Assessing Direct-to-Film Color Accuracy in Textiles

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Abstract

The market for printed textiles is a rapidly growing segment of the industry due in large part to the increase in on-demand and short run printing. “Fast fashion” is transforming the textile industry in ways that many perceive to be environmentally unfriendly and not sustainable. The focus of “fast fashion” is on cheap manufacturing processes, mass consumption, and short-term garment use (Niinimaki et al., 2020). While screen printing remains dominant for mass production, digital printing technologies are on the rise for the smaller, more customized print runs that feed the “fast fashion” trend. This study is designed to determine if digital technology could support a transition back to a more traditional “slow fashion” industry should consumer behavior and environmental advocates demand that change.

Direct-to-garment and direct-to-film printing are two relatively new technologies that are increasing in popularity. Direct-to-garment printing uses a modified inkjet technology that sprays ink directly onto the textile (Walker, 2022). Direct-to-film prints onto a heat-transfer film that is then transferred to the garment using a special adhesive powder and heat press (Montoya, 2025). Some advantages of these processes include greater image detail, higher energy efficiency, and versatility of fabric options (Walker, 2022, Montoya, 2025). However, these emerging technologies also introduce some challenges for manufacturers. Some notable issues include color accuracy, the ability to ensure consistent color when transitioning from spot colors in screen printing to CMYK in digital print methods and maintaining color durability over time. For this study, color accuracy refers to the recreation of a specified color onto the textile. This becomes significant in branding contexts where a brand insists on color accuracy across all products irrespective of manufacturing process or substrate type. Color consistency refers to the reproducibility of a color over repeated prints. In some cases, there may be external or environmental changes that result in diminished color consistency. Color durability refers to the ability for color to withstand wear and tear including stain treatments and laundering. This study will focus on color accuracy in direct-to-film printing using a variety of textile compositions, including polyester and

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cotton/polyester blends with a test target consisting of a broad spectrum of colors. Each color will be repeated three times on the target to ensure that the process does not introduce significant variance dependent on where a color is found in the design.

This study examines the questions: How accurately does the direct-to-film process reproduce color if we do not apply a custom color profile? Within that analysis, we will also examine the color accuracy difference with a base layer of white ink and without it. One of the goals of this study is to determine if there are specific colors that are more difficult to accurately and consistently print with the direct-to-film process.

The results will be meaningful for several different audiences including textile manufacturers, brand holders, educators, and consumers. They can provide textile manufacturers with color accuracy recommendations and potentially inform brand holders about whether short-run orders provide accurate brand color. Results will also benefit graphic communications educators who are seeking effective strategies for teaching students about color management, the difficulties associated with digital print technologies, and the unique challenges textile printing presents in the area of color management.

Introduction

The digital print market currently holds 11% of the total print market share with direct to fabric processes dominating the total revenue share at 66.9% (Chapman, et. al., 2025). Some factors that are currently contributing to this growth include the need for more on-demand printing, efficiency, sustainability, and maintaining low inventory (Chapman et al, 2025). Also fueling this increase is the "fast fashion" trend which is built on a "supply chain model that is intended to adapt rapidly to the newest clothing styles by often changing the products offered in retailers" (Centobelli et al, 2022). Fast fashion allows for the introduction of new products at a relatively low cost to the consumer, leading to significantly more consumer waste due to the tendency to "dispose" of the items and purchase more (Centobelli et al., 2022). The capabilities of digital print technologies have fueled this new trend, and have also led to new European Union (EU) regulations related to digital print technologies including more environmentally friendly inks and sustainable solvents (Chapman et al., 2025).

Slow fashion is now emerging as a means to combat environmental concerns related to the sustainability of digitally printed fast fashion (Centobelli et al., 2022). Slow fashion strategies are being implemented including extending the life of the garment by improving colorfastness and rip strength as well as the use of more sustainable materials, such as organic cotton (Centobelli et al., 2022). As a result, print companies have also begun to develop more environmentally friendly methods, such as a reduction in water and energy consumption, less waste, and

more eco-friendly materials (Gilboa, 2025). With these new improvements, the question now becomes whether these digital printing methods can support the demands of the textile industry. This study seeks to begin exploring whether or not digital printing, specifically direct-to-film printing, is capable of producing color accurate results leading towards more sustainable slow fashion models.

