

Ink Cartridge Reliability and Page Yield Comparison

HP Inkjet Print Cartridges vs. Refilled Brands

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1. Executive Summary

In May 2007, INNOVATIONSTECHNIK completed a study for Hewlett-Packard (HP) in the areas of page yield and cartridge reliability. The study was designed to evaluate the performance of Original HP inkjet print cartridges compared to 16 brands of refilled inkjet print cartridges for the HP DeskJet 970Cxi and the HP DeskJet 5850 printers. All brands tested were sold in Germany and/or the United Kingdom and/or Italy and/or France and/or the Netherlands.

The results of the study show that Original HP inkjet print cartridges outperformed the refilled inkjet print cartridges.

Page Yield – When looking at the total pages printed from those cartridges tested, on average Original HP inkjet print cartridges reached an average yield of 793 pages. This is 79.5% higher than the average yield of 442 pages of all refilled brands (as defined in Appendix 3 – Definitions).

Cartridge Reliability – None of the Original HP inkjet print cartridges tested resulted in reliability problems (as defined in Appendix 3 – Definitions) whereas, on average 24.0% of the refilled brands cartridges tested were either dead-on-arrival or failed prematurely (as defined in Appendix 3 – Definitions).

Additional Observations – For refill stations, the average waiting time to get a cartridge refilled was 42 minutes. The difference between the lowest and highest waiting time was more than five hours (as defined in Appendix 3 – Definitions).

Not all cartridges could be successfully refilled. Of all cartridges attempted to get refilled at refill stations, 19 units failed during refill process.

Refilled Brands Tested:

Store / Refill Brands

- Boeder – refill brand
- Carrefour – store brand
- Ecostore – refill brand
- Geha – refill brand
- KMP – refill brand
- PC Line – refill brand
- Pelikan – refill brand
- Staples – store brand
- Tesco – store brand

Refill Station Brands

- Cartridge World
- PC-Spezialist
- Prink
- Refill 24
- Refill Ink
- Tintenstation
- Vobis

2. Results

2.1 Page Yield Test

When looking at the total pages printed from those cartridges tested, on average Original HP inkjet print cartridges reached a 79.5% higher average page yield than the average of all refilled brands. This calculation is based on the 90% lower confidence bound (LCB) values (as defined in Appendix 3 – Definitions).

More specifically, when comparing HP to the store/refill brands tested only, based on the total pages printed for this subset of cartridges tested, on average Original HP inkjet print cartridges produced 46.6% more pages than the store/refill brands (brands A-J) tested based on comparing the 90% lower confidence bound values (as defined in Appendix 3 – Definitions).

