A Case Study of Remanufactured Inkjet Cartridges: Sustainability vs. Print Quality

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Keywords

Inkjet Cartridge, Remanufacture, Recycle, Sustainability, Print Quality

Abstract

Over 300 million printer cartridges are thrown away every year based on statistical data. It generates 75,000 tons of waste annually. To reduce waste, many printer manufacturers recycle ink cartridges. Aftermarket manufacturers also recycle and sell refilled ink cartridges for much lower cost then OEM (Original Equipment Manufacturer) products. This project focused on remanufactured (refilled) inkjet cartridges for home and small offices. Sixty different remanufactured inkjet cartridges from six aftermarket manufacturers and six OEM cartridges were studied. The following quality issues were investigated: defective rate, optical density, color difference, line raggedness, mottle, streaking, and inter-color bleeding. The test forms were printed on different substrates, including OEM inkjet paper, store brand inkjet paper, and multi-purpose paper. The results showed that the remanufactured inkjet cartridges rated lower than the OEM cartridges in the areas of evaluation. The most significant differences are in color, mottle, streaking, and inter-color bleeding. This provides an opportunity for remanufacturers to understand where their shortcomings lie and to explore steps for improvement.

Introduction

Inkjet printers for home and small offices are usually sold at or above cost. It does not take long for the users to find out that the majority of the money spent on printers is for purchasing new cartridges. The empty cartridges are either thrown away, “recycled” or “remanufactured.”

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Remanufactured inkjet cartridges are generally less expensive than OEM cartridges. Recycled and remanufactured inkjet cartridges are an alternative to reduce the impact of millions of cartridges that are thrown away and end up in landfills each year.

As shown in research (Pollock, 1998), over the life of an inkjet printer, the average user may go through 50 or more print cartridges. The inkjet cartridges are often perceived to be one of the largest sources of electronic waste associated with computer printing. The primary components of an inkjet cartridge are the ink, the pen body and plug, and the print head. The manufacturing process of inkjet cartridges involves the consumption of energy, chemicals, metals, and other materials. The inkjet cartridges which are sent to land fills, contribute to specific environmental issues such as global warming, ozone layer depletion, acidification, and depletion of natural resources.

The processes of remanufacturing inkjet cartridges include disassembling, inspection for safety and durability, cleaning, refilling inks, and reassembling. Remanufactured inkjet cartridges consume significantly less energy, chemicals, and other materials by reusing the exiting cartridge. Less discarded cartridges reduce the impact to the environment.

Despite the efforts of reducing environmental impact, customers are also interested in quality and reliability of remanufactured cartridges. This study focused on the quality issues of remanufactured inkjet cartridges. The cartridges were sent from six different aftermarket manufacturers. The quality of remanufactured inkjet cartridges was quantitatively described as defect rate, optical density, color difference, line raggedness, mottle, streaking, and inter-color bleeding. The quantitative parameters were compared to OEM cartridges.

Experiment

Remanufactured inkjet cartridges from six different aftermarket manufacturers were tested. The inkjet cartridge brands include HP, Canon, Lexmark, and Dell. Due to the availability of inkjet printers, only six types of HP inkjet cartridges were tested and reported. HP brand inkjet printing paper, Staples brand inkjet paper, and Staples brand multipurpose paper were used. Five cartridges of each model were printed and analyzed.

The specifications of tested cartridges are listed in **Table 1**.

Cartridge	Print Head Type	Colorant Type	Drop Size	Print Head Nozzles	Printer Used
HP 21 (black)	Thermal inkjet	Pigment-based	17 pl	416	HP Deskjet 1455
HP 22 (tri-color)	Thermal inkjet	Dye-based	5 pl	300	
HP 45 (black)	Thermal inkjet	Pigment-based	33 pl	300	HP Deskjet 1220C
HP 78 (tri-color)	Thermal inkjet	Dye-based	5 pl	408	
HP 94 (black)	Thermal inkjet	Pigment-based	15 pl	416	HP Officejet 6210
HP 97 (tri-color)	Thermal inkjet	Dye-based	5 pl	600	

Table 1: Inkjet cartridges specifications and printers used for testing cartridges.

For each inkjet cartridge, a print quality test form (**Figure 1**) was printed and then used for quality analysis.

