Fraunhofer IML

Whitepaper

Future Challenges in Logistics and Supply Chain Management

Supply chain resilience and total cost of supply chain improvements with digital printing

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Supply chain resilience and total cost of supply chain improvements with digital printing

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Future challanges in logistics and supply chain management

War, a pause or a break in the march to Globalization and technology driving changes to customer buying behavior, leads brands and converters to rethink how they can improve responsiveness and agility in their packaging supply chains in an ever-changing world. Using quantitative modeling based on converter production data and known waste factors, this paper explores how digital printing can become a critical tool to enable greater resiliency, lower environmental impact, improved utilization of resources, and lower overall total supply chain costs for folding carton packaging production.

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1. Management Summary

Increasing geopolitical risks and changes to consumer purchasing behavior, especially with the growth of e-commerce, are forcing brands to rethink their supply chains. Shorter time to react and a focus on agility and resilience is leading to the reestablishment of regional supply chains. Converters, as a result, are confronted with shorter turnaround times for packaging and lower production batches

Other societal mega trends such as sustainability are leading brands and converters to focus on waste and obsolescence over the whole product life cycle. They are also mitigating regulatory risk – as government considers new sustainability standards – by anticipating legislation and moving to more paper-based packaging and by focusing on the environmental impact across the total packaging supply chain. To cope with these supply chain challenges track and trace capability of individual products is being built in as a standard. In short, with high levels of uncertainty and unpredictability, a premium is being placed on speed and agility in the packaging supply chain.

Digital printing technology has matured to enable high-speed, high-quality production. It offers an alternative production method to offset printing for folding carton production with particularly strong attributes for low waste production and fast turnaround times and for these reasons is increasingly being explored as a viable complementary technology to offset printing to improve supply chain resiliency, lower waste and reduce total packaging supply chain costs.

As a tool to evaluate where digital printing fits in the unfolding paradigm for folding carton packaging production, Fraunhofer IML developed a quantitative model based on real time converter data and costs and applied known waste factors to show the effectiveness and fit of digital printing as a tool to meet current and future supply chain challenges.

From a pure printing cost perspective based on the jobs analyzed, digital printing was advantageous versus analog printing for run lengths up to 3,000 B1 sheets. Converters that have many runs at or below 3,000 sheets, can reduce print production costs by adopting digital print technology and can also improve the efficiency and throughput of their offset machinery.

When total supply chain costs are evaluated such as inventory holding, waste and obsolescence, the cross over point between digital and offset printing for folding cartons is approaching 6,000 sheets. Furthermore, the model shows that for run lengths between 6,000 to 10,000 sheets there is only a small advantage for analog over digital printing. For brands and converters committed to a sustainability agenda and who focus on total supply chain costs and agility to meet changing demands, digital printing offers an alternative and complementary technology to improve supply chain efficiency. It also offers brands increased marketing flexibility.

We are convinced that quantitative decision models like the one presented in this white paper can help to overcome the skepticism by performing scenario analysis based on real-world data. We propose to pursue – for the foreseeable future – a mixed strategy of operating digital printing lines for batch size of up-to 6,000 B1-sheets and analog printing machines for the long-running jobs. With changes in substrate and energy price, the break-even point will likely move to even higher average batch sizes.

2. Purpose and Content of this Whitepaper

This white paper looks at the potential of digital printing for packaging manufacturing. For this purpose, a quantitative model of the costs and benefits of digital printing compared to analog printing was developed based on real-life use cases. For the model development, an aggregated view of the total costs in the supply chain of packaging production was taken. Not only the current situation regarding customer demand and raw material procurement is considered, but also trends in sales and procurement are shown. Performance variables such as costs, delivery times and flexibility as well as sustainability aspects are considered. This study is therefore intended to shed light on the conditions under which digital printing is superior to "traditional" analog printing

The research question is focused on what is shaping the future of the supply chain for packaging and how these changes can be quantified. Therefore, we pursue an empirical approach based on a real-world application case for folding carton converting.

The remainder of this whitepaper continues with an account on supply chain mega trends and their impact on folding carton and corrugated cardboard production. This is followed by a description of the supply chain of packaging production for folding carton and corrugated cardboard from the sourcing of raw materials, the manufacturing, to the use of packages by the brand owner. Subsequently we present a quantitative in-depth analysis of the supply chain performance of analog and digital printing technology for box production. We determine the direct effects of the different printing technologies as well as the indirect effects of other processes in the box production supply chain. This analysis is based on real-world data application cases and covers several scenarios for different customer demands. Finally, we present recommendations for implementing digital technologies for manufactures of folding carton and corrugated boxes.

3. Supply Chain Trends

3.1. The past: The effects of the globalization on supply chains

Since the early 1990s, there has been a trend towards globalization of business and trade. Trade barriers have been dismantled around the world. Asia – and here especially the People's Republic of China – has been a driving force, both as a procurement market for products and services and as a sales market. This can be seen in the "trade openness index", which is defined by the sum of world exports and imports, divided by the world GDP.

3.2. The present: Increased vulnerability of international supply chains

Globalization has made the supply chains of companies much more vulnerable to worldwide disruptions. This has become remarkably evident during the COVID pandemic. Due to lockdowns, reduced port capacities because of high sickness rates of dockworkers, and unavailability of empty containers, reliability of inter-continental transports has dropped dramatically (cf. figure 2).

Globalization over 5 centuries
Shown is the „trade openness index". This index is defined as the sum of world exports and imports, divided by world GDP. Each series corresponds to a different source

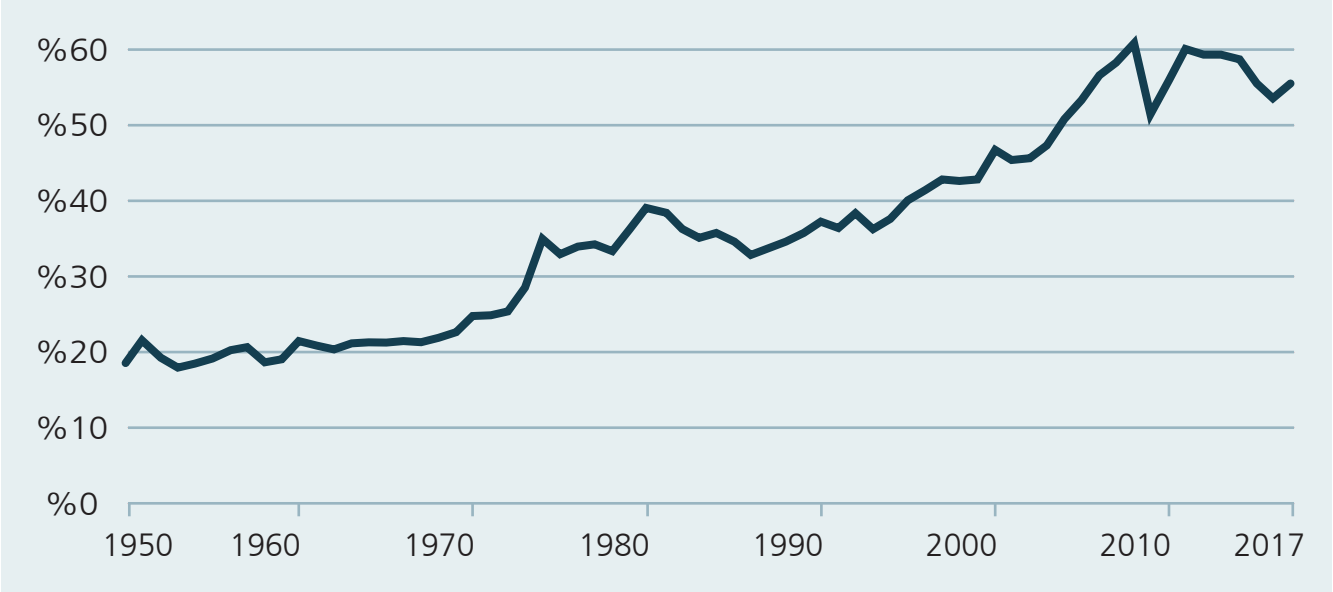

Figure 1 Trade openness index since 1950 [1]

In figure 1 one can see that in the early 1970's this index has risen from 20% to around 30% because of reducing trade barriers – especially within the European Economic Community and the European Free Trade Association.
Several social and trade related events have changed the business world-wide: In the early 1990's the states of the eastern bloc transferred from a planned economy to a market economy. Chinese economic reform introduced a private sector accounting for a growing percentage of China's GDP. The general Agreement on Tariffs and Trade (GATT 1994) lifted restrictions on foreign investment and opened trade in services like banking and insurance. The Expansion of the EU and the Maastricht Treaty deepened the economic and political integration within the Europe. Supply Chains across all business sectors have become global.