Direct-to-film (DTF) is a newer digital printing method that is quickly gaining in popularity. DTF was developed in 2002 by Kornit Digital, an Israeli company, for use with textiles, and is based on inkjet technology. DTF arrived on the print market in 2010 (Wunderlabel, 2024). The direct-to-film process prints on a heat-transfer film that is then transferred to the textile using adhesive powder (Montoya, 2025). The process is completed in four steps: printing the design, pinning or freezing the ink, applying the adhesive powder, and curing for a transfer-ready image (Hazen, 2025). According to Hazen, DTF printing is gaining in popularity due to several factors including versatility of substrate (cotton, polyester, blends, nylon, leather, etc.), print consistency, short set-up time, and minimal calibration compared to screen printing. Additional advantages include high-quality prints, high production speed, durability, and scalability (Hazen, 2025). DTF bridges the gap between on-demand and high-volume printing while maintaining quality and speed. Companies are also working on innovations in automation and sustainability leading to significant projected implementation in the textile print market (Hazen, 2025). The global direct-to-film printing market size was estimated to be 2,720.0 million USD in 2024 and is projected to reach 3,920.0 million USD by 2030, which is a 6% growth in five years (Grand View Research, 2025).

While DTF clearly has advantages, experts continue to agree that color accuracy is the biggest challenge in digital textile printing (Printing United Expo, 2025). Color accuracy is particularly important in a branding context and this study will explore how closely brand colors are reproduced on a variety of textiles using DTF printing, with and without the application of a white underbase. This study will also analyze whether there are specific color families that are more difficult to reproduce with the DTF method.

Methods

Target preparation began with 64 brand colors, representing each ACC (Atlantic Coast Conference division) athletic team's primary and secondary colors. Once duplicates were removed, this left 40 colors on the final target. Color values were provided by the brands in the following values–Pantone, CMYK, RGB, and hex values. Brand colors were then divided into color families, Table X. Conversions to the LAB values from the Pantone numbers provided were derived using the Esko Color Pilot software with the Pantone digital library installed. From there, Adobe Illustrator was used to build a test target. Each value was repeated three

times on the target to ensure measurements were collected in triplicate to prevent variances based on placement across the printed surface.

Color Name	Basic Color	Pantone	L	A	B
Blue	blue	Pantone 286 C	22.94	17.81	-67.95
Cal Navy	blue	Pantone 282 C	11.04	2.35	-26.33
Carolina Blue	blue	Pantone 542 C	68.58	-10.04	-25.38
Light Blue	blue	Pantone 659 C	65.87	-3.27	-33.52
Medium Blue	blue	Pantone 654 C	23.51	0.39	-37.18
Navy	blue	Pantone 2767 C	16.01	1.8	-24.78
Navy	blue	Pantone 289 C	13.07	0.18	-21.6
Navy	blue	Pantone 540 C	17.58	-7.17	-30.28
Pitt Royal	blue	Pantone 661 C	23.5	13.85	-59.75
Royal Blue	blue	Pantone 287 C	20.9	12.46	-56.07
Gold	yellow	Pantone 7502 C	75.92	3.82	27.62
Old Gold	yellow	Pantone 4515 C	67.5	0.74	32.44
Standard Dome Gold	yellow	Pantone 117 C	66.18	11.96	78.61
Vegas Gold	yellow	Pantone 468 C	82.48	3.21	21.79
Cal Gold	yellow	Pantone 123 C	84.1	12.68	77.8
Flesh Tone	yellow	Pantone 155 C	85.71	7.17	29.02
Pitt Gold	yellow	Pantone 1235 C	80.67	20.72	79.13
Yellow	yellow	Pantone 130 C	75.32	22.12	82.91
White	white	White			
Black	black and gray	Black C	17.07	1.33	2.59
Dark Grey	black and gray	Pantone 447 C	23.9	-2.31	1.79

Table 1 (part 1): Each of the 40 brand colors included on the target is notated as the specified brand name, color family designation, Pantone values, and Lab values

Dark Steel Gray	black and gray	Pantone 424 C	48.03	-0.57	-0.32
Gray	black and gray	Pantone 421 C	73.13	-0.73	0.35
Gray	black and gray	Pantone Cool Gray 3 C	80.83	-0.09	0.35
Gray	black and gray	Pantone 429 C	68.96	-1.74	-3.16
Medium Gray	black and gray	Pantone Cool Gray 9 C	50.19	-0.13	-2.4
Burnt Orange	orange	Pantone 173 C	50.68	55.19	52.72
Cavalier Orange	orange	Pantone 172 C	59.1	68.56	67.01
Clemson Orange	orange	Pantone 165 C	64.77	58.55	67.88
Light Orange	orange	Pantone 1585 C	65.3	57.16	71.67
Miami Orange	orange	Pantone 158 C	65.53	43.8	62.98
Orange	orange	Pantone 1665 C	53	59.53	64.43
Cardinal	red	Pantone 202 C	32.35	43.64	17.88
Chicago Maroon	red	Pantone 7428 C	28.04	31.05	3.81
Garnet	red	Pantone 195 C	31.35	34.34	8
Red	red	Pantone 200 C	41.44	65.61	34.2
Red	red	Pantone 186 C	44.68	67.82	40.02
Irish Green	green	Pantone 348 C	46.55	-54.22	26.07
Miami Green	green	Pantone 3435 C	26.23	-22.15	5.78
Regalia	Purple	Pantone 268 C	28.04	34.14	-41.12

