Color Reproduction Study on POP Display Media Using Pigment-based Inkjet Printers

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Pigment-based Ink-jet Printer

Abstract

There is a growing market for outdoor and retail advertising utilizing vinyl, film, or fabric as advertising look for unique ways to communicate brand message. A proper point of purchase (POP) display catches eye with strong wording and colorful branding. Vinyl, film, and fabric service customers with a range of applications at an affordable price, together with benefits of protecting digital output from abrasion, providing greater longevity, and aiding installation. Most media used for POP display are not paper-based substrates. The key to achieving the best quality color reproduction of POP display media is to combine the right equipment, software, and media. To examine the color reproduction capability of POP display media, sets of printed samples were prepared. Five commercially available display media (eco-friendly and traditional) were used. It was found that, the print combination of HP Designjet Z2100 printer with glossy paper setting produced largest color gamut with tested display media. However, the Epson Stylus Pro 4800 printer with matte paper setting was most capable of producing consistent color gamut for display media such as DuPont Tyvek, Polypripylene, and Satin Cloth. For the Eco-friendly display media, the highest gamut volume can be achieved when using HP Designjet Z2100 printer with glossy paper setting and DuPont Tyvek display media. For the Vinyl display media, the highest gamut volume can be achieved when using HP Designjet Z2100 printer with glossy paper setting and AqualVinyl display media.

1. Introduction

Most substrates used for POP display are not paper but durable substrates and mostly plastics. A variety of plastics are found in the makeup of POP display media, which include polyvinyl chloride (PVC), polypropylene (PP), polyethylene (PE),

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polycarbonate, polystyrene, polytetraflouroethylene, polyurethane, polymethyl methacrylate, polyimide, and polyester (Watson, 2013; Nonovan, 2013).

Today, display media manufacturers avoid using plastics that contain harmful additives to offer "green" materials that still provide durability and flexibility. The plastic itself usually isn't the problem. Instead, the additives used in the plastic are the problem. Certain plastics contain plasticizers, such as benzoates, phthalates like di-ethylhexyl phthalate, formaldehyde in the adhesive, or heavy metals including cadmium, lead, antimonies, phosphates, and chromium. Those chemicals do not break down properly in landfills and migrate into the ground and water supplies, which in turns to be toxic to human health and the environment (Nonovan, 2013).

Some plastics are considered more sustainable than others. For example, PE is considered as the most recycled plastic in the world, which contains no phthalate plasticizers, is light in weight, and is 100% recyclable. Dupont's Tyvek, for instance, is mainly composed of high-density PE (HDPE) polymer. The low additive content allows for its recyclability. Polyester is a clear and dimensionally stable polymer. It also has the benefit of not being a PVC-based film. Textiles are considered as another eco-friendly material, whether it is creating fabric from post-consumer materials or recycling the fabric after use. A finished textile graphic also incurs low shipping and handling costs because of its lightweight. For an eco-conscious customer, eco-friendly substrates become a way to advertise to a targeted market watchful of environmental footprint (Nonovan, 2010; Nonovan, 2013, Peck, 2013).

The key to achieving the best quality color reproduction of POP display media is to find the right combination of media and print technology. Display media is a significant variable in predicting and reproducing color. The interaction between display media and ink must be considered in the color reproduction process. This study used print driver (inkjet printer manufacturer's software) to control an inkjet printer. Print driver software drives printer to print data files in RGB mode. A user sends an RGB image and the print driver performs the conversion from RGB to CMYK. With print driver, the selected paper type or media type will control how much ink the printer places on the substrate (Rich, 2004).

2. Methodology

In order to examine the color reproduction capability of POP display media, sets of printed samples were prepared. Five commercially available substrates (eco-friendly and traditional display media) were used. Table 1 provides basic properties of substrates used in this study. All tested POP display media contain optical brightner agent (OBA).

Substrates	Material	Thickness	Substrate Color	Recyclability
DuPont Tyvek	High-density polyethylene	11 mil	99.7, 2.30, -8.50	100% Recyclable
Polypropylene	Matte Polypropylene	8 mil	98.4, 2.21, -8.03	100% Recyclable
Satin Cloth	Polyester fabric	6 mil	96.7, 2.33, -9.05	
AqualVinyl	Matte Calendared PVC	5 mil	94.7, 3.55, -9.57	
Opaque Vinyl	Matte Calendared PVC	6 mil	92.9, 1.95, -11.26	

Table 1: *Properties of tested substrates*

Two pigment-based ink jet printers were investigated in this work: an Epson Stylus Pro 4800 printer, and a HP Designjet Z2100 printer. Both printers were profiled as RGB printers using TC 9.18 test target. These color targets were formatted as a TIFF format and printed on tested display with printing resolution of 1440 dpi.