Globalization has transformed supply chains. A significant share of products is sourced and sold globally characterized by long shipping distances mainly by sea freight and long response times to changes in demand.

- Packaging has been produced well in advance of the consumer's demand.
- Large order batch sizes of packaging production became the norm

The percentage of shipments that arrive on time has improved in 2022, but is still a fraction of what it's been in previous years

Figure 2 Reliability of sea shipments before and during the COVID pandemic [38]

There are many other incidents showing the vulnerability of today's supply chains.
The following table illustrates this further with a few examples from the last decade.

Table 1 Examples of events causing global supply chain disruptions

	Event	Global effects
2011	Great East Japan Earthquake / Fukushima nuclear disaster	Parts that could not be manufactured in Japan lead to reduction of production output in China and Thailand of up-to 33 % [4]
2016	Earthquakes and typhoons in Asia	Earthquakes and typhoons in Japan and Taiwan disrupted global supply chains
2020	Brexit	Many companies planned or have relocated production facilities from the UK to the EU, and distribution centers (DCs) from the EU to the UK [5].
2021	Suez Canal blockage by the Ever Given	A six-day lodging of the ship Ever Given lead to a backlog of up to 367 ships waiting to pass the canal. It took more than a month to clear the congestion [6]. Because nearly 15% of the world's trade passes the Suez Canal this lead severe disruptions of supply chains in Europe and Asia [7].
2020ff	COVID	The COVID pandemic has resulted in major disruptions on both the consumer behavior and the supply chains. Six-in-ten U.S. workers who say their jobs can mainly be done from home are working from home all or most of the time. Three quarters of those prefer to work from home in the future [8]. This has consequences to consumer's demand behavior – more home-cooking and more e-commerce shopping.
2022	Shanghai Port lock-down	The lock-down of the Shanghai port – the world's busiest container port – from March to May 2022 has tripled the dwell time of imported containers from an average of 4 days to roughly 12 days [9]. On June 24th, 2022, the import dwell time was still more than 9 days. This led to global shortages of containers and induced bottlenecks at other ports worldwide.
2022	Ukraine war	Russia invaded Ukraine on 24 February. Besides the humanitarian victims, the military conflict has worldwide implications on oil, gas and grain prices leading to inflation.

In addition, tensions between the US and China have resulted in increasing tariffs and trade conflicts. The risks to brands of pursuing a global supply strategy based purely on lowest unit cost is looking increasingly vulnerable. Changes to the geo-political landscape is leading brands to look for shorter, more regional supply chains with greater resiliency against unforeseen disruptions.

The main consequences of the increased supply chain vulnerability for the packaging industry can be summarized as followed:

- Customer demand has become less predictable and the shift towards e-commerce is continuing.
- Prices for raw materials and logistics services are rising. The traditional frame contracts between box producers and brand owners do not fit to the changed situation.
- Brands are looking at regionalization of supply chains and are requiring converters to have greater agility and flexibility to meet their changing demands and mitigating supply chain risks.

3.3. The future of supply chains

A witty quote from the Danish politician Karl Kristian Steincke says that "It is difficult to make predictions, especially about the future" (cf. [10]) and there is much truth in this. Nevertheless, many mega trends that build on the recent supply chain "revolution" are foreseeable. Major economic, social, and technological disruptions have and will have even more a considerable effect on how companies manage their supply chains. From a market and environment perspective, companies are faced more and more with uncertainty. Customer demand has become much more unpredictable in many industries. Likewise, the supply of materials and components has become much more difficult.

A scientific analysis of these megatrends has been performed from 2017 to 2019 in the EU funded project NextNet. Six European research institutions – one of which was Fraunhofer IML – with a strong background on supply chain management have developed scenarios for future supply chain trends and grouped these into political, social, legal, economic, technological, and environmental mega trends (cf. figure 3).

Figure 3 Supply Chain Megatrends (11)

This situation has been intensified in recent years by events such as Brexit, the COVID19 pandemic, the prolonged outage of the Suez Canal and the Ukraine war and associated sanctions against Russia. Consequently, supply chain megatrends lead to disruptive changes in the way how companies conduct their business.

Companies must adapt to this VUCA (volatility, uncertainty, complexity, and ambiguity) world by putting themselves in a position to anticipate changes as far as possible and take appropriate action quickly. This applies to both the manufacturing and retail industries and has direct implications for the packaging industry. Short time-to-market for new packaging designs is a significant competitive advantage, and with this comes a reduction in the typical production batch size. Packaging designs used to remain unchanged for long periods of time and production batch size were therefore large. Now the share of production runs with small lot sizes in the thousands or even hundreds range is increasing.

Furthermore, the environmental sustainability will be a dominating impact factor for the coming decades. Achieving substantial progress in reaching environmental goals such as climate-neutral production and reduction of materials and energy consumption is becoming a necessity to conduct business (see also [12]).

Regionalization of supply chains will increase

Companies will source closer to their production sites and will be closer to their customers [13]. This makes them less vulnerable to disruptions and will reduce resource consumption for transport thus leading to less greenhouse gas emissions and less energy demand. Consequently, the design of packaging will become more regional and the ordering batch sizes for folding carton and corrugated board will be reduced.

Digitalization and e-commerce will continue to gain in importance

The Internet and devices such as smartphones, tablets, and smart appliances has changed how consumers shop. The importance of e-commerce will continue to grow. This gives companies highly individualized data which is more and more used to tailor the services offered to an individual consumer. These consumers require tracking and tracing services of their orders as a commodity service. Here serialized packaging will be a prerequisite to fulfill such services. The need to ship single units and introduce more-shippable product design has increased economic risk and reduced margins [14].

A May 2022 survey of 300 U.S.-based, mid- to senior-level professionals from procurement, brand marketing, and packaging engineering across a variety of industries also showed the increased importance of e-commerce for packaging. 92% have increased packaging needs due to online orders (cf. [15]).

Furthermore, direct-to-consumer (D2C) supply chain models provide will gain importance. Again, this will lead to specialized packaging design and lower order lot sizes for packaging (cf. also table 2).

Sustainability will become mopre relevant

Environmental, social, and governance (ESG) expectations are of high importance that are driven by governmental requirements as well as consumer expectations. Many governments pursue an Extended Producer Responsibility (EPR) policy approach under which producers are given a significant responsibility – financial and/or physical – for the treatment or disposal of post-consumer products [17]. The top three reasons why consumer trust is lost are not being open and transparent, not meeting ESG expectations, and engagement in greenwashing (cf. Figure 4). Consequently, consumer goods producers will stress the importance for ESG for their suppliers. For the packaging industry this means that the reduction of waste will have much higher importance.

Almost all (94%) packaging experts surveyed by RR Donnelly agree that sustainability is a key consideration in packaging and label decisions.
66% of respondents said they have shifted to more sustainable packaging than what was used previously [15].

The supply chain trends presented on the previous pages can be condensed to three major challenges for the management of supply chains:

- There will be a shift towards smaller lot-sizes. As a result, the order frequency will increase.
- Agility, i.e., the ability to rapidly react to and even anticipate market changes will become a competitive advantage.
- Sustainability by avoiding waste and saving resources will become essential.

Digitalization technology for all processes for the operation of efficient supply chains are required for converters and brands to better cope with these challenges.

Table 2 Examples of events causing global supply chain disruptions

Application	Vendor	Platform	Description
Traceability	Bosch	Carton Pricing System	Fulfills the serialization requirement in the pharmaceutical industry to track and trace the movement of products in the manufacturing line
Agility	Stora Enso	Smart VMI	An RFID-enabled system that identifies and reports inbound-outbound movements of stock and automates the reordering, invoicing, and stock-taking processes
Sustainability	Avery Dennison	CleanFlake Technology	Helps brand keeps promises by using technology to clean separate the label from plastic bottles/containers, leaving no adhesive residue and enabling higher quality recycling

Percentage of executives who agree consumer trust is lost in CP companies when . . .