Table 1 (part 2): Each of the 40 brand colors included on the target is notated as the specified brand name, color family designation, Pantone values, and Lab values

Three textile materials were tested. All were the same brand ordered from the same vendor. Materials included 100% polyester; 60% polyester, 40% cotton blend; and 50% cotton, 50% polyester blend. All samples were printed with a base

of white ink at 100% coverage to help with the transfer of ink to the substrate for the lighter tint patches. The white under base was not originally intended to be used, however; it became necessary due to breaks in the ink on the lighter color patches.

A Roland VersaSTUDIO BY-20 Direct-to-Film printer was used in this study. The BY-20 utilizes a Piezo style ink-jet technology for ink delivery. It comes equipped with cyan, magenta, yellow, black, and white ink cartridges, allowing for versatile print production and application to a variety of colored fabrics. Printed samples were transferred to the substrate using a Pro World MP995 Transpo manual heat press with max press dimensions of 16”x20”. The test target was printed via FlexiDESIGNER VersaSTUDIO Edition software which works directly with the BY-20s raster image processor (RIP), VersaWorks. The target was printed by the BY-20 onto the appropriate film for transfer onto three different white fabrics. The BY-20 utilizes CMYK printing inks with the option of white as either a base color or a spot color within a design. The BY-20 prints a reverse image onto the film so that the design is right reading once transferred to the substrate. When a full white base is used, the white ink is applied over top the CMYK inks during the printing process. Once printed, a proprietary Roland adhesive powder (S-POWDER) was applied to the printed surface and heated at 350 degrees Fahrenheit for four minutes. This allowed the powder beads to soften and melt together, enabling the transfer of the printed test target to the various fabrics.

Once the adhesive was ready, the test target was laid on a fabric sample and returned to the heat press and placed under constant heat (350 degrees Fahrenheit) and pressure for 45 seconds. The combination of the heat and pressure reactivated the adhesive and created the bond of ink to fabric. Once removed from the heat, the material was allowed to fully cool before the film was slowly removed from the fabric. Once the film was removed, the fabric was once again returned to the heat press (350 degrees Fahrenheit for 20 seconds) and a T-Seal sheet was placed overtop the design to further encourage penetration of the ink and adhesive into the fabric.

The i1Basic Pro 3 Plus spectrophotometer, set to D50/2°, was used for measuring the color patches after printing. This device has a wider aperture of 8 millimeters, which is recommended for measuring textiles. All measurements were taken manually using the Xrite i1 Profiler software set to M1 (D50). LAB values for each patch were recorded and averaged using Microsoft Excel. LAB reference values were then calculated against the averaged LAB values to produce the Delta E 2000 results. Delta E values were calculated using the ColorTools 3.5 Microsoft Excel add-in. Prior to each set of measurements, calibration was performed using the manufacturer provided white patch. A white backing was placed under each sample before measurements were taken, and lighting conditions were UV natural light.

Results

Similar to previous results with dye sublimation, the neutral color family containing black and gray had the lowest DE values across all types of fabrics, Figure 1. Within each color family, results were mixed for which textile type reproduced colors most accurately. For example, 100% polyester was the least accurate fabric for black and gray, greens, and purples but reproduced yellows, oranges, and blues most accurately.

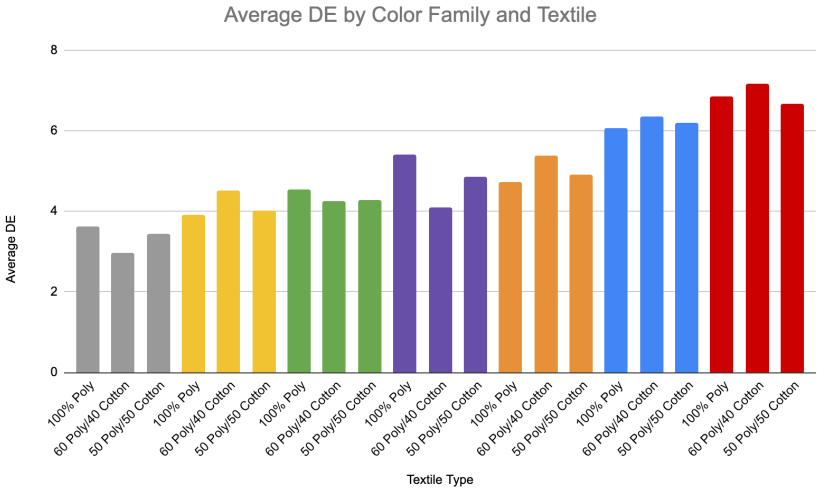


Figure 1: The average DE values for each color family notated by fabric type.
Color family indicated by the color on the bars

