WHITE PAPER

SOFTWARE CONSIDERATIONS FOR INKJET IN THE SMART FACTORY

A white paper by Global Graphics Software, the OEM Software business unit of Hybrid Software

GLOBAL GRAPHICS® software

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Introduction

Abstract

The use and reach of inkjet for printing, coating, patterning and deposition have increased massively over the last few years. While it's still an emerging technology in some industries, it's maturing and evolving further in others. In each industry inkjet is usually introduced to address one or a very small number of specific requirements. This white paper sets out some of the opportunities that inkjet is well suited to once that low hanging fruit has been harvested, along with some of the challenges that must be mitigated to seize those opportunities.

Many of the opportunities, challenges and mitigations are interconnected, often in ways that enable the same innovation to assist in reaching multiple opportunities across multiple industries.

Much of this white paper is worded in terms of 'printing', but there are many industries that use inkjet to deliver or deposit substances who would not regard themselves as 'printing' per se. These include manufacture of products such as laminate and vinyl flooring, wall coverings and textiles, but also of electronics such as OLED displays, 3D components using additive manufacturing, and of 3D objects printed "direct to shape". In the interests of making the text concise and understandable the terminology of printing is used in this white paper, but many of the same risks, opportunities and benefits apply across all industries using inkjet and related technologies for deposition.

Over the last 25 years digital printers have grown from being "the next big thing" to being well entrenched in some industries. They've grown out of transactional print into direct mail and commercial, then into books and labels. In parallel the wide format market has grown primarily on digital, from signage to soft signage and into sportswear and product decoration. And coding and marking has converged with labels, pushing into corrugated, folding cartons and flexible packaging. Digital printing and deposition, almost exclusively inkjet of various forms, has also pushed hard into some industrial markets[1], most obviously ceramics, but also into fashion and décor textiles, wall coverings, laminate and vinyl flooring, and some parts of the electronics market.

Some of the early adopter markets had no choice but to use digital print to deliver personalized content such as phone bills, credit card statements and direct mail. In others adoption has been driven by an acceptance that run lengths and batch sizes have been dropping for years, and that digital print and deposition can be more profitable on short-run jobs.

"What's really exciting", says Eric Worrall from Global Graphics Software, "is that the word 'inkjet' has become something of a misnomer. It's no longer just about jetting ink; the heads in modern printers can accommodate a wide variety of different fluids."

As the use of inkjet has spread across multiple industries each one has often benefited by learning from the experience in those where it's already established. Ideas, technologies and even vendors have expanded from the use cases that were first to market because they could only be addressed with digital printing. As a result vendors who would have traditionally been regarded as office printer suppliers, such as HP, Ricoh and EFI, have become major players in multiple industries, from commercial print through labels and packaging and into some industrial sectors such as wallcoverings and textiles. This sharing of ideas and technology from industry to industry means that manufacturers, converters and printers should be watching what's happening in other industries using inkjet because often an innovation in one space may prove effective and profitable in other industries.

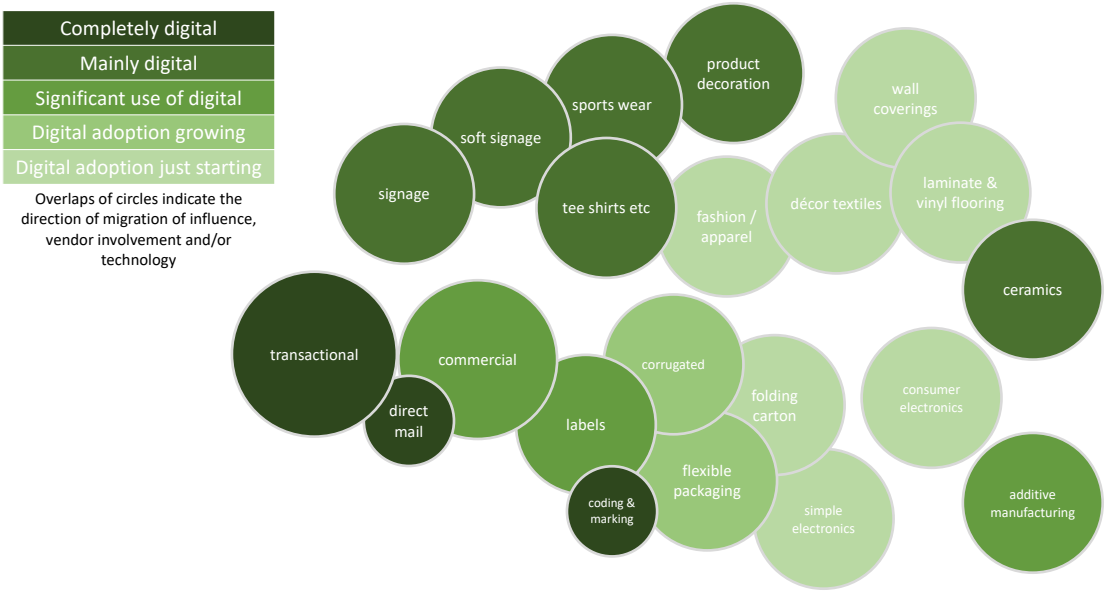


FIG 1: the degree of adoption of digital printing technology across multiple industries.

The benefits of inkjet are often cited as enabling rapid turnround, with virtually no makeready time for each job. That's an obvious benefit for short run because the costs of switch-over and makeready between jobs increase as a proportion of the whole as the time taken to produce each job gets shorter.