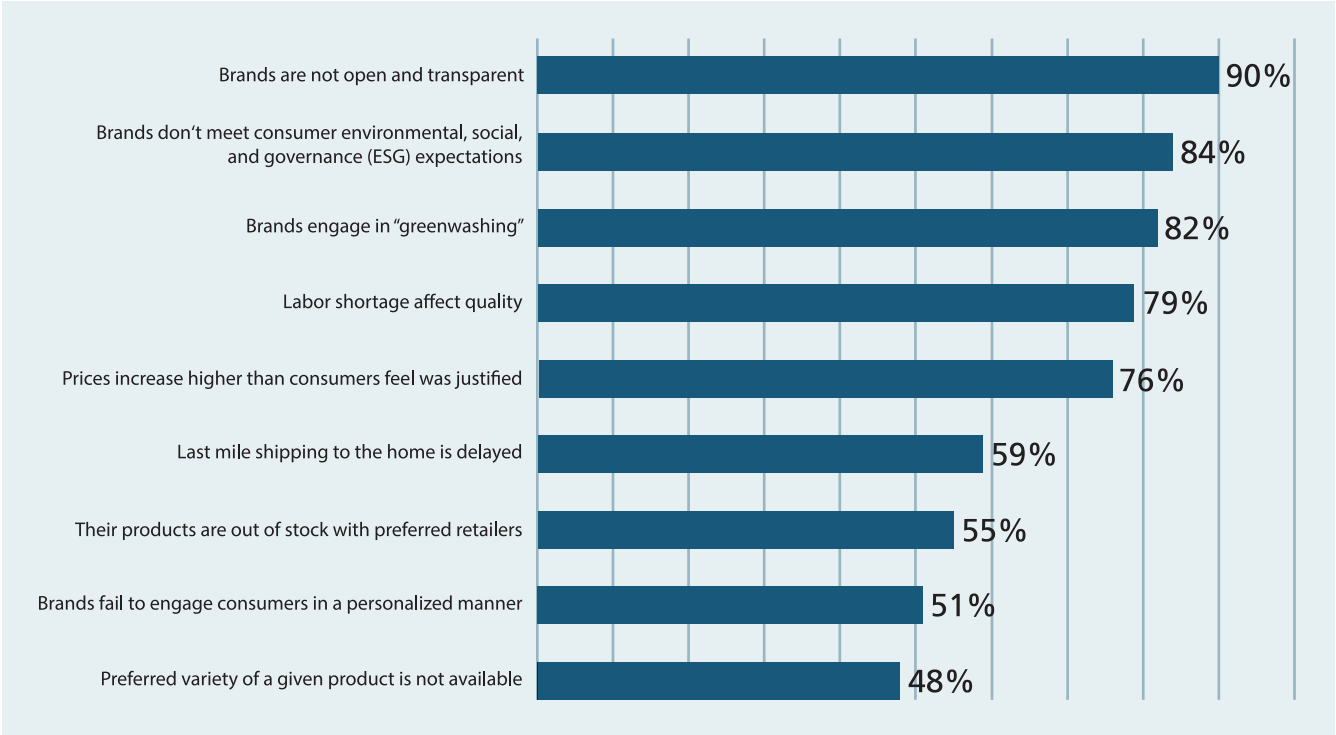

Figure 4 Consumer trust in consumer products companies [16].

4. Effects of Supply Chain Mega Trends on the Packaging Industry and the Production Methods

Sustainability of packaging Types

An analysis by McKinsey for the packaging industry shows that consumers rank paper-based packaging favorably compared to plastic, metal or mixed packaging (cf. figure 5). As a result, paper-based packaging will likely grow share.

Packaging designs must have a strong sustainability narrative and will be e-commerce oriented, ship-ready, and suited for direct-to-consumer business models [19].

How sustainable do you think each of these packaging types is?

Packaging substrates ranked by number of respondents who indicated "extremely" or "very" strong

Ranked top 3 · Ranked 4-7 · Ranked lowest 3

	United States	United Kingdom	France	Germany	Italy	Japan	China	India	Indonesia	Brazil
Paper-based cartons	1	2	4	3	3	4	4	1	4	5
Glass bottles and jars	2	1	1	1	1	6	6	3	7	7
Plastic films made from renewable, compostable raw materials	3	4	2	2	2	1	1	4	1	1
Flexible paper	4	3	5	4	6	5	5	2	5	6
Plastic bottles and containers that are fully recyclable	5	5	3	6	4	2	2	5	2	3
Plastic films that are fully recyclable	6	7	6	5	5	3	3	6	3	2
Metall containers	7	6	7	8	8	8	8	7	8	8
Plastic bottles and containers made from recycled plastic materials	8	8	8	7	7	7	7	9	6	4
Aluminum foil wraps	9	9	9	9	9	9	10	8	9	9
Packaging combining plastic, paper, and aluminum foils	10	10	10	10	10	10	9	10	10	10

Figure 5 Consumer perception around the world regarding packaging substrates [19]

Digitalization of printing technology

Digitalization of manufacturing and logistics will be a key enabler for companies to take their supply chain performance regarding speed and agility to the next level. Alexandre Pauchard, Head of Group R&D, at BOBST stated "The know-how of packaging designers, pre-press specialists, printers, converters, tool makers and machine manufacturers is disconnected into silos, each step being performed without an end-to-end view of the constraints in the other segments of the value chain. When designers conceive a new package, they are lacking crucial process information that would allow them to better take into account downstream operations such as tool and job preparation [21]".

In the same direction is the argumentation of a white paper of Domino, a manufacturer of coding, marking and printing technologies [22]: "Inkjet is winning work from litholam and flexo, it is the preferred method for short to medium runs in colour, particularly when there are multiple versions of jobs required. Brand owners and corrugated buyers, but more importantly their customers, are demanding more sustainable packaging. New artisan brands and companies moving into e-commerce also often highlight their environmental credentials and inkjet printing has an important role to play.
Consequently, there is continued growth for colour corrugated, with more versioning and short to medium runs needed at increasingly short notice. This increased demand for shorter runs favours the economics of digital production. "

Digital printing is well-suited for the fast turnround of new products, given the easier, low-cost print set-up. Especially for the fast-moving consumer products sector the time-to market has become a key requirement. Here, digital printing is considerably faster than analog printing because printing tools are not needed (cf. [20] and [21]). Faller Packaging, a company producing packaging for the pharmaceutical sector, confirms these trends: Batch sizes will become smaller, the number of packaging variants will further increase, ordering cycles are getting more chaotic, and the time-to-market will get shorter (cf. [23]). To address these challenges, Faller is transforming its business to a highly digitized supply chain.

Suppliers of packaging products are transforming their business models towards packaging solution providers by integrating fulfillment services such as commissioning, packaging, and shipment for their customers. Consequently, digitalization will have a high impact for the packaging industry (cf. figure 6).

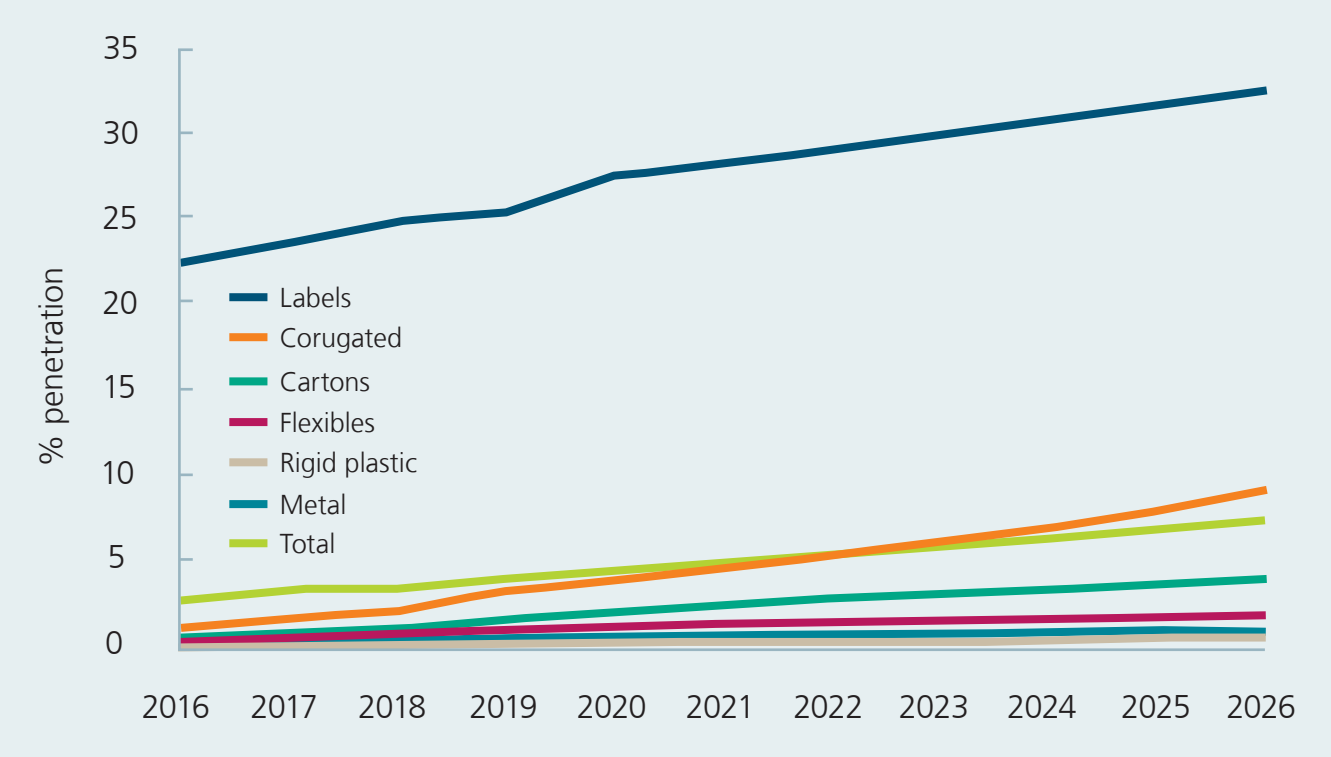

Figure 6 Penetration of digital print in all printed packaging & label output, 2016–26 [20]

For these reasons, digital printing is gaining adoption in the packaging sector. Smithers Consultancy shows digital printing growing in every packaging segment.[Figure 7].
Supply chain resilience and total cost of supply chain improvements with digital printing.