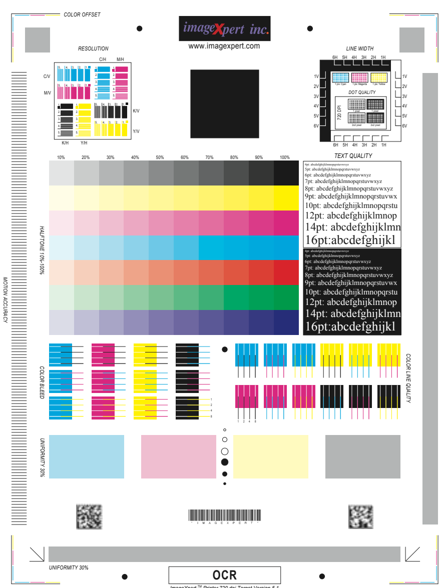

Figure 1: Print quality test form provided by ImageXpert Inc.

Results and Discussions

Printed test forms on three different substrates were printed and evaluated. The three different substrates are OEM inkjet paper (HP brand), store brand inkjet paper (Staples brand), and multipurpose paper (Staples brand). Prints on multipurpose paper showed the lowest quality when visually compared to inkjet papers. For comparison purposes, only the data for the test forms printed on store brand inkjet paper is presented. Each model has five cartridges. The presented data is based on the average value of five cartridges.

Optical Density

Optical density is an important quality parameter. It determines the contrast of a printed image. The density of solid cyan, magenta, yellow, and black were measured by an X-Rite 500 Series Spectrodensitometer. The comparison of remanufactured inkjet cartridges to OEM cartridges are shown in **Figure 2**, **3**, and **4**.

In each figure, solid black (upper left), yellow (upper right), magenta (lower left), and cyan (lower right) are presented. The y-axis represents average density. The first column in the chart is for the OEM cartridge. The second to the seventh columns are for the cartridges from six different aftermarket manufacturers. The blue column represents the average optical density of five cartridges from the same manufacturer. The red column represents the standard deviation of optical densities for each manufacturer.

The results show that the optical density of solid colors are relatively consistent. Among different manufacturers, the optical density of solid cyan, magenta, and yellow are close. The color that has the largest difference among six manufacturers is black.

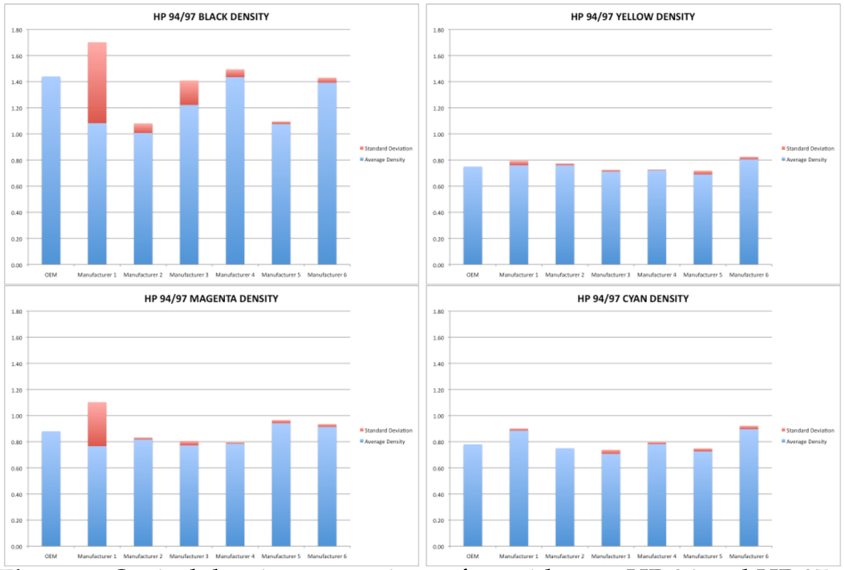

Figure 2: Optical density comparison of cartridge set HP 94 and HP 97.