[1] *In this document the term 'industrial' will be used when the printed or deposited material is an intrinsic part of a product being manufactured.*

There are also markets where digital has or is expected to bring its own unique benefits, such as ceramics, textiles and OLED displays (see box). In these cases mass adoption was not or will not be driven by the potential for short runs, but adoption of inkjet for other reasons does then raise the potential for using short runs, for print on demand or lean manufacturing, for instance.

Once inkjet devices achieved a number of threshold requirements, adoption in the ceramic market was extremely rapid. In this case it was not driven by economic benefits for short runs, but because, as a non-contact printing technology, it puts less pressure on the tile being produced. As a result, tiles may be made thinner, reducing costs for materials, firing and shipping. Adoption of digital for those reasons introduced a number of additional opportunities, including:

- The ability to randomize the imagery on each tile so that they all look different when applied to a wall or floor
- The ability to produce larger single tiles without excessive weight
- The removal of limitations on repeat lengths from cylinder circumference; the repeat length on inkjet can be whatever is required.

The setup cost for rotary screen print, widely used for ceramics before digital, can also be extremely high, which means that it would normally only be used for very long runs. Storage of screens between production runs also carries risks and costs.

The same kinds of advantage are expected to be seen in several parts of the textile printing market, mainly around dramatic reductions in water and power usage. But these are, to at least some extent, still dependent on development of appropriate inks that can be used on a variety of different types of textiles, and that yield results that are light- and water-fast, that have a pleasant 'hand feel' and that can be made at an economical cost.

And a variety of technical advantages have been suggested for inkjet printing of OLED displays, including reduced wastage of materials when using an evaporation process, and reduced risk of contamination by dust or stray particles reducing yields.

A future growth strategy

Once inkjet technology has been adopted in a market, what are the next steps, and the remaining barriers in the way of maximizing profitability?

Two obvious opportunities in many industries using inkjet are either to do something new and unique, and/or to deliver a solution responding to increasing demand for sustainability.

Doing something that could not be done at a reasonable cost point before will often support a higher margin.

Sustainability is one of the most significant global trends at present, responding to concerns around global warming, the use of plastics and other forms of pollution. Working to increase sustainability is obviously a good thing in its own right, but it also plays well with many parts of the market and with investors, brands and buyers demanding ethical, ESG (Environmental, Social, and Governance) and CSR (Corporate Social Responsibility) behavior.

Alongside those opportunities are the challenges of delivering products fast and efficiently enough to maximize profit, while responding to continual demands for increases in perceived quality, and navigating the impact and aftermath of Covid-19.

Before we look at each of those opportunities and challenges in turn, let's quickly review a couple of important underlying areas.

The brains of an inkjet unit

The suitability of an inkjet unit for any particular use case depends on many factors, which stem from every component, from the transport mechanism through inks and ink systems, heads and drivers. But the brains of the unit are found inside the controller, often called the Digital Front End or DFE. In anything more complex than a simple coding and marking system the DFE performs multiple processes:

- Providing a user interface to allow the machine operator to configure the system correctly and to track status and progress of jobs and of the machine itself.
- Reception of submitted jobs.
- Analysis and preparation of jobs, including imposition, such as step and repeat or tessellation for seamless patterns.
- Transforming the job into a raster format at the correct resolution for delivery through the inkjet heads.
- Color management and calibration to convert the job into the correct color space for the inks being used, in such a way that both brand and process colors are reproduced accurately.
- Halftone screening the job to the correct bit depth for the inkjet heads being used.
- Optimizing output quality by applying the correct screening for the ink, bit depth and substrate in use, and by compensating for uneven tonality across one or more inkjet heads.
- Connectivity and communication with other workflow components, both other processors and management systems.

Almost all of these steps are usually performed in software, partly because some of them (such as rendering PDF files to raster) are far too complex for other approaches. Software is also much

more adaptable than, for example, firmware on FPGAs and PICs, and can be updated relatively easily to respond to new requirements.

The DFE is therefore a critical component of the inkjet unit when it comes to delivering increases in speed, efficiency and quality. It's also key for at least some examples of doing things differently, especially in enabling the system to process shorter and shorter run lengths, variable data and mass customization.

Automation and integration

Many environments in which inkjet is used have benefited hugely from the third industrial revolution, adopting computers and automation. After all, using inkjet is pretty much impossible without a complex control system based on digital techniques. More recently there has been a lot of talk, and a lot of development, aimed at delivering "Smart Factories" and "Smart Manufacturing", based on the "fourth industrial revolution", or "Industry 4.0". These use interconnected smart machines, cloud computing, artificial intelligence (AI) and robotics in what are sometimes described as "cyber-physical systems". These systems may also be described as the "Internet of Things" (IoT) and the "Internet of Systems". As Forbes put it: "Industry 4.0 optimizes the computerization of Industry 3.0"[2].

It's not just industry themselves who have recognized the potential for Industry 4.0 and Smart Factories; governments are also on board, recognizing its importance for increasing productivity. For an example, see the "Made Smarter Review", delivered in response to a call from the UK government to set out a vision for growth[3].

> The National Institute of Standards and Technology (NIST) defines Smart Manufacturing as systems that are "fully-integrated, collaborative manufacturing systems that respond in real time to meet changing demands and conditions in the factory, in the supply network, and in customer needs." [4]

Many of the opportunities and pressures on industries using inkjet technologies at the moment tend to push in the direction of a need for greater intelligence and integration of automation, connecting the inkjet step more directly and more reactively with the rest of the supply chain around it in order to maximize productivity, minimize errors and respond as quickly as possible to changing circumstances. All of these factors drive towards a need for an approach based on industry 4.0:

- Job and inkjet unit management for shorter and shorter production runs.
- Assisting with graphically richer coding and marking and convergence with inkjetting primary graphics.