Color measurements were taken using an X-rite i1iO Spectrophotometer with illuminant D50 and a 2-degree observer for tested display media. The measurement files were used to generate ICC profiles with ProfileMaker Pro 5.0.10. The color gamut was then determined by using CHROMiX ColorThink Pro 3 software. The color reproduction capability of POP display media was evaluated in terms of color gamut.

3. Results and Discussion

3.1. Color Gamut Reproduction

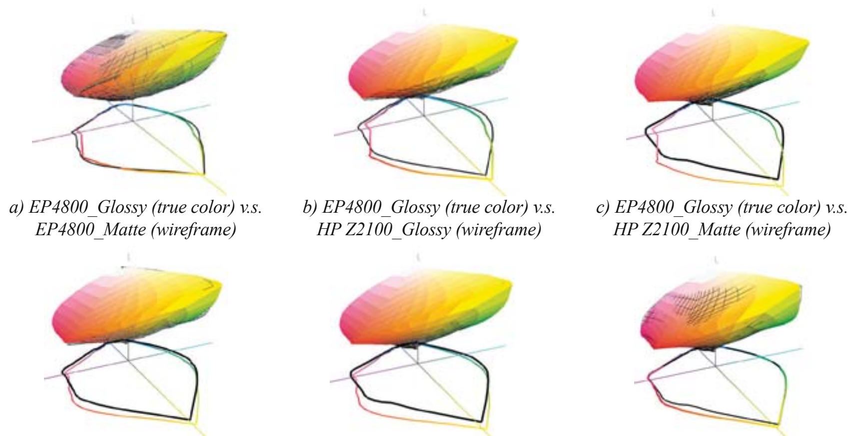
Table 2 lists color gamut measurement as a function of media setting and ink set for the DuPont Tyvek display media. The print combination of HP Designjet Z2100 printer with glossy paper setting produced a wider color gamut, while Epson Stylus Pro 4800 printer with glossy paper setting combination yielded smallest gamut volume and had larger color reproduction variability.

	Glossy Paper		Matte Paper	
Printers	Mean	S.D.	Mean	S.D.
Epson 4800	461,110	5,734	484,908	3,509
HP Z2100	493,786	5,147	475,479	4,134

Note: S.D. represents Standard Deviation (Sigma).

Table 2: *Gamut volume as a function of media setting and ink set for DuPont Tyvek*

The color gamut comparisons for the DuPont Tyvek display media are shown in Figure 1. The HP Designjet Z2100 printer tended to produce a wider color gamut in green, cyan, and magenta areas (b, c, d, and e). The Epson Stylus Pro 4800 printer, on the other hand, yielded a wider color gamut in yellow and orange regions. When using Epson Stylus Pro 4800 printer, matte paper setting yielded larger gamut volume and had less color reproduction variability, compared to glossy paper setting.



a) EP4800_Glossy (true color) v.s. EP4800_Matte (wireframe)
b) EP4800_Glossy (true color) v.s. HP Z2100_Glossy (wireframe)
c) EP4800_Glossy (true color) v.s. HP Z2100_Matte (wireframe)
d) EP4800_Matte (true color) v.s. HP Z2100_Glossy (wireframe)
e) EP4800_Matte (true color) v.s. HP Z2100_Matte (wireframe)
f) HP Z2100_ Glossy (true color) v.s. HP Z2100_ Matte (wireframe)

***Figure 1:** Color gamut comparison for the DuPont Tyvek display media*

Table 3 shows the color gamut measurement for the Polypropylene display media. Among tested print combination, the HP Designjet Z2100 printer with glossy paper s etting produced a wider color gamut but larger color reproduction variability. Compared to the HP Designjet Z2100 printer, Epson Stylus Pro 4800 printer yielded smaller color gamut volumes but less color reproduction variability.

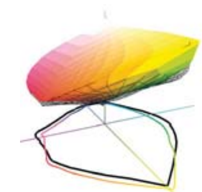
Printers	Glossy Paper		Matte Paper	
	Mean	S.D.	Mean	S.D.
Epson 4800	443,495	3,341	456,913	1,959
HP Z2100	479,399	6,605	477,902	4,439

Note: S.D. represents Standard Deviation (Sigma).