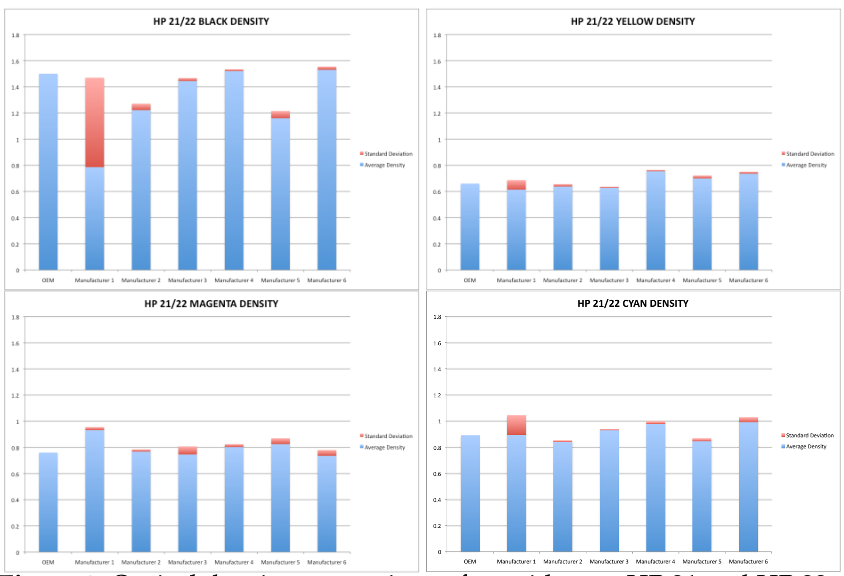

Figure 3: Optical density comparison of cartridge set HP 21 and HP 22.

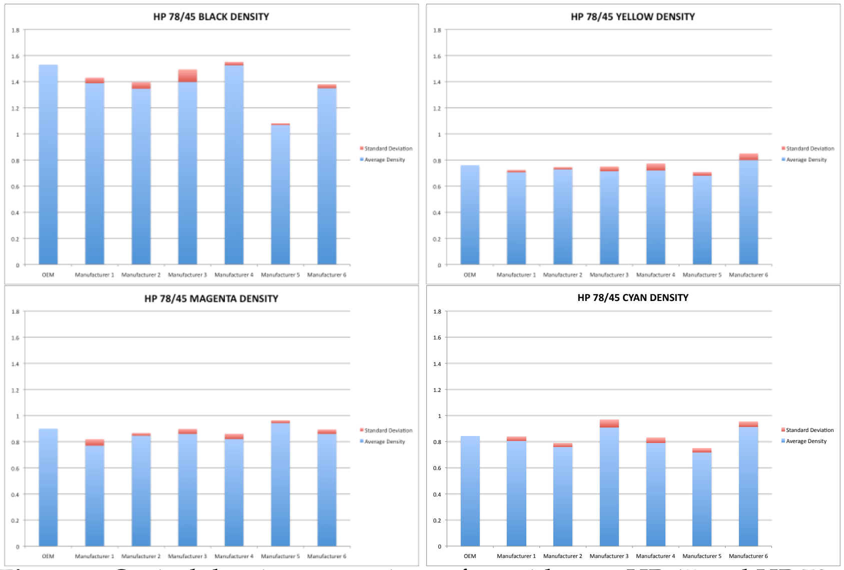

Figure 4: Optical density comparison of cartridge set HP 45 and HP 78.

Color Difference

Color difference is described as delta E in CIELAB color space. The delta Es were calculated by comparing solid colors printed by OEM cartridges to the ones printed by remanufactured cartridges. The average deltas E of cartridges from different manufacturers are presented. The comparison charts are shown in **Figure 5**, **6**, and **7**.

In each figure, black (upper left), yellow (upper right), magenta (lower left), and cyan (lower right) are presented. The y-axis represents average delta E. The columns are for six different aftermarket manufacturers. The blue column represents the average delta E of five cartridges from the same manufacturer. The red column represents the standard deviation of average delta Es for each manufacturer.