According to Smithers megatrends report [20], sustainability, supply chain disruptions, e-commerce proliferation, and regulatory obligations are critical drivers of digital growth.

Table 3 Digital print impact on packaging megatrends according to Smithers [20]

Trend	Digital print contribution
Sustainability: CO2 reduction targets are new brand goals (light weighting, recyclability); anti-plastic sentiment	Digital eliminates plates and associated chemistry; reduces set-waste, and brands can change order patterns to meet the demand forecasting and minimize supply chain waste
Consumer focus: hygiene, freshness, convenience – speed to market	Digital is well suited to meet growth in packaging, with fast response available
Regulatory: CO2 reduction targets – waste legislation and taxes; minimize emissions; food safety	Digital helps remove VOCs (volatile organic compounds) from ink and fountain solutions. Lower potential for redundancy in supply chains. Inks and coating can be accredited for food use
Retail changes: e-commerce sites exploding; online grocery shopping is up sharply	Digital print allows personalized and versioned packaging, boosting unboxing experience. Potential to generate revenue from advertising changing packaging from a cost
Technology and innovation: smart packaging, personalization/ engagement, surface printing replacing lamination, mono materials	Digital enables main innovative campaigns, versioning and personalization to boost engagement
Supply chain disruptions: global supply chains are not resilient, drive towards local (while managing costs); shortages of some materials	Digital allows rapid replenishment of part orders, helping maintain supply while reducing the cost of inventory

Consequences of supply chain trends for box production

The consequences presented on the last pages of the supply chain mega trends for the box production for the paper-based packaging sector can be summarized as follows:

- Sustainability in respect to substrate shift, waste avoidance, and reduction of energy consumption will become more and more a business prerequisite.
- E-Commerce and regionalization will lead to an increase of the percentage of customer orders with small batch size.
- In the same manner short-term customer orders that require a fast lead time – from order to delivery – will grow.
- Digitalization technology for production and logistics will have a high impact transforming the packaging industry.

For these reasons, digital print – especially of labels – has already gained a significant production share. With solutions now available for converters to integrate high speed digital printing into their logical workflows in the folding carton segment, this also predicted to have strong digital growth in the future.
To enable brands and converters to make consequential decisions in this area, it is our conviction that companies need better models to show costs and benefits before investing in digital printing facilities. This will be addressed in the following section of this white paper.

5. Supply Chain Process for Box Production

For readers not familiar with the packaging industry the folding carton box supply chain can be split into four stages:

1. **Supplier**
   Raw material supplier delivers raw materials – paper, ink and coating, as well as adhesive materials – for the production of boxes. Paper is supplied in large rolls for corrugated box production and in B1-sheets to produce folding cartons. Additional service providers can be employed for the replenishment of production tools, namely printing plates and die-cutting plates.
2. **Converters**
   These companies produce the boxes from the raw materials and deliver these boxes – usually in large quantities – for the packaging to the brand owners. The finished boxes are shipped on palettes in larger quantities to the places where the brand owners package their products.
3. **Brand owners**
   These companies order boxes so that they can package their products in these boxes. Subsequently the packaged goods are shipped to groceries, pharmacies, and other retail businesses and more and more as direct shipment to the consumers
4. **Consumers**
   The packaging goods finally arrive at the consumers for their consumption.The supply chain processes considered in this white paper starts with the package design, includes the sourcing of
   materials by the converters, the various manufacturing steps at the converter plant, the shipment from the converter to the brand owner, and finishes with the warehousing at the brand owner plant.

These processes are considered on an aggregated level based on the SCOR main processes and will be described briefly in the following (cf. [24] and figure 8). SCOR is the abbreviation for the supply chain operations reference model. This is a process reference model that was developed since 1996 by the cross-industry non-profit organization Supply Chain Council as a standard diagnostic tool for supply chain management. The supply chain council merged in 2014 with APICS,
which operates under the name Association for Supply Chain Management (see [25]).

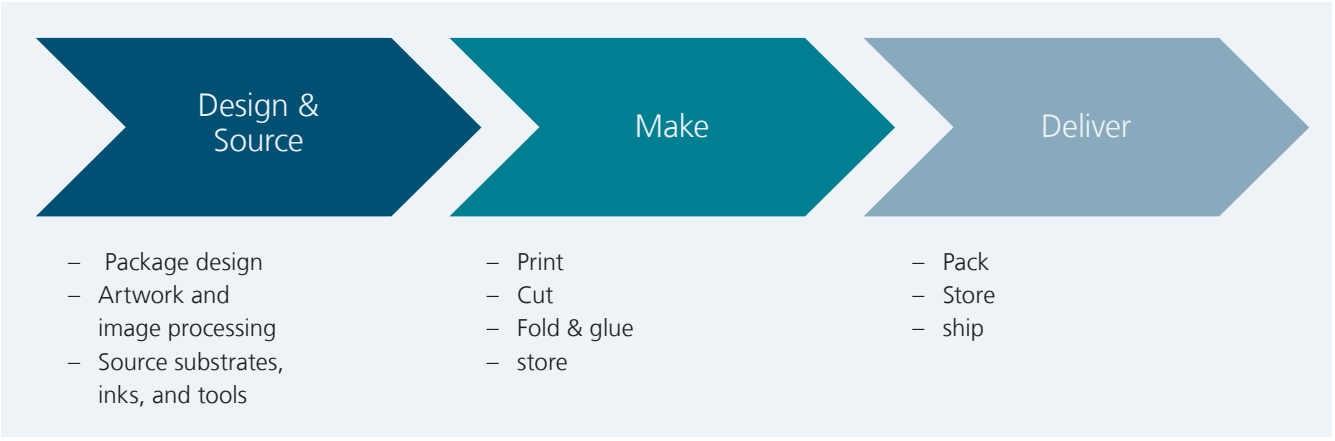

Figure 7 Aggregated processes for the packaging supply chain based on SCOR [24]

5.1. Design & Source

The design & marketing department of a brand owner specifies – often with the help of an agency – the box design and communicates this with the converter. The result of this first step of the box supply chain is a concept for a packaging and usually a prototype. Then, the design department from the converter translates the box specifications from the brand owner to map the boxes on the substrate B1-sheets – typically several boxes are printed on a single sheet –, determine the ink to be used, and specify how the B1-sheets are cut, creased, folded, and glued.

In a similar fashion, tools for cutting and creasing are either manufactured in-house or ordered from tool manufacturers. Design changes for the printing are much more likely than changes for the format. New tools for cutting and creasing are purchased considerably less frequently than the printing plates.

The converter purchases, receives and stores substrate B1-sheets. These B1-sheets are sourced from substrate suppliers with order lot sizes of whole palettes. The sourced substrates vary according to dimensions – thickness, width, and length –, grammage, color, quality, surface, and price. The sourcing of the substrates is not directly affected by the introduction of digital printing technology.

5.2. Make

The major difference between analog and digital printing lies in the necessity for printing plates for analog printing. Analog printing of folding carton – also called offset – printing works by transferring an image onto a sheet known as printing plates through a photomechanical or photochemical process. Each color in the design to be printed requires its own plate. To print a folding box with analog printing it is necessary to manufacture several plates. This manufacturing step has costs and takes time -especially if an external service provider produces the plates. Digital printing technology does not use such plates with the image directly printed on the substrate.

Once substrates, ink, and tools are available, the box plant starts to print the box design on the B1-sheets. Therefore, the printing press is set up and the actual printing starts. The box plant then feeds the printed B1-sheets into a die-cutting machine, which cuts and crease the printed B1-sheets. Some set-up time is necessary for this manufacturing step. In a last production step, the box plant glues the cut and creased boxes. Finally, the boxes are put on palettes, wrapped, and shipped to the brand owner.

Traditional analog printing processes such as offset printing and flexographic printing are characterized by – in comparison to digital presses – long set-up runs in which there is waste of printed substrates until the required printing quality is reached. A typical print job – both for folding boxes and corrugated fiberboard boxes – consumes a few hundred B1-sheets for set-up. These B1-sheets and the ink printed on these B1-sheets are waste material. The same is true for the energy consumption during the set-up time.