***Table 3:** Gamut volume as a function of media and printer type for Polypropylene*

Figure 2 illustrates the color gamut comparisons for the Polypropylene display media. The HP Designjet Z2100 printer tended to produce a wider color gamut in green, cyan, and magenta areas (b, c, d, and e). The Epson Stylus Pro 4800 printer yielded a wider color gamut in yellow and orange regions. Overall, the HP Designjet Z2100 printer yielded larger gamut volumes but more color reproduction variability. Epson Stylus Pro 4800 printer tended to produce a smaller color gamut with less color reproduction variability.

a) EP4800_Glossy (true color) v.s. EP4800_Matte (wireframe)

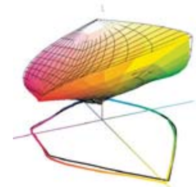


b) EP4800_Glossy (true color) v.s. HP Z2100_Glossy (wireframe)

c) EP4800_Glossy (true color) v.s. HP Z2100_Matte (wireframe)

d) EP4800_Matte (true color) v.s. HP Z2100_Glossy (wireframe)

e) EP4800_Matte (true color) v.s. HP Z2100_Matte (wireframe)



f) HP Z2100_ Glossy (true color) v.s. HP Z2100_ Matte (wireframe)

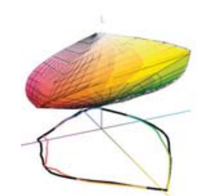
Figure 2: *Color gamut comparison for the Polypropylene display media*

For the Satin Cloth display media (as shown in Table 4 and Figure 3), the HP Designjet Z2100 printer with glossy paper setting yielded the largest gamut volume, but again with larger color reproduction variability. The Epson Stylus Pro 4800 printer with glossy paper setting combination produced smallest gamut volume and had smaller color reproduction variability. The Epson Stylus Pro 4800 printer yielded a wider color gamut in yellow and orange regions (b, c, d, and e).

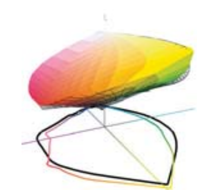
	Glossy Paper		Matte Paper	
Printers	Mean	S.D.	Mean	S.D.
Epson 4800	405,321	1,704	434,361	1,279
HP Z2100	441,791	3,672	430,071	3,166

Note: S.D. represents Standard Deviation (Sigma).

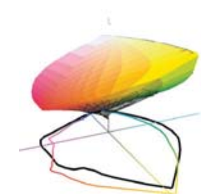
Table 4: *Gamut volume as a function of media setting and ink set for Satin Cloth*



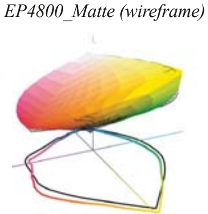
a) EP4800_Glossy (true color) v.s. EP4800_Matte (wireframe)



b) EP4800_Glossy (true color) v.s. HP Z2100_Glossy (wireframe)

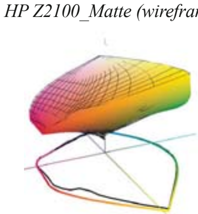


c) EP4800_Glossy (true color) v.s. HP Z2100_Matte (wireframe)



d) EP4800_Matte (true color) v.s. HP Z2100_Glossy (wireframe)

e) EP4800_Matte (true color) v.s. HP Z2100_Matte (wireframe)



f) HP Z2100_ Glossy (true color) v.s. HP Z2100_ Matte (wireframe)

Figure 3: *Color gamut comparison for the Satin Cloth display media*

For the AqualVinyl display media, the HP Designjet Z2100 printer with glossy paper setting combination resulted in a wider color gamut (Table 5). The Epson Stylus Pro 4800 printer with glossy paper setting combination again produced smallest gamut volume and had less color reproduction variability.

Printers	Glossy Paper		Matte Paper	
	Mean	S.D.	Mean	S.D.
Epson 4800	405,321	1,704	434,361	1,279
HP Z2100	441,791	3,672	430,071	3,166

Note: S.D. represents Standard Deviation (Sigma).