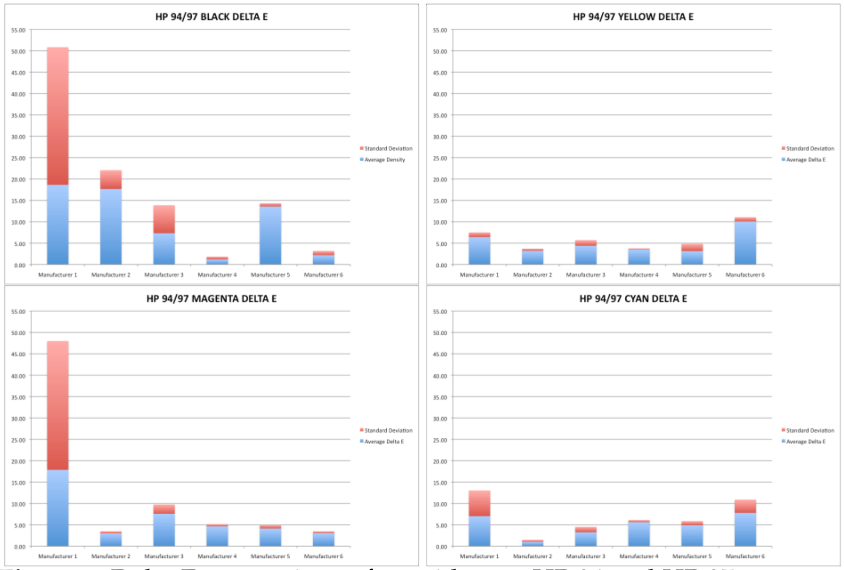

Figure 5: Delta E comparison of cartridge set HP 94 and HP 97.

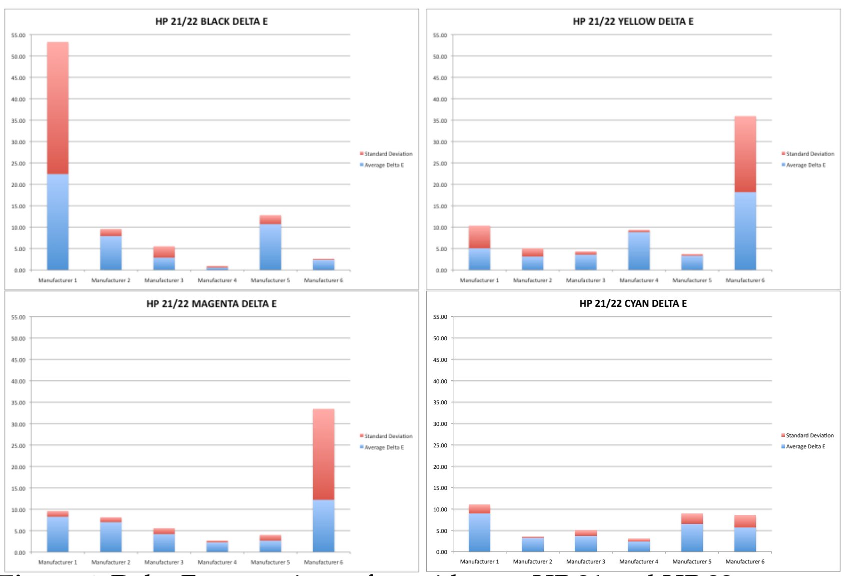

Figure 6: Delta E comparison of cartridge set HP 21 and HP 22.

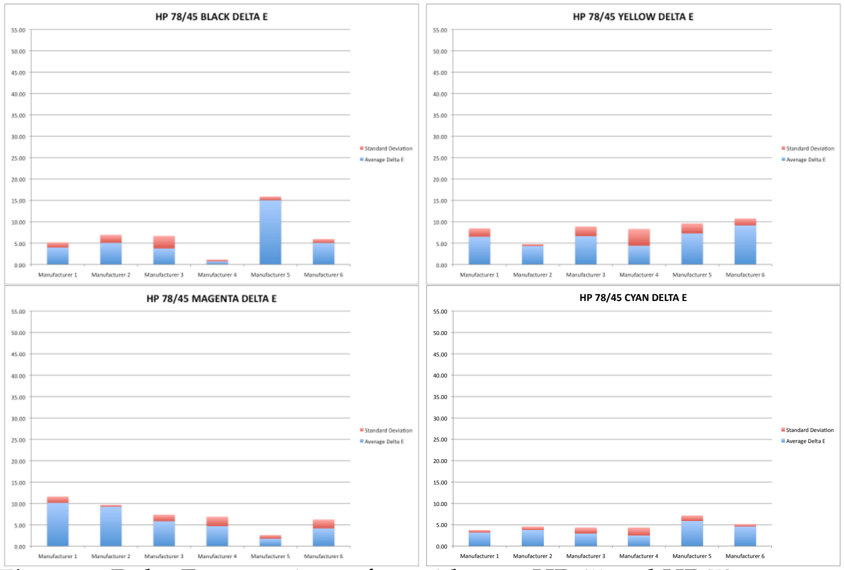

Figure 7: Delta E comparison of cartridge set HP 45 and HP 78.