[2] *https://www.forbes.com/sites/bernardmarr/2018/09/02/what-is-industry-4-0-heres-a-super-easy-explanation-for-anyone/*
[3] *https://www.gov.uk/government/publications/made-smarter-review*
[4] *https://www.nist.gov/programs-projects/product-definitions-smart-manufacturing*

- Ensuring that process control and workflow steps upstream and downstream of inkjetting can react appropriately to inkjet faults, and vice versa.
- Routing inkjetted items to wherever they need to go, whether the following step is finishing or converting, filling, application to some other product in the workflow, combining the inkjetted item with other components or shipping.
- Mitigating increased labor costs from reshoring.
- Ensuring that just-in-time (JIT) supply chains and lean manufacturing can run as robustly as possible, even in the face of global headwinds.

These pressures mean that several different classes of vendors building, or intending to build, inkjet printing and deposition units may need to consider how their solutions can be integrated into factory-wide systems. Examples include:

a) Manufacturers transitioning from conventional press technology such as screen print or gravure to use inkjet for textiles, ceramics, décor, etc.

b) Vendors of label, folding carton, corrugated or flexible packaging presses who have customers who wish to integrate those devices more tightly into a filling, bottling or manufacturing line, or who wish to offer direct to product printing units as an alternative to labels.

c) Vendors of converting and filling line systems who currently include coding and marking within those systems, but who wish to expand the capabilities of those systems to support richer graphics and even primary graphics printing.

In all of these cases the inkjet unit must be connected to the factory management systems, so that appropriate requests can be submitted to the unit and so that any problems arising in jetting can automatically adjust processing both up- and downstream of the inkjet unit, and vice versa. As an example, a problem in inkjetting on ceramic tiles might require kiln temperatures or speed to be altered, or defective tiles to be diverted out of the manufacturing process altogether.

Such interactions are usually by connection to a Supervisory control and data acquisition (SCADA) system. A typical SCADA system will:

- Control industrial processes locally and/or at remote locations.
- Gather and process real-time data.
- Interact with devices throughout the factory directly or via interfaces for operators.

Connections between a SCADA system and individual factory devices may be through proprietary communications, but they are increasingly being made using standards such as those defined and promoted by the OPC Foundation[5] as OPC-UA or by OASIS[6] as MQTT. Collaborative standards like these greatly reduce the effort required to develop robust and efficient systems built with products and solutions from multiple vendors.

Fully integrated systems, rather than those relying on consoles to deliver instructions to machine operators and to allow them to enter data in return, are very effective in reducing delays and errors. As run lengths get shorter and systems more interdependent those benefits become more and more important in avoiding the potential for delays and the impact of human error.

This automation may be usefully extended in many cases by using Artificial Intelligence (AI) for process control and for broader decisions such as equipment scheduling, including maintenance windows. One area currently being developed is around prediction of machine failures to maximize uptime without adding unnecessary risk of unscheduled failures. Any decisions or recommendations from a SCADA that makes use of AI system will almost always be better if a larger volume of accurate data is available. So AI also benefits from interconnections between systems, enabling a wider overview of the whole factory rather than basing judgements on only the data from one fraction of it.

> "Ultimately, it's the application of intelligence at the factory level that creates a dynamic production environment and the desired results - reducing costs while improving quality and reliability." - OTTO Motors [7]

This interface to a SCADA system may be in addition to, or instead of, a connection to a Management Information System (MIS), which would typically be more focused on costing than on near-real-time system management.

In a purely commercial print or labels & packaging workflow, connections between systems would normally be achieved using the Job Definition Format from CIP4[8] (JDF/JMF), but that is almost unknown in the wider manufacturing context. On the other hand, OPC-UA and MQTT provide cross-vendor and cross-industry transport and event handling mechanisms for such messages.

[5] *https://opcfoundation.org/*
[6] *https://www.oasis-open.org/*
[7] *https://www.manufacturingtomorrow.com/article/2017/01/what-is-the-smart-factory-and-its-impact-on-manufacturing/9043*
[8] *https://www.cip4.org/*

Being new and unique

Inkjet can achieve unique results in a variety of different industries, and being unique in a useful way is a very effective lever for premium pricing and increased profitability.

As an example, replacing offset, flexo, screen-print or gravure with inkjet units usually immediately enables an almost unrestricted range of repeat lengths, because that length is no longer constrained to match the physical circumference of a cylinder or a plate size. For some décor and other textile manufacturing, for instance, this suddenly allows a lot of creativity in designs that could not have been achieved affordably before.

Shorter and shorter production runs

At the extreme, even short runs can be regarded as a unique capability, if they reach a length that could not be produced conventionally at a price that is acceptable to both the buyer and the printer, converter or manufacturer. The ability to deliver a few thousand, a few hundred or a few dozen, copies of something like a label for craft beer cans customized for a local sporting event or music festival has opened up some opportunities.

> At Inland Packaging in La Crosse, Wis., average order sizes for cut and stack, pressure sensitive, and in-mold labels, as well as shrink sleeves, are decreasing " regardless of vertical or end-use market," says Jason Berger, VP of operations. [9]

The growth of short runs has been driven by many different factors, including:

- A desire for marketing differentiation and developing brand loyalty by selling specifically labeled product for events or local celebrations.
- The rise of craft and artisan brands and the changing face of retail mean that there are more small companies wanting product and packaging in smaller volumes.
- Global adoption of just-in-time (JIT) workflows and a demand for zero warehousing, combined with regionalization of reshored production.
- Regulatory changes and, especially in markets outside the USA, multiple language requirements.