Table 5: *Gamut volume as a function of media setting and ink set for AqualVinyl*

Figure 4 displays the color gamut comparisons for the AqualVinyl display media. The HP Designjet Z2100 printer tended to produce a wider color gamut in green and magenta areas (b, c, d, and e). The Epson Stylus Pro 4800 printer yielded a wider color gamut in yellow/orange regions. Overall, the HP Designjet Z2100 printer yielded larger gamut volumes.

a) EP4800_Glossy (true color) v.s. EP4800_Matte (wireframe) *b) EP4800_Glossy (true color) v.s. HP Z2100_Glossy (wireframe)* *c) EP4800_Glossy (true color) v.s. HP Z2100_Matte (wireframe)*

d) EP4800_Matte (true color) v.s. HP Z2100_Glossy (wireframe) *e) EP4800_Matte (true color) v.s. HP Z2100_Matte (wireframe)* *f) HP Z2100_ Glossy (true color) v.s. HP Z2100_ Matte (wireframe)*

Figure 4: *Color gamut comparison for the AqualVinyl display media*

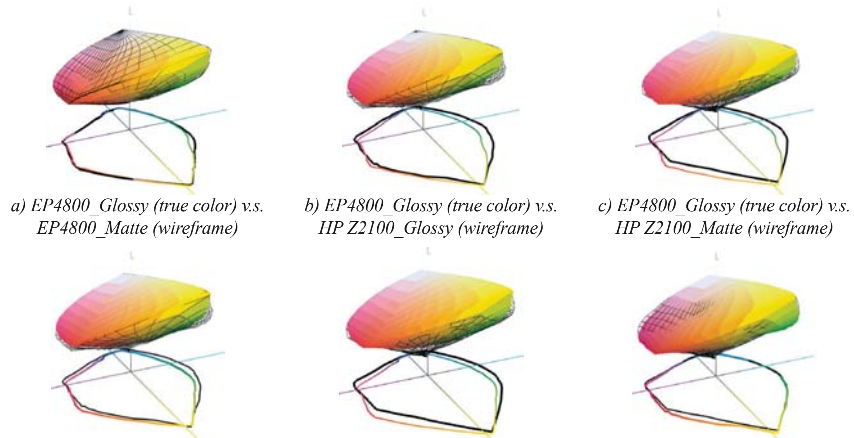
For the Opaque Vinyl display media, the HP Designjet Z2100 printer with glossy paper setting combination resulted in a wider color gamut (Table 6). The Epson Stylus Pro 4800 printer with glossy paper setting combination again produced smallest gamut volume and had less color reproduction variability.

Printers	Glossy Paper		Matte Paper	
	Mean	S.D.	Mean	S.D.
Epson 4800	316,379	2,591	325,920	4,866
HP Z2100	369,871	3,530	363,882	3,410

Note: S.D. represents Standard Deviation (Sigma).

Table 6: *Gamut volume as a function of media setting and ink set for Opaque Vinyl*

The color gamut comparisons for the Opaque Vinyl display media are shown in Figure 5. The HP Designjet Z2100 printer tended to produce a wider color gamut in green, cyan, and magenta areas (b, c, d, and e). The Epson Stylus Pro 4800 printer, on the other hand, yielded a wider color gamut in orange region. The HP Designjet Z2100 printer yielded larger gamut volumes, compared to Epson Stylus Pro 4800 printer.



a) EP4800_Glossy (true color) v.s. EP4800_Matte (wireframe)

b) EP4800_Glossy (true color) v.s. HP Z2100_Glossy (wireframe)

c) EP4800_Glossy (true color) v.s. HP Z2100_Matte (wireframe)

d) EP4800_Matte (true color) v.s. HP Z2100_Glossy (wireframe)

e) EP4800_Matte (true color) v.s. HP Z2100_Matte (wireframe)

f) HP Z2100_ Glossy (true color) v.s. HP Z2100_ Matte (wireframe)

Figure 5: *Color gamut comparison for the Opaque Vinyl display media*

3.2. Capability Analysis

The tools within the Minitab software used to analyze the consistency for color gamut measurements are individual control chart (I chart), moving range charts (MR chart), and capability analysis. Individual control chart (I chart) and moving range charts (MR chart) were used to remove the outlier data. The capability analysis tool was used to calculate Cp index for each display media type. In order to perform the capability analysis, lower specification limit (LSL) and upper specification limit (USL) are required input parameters. However, due to lack of historical parameters of LSL and USL for color gamut measurement of print combinations for each display medium, relative specification limits were determined using test data. After eliminating all outlier points, revised Sigma (the process standard deviation) was calculated for each print combination. In addition, average Sigma was computed for all six tested print combinations for each display medium. The relative LSL and USL (Table 7) were obtained by subtracting and adding the appropriate average 3*Sigma value from each individual print combination mean, respectively. Using LSL and USL values in Table 7, the relative Cp indices were calculated.