The results showed that overall, black inks have higher delta Es than color inks. The quality of black ink varies from manufacturer to manufacturer.

Line Raggedness

Line raggedness was evaluated only for black ink. A 2-pixel line was printed horizontally as a positive line and negative line. The same lines were printed vertically as well. Line raggedness was determined by measuring the standard deviation of the upper edge and lower edge of the horizontal line, as well as the left edge and right edge of the vertical line. The standard deviation of the line edge is described as the deviation from the best-fit line to the maximum positive or negative point. The raggedness of the line was evaluated by ImageXpert software. The results are shown in **Figure 8**, **9**, and **10**.

In each figure, raggedness of the 2-pixel positive horizontal line (upper left), 2-pixel positive vertical line (upper right), 2-pixel negative horizontal line, and 2-pixel negative vertical line are presented. The y-axis represents the average line raggedness. The first column is for the OEM cartridge. The second to the seventh column are for the cartridges from six different aftermarket manufacturers. The blue column represents the average line raggedness of five cartridges from the same manufacturer. The red column represents the standard deviation of five cartridges for each manufacturer.

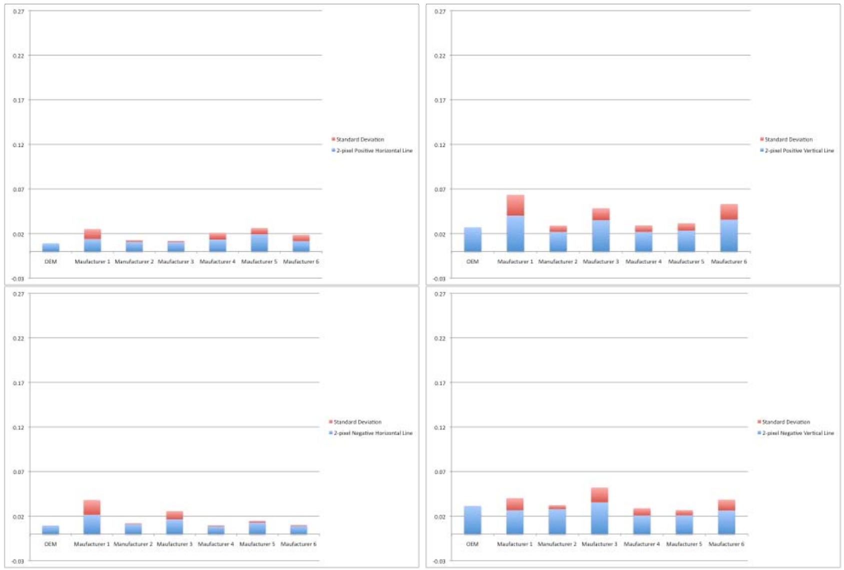

Figure 8: Line raggedness comparison of cartridge set HP 94 and HP 97.

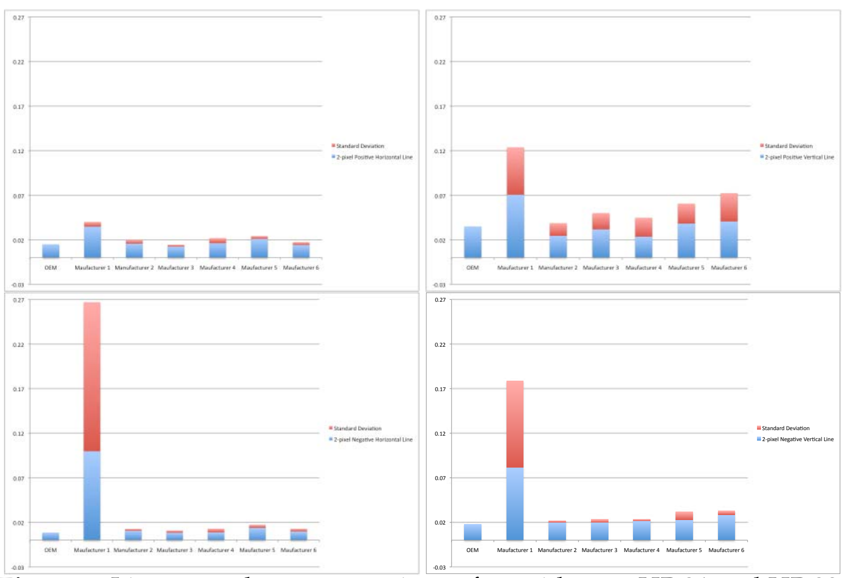

Figure 9: Line raggedness comparison of cartridge set HP 21 and HP 22.