The supply-chain difficulties triggered, at least in part, by the Covid-19 pandemic have exposed the fragility of some JIT supply chains. On the other hand, the factors that led to widespread adoption

[9] *https://www.packagingimpressions.com/article/short-runs-from-industry-trend-to-packaging-reality/*

of JIT business models and lean manufacturing remain compelling. The alternative is to print or manufacture in large volumes and hold them in a warehouse, which often leads to significant extra risks and costs:

- Items may be damaged in a warehouse, especially as global warming increases the prevalence of extreme weather events.
- Items can degrade over time, because of lack of light fastness, incorrect humidity control, or simply colorants that would be stable enough for the intended lifetime of the item, but not if they have been stored for any significant time before being shipped or used.
- The warehousing process itself can be expensive, in terms of buildings, maintenance, staffing and charges such as rates and taxes.
- Excess inventory in warehouses ties up significant amounts of cash, which could be used in many more productive ways.
- Items in a warehouse may become obsolete because a brand changes a design or new legislation requires that certain aspects are changed. Several studies have shown that multiple industries regularly destroy out-of-date product held in warehouses, often at a rate of 25-30%, from packaging to books etc.[10]

All of these factors change how the cost of inkjet needs to be viewed, alongside the likelihood of being able to set higher pricing for unique items and the premium from the ability to deliver more quickly and to react rapidly to changing requests from customers. It's true that, in many industries, a simple cost of each item produced using inkjet will be higher than the cost per item produced using traditional methods. But factoring in reduced risk, reduced wastage, and the potential for pricing premiums will often mean that inkjet is more profitable.

But it's also worth noting that the use of digital for longer production runs is increasing. As an example an HP report, using survey data managed by IDC, found that healthcare/ pharma/ nutraceutical expect to see the biggest move towards digital-only printing. "With their volumes in long run and ever-changing regulatory mandates, digital print packaging helps them to be more dynamic and agile." [11] The same report shows that warehousing costs had the greatest influence from a basket of factors influencing whether packaging is printed conventionally or digitally.

[10] *https://www8.hp.com/h20195/v2/GetPDF.aspx/4AA7-4151ENW.pdf. Hard figures for book returns are difficult to assess, and may actually be decreasing as more books are printed on demand instead of in long runs and warehoused.*
[11] *https://www8.hp.com/h20195/v2/GetPDF.aspx/4AA7-4151ENW.pdf*

As Clive Ayling of Meteor Inkjet explains: "Businesses have become much more aware of the benefits delivered through digital processes, even though they could still be done with traditional methods, because it's not only commercially more viable to do so, it also allows you to greatly reduce your batch sizes. You no longer need to keep warehouses full of stock or have the space to store offset rollers, or wait for goods to arrive via cargo ship. You don't need to have a minimum six-week reaction time. You can do it all now – quickly, efficiently and at a price that's competitive."

The rise of variable data and mass customization

Taking short runs to the extreme, a significant advantage for inkjet that applies across the majority of industries is that it does not need to simply reproduce the same invariant design repeatedly, even for a short run; instead it can make every item different.

It's common to think of variable data printing, where at least some of every instance is different from every other instance, as being the preserve of transactional and direct mail printing. Admittedly, that's where much of it started, but in the broadest sense of the term, variable data printing is now used far more widely, across multiple industries.

In situations where the delivery of the product is through a push model (where there is no direct connection between each item produced and a specific recipient at the time of production) several cases are common. Most of these cases are in B2B environments, where the buyer then sells or delivers the result, often B2C.

- In packaging for pharmaceuticals and for premium good such as spirits, wine and beauty products, the use of unique marks on every item in support of track and trace and anti-counterfeit has become a normal part of the workflow. Inkjet is only one part of the solution here, which can involve special substrates and inks, logistics management and tooling for authentication, amongst other things, but it's a key part of the whole system.

  Similar track and trace efforts are appearing in a variety of markets that are perhaps surprising, from books to wallcoverings, where they can be useful in identifying and preventing abuses of distribution systems, and in supporting safety recalls.

- In labels and packaging again, there has traditionally been a significant divide between printing of rich graphics intended for the consumer, and variable graphics intended for logistics, such as serial and batch numbers, best before dates, etc. The consumer graphics have been printed at high quality using an offset, flexo or inkjet press, while the logistics marks have been printed using a lower resolution, lower-quality print head in a system designed for high speed at low cost: a coding and marking device.

FIG 2: typical print from a coding and marking device

This use of two different printing systems is rather similar to early variable data being printed with a simple digital press on top of a pre-printed shell (usually produced on an offset or flexo press). In some cases brands are deciding that they want the logistics data to be more visually seamless with the rest of the design, which is driving a similar change to that towards "white paper workflows" in the transactional space, where everything is printed in a single pass.

Obviously, this convergence is also aligned with anti-counterfeit and track and trace requirements, allowing higher-quality inkjet to be used to convey sometimes-significant amounts of unique data in a small area.