	Du Pont		Polypropylene		Satin Cloth	
	LSL	USL	LSL	USL	LSL	USL
Epson 4800_ Glossy Paper	448057	474163	434587	452403	399240	411402
Epson 4800_ Matte Paper	471855	497961	448005	465821	428280	440442
HP Z2100_ Glossy Paper	480733	506839	470491	488307	435710	447872
HP Z2100_ Matte Paper	462426	488532	468994	486810	423990	436152
	AqualVinyl		Opaque Vinyl			
	LSL	USL	LSL	USL		
Epson 4800_ Glossy Paper	378142	390376	307648	325110		
Epson 4800_ Matte Paper	391095	403329	317189	334651		
HP Z2100_ Glossy Paper	400001	412235	361140	378602		
HP Z2100_ Matte Paper	397363	409597	355151	372613		

Table 7: *The relative LSL and USL using average Sigma for tested print combinations*

Results for color gamut for each paper-printer combination are shown in Table 8. A higher Cp index indicates more capable or more consistent results from the digital printing process. For the Du Pont Tyvek media, Epson Stylus Pro 4800 printer with matte paper setting had the largest relative Cp index (1.21), followed by the print combination of HP Designjet Z2100 printer with Matte paper setting (Cp = 1.14). Epson Stylus Pro 4800 printer with glossy paper setting, on the other hand, was the least capable print combination for delivering consistent results in color gamut reproduction. For the Polypropylene media, Epson Stylus Pro 4800 printer with matte paper setting had the largest relative Cp index (1.79). HP Designjet Z2100 printer with either glossy or matte paper setting was less capable for delivering consistent results in color gamut reproduction. For the Satin Cloth media, Epson Stylus Pro 4800 printer with either glossy or matte paper settings had the larger relative Cp index (1.48 and 1.73, respectively). For the AqualVinyl media, HP Designjet Z2100 printer with matte paper setting had the largest relative Cp index (1.68). For the Opaque Vinyl media, HP Designjet Z2100 printer with matte paper setting, together with Epson Stylus Pro 4800 printer with glossy paper setting, were the most capable print combinations for delivering consistent results in color gamut reproduction. Overall, Epson Stylus Pro 4800 printer with matte paper setting was most capable of delivering consistent results in color gamut reproduction for DuPont Tyvek, Polypropylene, and Satin Cloth media, while HP Designjet Z2100 printer with matte paper setting was most capable of delivering consistent results in color gamut reproduction for AqualVinyl and Opaque Vinyl media.

	Du Pont Tyvek	Polypropylene	Satin Cloth	Aqual Vinyl	Opaque Vinyl
Epson 4800_ Glossy Paper	0.80	1.09	1.48	1.31	**1.24**
Epson 4800_ Matte Paper	**1.21**	**1.79**	**1.73**	0.91	0.64
HP Z2100_ Glossy Paper	0.96	0.68	0.59	0.65	1.20
HP Z2100_ Matte Paper	1.14	0.95	0.96	**1.68**	**1.24**

Table 8: *The relative Cp index for tested print combinations for each display medium*

Note: **Bold** indicates the best performance in the category.

3.3. Factorial Analysis for Eco-friendly Display Media

This section discusses the results of the ANOVA and Regression analyses for the main effects of the independent variables (ink set, media setting, display media type) and their interaction effects on the dependent variable (color gamut). The significant level was set to be .05 for all the analyses, i.e., $\alpha = .05$. The full model derived from 2^3 the factorial design is:

$\hat{Y}=\alpha + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_1X_2 + \beta_5X_1X_3 + \beta_6X_2X_3 + \beta_7X_1X_2X_3 + \varepsilon$,
where X_1 = ink set; X_2 = media setting; X_3 = display media type.

Table 9 shows that the p-values for the set of main effects, the set of two-way interactions, and the set of three-way interactions are less 0.05, with exception of media setting and media type (X_2X_3) interaction. In other words, at least one factor, two-way interaction, or three-way interaction has a significant effect on the color gamut reproduction. The p-value of 0.183 for the set of media setting and media type interaction is greater than 0.05, which means there is no evidence that the interaction between media setting and media type has a significant effect on the color gamut reproduction.

Table 10 and Figure 6 show that the ink set (X_1) has the greatest effect (20035) on the color gamut reproduction for Eco-friendly display media. Display media type (X_3) has the second greatest effect (-14393), followed by ink set and media setting interaction (X_1X_2). The interaction between media setting and media type (X_2X_3) has the least effect (1608) on the color gamut reproduction for Eco-friendly display media.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	3	6275212323	6275212323	2091737441	150.11	0.000
X_1	1	4014032285	4014032285	4014032285	288.07	0.000
X_2	1	189494796	189494796	189494796	13.60	0.001
X_3	1	2071685242	2071685242	2071685242	148.67	0.000
2-Way Interactions	3	2765560470	2765560470	921853490	66.16	0.000
X_1X_2	1	2032178547	2032178547	2032178547	145.84	0.000
X_1X_3	1	707533322	707533323	707533323	50.78	0.000
X_2X_3	1	25848601	25848601	25848601	1.86	0.183
3-Way Interactions	1	462087253	462087253	462087253	33.16	0.000
$X_1X_2X_3$	1	462087253	462087253	462087253	33.16	0.000
Residual Error	32	445898712	445898712	13934335		
Pure Error	32	445898712	445898712	13934335		
Total	39	9948758758				