Digital printing is characterized by a plate-less printing process. Pigments (inkjet printing) or toner (laser printing) are deposited directly on the substrates. New innovative products such as the VariJET 106 of Koenig & Bauer Durst integrate inkjet technology into platforms for high-performance offset printing.

Figure 8 High-performance offset sheet press Rapida 106 X [26]

Figure 9 Digital printing press VariJET 106 [27]

The result of the printing step -both for digital and analog printing – are printed B1-sheets. A single sheet usually contains several copies (n-ups) of the folding boxes. Therefore, these n-ups must be separated. Also, it is necessary to imprint creases in the cardboard so that the boxes can be folded. For this purpose, so-called flat-bed die-cutters are employed, which need to be made for the respective box design geometry. These plates are usually manufactured by external providers. Also, they require maintenance after each cutting-and-creasing batch run. In recent years solutions for digital cutting and creasing which do not require plates have become available.

The last manufacturing step of a box production is the folding and gluing of the boxes. The respective machines take the printed, cut, and creased boxes and convert these in the finished packaging. These finished goods are then stacked on palettes. Finally, the packed palettes are foil-wrapped for shipping and warehousing.

5.3. Deliver

The converter delivers finished folding cartons in whole pallets to its brand owners. Smaller quantities – up to 3 pallets – are often shipped as express delivery but most shipments happen with trucks, either as full or partial truck loads. The cost and time of shipment depends on the distance to the brand owner and the quantity required. In general, truck transport of several pallets is significantly cheaper than express delivery of individual pallets.

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6. Evaluating Digital and Analog Printing

For this whitepaper, Fraunhofer IML, in close cooperation with Koenig & Bauer Durst, has created a quantitative model for the comparative evaluation of digital and analog printing. In this model, the total costs of the supply chain for both the converter and the brand owner were considered. In addition, sustainability was also evaluated quantitatively. Scenarios with different customer demands (different run length scenarios) were defined for the analysis.

6.1. Quantitative modelling of different scenarios

The model includes the supply chain processes from design to warehousing finished products at the brand owner's site and has over 70 input variables such as the average size of printed B1-sheets, acquisition costs for printing and die-cutting machines, warehousing cost rates, production output or transport costs for FTL, part loads or express shipment. Table 4 contains all the input factors used in the model. The model is based on data from Koenig & Bauer Durst for digital printing. The Richard Bretschneider GmbH (see [28]), a folding carton converter, provided the data for the folding box production processes – from substrate purchasing to delivery of finished goods. The supply chain data came from Fraunhofer IML. All real-world data has been applied to different production scenarios to create a robust comparative model.

The economic viability of digital printing highly depends on the production batch sizes. Digital printing requires fewer set-up times, and produces less waste, but has a lower top speed (B1-sheets/hour) and comparably higher costs for consumables, especially ink.

Consequently, we have computed the total cost of supply chains for different demand scenarios in which the average batch size per customer order varies from 1,000 to 40,000 B1-sheets. The model foresees that the overall production volume per year of 12.5 m B1-sheets is done with each batch size to compare the effect of batch size on printing cost and total cost of supply chain.

The model is based on the input factors in Table 4 and on 200 different customer-ordering scenarios.

Table 4 Input factors for the quantitative evaluation model for analog and digital printing

Model Section	Factors
Customer demand	Average sheet size, number of boxes per sheet, number of boxes per pallet, number of customers, annual demand of all customers (=shipping volume), values for 10 scenarios with different average customer order size
Design and source	Design costs for the converter, percentage of orders with new design, average price for substrates, purchase order admin costs, costs for handling and warehousing substrate pallets at the converter, average warehousing retention time for substrates
Make: Print	Digital helps remove VOCs (volatile organic compounds) from ink and fountain solutions. Lower potential for redundancy in supply chains. Inks and coating can be accredited for food use
(differentiated by analog and digital technology)	Printing capacity per machine, average net productivity, set-up times, wasted B1-sheets per production order, average ink costs, plate costs (analog printing only), energy costs, machine labor costs, costs for printing machines, deprecation costs for the printing press, maintenance costs, obsolescence costs (analog printing only)
Make: Cut	Cutting capacity per machine, average net productivity, set-up times, wasted B1-sheets per production order, plate costs (analog cutting only), energy costs, machine labor costs, deprecation costs for the die cutter, maintenance costs, tooling costs
Make: Fold	Folding and gluing capacity per machine, average net productivity, set-up times, wasted boxes per production order, energy costs, machine labor costs, deprecation costs for machines, maintenance costs, tooling costs
Deliver	Average shipping costs per palette for large shipments, average shipping costs per palette for small shipments (express shipment); costs for handling and warehousing finished goods at the customer, obsolescence costs at the customer plant
Other	Total overhead costs (sales, marketing, administration, management)

The evaluation of the pros and cons of digital and analog printing to produce folding carton boxes must consider both the direct costs for the printing process as well as indirect effects.

The modeling approach is comprehensive and complex. For a better understanding of the results of this analysis, we present the differences between analog and digital printing in steps.

We start with the performance difference for the printing process at the converter, and then take the indirect effects of printing technologies for the converter – especially the raw material supply – into account, and finally we compute the total effects of printing technology on the supply chain by considering intermediate consequences for the brand owners.

6.2. Cost differences between analog and digital printing technology

A consideration of the pure printing costs – resources for machine operation, ink costs and depreciation costs – show that digital printing is worthwhile for the converter for batch sizes of up to 2000 B1-sheets (cf. figure 10). The set-up times for analog printing for batch sizes of 1,000 or less is so long that an additional printing machine is required. For average job quantities of 3,000 or more, analog printing has lower direct printing costs.

However, this comparison is incomplete. As one can see in figure 11, the percentage of wasted sheets for analog printing is by orders of magnitude higher than for digital printing as analog printing requires on average 250 sheets for set-up while digital printing only needs 5 sheets on average.

Costs for printing per technology without costs for substrates (200 mio. boxes = 12.5 mio. sheets)

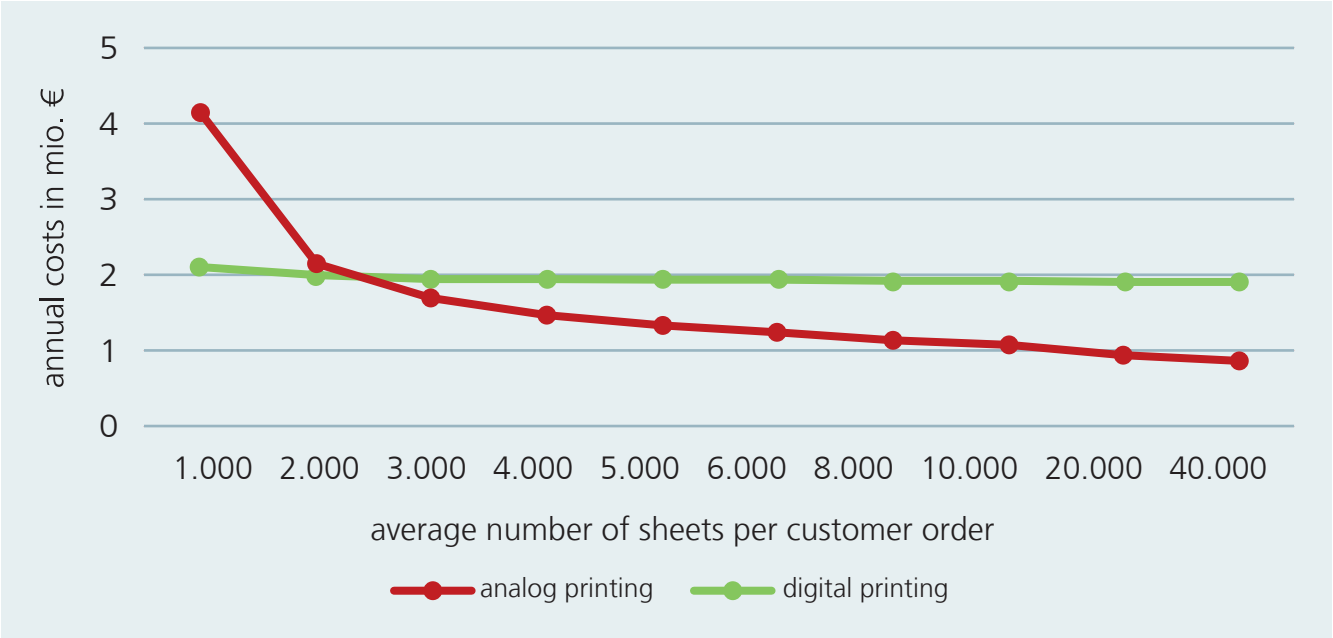


Figure 10 Comparing direct printing costs per technology.