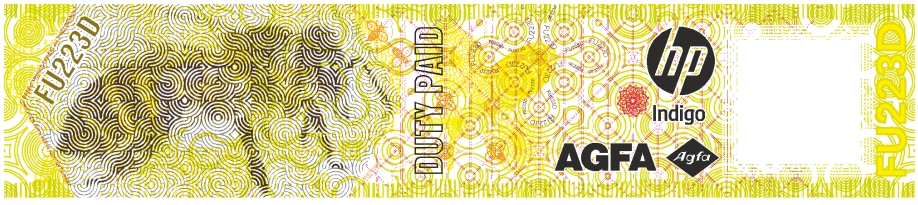


FIG 3: security marking may require high-quality print

That convergence is not without its own challenges, of course. If some of the data to be printed must be closely matched with the product that a label is applied to, or that a package is filled with, then great care must be taken to ensure that the right print goes with the right product.

That challenge falls into the realm of efficiency and automation, as described below.

- When natural-looking designs are used for ceramic tiles, vinyl tiles, laminate flooring etc, it's better if there is no obviously repeated pattern when they are applied to a wall or floor, because that breaks the illusion of naturalness. In this case sometimes a very large design is created, much larger than an individual tile. A window the size of one tile can then be (more or less) randomly selected from that design and imaged onto one tile. A different window is imaged onto the next tile.
- Back in labels and packaging, a perennial struggle for most brands is to continually increase the "shelf appeal" of their products. This has driven changes such as adoption of full-color corrugated primary packaging rather than using plain manilla cartons with simple labels and low-quality monochrome logos.

  A more recent trend has been towards making every label or container unique, using tools such as HP's Mosaic or Hybrid Software's Patchworker. Uniqueness here does not imply personalization, because there is no connection between the production and a target individual, but it does make a shelf full of the product look more exciting and engaging.

  The same goal is also leading to an increase in embellishment of packaging, sometimes including variable data in varnish, white or foils.
- Marketing involvement also leads to a wide range of variable data printing across many industries. Examples include QR Codes to access more information about a package, poster, product etc, but that also deliver data back upstream to the marketing team to help understand how and where that item is being used. In the same way, printed triggers for augmented reality do not have to involve variable data, but they can do for the same reasons as QR Codes. And unique text or barcodes etc can also be included on items for competition entries and the like.

The majority of the examples above are described in the context of labels and packaging, but inkjet ideas, vendors and technologies have repeatedly crossed the borders between industries as each one learns from the experience of those that adopted sooner. If there is a need for anti-counterfeit marking while creating a product such as an OLED display, or for tracking which store a roll of wallcovering was bought through when the purchaser reads the QR Code on it, for example, it may well make sense to image that in a single pass with the display elements themselves rather than requiring a separate processing step.

In mainstream commercial print, labels, packaging and industrial manufacturing, it's difficult to imagine an alternative to the push model, even given the huge amount of metadata that some companies, such as luxury goods brands and supermarkets, are collecting on their customers.

But there are many situations where there's a much closer relationship between an end user of the product and the organization that printed or manufactured it, which can be described as a pull model instead. Many of these cases move beyond the traditional idea of variable data as being text and barcodes imaged on top of a static background to each piece being truly unique. They deserve to be described as mass customization, and all of them have been enabled by web-to-print or other forms of online ordering.

- The wide format market has long provided display and soft signage, sportswear, tee shirts and car wraps to custom designs on very short runs, down to a single copy. Both signage and sportswear are aimed at both B2B and B2C markets.
- Photofinishing has long been a B2C business and has used digital printing for decades. The industry has learned that simply producing 5" x 7" prints does not generate significant profits, but has grown first into photobooks, and then into many other forms of product decoration, printing photographs on hats, shoes, apparel, bed linen, mugs etc and converging with what have historically been wide format opportunities.

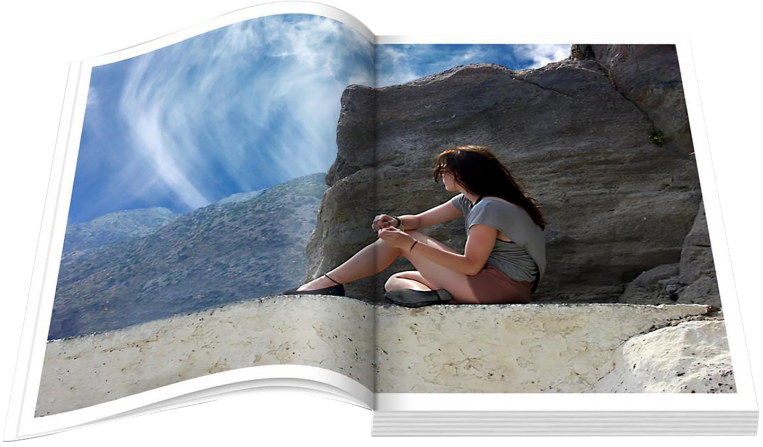


FIG 4: photobooks offer higher margins than simple print finishing

Each individual order, perhaps for one mug with a photo printed on it, may not appear to be variable data printing. But when orders are aggregated at the producer there may be hundreds or thousands of mugs to be printed per day, each with a different image.

- The same business model is applied more broadly to print designs which may be uploaded by the customer and/or created in a web portal by combining the customer's text and graphics from a library. Examples include phone cases, tee shirts, postcards and greetings cards.

- And a number of providers effectively act as publishers for customer designs, managing printing and fulfilment for a variety of products or lengths of custom-printed textile. Examples include Red Bubble (redbubble.com) and Spoonflower (spoonflower.com, recently acquired by Shutterfly).
- Several brands have run campaigns whereby products can be ordered with a name on them, usually for gifting. Examples include "My Nutella" and "My Marmite". A variant of this is where only a label is purchased, often for bottles of spirits, to be applied to the product by the purchaser themselves.