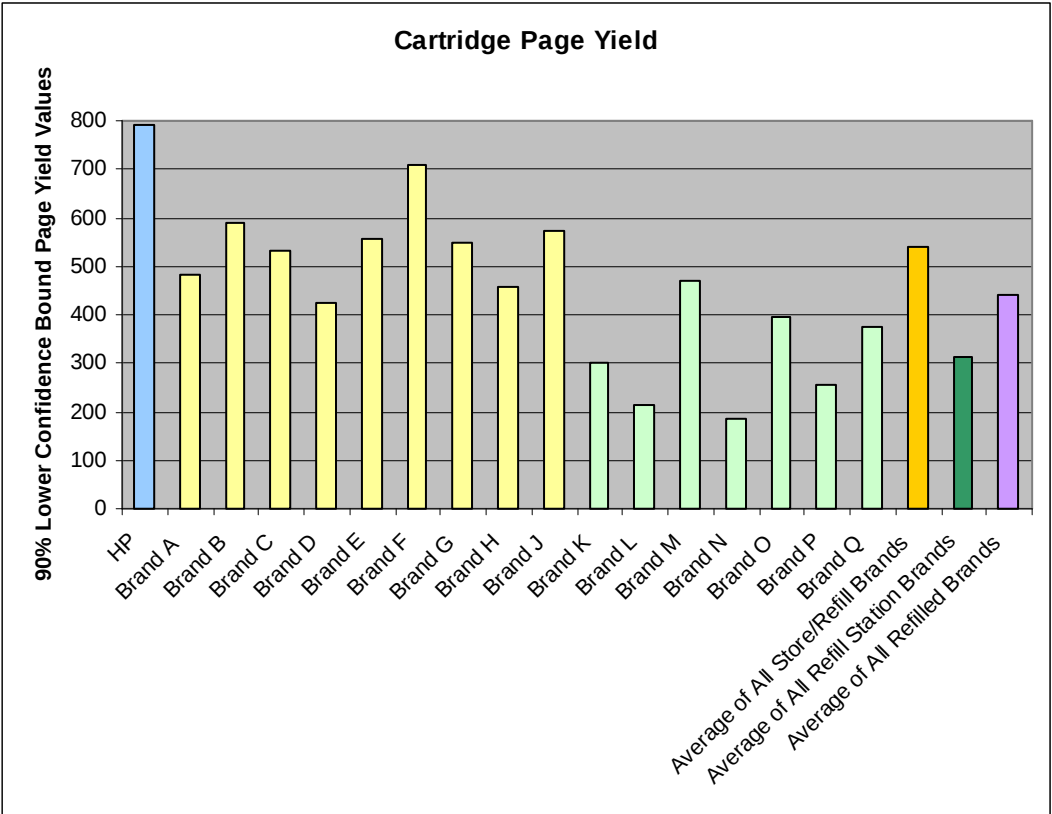
When comparing HP to the refill station brands tested only, based on the total pages printed for this subset of cartridges tested, on average Original HP inkjet print cartridges produced 152.5% more pages than the refill station brands (brands K-Q) tested based on comparing the 90% lower confidence bound values (as defined in Appendix 3 – Definitions).

Brand Type	Brand	Number of Cartridges Tested	90% Lower Confidence Bound Page Yield	HP/Brand Relative Page Yield Difference
HP	HP	68	793	0.0%
Store/Refill Brand	Brand A	68	481	64.9%
Store/Refill Brand	Brand B	68	589	34.6%
Store/Refill Brand	Brand C	68	534	48.5%
Store/Refill Brand	Brand D	68	424	87.0%
Store/Refill Brand	Brand E	68	555	42.9%
Store/Refill Brand	Brand F	68	711	11.5%
Store/Refill Brand	Brand G	68	548	44.7%
Store/Refill Brand	Brand H	68	456	73.9%
Store/Refill Brand	Brand J	68	573	38.4%
Refill Station	Brand K	68	299	165.2%
Refill Station	Brand L	68	215	268.8%
Refill Station	Brand M	68	469	69.1%
Refill Station	Brand N	68	187	324.1%
Refill Station	Brand O	68	396	100.3%
Refill Station	Brand P	71	257	208.6%
Refill Station	Brand Q	68	374	112.0%
Sum/Average of All Store/Refill Brands		612	541	46.6%
Sum/Average of All Refill Station Brands		479	314	152.5%
Sum/Average of All Refilled Brands		1091	442	79.5%

Table 1: Page Yield

Table 1 summarizes the page yield results achieved during the study. It shows the number of cartridges tested per brand as well as the individual page yields. All page yields refer to the 90% lower confidence bound page yield values with dead-on-arrival cartridges included in the calculation. The values from each cartridge type tested were combined to create a single index value for each brand tested. The right most column displays the percentage of the higher page yield of HP versus each brand. The individual results were then combined to create a sum/average value for the store/refill brands, refill station brands and all refilled cartridges tested.

For example Brand A had a total of 68 cartridges in the test and reached a 90% lower confidence bound page yield of 481 pages. This indicates that HP printed 64.9% more pages than Brand A.



Graph 1: Cartridge Page Yield HP vs. Refilled Brands

2.2 Cartridge Reliability

None of the Original HP inkjet print cartridges tested resulted in a dead-on-arrival or premature failure (as defined in Appendix 3 – Definitions) whereas, on average 24.0% of the refill cartridges tested were either dead-on-arrival or failed prematurely. The average value of problem cartridges for a single brand varies between 2.9% and 44.1%.

