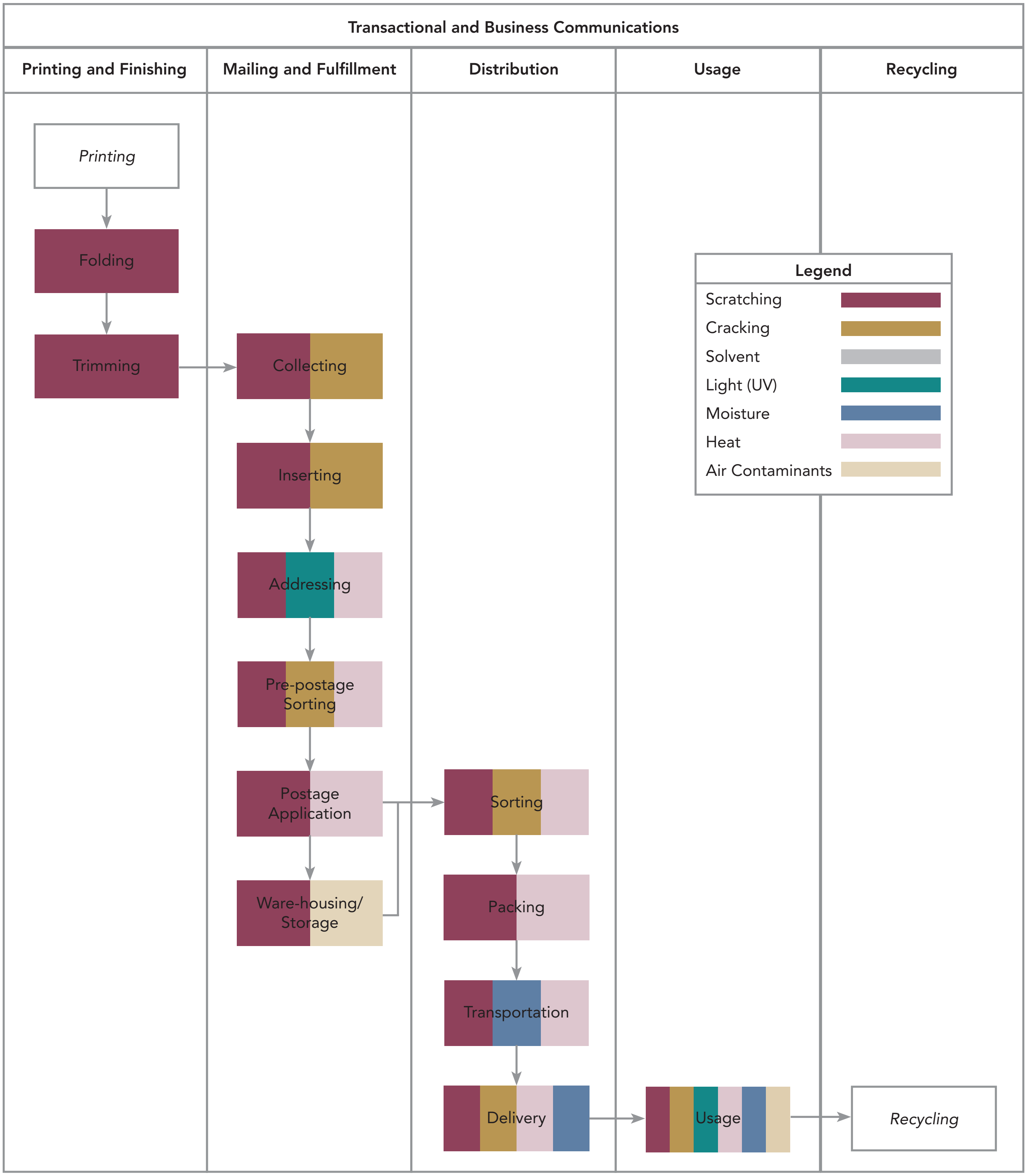
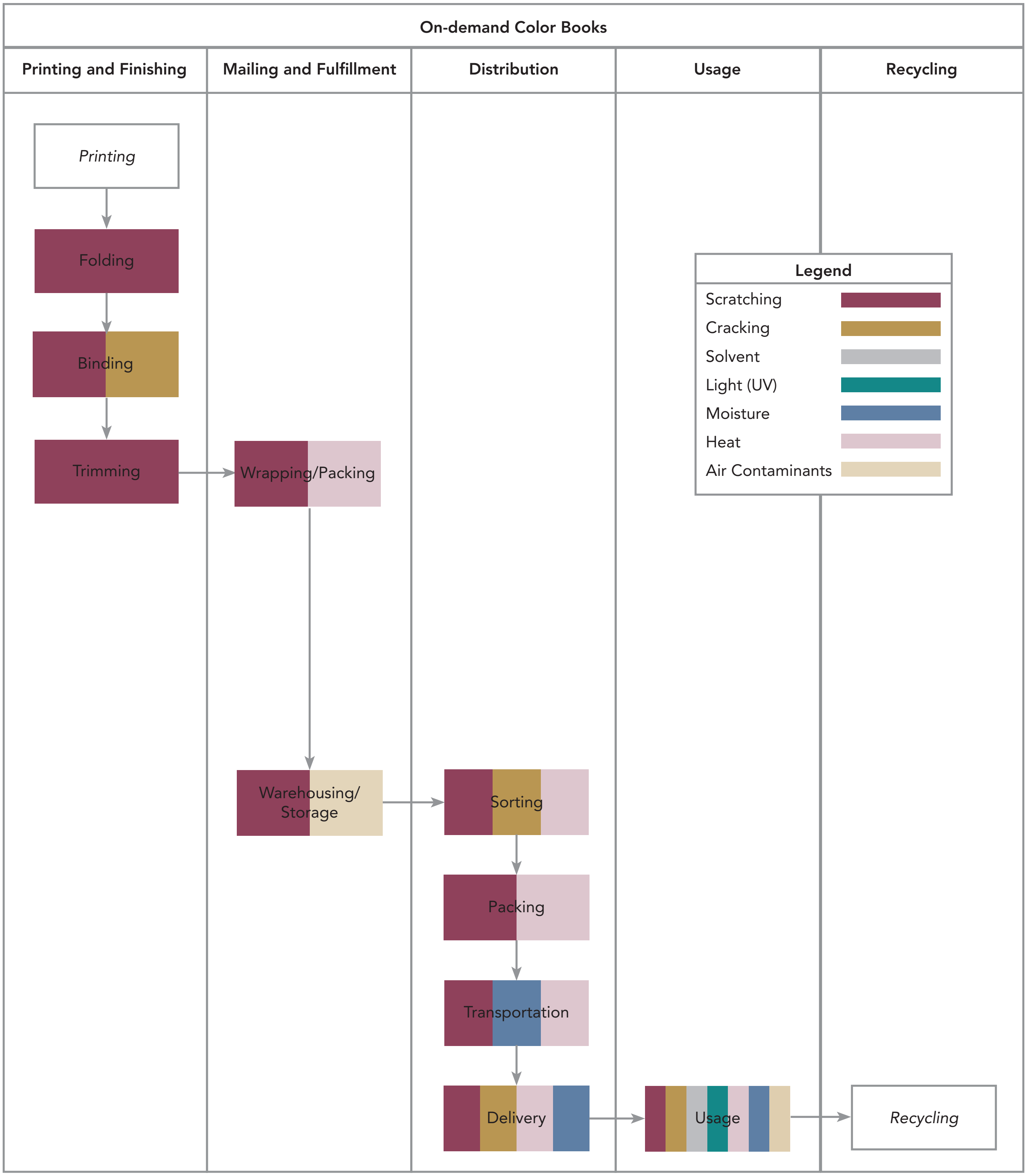