  The most famous campaign for 'personalized' labels was Coca-Cola's "Share a Coke", but in practice most labels were printed in long runs, randomizing the most common names in each country; only labels from roadshows and purchases from the web were actually printed on demand for specific recipients. This makes it an excellent example of a hybrid model taking advantage of the benefits of multiple print technologies.

FIG 5: personalized product for gifting can attract a significant premium[12]

- Even in industries producing a design that would historically have been created in multiple mile or kilometer lengths, such as wallcoverings, there are opportunities for increased margins in custom delivery. As an example, consider a decorating company that has been contracted to apply wallcoverings to a large office. If a wallcovering vendor could deliver pre-cut drops of the wallcovering, each of exactly the right length, and with the pattern starting in exactly the right place so that each drop aligns with those on either side, that would save the decorating company a lot of time. And that, in turn, would allow the vendor to charge a sufficient premium to more than cover the reduced total length required because there is no longer any wastage from the decorators cutting each drop to ensure alignment.

[12] *https://www.marmite.co.uk/products/shop/marmite-personalised-classic-jar.html*

A lot of the demand for this mass customization is ascribed to the changing attitudes and communication preferences of millennials and Gen-Z. To generalize, it's often said that such audiences demand to be treated, and be able to represent themselves as unique, requiring them to be able to obtain unique product in support of that position.

FIG 6: demand for customized product is not restricted to any particular age group

But the demand is not specific to any age group, according to "The Deloitte Consumer Review - Made-to-order: The rise of mass personalization"[13], based on survey results from YouGov, which also went on to say: "1 in 5 consumers who expressed an interest in personalized products or services are willing to pay a 20% premium"; that figure rises to around 1 in 2 for customized clothing, furniture, homeware and DIY.

Of course, personalized and customized products are not warehoused at all; they've been created for a specific recipient, and will usually be shipped immediately.

Opportunities from sustainability

One of the biggest demands from consumers and brands at the moment is for more sustainable manufacturing, packaging and transport, countering global warming, but also the use of plastics and other forms of pollution.

The response to this demand has had multiple different aspects, including:

- Onshoring or reshoring; manufacturing and packaging closer to the recipients of the product,

[13] *https://www2.deloitte.com/content/dam/Deloitte/ch/Documents/consumer-business/ch-en-consumer-business-made-to-order-consumer-review.pdf*

reducing the distance that items must be transported. This is most clearly requested with demands to minimize "food miles".

> In the USA "The pandemic has spurred a national push to strengthen the domestic supply chain, especially of essential products, driving reshoring numbers higher. If 2H2021 progresses at the same rate as 1H2021, reshoring and foreign direct investment (FDI) job announcements for 2021 are projected to be over 220,000 – 38% above an excellent 2020 and, by far, the highest yearly number recorded to date". [14]

Onshoring enables much faster turnround from order to delivery, but often that comes at the expense of higher labor costs; after all, many processes were moved offshore to take advantage of lower cost markets in the first place (although wage costs in popular offshore locations have been rising much faster than those in the West). A common response to higher labor costs is to increase automation; see above.

The higher labor costs may also be mitigated by a reduction in transportation costs, especially at the time of writing, when the Covid-19 pandemic has seriously impacted global supply chains and greatly increased shipping prices. Fortunately industry consensus is that the current situation is likely to be only a relatively short-term effect.

Reshoring can also be a catalyst or opportunity for reinventing a brand, by dropping the least profitable markets and/or adding or expanding those that have most promise. The same may apply to manufacturing and packaging processes; a move onshore may trigger innovation in using more, smaller sites for regionalized production, or in tighter integration within large sites.

- Use of less packaging and lighter-weight packaging. An example is printing direct to the foil on a product rather than printing a label and applying it. Such changes may benefit from, or even demand, tighter integration in the supply chain to ensure correct matching of print and product.
- Reducing wastage in manufacturing and packaging. This pays in reduced printing or deposition costs as well, and is an area where inkjet can assist in comparison to offset, flexo or screen print because of the ability to switch between jobs without clean-down and make-ready.

  Minimizing wastage gains from careful automation and process control, and is also an argument in favor of zero warehousing.

  And in some industries, such as fashion textiles, ink wastage can be reduced by only printing the design on the areas of fabric that will actually be used for finished product.

[14] *https://reshorenow.org/blog/reshoring-initiative-ih2021-data-report/*

- Use of more ecologically sound substrates and ink technologies, for instance those that require lower power and water consumption.
- Use of deinkable printing technologies in packaging and product to enable recycling.

Greater efficiency: faster and cheaper

Are just-in-time print-on-demand and lean manufacturing still feasible?

The benefits of zero warehousing were set out under Shorter and shorter production runs and Opportunities from sustainability above; demand for them usually flows from some form of just-in-time (JIT), lean manufacturing or print-on-demand (POD) supply chain. On the other hand Covid-19 challenges and trade disputes in 2020 and 2021 have shown that global JIT networks are far more fragile than had previously been thought. So how can the benefits of zero warehousing be maintained while riding out the potential for the kind of supply chain disruption that Covid-19 has triggered?

Two obvious answers are to locate the creation of an item used for a later step in the supply chain physically closer to where it will be required. If no shipping, either international or national, is required, then it's far harder for that connection to be disrupted. And secondly, JIT requires information flow in parallel with products. If a manufacturing site requires item X to be delivered JIT, but X is made from product Y, then the manufacturer must know not only what is happening in the creation of item X, but also information about the required ingredients/components for manufacturing product Y, and all its precursors, in order to plan for potential future shortages.