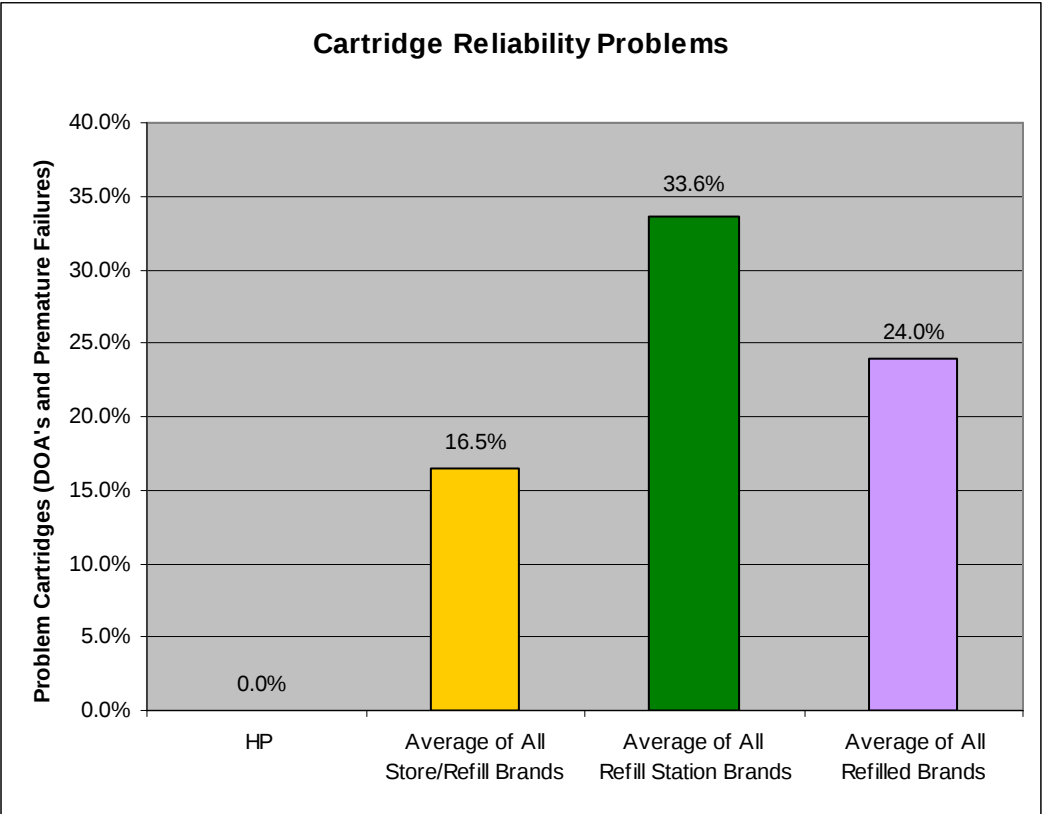
More specifically, none of the Original HP inkjet print cartridges tested were dead-on-arrival or premature failure (as defined in Appendix 3 – Definitions), whereas 16.5% of the store/refill brand cartridges (brands A-J) tested were either dead-on-arrival or failed prematurely, and 33.6% of cartridges refilled at refill stations (brands K-Q) were either dead-on-arrival or failed prematurely.

Brand Type	Brand	Number of Cartridges Tested	Dead-on-Arrival		Premature Failures		Problem Cartridges	
			No.	%	No.	%	No.	%
HP	HP	68	0	0.0%	0	0.0%	0	0.0%
Store/Refill Br.	Brand A	68	8	11.8%	4	5.9%	12	17.6%
Store/Refill Br.	Brand B	68	6	8.8%	7	10.3%	13	19.1%
Store/Refill Br.	Brand C	68	9	13.2%	3	4.4%	12	17.6%
Store/Refill Br.	Brand D	68	16	23.5%	1	1.5%	17	25.0%
Store/Refill Br.	Brand E	68	4	5.9%	3	4.4%	7	10.3%
Store/Refill Br.	Brand F	68	2	2.9%	0	0.0%	2	2.9%
Store/Refill Br.	Brand G	68	8	11.8%	1	1.5%	9	13.2%
Store/Refill Br.	Brand H	68	17	25.0%	3	4.4%	20	29.4%
Store/Refill Br.	Brand J	68	9	13.2%	0	0.0%	9	13.2%
Refill Station	Brand K	68	13	19.1%	14	20.6%	27	39.7%
Refill Station	Brand L	68	16	23.5%	12	17.6%	28	41.2%
Refill Station	Brand M	68	1	1.5%	10	14.7%	11	16.2%
Refill Station	Brand N	68	17	25.0%	13	19.1%	30	44.1%
Refill Station	Brand O	68	9	13.2%	8	11.8%	17	25.0%
Refill Station	Brand P	71	16	22.5%	10	14.1%	26	36.6%
Refill Station	Brand Q	68	9	13.2%	13	19.1%	22	32.4%
Sum/Average of All Store/Refill Brands		612	79	12.9%	22	3.6%	101	16.5%
Sum/Average of All Refill Station Brands		479	81	16.9%	80	16.7%	161	33.6%
Sum/Average of All Refilled Brands		1091	160	14.7%	102	9.3%	262	24.0%