Table 9: *Analysis of variance for the Eco-friendly display media (full model)*

Term	Effect	Coef	SE Coef	T	P
Constant		471624	590.2	799.07	0.000
X_1	20035	10018	590.2	16.97	0.000
X_2	4353	2177	590.2	3.69	0.001
X_3	-14393	-7197	590.2	-12.19	0.000
X_1X_2	-14255	-7128	590.2	-12.08	0.000
X_1X_3	8411	4206	590.2	7.13	0.000
X_2X_3	1608	804	590.2	1.36	0.183
$X_1X_2X_3$	6798	3399	590.2	5.76	0.000

Table 10: *Estimated effects and coefficients for the Eco-friendly display media (full model).*

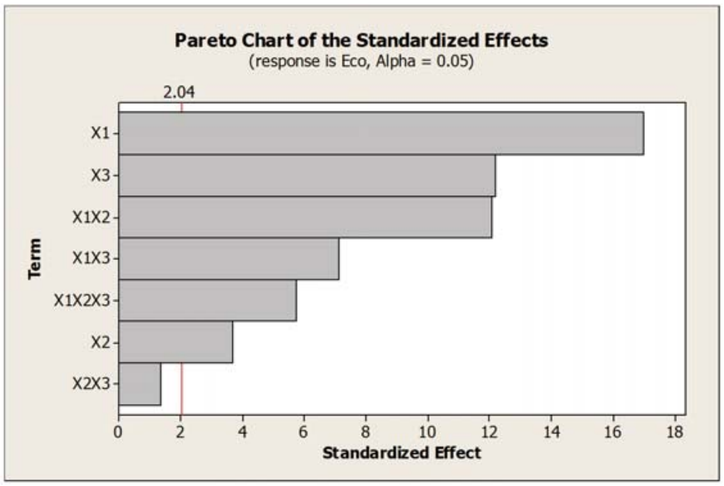


Figure 6: *Main effects plot for the Eco-friendly display media.*

Based on Figure 6 and Table 10, it was suggested that the terms of X_1, X_2, X_3, X_1X_2, X_1X_3, and $X_1X_2X_3$ should be included in the reduced model. Therefore, a Fit Factorial procedure and a regression analysis that included only the terms of X_1, X_2, X_3, X_1X_2, X_1X_3, and $X_1X_2X_3$ were performed and obtain the prediction information for the color gamut reproduction for Eco-friendly display media. Table 11 displays the ANOVA information, and the estimated effects and coefficients are exhibited in Table 12. The regression equation used to predict the color gamut reproduction for Eco-friendly display media is:

Color gamut of Eco-friendly display media $= 471624 + 10018\, X_1 + 2177\, X_2 - 7197\, X_3 - 7128\, X_1X_2 + 4206\, X_1X_3 + 3399\, X_1X_2X_3$ *(Equation 1)*

The R2 value (95.3%) in Table 12 implies that the reduced model explains approximately 95.3% of the total variability in the color gamut reproduction for Eco-friendly display media.

Source	DF	SS	MS	F	P
Regression	6	9477011446	1579501908	110.49	0.000
Residual Error	33	471747313	14295373		
Total	39	9948758758			

Table 11: *Analysis of variance for the Eco-friendly display media (reduced model).*

Predictor	Coef	SE Coef	T	P
Constant	471624	598	788.91	0.000
X_1	10017.5	597.8	16.76	0.000
X_2	2176.5	597.8	3.64	0.001
X_3	-7196.7	597.8	-12.04	0.000
X_1X_2	-7127.7	597.8	-11.92	0.000
X_1X_3	4205.8	597.8	7.04	0.000
$X_1X_2X_3$	3398.9	597.8	5.69	0.000

Prediction Equation:

Color gamut of Eco-friendly display media = $471624 + 10018\,X_1 + 2177\,X_2 - 7197\,X_3 - 7128\,X_1X_2 + 4206\,X_1X_3 + 3399\,X_1X_2X_3$