When considering each textile type individually, 50-50 DEs ranged from 3.43-6.17, 60-40 DEs from 2.97-7.15, and 100% polyester DEs from 3.61-6.85. Although the best performing color family (black and gray) and worst performing (red followed by blue) remained consistent across textile types, the order of performance varied for the other color families. For example, purple performed better on 60-40 (DE=4.11) than on 100% polyester (DE=5.42). The yellow color family was the most accurate on 100% polyester (DE=3.91) and 50-50 (DE=4.02) and least on 60-40 fabric (DE=4.51), Figure 2.

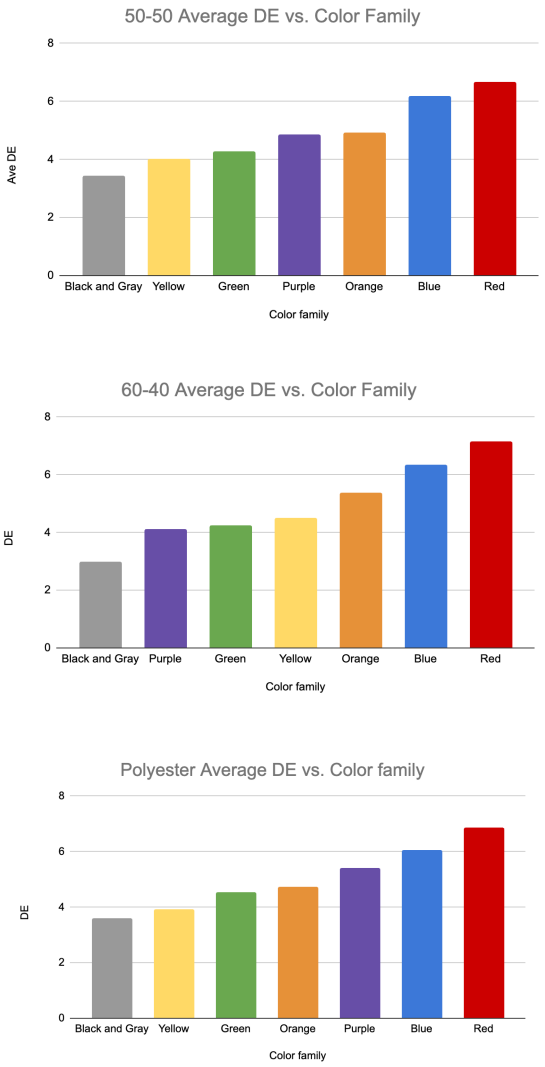


Figure 2: Comparison of fabric type showing accuracy of each color family

When looking for individual colors that reproduced with a DE of three or less, 50-50 fabric reproduced eight colors with a DE of less than three, including four yellows, three black and grays, and one orange color value. Three yellows and five black and gray tones read as a DE of less than three on the 60-40 textile, a total of eight color patches. The polyester fabric had seven colors registered as a

DE of below three including four yellows, two black and grays, and one orange brand color. In fact, the 50-50 fabric and the 100% polyester reproduced the same color patches except for one gray tone as less than a DE of three, Table 2. In general, individual yellow tones reproduced with accuracy across all textile types with one exception, “Standard Gold Dome,” (DE=10.72, 11.69, and 10.61), a color that is more metallic than the other yellow tones included in this study.

Color family	50-50	Polyester
Gray	1.96	1.69
Orange	2.24	1.71
Yellow	2.12	1.95
Yellow	2.45	2.27
Yellow	2.59	2.35
Gray	2.29	2.82
Yellow	2.88	2.95
Gray	2.52	3.16

Table 2: Comparison of the best performing individual colors on 50-50 blend and 100% polyester textiles. There is significant overlap between these two subsets, except for the “Dark Gray” brand color on 100% polyester, even though the exact order of the DE readings varies

The 60/40 polyester was analyzed with samples printed both with and without the white ink base as a variable. There were two samples without the white underbase. In the case of some color families such as green, blue, and red, the no underbase 60-40 textile performed better than the one with the white underbase. No underbase 60-40 produced much lower DE values for black and grays, yellows, and oranges, Figure 3. It should be noted that though DE readings are lower in some color families on the samples with no white ink base applied, upon visual inspection, there are obvious differences in color with those samples having an “acid wash” appearance with dots and breaks throughout the color patch. This defect is primarily visual and not reflected in the color readings, Figure 4.