Table 2: Cartridge Reliability

Table 2 summarizes the cartridge reliability results achieved during the study. It shows the number of cartridges tested per brand as well as the number, percentage and type of failure. The dead-on-arrival and premature failure cartridges are listed separately for each brand and also combined in the right most column to create a total problem cartridge value for each brand. The percentages shown are referenced to the number of cartridges tested per brand. These individual results were then combined to create a sum/average value for the store/refill brands, refill station brands and all refilled cartridges tested.

For example Brand A had a total of 68 cartridges in the test. Eight cartridges (11.8%) were found to be dead-on-arrival and four cartridges (5.9%) were found to fail prematurely for a total of twelve (17.6%) problem cartridges in the test for Brand A.



Graph 2: Cartridge Reliability Problems

Appendix 1: Methodology

The following is a summary of the methodology used for this study:

The printers and print cartridges selected for the study were as follows:

Printer	Black Cartridge	Colour Cartridge
HP DeskJet 970Cxi	51645A	C6578A
HP DeskJet 5850	C6656A	C6657A

A total of 1091 refilled print cartridges and 68 Original HP inkjet print cartridges were tested using a total of 27 HP DeskJet 970Cxi printers and 15 HP DeskJet 5850 printers.

INNOVATIONSTECHNIK procured all printers, paper and cartridges through normal distribution channels. To represent customer behaviour the empty cartridges to be refilled as well as the refilled cartridges were transported by typically used vehicles, e.g. cars.

For the refill station brands tested, approximately 50% of the test data is based on cartridges that were refilled once, approximately 30% is based on cartridges that were refilled twice and approximately 20% is based on cartridges that were refilled three times.

For each brand at least 68 cartridges/refills (17 black and 17 tri-colour per printer type) were tested. A minimum of 9 black and 9 colour cartridges/refills had to be printed successfully to end of life due to fade, in order for page yield results to be statistically significant.

Before printing, all cartridge details were recorded (e.g. serial number and start weight) and a visual inspection for substantial ink leaks was performed. Passing cartridges were inserted into printer as per cartridge or printer manual instructions. Any additional cartridge care steps described by the refill brands were followed and recorded. Print head alignment was performed to ensure the quality of the print jobs.

The impact of the print cartridge on the printer's functionality was also recorded in the areas of consistent operation, leakage of ink inside the printer and failure of printer components.

Colour and black cartridges were tested in parallel. As 17 colour or black cartridges were completed for a brand, Original HP inkjet print cartridges were used to complete the rest of the brand. All results and effects of these Original HP inkjet print cartridges were ignored in the test.

For each brand a minimum of 3 printers was used for the study to assure uniformity and accuracy of the test data independent of a particular printer. Before its first use in the study each printer was inspected, cleaned of any residual ink and/or paper dust and tested. Before any new cartridge was installed, the printers were inspected and cleaned if necessary.

The paper used in the test was XEROX Business paper for Laser, Copier and Inkjet printings with a common medium weight of 80 gsm and size A4.

All PC's used were identical in hardware and software setup and at today's standard for home/office use.