Percentage of wasted sheets per technology (200 mio. boxes = 12.5 mio. sheets)

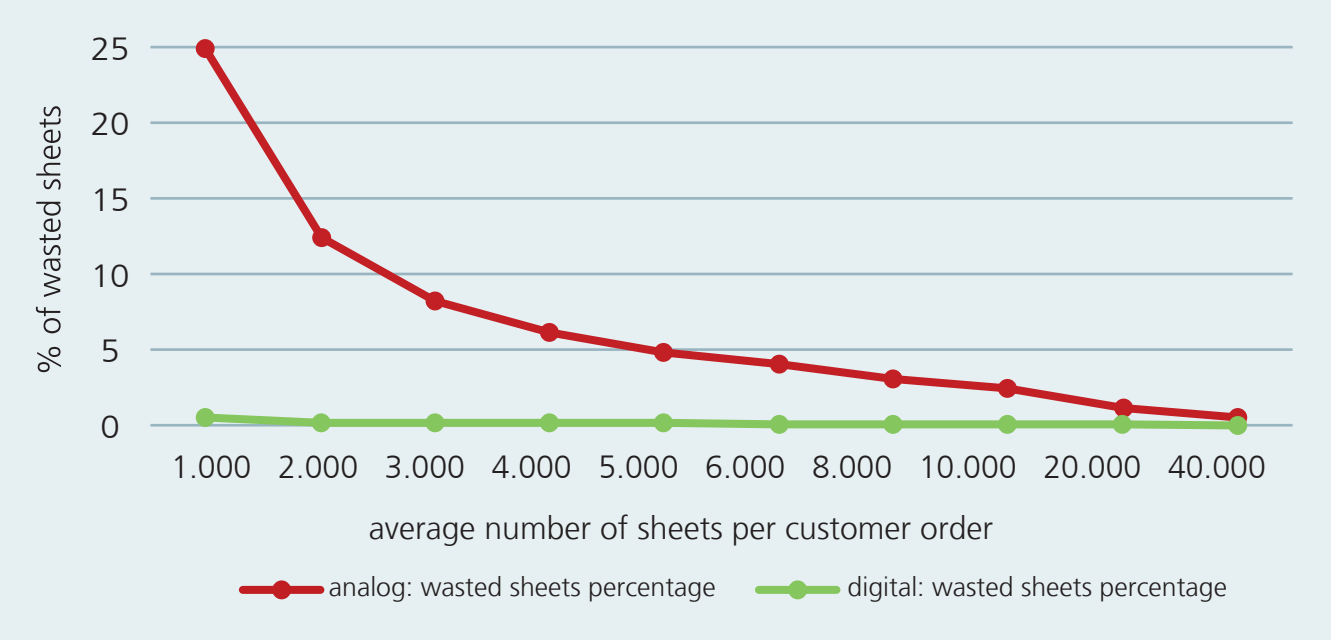


Figure 11 Wasted sheets per technology

Analog printing has less costs than digital printing for average production batch size of 3,000 sheets or more (cf. figure 12).

Costs for printing including costs for sourcing substrates (200 mio. boxes = 12.5 mio sheets)

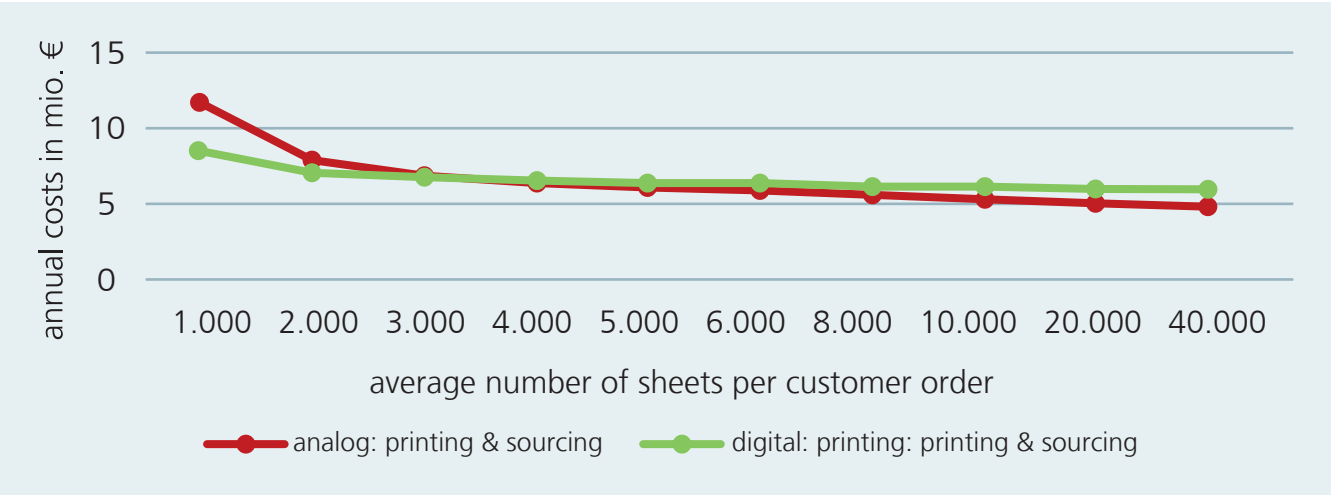
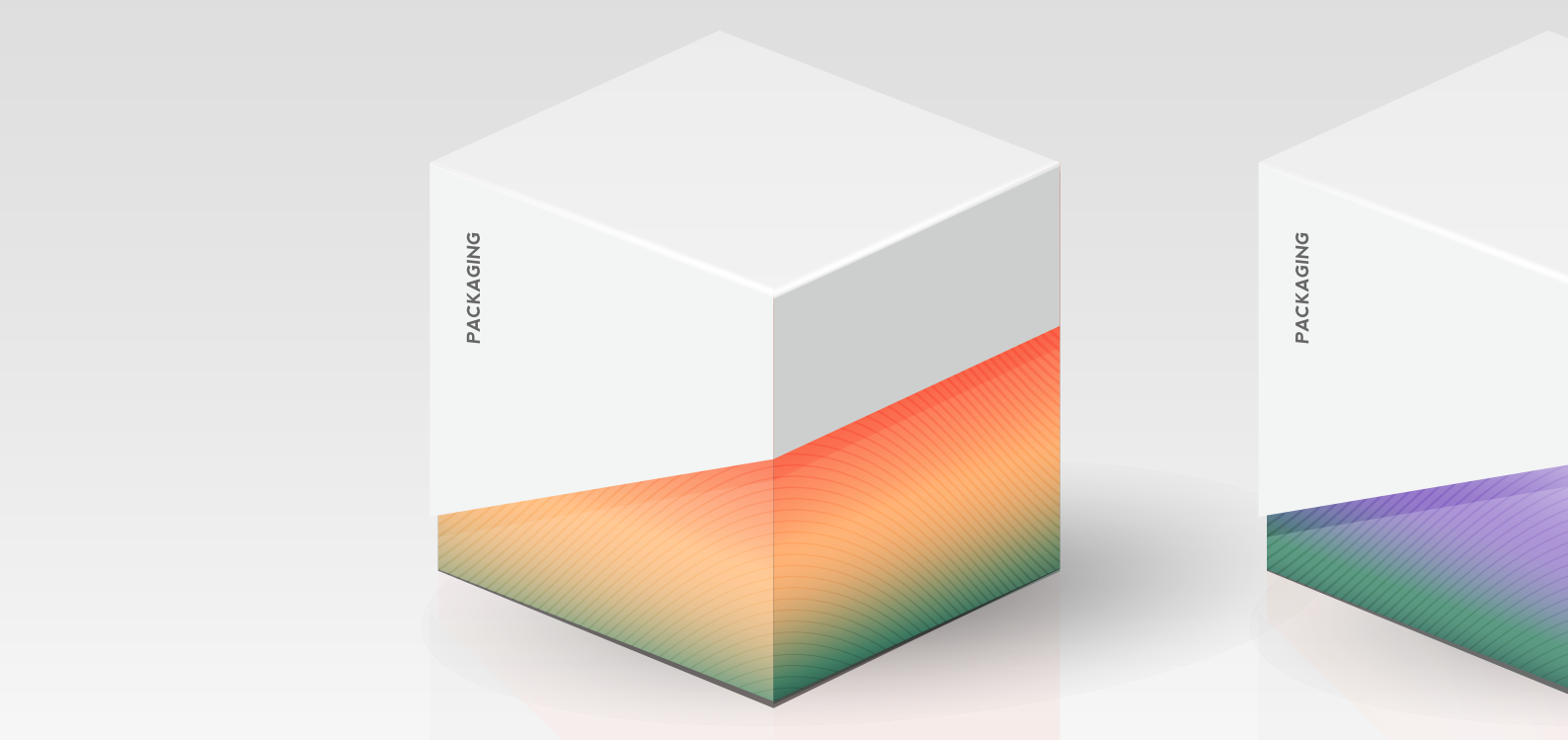


Figure 12 Comparing printing and associated sourcing costs per technology



The main drivers for the breakeven between the two technologies are based on make-ready times (5 minutes for digital and 30 minutes for analog), waste (5 B1-sheets per job for digital and 250 B1-sheets per job for analog) which leads to higher waste costs for both substrates and ink, and the differences in ink costs and plate making. A converter with analog technology must choose between two bad options to produce batch sizes with less than 3,000 B1-sheets.