R-Sq = 95.3%   R-Sq(adj) = 94.4%

Table 12: *Estimated effects and coefficients for the Eco-friendly display media (reduced model).*

3.4. Factorial Analysis for Vinyl Display Media

Table 13 shows that the p-values for the set of main effects and the set of two-way interactions are less 0.05, with exception of media setting and media type (X_2X_3) interaction and the set of three-way interactions ($X_1X_2X_3$). In other words, at least one factor or two-way interaction has a significant effect on the color gamut reproduction. The p-value of 0.449 for the set of media setting and media type interaction is greater than 0.05, while the p-value of three-way interactions is 0.956. In other words, there is no evidence that the interaction between media setting and media type (X_2X_3) or the interaction among ink set, media setting and media type ($X_1X_2X_3$) has a significant effect on the color gamut reproduction for Vinyl display media.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	3	37751906164	37751906164	12583968721	1260.99	0.000
X_1	1	9226087315	9226087315	9226087315	924.51	0.000
X_2	1	64634164	64634164	64634164	6.48	0.016
X_3	1	28461184685	28461184685	28461184685	2851.98	0.000
2-Way Interactions	3	2974543368	2974543368	991514456	99.36	0.000
X_1X_2	1	611606113	611606113	611606113	61.29	0.000
X_1X_3	1	2357061649	2357061649	2357061649	236.19	0.000
X_2X_3	1	5875606	5875606	5875606	0.59	0.449
3-Way Interactions	1	30498	30498	30498	0.00	0.956
$X_1X_2X_3$	1	30498	30498	30498	0.00	0.956
Residual Error	32	319342754	319342754	9979461		
Pure Error	32	319342754	319342754	9979461		
Total	39	41045822783				

Table 13: *Analysis of variance for the Vinyl display media (full model)*

Table 14 and Figure 7 show that the display media type (X_3) has the greatest effect (-53349) on the color gamut reproduction for Vinyl display media. Ink set (X_1) has the second greatest effect (30374), followed by ink set and display media type interaction (X_1X_3). The interaction between media setting and media type (X_2X_3) or the interaction among ink set, media setting and media type ($X_1X_2X_3$) have the least effect on the color gamut reproduction for Vinyl display media.

Term	Effect	Coef	SE Coef	T	P
Constant		370687	499.5	742.14	0.000
X_1	30374	15187	499.5	30.41	0.000
X_2	2542	1271	499.5	2.54	0.016
X_3	-53349	-26675	499.5	-53.40	0.000
X_1X_2	-7821	-3910	499.5	-7.83	0.000
X_1X_3	15353	7676	499.5	15.37	0.000
X_2X_3	-767	-383	499.5	-0.77	0.449
$X_1X_2X_3$	55	28	499.5	0.06	0.956

Table 14: *Estimated effects and coefficients for the Vinyl display media (full model).*

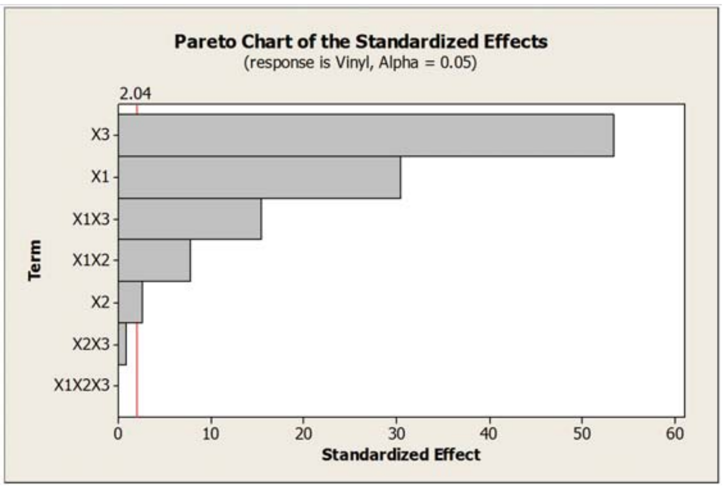


Figure 6: *Main effects plot for the Eco-friendly display media.*

Based on Figure 7 and Table 14, it was suggested that the terms of X_1, X_2, X_3, X_1X_2, and X_1X_3 should be included in the reduced model. Therefore, a Fit Factorial procedure and a regression analysis that included only the terms of X_1, X_2, X_3, X1X2, and X_1X_3 were performed and obtain the prediction information for the color gamut reproduction for Vinyl display media. Table 15 displays the ANOVA information, and the estimated effects and coefficients are exhibited in Table 16. The regression equation used to predict the color gamut reproduction for Vinyl display media is:

$$\textit{Color gamut of Vinyl display media} = 370687 + 15187\,X_1 + 1271\,X_2 - 26675\,X_3 - 3910\,X_1X_2 + 7676\,X_1X_3 \quad \textit{(Equation 2)}$$

The R^2 value (99.2%) in Table 16 implies that the reduced model explains approximately 99.2% of the total variability in the color gamut reproduction for Vinyl display media.