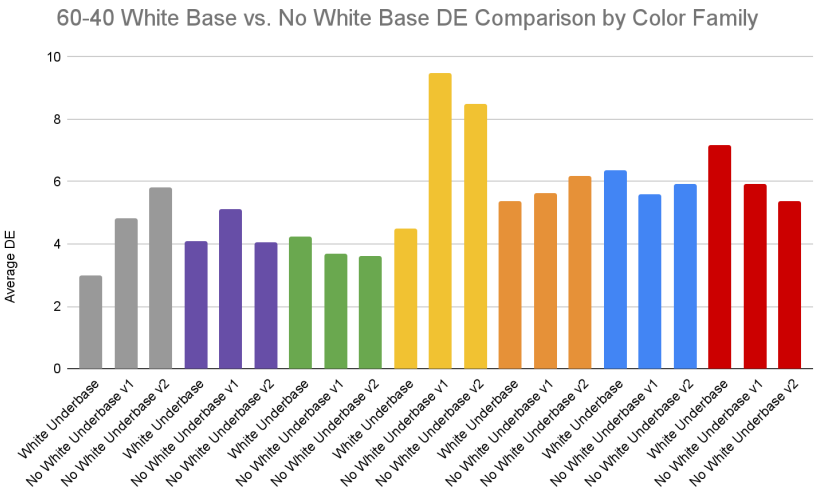


Figure 3: Some, but not all, color families produce better on 60-40 fabric with the white underbase in comparison with 60-40 without the white underbase



Figure 4: 60-40 polyester blend sample printed with no white ink base

Discussion

One goal of this research was to determine how accurate brand colors can be reproduced using the direct-to-film process with manufacturer-provided color profiles. This is an important consideration for small-scale production operations that may not have the capabilities to create custom color profiles for every textile option. This experimental study also sought to test the effectiveness of the white ink base, which is applied during printing. The results were mixed based on textile type and color family. Overall, neutral colors had the most accurate color reproduction across all fabrics with Delta E scores below 4. Color accuracy then varied based on color and textile type. The yellow color family on 100% polyester had the next lowest Delta E readings followed by yellows on the 50-50 blend and purples on the 60-40 blend. When considering each textile type, the 100% polyester and 50-50 blend had the most accurate colors reproduced in the neutral and yellow families while the 60-40 blend was most accurate for the neutrals and purples. Blues and reds consistently had the highest Delta E's across all fabric samples. It is interesting to note that the 50-50 blend and 100% polyester had similar color accuracy readings in the yellow and green color families while the 60-40 blend had greater color accuracy in purples and greens followed by yellows.

In order to test the impact of the application of the white ink base, two 60-40 polyester blend samples were printed and analyzed for color accuracy. This is important for understanding the purpose of the white ink base, both for manufacturers and educators. In some instances, the color families had better Delta E readings than those that were coated with the white ink base; however, when the samples were analyzed visually they would not have been acceptable in a manufacturer print setting. This demonstrates that the white ink base is a necessary step in the direct-to-film process for ensuring consistent, industry-standard color reproduction especially for the light colors. Darker colors were able to produce visually acceptable consistency whether the white base layer was applied or not.

Conclusion

With the growth of the textile market in the print industry, manufacturers are seeking out ways to meet custom, on-demand production while also considering environmental impacts. Many are incorporating newer, digital technologies such as direct-to-garment and direct-to-film printing. As these technologies grow in popularity, printers must ensure that quality is not being sacrificed, particularly color accuracy and durability. This is especially crucial when reproducing brand colors for athletic teams and fan apparel.

The results of this study show that some color families are more difficult than others to reproduce and color families should be a consideration when choosing textile types to print brand colors. It was encouraging that the data also revealed

the majority of colors printed with the direct-to-film process were within or close to an acceptable Delta E range. However, much research is left to be done in DTF as it is still a relatively new print production process.

Future research could test color fastness to determine how durable the color is after laundering. Additional testing in color accuracy could be done to include more types of textiles and fabric blends. This work could warrant the demand to develop a library of standardized profiles for specific textiles printed with this process. Though this study served as a starting point for assessing the feasibility of digital technologies in slow fashion as well as the environmental implications, more research is needed to equip brand stakeholders and printers with the necessary information to expand this segment of the printing industry.

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