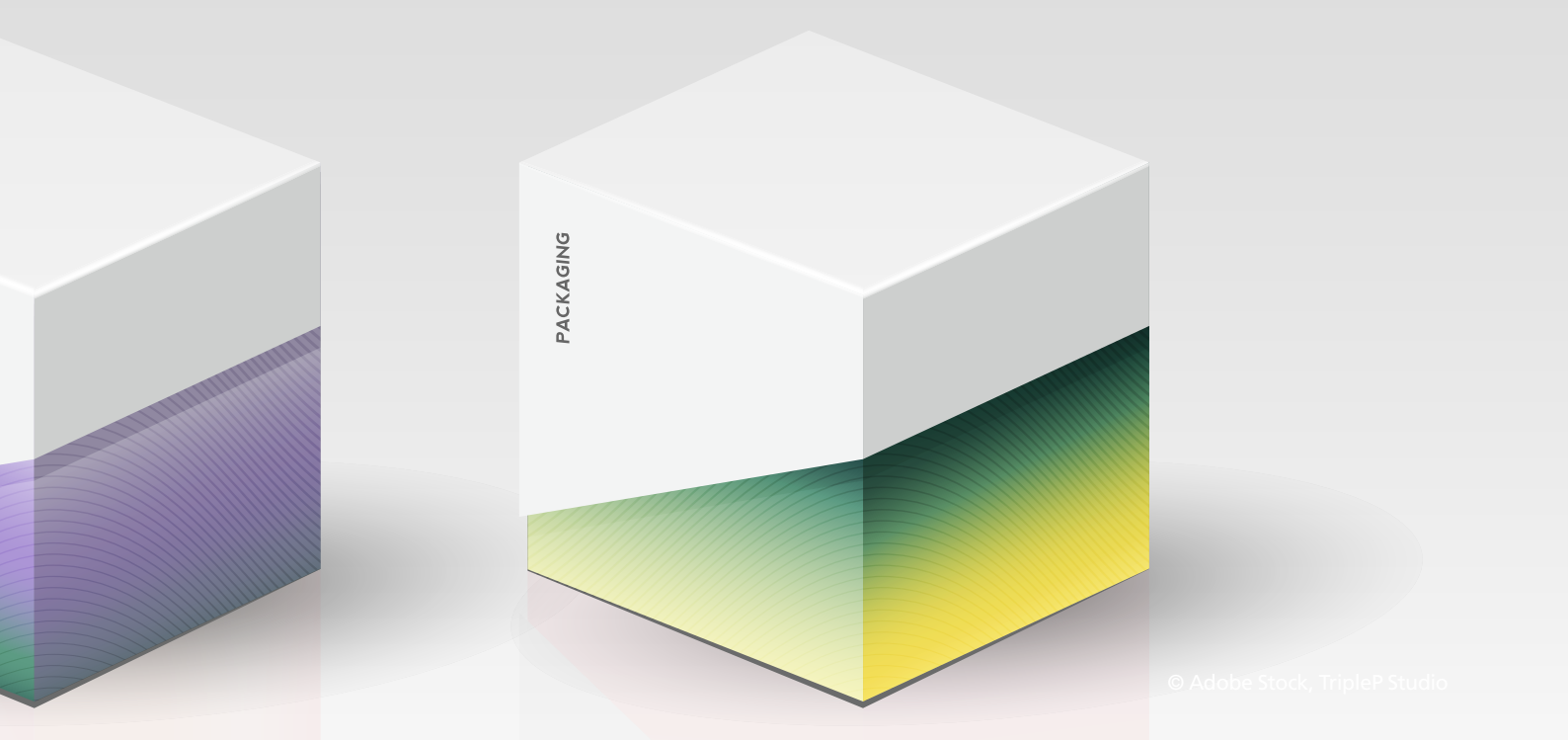
Option 1 is to print in small batch sizes. In this case, the comparative large time for set-up time would require an additional production line for the 1,000 B1-sheets average batch size scenario. Option 2 is to require a minimum order quantity of at least 2,000 B1-sheets from the brand owners. This would lead to considerable costs for warehousing, capital commitment and obsolescence risks for the brand owners.

6.3. Cost differences taking all converter processes into account

However, looking at printing costs alone does not go far enough. Analog printing requires more make-ready B1-sheets for which substrates and ink must be sourced. The sourcing costs for waste B1-sheets have a major impact on the smaller batch sizes up to 6,000 B1-sheets. This can be explained by the waste amount, especially in the short runs. In a batch with 1,000 B1-sheets, analog has 25% waste compared to digital with 0.5% waste. The offset waste amount decreases proportionally with higher batches.

With batches above 6,000 B1-sheets, the difference becomes negligible. The break-even point shifts towards sales order sizes with 4,000 B1-sheets and the gap between analog and digital for 5,000 and 6,000 is negligible (cf. figure 13).

Furthermore, a parallel shift of the curves can be observed, as the following cost parameters come into the model: shipping, overhead, design, cutting, and folding. They are being constant for both technologies.



Total supply chain costs (sourcing, printing, cutting, folding, shipping and overheads) for a converter (200 mio. boxes = 12.5 mio sheets)

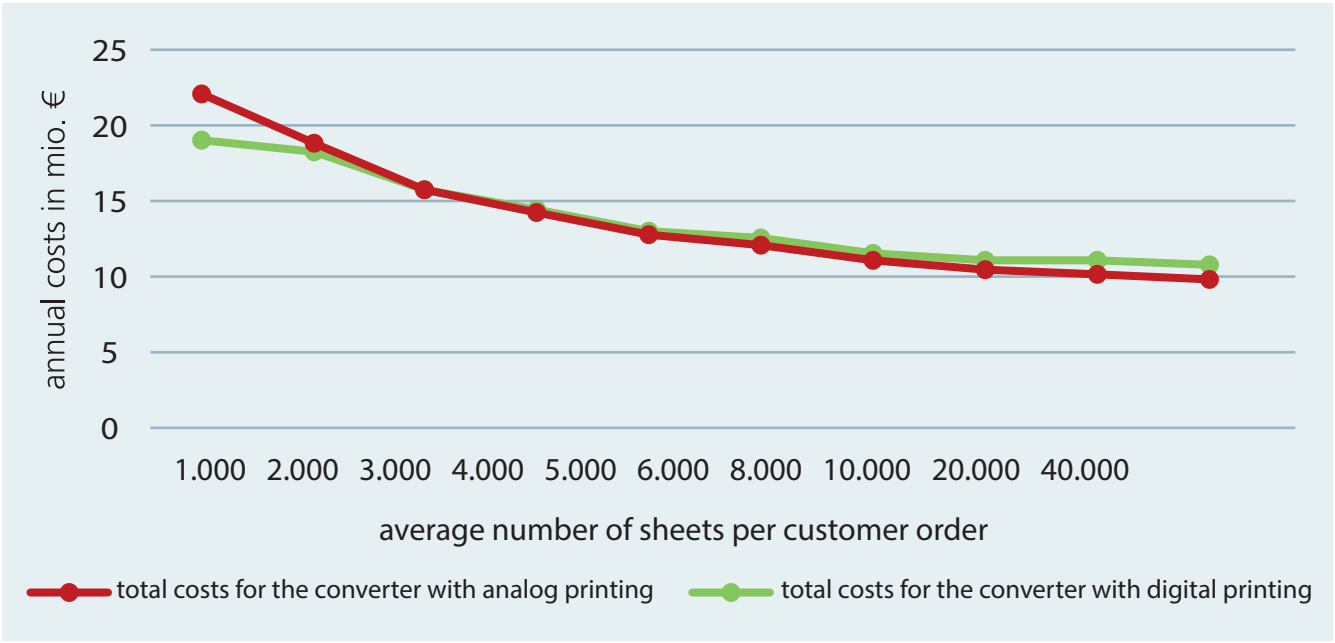


Figure 13 Comparing supply chain costs for the converter per technology

6.4. Total supply chain costs

A complete analysis of total supply chain costs considering the cost differences between analog and digital printing technology requires an examination of transactions with the brand owner. The model adds the costs for handling, warehousing, capital commitment and obsolescence risk to the model for the brand owner without any distinction for analog or digital.