The first of these, physical proximity, is in line with requirements to increase sustainability by reducing transportation. The second, tighter integration, is a significant part of increasing the efficiency and profitability of processes using inkjet.

The impact of short runs

If inkjet is adopted to replace an offset, flexo or screen print workflow for industry-specific reasons, such as reduced tile thickness in ceramics, there will often be significant changes required in those workflows. But those will not necessarily introduce any requirements for greater efficiency. To continue with the ceramics example, the rotary screen printing being replaced by digital is not a particularly high-speed process; if the same run lengths are being produced digitally they probably take around the same amount of time.

But where inkjet is adopted in order to produce shorter runs, that immediately requires increases in efficiency across the entire plant. An inkjet unit is very effective at helping with that migration, by greatly reducing clean-up and make-ready times, and associated materials wastage. But moving from a handful of long-run jobs per day on a conventional press to a much larger number of short-run jobs produced digitally requires significant changes to intake, customer services, job preparation, job

management, shipment of jobs, and planning of equipment schedules. If a job will be on press for two shifts it doesn't matter if the processes upstream and downstream from it are largely manual. If a job is being processed on the inkjet unit for only a few minutes then those processes must be connected and automated, or your inkjet unit will likely be sitting idle enough of the time that it impacts profitability.

In the same way, running large numbers of short-run jobs may require you to limit the formats of whatever you're producing. If post-press equipment (e.g. cutters and binders in commercial print) must be adjusted for different job sizes and form factors, it may be too time-consuming to accept much variety in jobs. There is increasing adoption in some industries, most obviously labels and packaging, of laser cutting, which helps to mitigate this concern, but laser cutters can still be slower than the inkjet unit, at least for very complex shapes.

Looking more widely than the inkjet unit itself, short runs require the whole of the workflow to be able to handle large numbers of different products. As an example, in labels and packaging, printing and shipping a roll of labels or the packaging alone has some challenges, but nothing too complex. But if each short-run product needs filling and shipping differently it very rapidly becomes very difficult for a converter.

> "Although the trend to shorter run lengths is seemingly ubiquitous, it hasn't necessarily been widely welcomed," says Jeff Wettersten, president of Karstedt Partners. "When converters face short runs, they feel 'pain points' according to their ability — and their willingness — to handle 'non-conforming order demand." He defines this as "anything that's non-repetitive, or difficult to set up in production." [15]

Of course, anything that is very difficult, but delivers real value, can itself be an opportunity, at least for niche providers. Ensuring that the inkjet unit is integrated into an automated system that extends over much more of the workflow than printing and finishing is almost a prerequisite here; see Automation and integration.

The impact of variable data and mass customization

A variable data or mass customization production run can be a short run, but more often it's quite long because many variations have been amalgamated into a single submission, such as a PDF file. So the short-run challenges described above may not apply, but two other challenges often will:
For a variable data or mass customization job at least some of every item produced will be unique, whether that's just some simple text and/or barcodes for a transactional or label job, or much more extensive differences for many direct mail, wide format and product decoration. At the

[15] *https://www.packagingimpressions.com/article/short-runs-from-industry-trend-to-packaging-reality/*

extreme everything on every page is different, e.g. for many photobooks, or for ceramic tiles imaging randomized windows into a single large design. What this means is that the digital front end (DFE) or controller for the inkjet unit must do much more processing in order to produce every instance.

To take an example: if an inkjet workflow can produce 300 items per minute, and it's producing a series of jobs, each of which comprises 30,000 identical copies, the DFE has 100 minutes (30,000 / 300) to prepare each job while the previous one is running on the inkjet unit. Preparation in this case includes everything that the DFE must do for each instance, such as interpreting a submitted PDF file, color managing it to the correct device color space, rendering it to the correct device resolution and screening it to the correct bit depth, etc.

If each job comprises only 300 copies, the DFE has one minute (300 /300) to prepare each job while the previous one is running. But if every copy is different, even if that's through the use of variable data or mass customization within a long-run job, the DFE must prepare the raster for each instance in 1/300 minutes, or 1/5 second in order to avoid the need to slow the inkjet process. Clearly that places a much greater demand on the DFE than is required even for producing 300 copies; but slowing the inkjet unit to mitigate that increase in demand will reduce throughput and therefore profit.

The second challenge for variable data and mass customization jobs, at least for those that are not simply randomization of designs, is to connect the output from the inkjet unit to the right product and/or the correct shipment route and address:

- At one end of the scale, printing transactional documents and stuffing into a window envelope is relatively easy because the item is self-addressing, as long as regulatory requirements around ensuring that one and only one instance of every document is printed and posted are observed.
- Something like a length of custom fabric must be wrapped in such a way that the correct shipping address is on the outside of the package, and it's delivered to the correct courier service. This may be assisted by, for instance, printing a barcode in the selvedge or trailing edge of the fabric that can be read in shipping.
- A more complex example might be a custom tee-shirt, where the buyer has selected an underlying shirt (men's or women's, slim-fit or relaxed, small or large, short- or long-sleeved, white or black etc), as well as the design to be printed on the front. Again, that shirt must be packaged and shipped to the correct recipient, but there's less opportunity for visible coding on the article itself that the customer would accept.
- Even in labels and packaging, the convergence of coding and marking with the printing of the primary graphics ties each individual instance to a batch of products that the labels will be applied to, and maybe even a single individual product, because it may include serial numbers, batch codes and "best before" dates. It's imperative that incorrect or out-of-date prints are not associated with goods being shipped, especially if those goods are perishable.