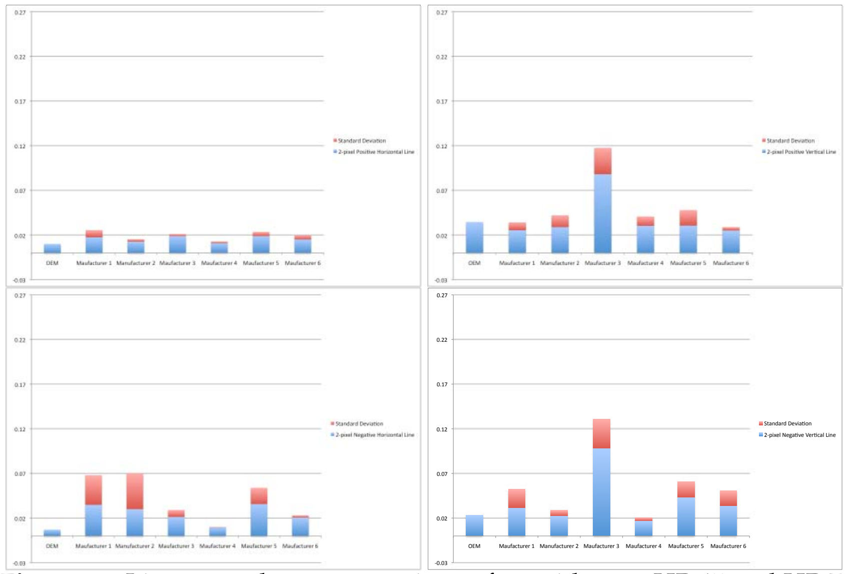

Figure 10: Line raggedness comparison of cartridge set HP 45 and HP 78.

Overall, the remanufactured inkjet cartridges show more raggedness than the OEM cartridges. The vertical lines are rougher than the horizontal lines. This is due to the mechanism of the print head moving back and forth to print the lines.

Mottle and Streaking

Mottle is the manifestation of optical density variation on a solid color, most frequently seen in solid black and cyan. Streaking is usually caused by nozzle clogging. In some cases, it is related to inappropriate filling of inks. Since the print head moves back and forth horizontally, horizontal streaking is more obvious. Due to the accuracy of movements, some print heads also show streaking vertically.

In this study, mottle and streaking of solid black was evaluated by ImageXpert software. Mottle was evaluated as optical density variation, and presented as mottle index. Streaking was evaluated as the number of streaks horizontally and vertically. The gray level of streaking was evaluated as well. The streaks are more noticeable when they have a higher gray level, which means they are lighter. Mottle and streaking results are shown in **Figure 11**, **12**, and **13**.

In each figure, mottle index of solid black (upper left), number of horizontal streaks (upper right), average gray level of streaks (lower left), and number of vertical streaks (lower right) are presented. The first column is for the OEM cartridge. The second to the seventh columns are for cartridges from six different aftermarket manufacturers. The blue column represents the average mottle or streaking value of five cartridges from the same manufacturer. The red column represents the standard deviation of five cartridges for each manufacturer.

According to the results, remanufactured inkjet cartridges showed more unevenness on solid black. Remanufactured inkjet cartridge also showed more streaking with a higher gray level than the OEM cartridge. This reveals that the nozzles of remanufactured inkjet cartridges may be clogged. The print head may not be cleaned thoroughly during the refill process, or the nozzles may be damaged due to intensive usage.