Figure 4. The processes in the life cycle of on-demand color books



Summary and Conclusion

This literature review has outlined the life cycle of digitally printed marketing and promotional materials, transactional and business communications, direct mail, and on-demand color books. Enumerating the stresses involved in each stage of the digital printing life cycle of these products has identified specific areas in print production and distribution that require more attention and research.

Digital printing has been projected to be the fastest growing print provider service over the next two years, and therefore understanding the variables that cause stress to the process is valuable. Stressors that potentially affect permanence were examined in each stage of digital printing's life cycle:

- In the printing and finishing stage, little stress is induced by the actual printing, but physical scratching and cracking occur during finishing. During the mailing and fulfillment stages, scratching and cracking, and heat, light, and air contaminants were seen as stressors.
- Similarly, scratching, cracking, heat and moisture were identified as problems in the distribution stage.
- In the usage stage, printed materials are subjected to every type of stress found in Table 1 such as: scratching, cracking, solvents, light, humidity, heat and air contaminants.
- Lastly, recycling digitally printed products presents obstacles not encountered in the processes used for offset printed materials.

With one-to-one marketing, variable data, and print-on-demand becoming so popular, research in this area is necessary for every player in the printing industry.

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R·I·T Printing Industry Center
An Alfred P. Sloan Foundation Center

Rochester Institute of Technology
College of Imaging Arts and Sciences
55 Lomb Memorial Drive
Rochester, NY 14623
Phone: (585) 475-2733
http://print.rit.edu