Source	DF	SS	MS	F	P
Regression	5	40720573926	8144114785	851.35	0.000
Residual Error	34	325248858	9566143		
Total	39	41045822783			

Table 15: *Analysis of variance for the Vinyl display media (reduced model).*

Predictor	Coef	SE Coef	T	P
Constant	370687	489	758.00	0.000
X_1	15187.2	489.0	31.06	0.000
X_2	1271.2	489.0	2.60	0.014
X_3	-26674.5	489.0	-54.55	0.000
X_1X_2	-3910.3	489.0	-8.00	0.000
X_1X_3	7676.4	489.0	15.70	0.000

Prediction Equation:

$$\textit{Color gamut of Vinyl display media} = 370687 + 15187 X_1 + 1271 X_2 - 26675 X_3 - 3910 X_1X_2 + 7676 X_1X_3$$

R-Sq = 99.2%   R-Sq(adj) = 99.1%

Table 16: *Estimated effects and coefficients for the Vinyl display media (reduced model).*

4. Conclusions

Table 17 summaries the color reproduction study for tested display media. It was fund that, the print combination of HP Designjet Z2100 printer with glossy paper setting produced largest color gamut. However, the Epson Stylus Pro 4800 printer with matte paper setting was most capable of producing consistent color gamut for display media such as DuPont Tyvek, Polypripylene, and Satin Cloth. In other words, users can choose Epson Stylus Pro 4800 printer/matte paper setting combination as alternative when consistency is the highest priority. For the AqualVinyl and Opaque Vinyl display media, HP Designjet Z2100 printer with matte paper setting gives more consistent in color reproduction.

For the Eco-friendly display media, ink set and display media type are ranked as top two dominant effects on the color reproduction. The print combination of (X_1, X_2, X_3) = (1, -1, -1) is suggested to achieve the maximum yield of color gamut. In other words, the highest gamut volume can be achieved when using HP Designjet Z2100 printer (X_1 = 1) with glossy paper setting (X_2 = -1), and DuPont Tyvek display media (X_3 = -1).

For the Vinyl display media, the display media type (X_3) has the greatest effect on the color gamut reproduction, followed by ink set (X1). The print combination of (X_1, X_2, X_3) = (1, -1, -1) is suggested to achieve the maximum yield of color gamut. That is, the highest gamut volume can be achieved when using HP Designjet Z2100 printer (X_1 = 1) with glossy paper setting (X_2 = -1), and AqualVinyl display media (X_3 = -1).

Print Combination		Color Gamut	Process Capability
DuPont Tyvek			
EP4800/Glossy Paper		450,698 – 468,580	
EP4800/Matte Paper		477,451 – 488,706	√
HP Z2100/Glossy Paper	√	**488,080 – 504,583**	
HP Z2100/Matte Paper		468,680 – 482,608	
Polypropylene			
EP4800/Glossy Paper		436,654 – 447,639	
EP4800/Matte Paper		453,807 – 460,898	√
HP Z2100/Glossy Paper	√	**467,656 – 490,221**	
HP Z2100/Matte Paper		471,308 – 484,261	
Satin Cloth			
EP4800/Glossy Paper		402,390 – 408,002	
EP4800/Matte Paper		430,981 – 435,625	√
HP Z2100/Glossy Paper	√	**432,840 – 446,351**	
HP Z2100/Matte Paper		425,265 – 433,777	
AqualVinyl			
EP4800/Glossy Paper		380,243 – 387,206	
EP4800/Matte Paper		379,525 – 399,759	
HP Z2100/Glossy Paper	√	**398,182 – 416,499**	
HP Z2100/Matte Paper		394,570 – 406,155	√
Opaque Vinyl			
EP4800/Glossy Paper		312,812 – 321,157	√
EP4800/Matte Paper		320,398 – 333,552	
HP Z2100/Glossy Paper	√	**365,248 – 375,378**	
HP Z2100/Matte Paper		357,096 – 367,761	√

Table 17: *Summary of color reproduction study for tested display media*

Note: √ represents the specific print combination gives the largest color gamut, less color reproduction variability, and most consistent result in color reproduction.

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