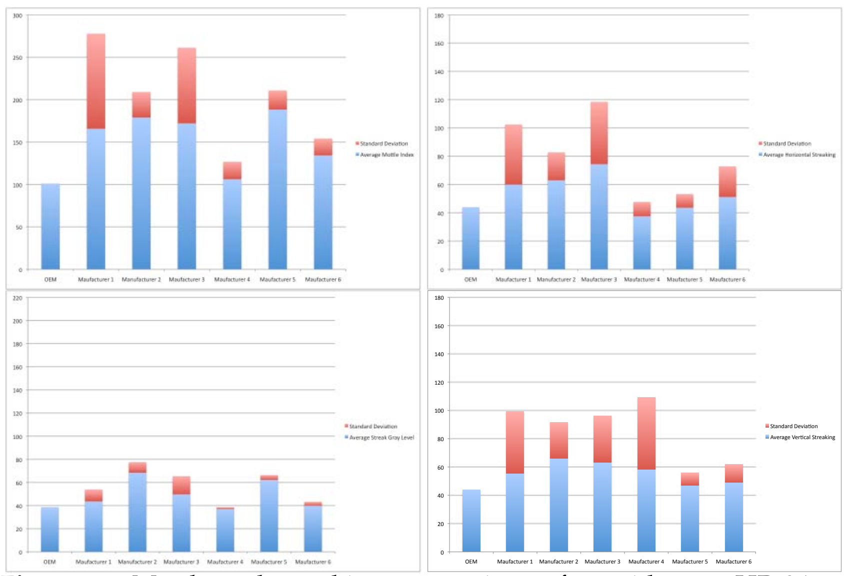

Figure 11: Mottle and streaking comparison of cartridge set HP 94 and HP 97.

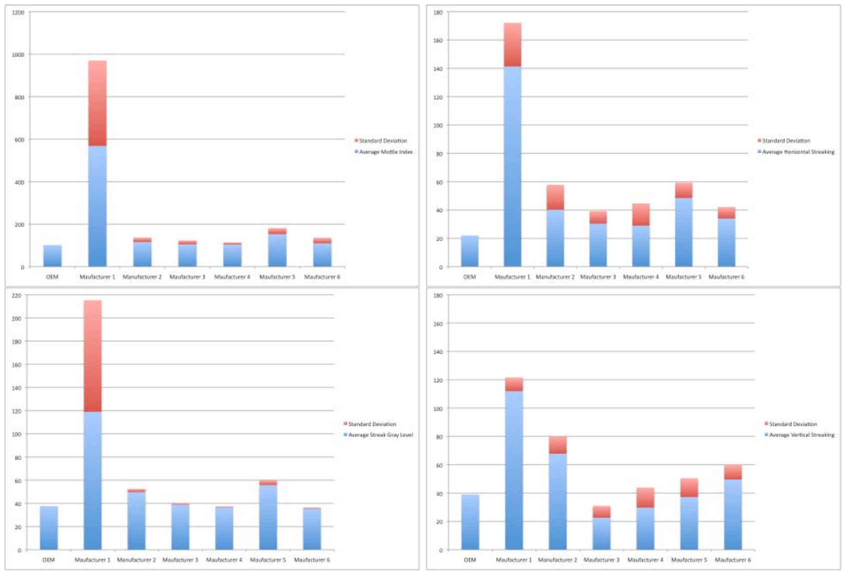

Figure 12: Mottle and streaking comparison of cartridge set HP 21 and HP 22.

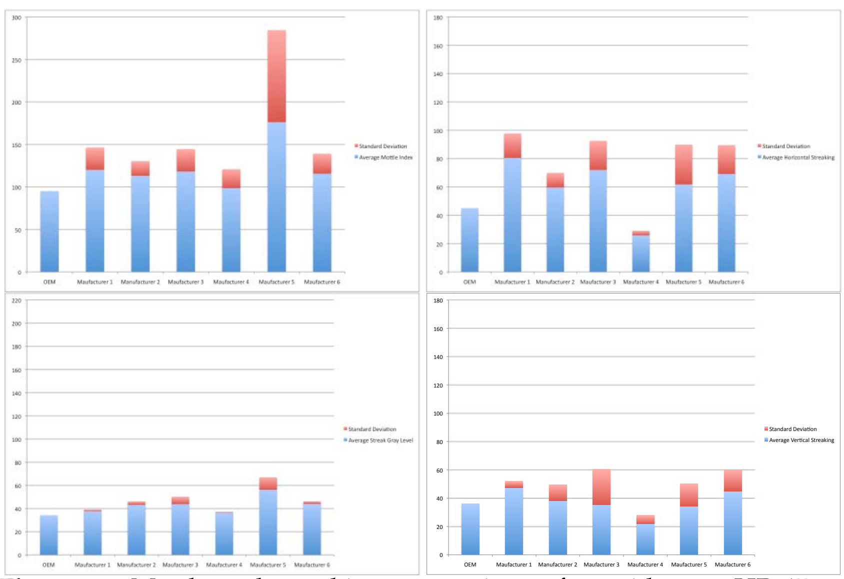

Figure 13: Mottle and streaking comparison of cartridge set HP 45 and HP 78.