The parallel sharp rise of both curves for run lengths of 20,000 and 40,000 B1-sheets is explained by the obsolescence risk for the long runs in the model for both printing technologies.

Waste factors used in the model are based on industry norms.

Based on Smithers Consultancy and on NAPCO Research 2020 we have assumed that 50% of the quantity produced 90 days or earlier in advance will be wasted (cf. [29]. Average Orders of 20,000 B1-sheets or even 40,000 B1-sheets lead to warehousing and the packaging in stock which is exposed to obsolescence risk. The obsolescence risk and costs are equally applied for both technologies in the model. Although we assume that, the obsolescence risk with digital printing technology available will be decrease. Brand owners would take advantage of the opportunity to place the 20,000 and 40,000 orders differently in order to reduce costs and increase sustainability with having less waste.

Total cost of supply chain including converter and brand (200 mio. boxes = 12.5 mio. sheets)

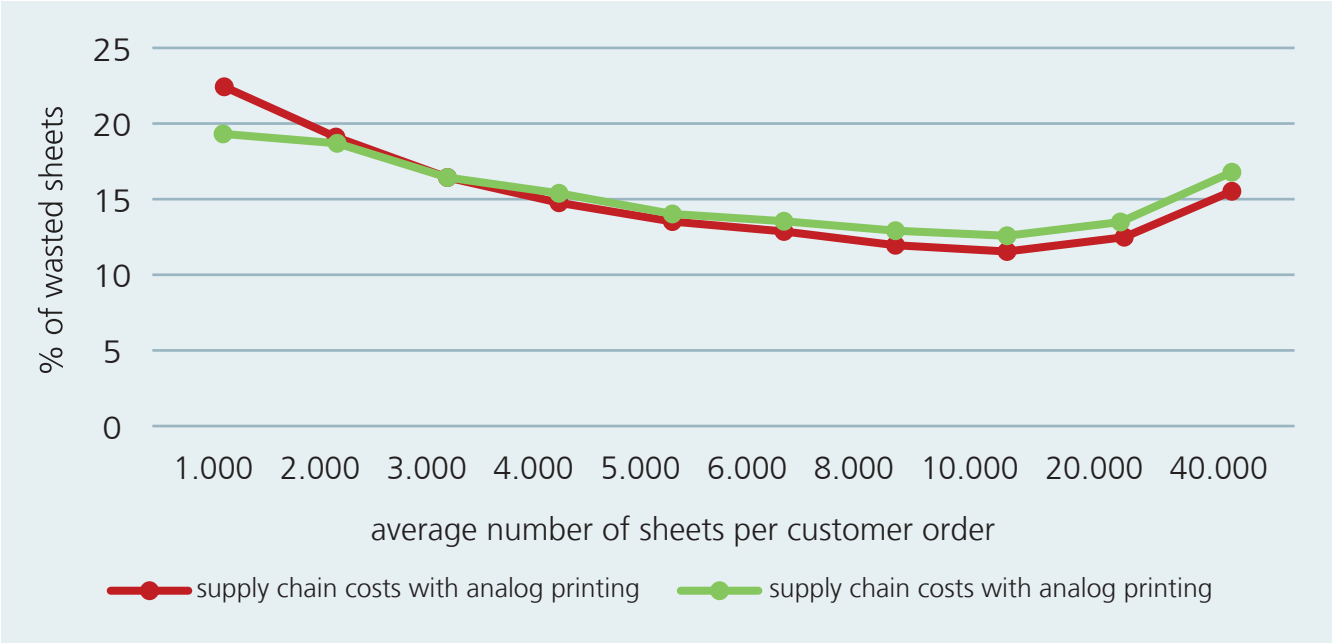


Figure 14 Total costs of supply chain per technology

One can see that following from this diagram:

- Printing costs decrease with increased average customer order sizes. However, the economies of scales effects compete with costs associated to obsolescence, warehousing, and capital commitment so that average lot-sizes of more than 10,000 B1-sheets constitute the optimal point. After that, the obsolescence costs at the brand owner kick in (see also figure 14).

- The cost differences between analog and digital for lot sizes of 3,000 to 6,000 B1-sheets are negligible.

6.5. Effects of printing technology on sustainability

Digital has advantages to analog printing technology with respect to sustainability for three reasons.

1. Digital printing requires far fewer B1-sheets for make-ready than analog printing and thus avoids scrapping not only the substrates but also the ink that is printed on these set-up B1-sheets. In addition, energy and labor costs associated with the "production" of wastepaper are much higher for analog printing.
2. Digital printing enables the brand owners to order more frequently and in smaller batch sizes to reduce the retention time of finished goods in their warehouse and to reduce obsolescence risk and costs due to design changes.
3. The reduction of waste B1-sheets and the associated energy consumption can result in more revenue. A survey by Simon Kucher & Partners shows, that more than 80% of consumers are willing to pay more for sustainable packages (cf. [30]). The importance of sustainable packaging for consumers is also highlighted in the 2nd European Consumer Perception Study (cf. [31]).

Note that other sustainability aspects like energy consumption have not been analyzed with the quantitative model. However, especially for small batch sizes it is reasonable to assume that digital printing will have again a positive impact.

6.6. Effects of printing technology on delivery performance

The supply chain delivery performance can be measured with three performance attributes responsiveness, reliability, and agility [24].

1. Responsiveness stands for the lead time from a brand owner perspective, i.e., the total time from the transmission of a sales order to the converter until the finished goods are delivered to delivery time.
2. Delivery reliability is often measured as a percentage of sales orders which are delivered on time and in full according to the delivery date and quantity confirmed by the converter. As such, delivery reliability KPIs, measure the trustworthiness of the converter.
3. Delivery performance attribute of delivery agility comes into play. With agility KPIs the brand owner perspective on lead times and the ability to change customer orders comes into play.

All three delivery performance attributes are positively affected by the introduction of digital printing technology. Table 5 shows the effects of replacing analog with digital printing technology.

Performance Attribute	Effects of replacing analog with digital printing technology
Lead time	The lead time for digital printing will be shorter because printing plates are not required, especially if these plates are manufactured not at the converter but by an external service provider. Converter's target for lead times with digital are between several days up to one week. Note: The logistics time depends only on the transport process, i.e., is independent from the printing technology.
Reliability	Both printing technologies depend on the reliability of the machines in production. The advantage of digital however is that no third party is involved to supply printing plates. Digital printing increases the resilience for printers in that regard.
Agility	The suitability of digital printing for small to medium run lengths combined with the ability to quickly implement design changes will have a substantial effect on increasing agility.

Table 5 Effects of digital printing on delivery performance

6.7. Further benefits of digital printing technology

A further major advantage of digital printing is to serialize boxes. This is especially relevant for the pharmaceutical industry. The EU regulation "Commission Delegated Regulation (EU) 2016/161" lays down detailed rules for the safety features appearing on the packaging of medicinal products for human use (cf. [32]). This regulation requires that each individual package of drugs for human use must have a unique identifier that enables the authenticity of medicinal products to be verified and individual packs to be identified. Folding boxes produced with analog printing technology require the addition of serialized labels that have been digitally printed and which must be glued on the package. In digital, variable data printing is just another feature easily to be added within the pre-press process.

Montserrat Peidro, former head of Heidelberg's digital printing business, states also that the ability to profitably produce unique boxes for packaging with security features, unique markings for tracking goods, codes for networked packaging and those personalized for specific profiles or target groups are further advantages of digital printing (cf. [33]).

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7. Conclusions and recommendations

The real-world data-based model evaluating costs and sustainability as well as the qualitative considerations on delivery performance for analog and digital printing technology showed the advantages of digital The real-world data-based model evaluating costs and sustainability as well as the qualitative considerations on delivery performance for analog and digital printing technology showed the advantages of digital printing for small to medium batch sizes. These advantages become more prominent if the market share of these smaller batch size is growing.

We are convinced that quantitative decision models like those that the one presented in this white paper can help to overcome prejudices and facilitate data-based objective decision-making processes.

Based our analysis we summarize our recommendations as follows:

- We propose to pursue – for the near future – a mixed strategy of operating digital printing lines for batch sizes of up-to 6,000 B1-sheets and analog printing machines for the long-running jobs.
- Start to get in contact with new technology available and calculate digital printing along the complete value chain. For those converters who choose a defensive strategy as followers will have a hard time to catch up until the tipping point has been reached and the market demands changed.
  It takes up to 2 years to successfully complete the learning curve and take full advantage of the digital printing technology. One needs to train staff, including pre-press, operators, and sales to completely be able to take full advantage of digital.
- Align the digitalization of printing with further digitalization activities. With lower batch sizes the frequencies of customer orders, shipments, production orders, and raw material purchase orders will increase significantly. The respective planning and administration tasks should be automated as far as possible.
- The supply chain megatrends of volatility and the gaining importance of sustainability will reinforce the benefits of digital printing.

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