At the end of this spectrum is the growth of in-house print for items such as labels. In many cases this has been a fairly manual process, printing very small numbers of items, but it does also have the potential to drive tight integration of printing processes into manufacturing and filling systems.

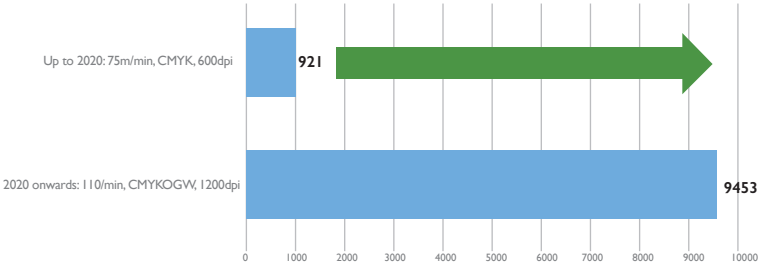
Wider, higher, faster, better

Two of the most prominent developments in inkjet over the last few years have been drives for higher and higher quality and at ever greater speeds.

Quality is demanded in many different ways, from being able to perceive fine detail (especially small text), to ensuring that barcodes are readable, to increasing the color gamut of the output (and therefore making more brand and natural memory colors reproducible accurately and more saturated colors available), to reducing inkjet artifacts such as streaking and banding. And speed can be achieved by moving heads or substrates faster, or by using wider substrates at the same speed to increase the area produced in each time period.

All of these mean that vendors in many areas are using higher-resolution heads, firing at higher frequencies, and often jetting more colorants (perhaps adding Orange, Green and Violet alongside CMYK). Halftones and compensation processes have been specifically developed to combat streaking and mottling.

While these steps are often necessary to enable manufacturers, converters and printers to remain competitive, and to achieve the opportunities outlined above, they do have an impact on other parts of the system, especially the DFE. To take a simple example, a narrow-web label press sold in 2019 might have been 330mm wide, printing in CMYK at 75m/min and 600x600dpi. The next generation press from the same vendor for 2021 might be the same width, but printing in CMYKOG plus White, at 110m/min and at 1200x1200dpi.



If you calculate the number of pixels required per second, you'll find that the data rate requirement for the new press is approximately ten times higher than the old one[16] . So obviously a DFE that's designed for that increased data rate is required.

As speeds and demands for quality rise, process control and inspection systems must keep up; producing faster without appropriate checks is simply a good way to make more waste, faster. The biggest challenge for quality control in faster solutions is not only in ensuring that faulty output

[16] *7 inks instead of 4 = 1.75x; 110m/s instead of 75m/min = 1.47x; 1200x1200dpi instead of 600x600dpi = 4x. 1.75 x 1.47 x 4 = 10.29x higher data rate requirement.*

can be identified and the inkjet process corrected automatically (e.g. by compensating for missing nozzles and calculating optimal emulations for brand colors), but also that the whole system can react appropriately to the faulty items in the workflow, for example by diverting them from the delivery line and, if necessary, reprinting them. The inkjet unit must therefore be able to communicate with other parts of the system in something close to real time.

Covid-19 and beyond

Any review or prediction of the state of the use of inkjet at the moment must take the effects of the Covid-19 pandemic into account, even though any estimate of what a "new normal" might look like is still changing from month to month.

That uncertainty means that brands are being more cautious about filling warehouses from long print runs, because the level of future demand for many products can be difficult to predict.

The most immediately obvious impact of Covid-19 has been on supply chains, greatly reducing resilience and increasing shipping costs. But the associated lockdowns in various countries have also accelerated some changes in how and what consumers want to buy. Put together those all increase the potential benefits for reshoring, for more robust supply chains, faster turnround and reduced transportation requirements.

> In talking about digital print growth, Marco Boer of IT Strategies says "We predict that offset will disappear two years faster than we originally thought. The pandemic has accelerated that decline."[17]

Covid's disruption of supply chains also created some opportunities for onshore companies with inkjet units because they were able to respond to urgent requests for assistance in situations where offshore production was suddenly no longer feasible, either because it could not deliver fast enough, or because it could not deliver at all. It remains to be seen whether the new relationships formed as a result will prove to be long lasting, and whether this, too, will reshape how printed items are ordered.

Even while welcoming extra work, onshore companies were suffering from staff shortages caused by the pandemic, so those who had invested in automated systems with remote monitoring were well placed to maximize that opportunity.

[17] *https://whattheythink.com/articles/102039-marco-boer-it-strategies-how-pandemic-will-drive-inkjet-growth/*

About the author

Martin Bailey, former Distinguished Technologist, Global Graphics Software

Now retired, Martin Bailey worked for Global Graphics Software as the Chief Technology Officer, working to analyze and understand current and future needs for workflows across many sectors of print. This enabled him to guide Global Graphics' industry-leading printing technology. He represented Global Graphics on a number of industry bodies and standards committees including acting as the primary UK expert on the committees working on PDF, PDF/X and PDF/VT.

Martin worked for over 30 years in the industry, building, using, supporting and improving products for processing digital documents and the print industry in technical support, product management and programming as well as in consulting, and production environments.

About Global Graphics Software

Global Graphics Software (www.globalgraphics.com) develops innovative software components for digital printing, including the Harlequin RIP®, SmartDFE, ScreenPro and Mako. Customers include HP, Canon, Durst, Mimaki, Mutoh, Roland, Kodak and Agfa. The roots of the company go back to 1986 and to the iconic university town of Cambridge, and, today the majority of the R&D team is still based near here. Global Graphics Software is the OEM Software business unit of Hybrid Software (Euronext: HYSG)..

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