Inter-color Bleeding

Inter-color bleeding is visible on printed areas where one of the colors is seen crossing intended boundaries, and is moving into spaces where that specific color is not intended (Quality Logic, 2005). The cause of inter-color bleeding is usually a combination of ink formulation and paper property (Le, 1998). When ink dries slowly on paper's surface, the two adjacent colors are intended to blend, which appears as inter-color bleeding. It is often that black bleeds into the other colors, especially yellow.

Inter-color bleeding was evaluated by ImageXpert software. The line width of black on paper and the line width of black over yellow were measured. The difference between two black lines in width was defined as bleeding. The results are shown in **Figure 14**.

In the figure, the y-axis represents bleeding. Each manufacturer including OEM brand has three sets of cartridge. The blue one represents cartridge set HP 94 and HP 97. The red one represents cartridge set HP 21 and HP 22. The green on represents cartridge set HP 45 and HP 78. The first three sets of date are for the OEM inks. The rest of the sets represent the aftermarket manufacturers.

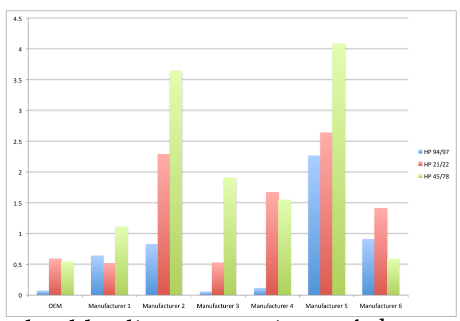

Figure 14: Inter-color bleeding comparison of three cartridge sets: HP 94/97, HP 21/22, and HP 45/78.

Defect Rate

Defective inkjet cartridge in this study is defined as: 1) the cartridge is "dead on arrival" (DOA), which means the printer rejects or could not recognize the cartridge; 2) the printer recognizes the cartridges, but cannot print any image; 3) the cartridge leaks. Another quality issue besides the ones discussed is color misalignment. A tri-color cartridge is expected to align with a black cartridge for good registration quality. Although the printer driver can align color and black cartridges, this study evaluated the registration quality before any registration adjustment. The results are shown in **Table 2** in percentage, which is calculated as the number of defective or misaligned cartridges over five tested cartridges for each manufacturer.

	Manufacturer	1	2	3	4	5	6
HP 94 HP 97	Defective (%)	40	20	0	0	0	0
	Misalignment (%)	40	20	20	20	0	20
HP 21 HP 22	Defective (%)	40	0	0	0	20	0
	Misalignment (%)	100	100	100	100	80	100
HP 45 HP 78	Defective (%)	0	0	0	0	40	0
	Misalignment (%)	0	0	60		40	0

Table 2: Defective rate and misalignment of results of tested cartridges.

The defect rate varies from manufacturer to manufacturer. The remanufactured inkjet cartridges are considered to have low reliability as compared to the OEM cartridges.

Conclusions

Sixty remanufactured inkjet cartridges and six OEM inkjet cartridges were tested and analyzed. The quality of remanufactured inkjet cartridges is not consistent from model to model. Remanufactured color cartridges did not match OEM colors. In this study, remanufactured black ink cartridges had more quality issues, and had significantly lower quality than OEM black cartridges. The quality of remanufactured cartridges depends on the remanufacturing process and ink formulation, as well as on the quality of cartridges themselves. It may be difficult to get the nozzles clean of intensively used cartridges.

Although using remanufactured inkjet cartridges could reduce the impact on the environment, and cost less than OEM cartridges, quality and reliability of the cartridges are still important if high quality prints are needed. The results of this study can be useful to remanufacturers for identifying areas of importance for quality control and where steps can be taken to improve quality.

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