According to ISO/IEC 24711, normal office environmental conditions of temperature 21-25°C and relative humidity 40-60% were maintained for the duration of the study. All printers, cartridges and paper were stabilized in these conditions for a minimum of 12 hours prior to use to eliminate the effects of storage variation.

Printer settings were left at the factory default, except for the media type which was selected manually to 'Plain Paper' and printing quality which was set to 'Normal'. ISO/IEC 24712 test page suite was used to achieve a balanced representation of printing samples (see Appendix 2: ISO/IEC 24712 Test Page Suite).

Page yield for each brand was determined by inspecting the last page in the ISO/IEC 24712 test page suite, which is a diagnostic page. Each diagnostic page inspected was judged by visual inspection to perceive any signs of fade or streak (definitions and examples for fade and streak are shown in Appendix 3 – Definitions).

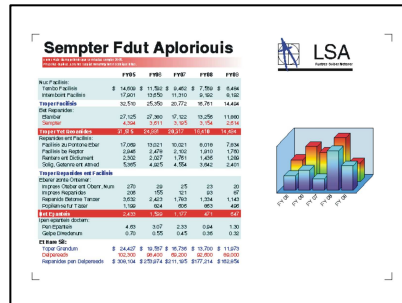
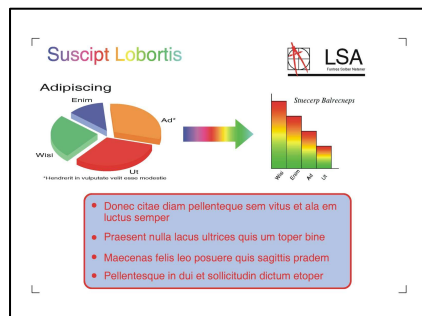
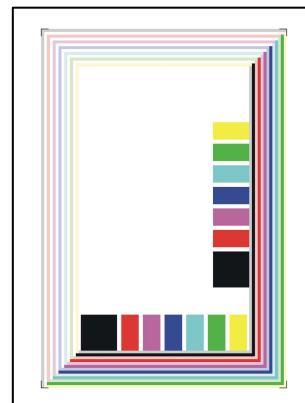
In the case of fade the cartridge was declared to be at end of life (as defined in Appendix 3 – Definitions). It was removed from the printer, the end weight recorded and the page yield noted down.

If streaks occurred on 3 consecutive pages a streak removal procedure was initiated. Streak removal operations were conducted according to the HP printer manual documentation. For non-HP cartridges additional cleaning steps were included to the removal operations if advised by the store or refiller. Printing continued as long as the cartridge could be restored. Pages printed during the nozzle cleaning operation were not counted in the yield calculation. Due to the significant amount of ink that is used for cleaning, the maximum permissible number of times that the streak removal operation was used on a given cartridge was 3 times. Cartridges which required a fourth service were considered to be at end of life. All cleaning steps were recorded and reported.

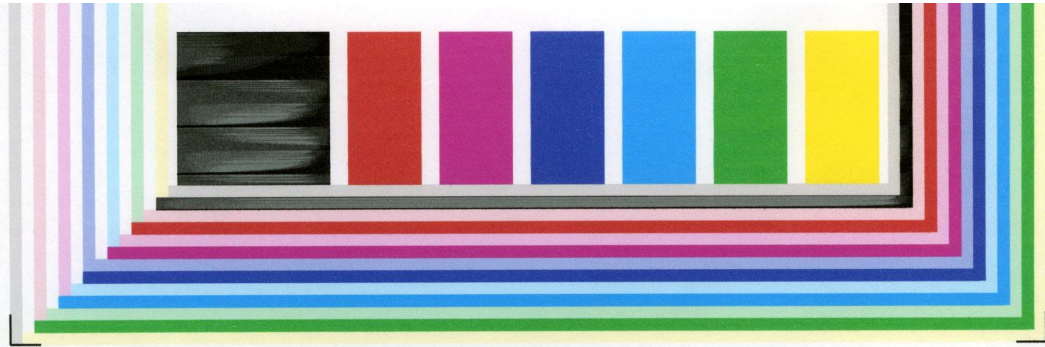
To account for reliability-driven cartridge issues, defective cartridges were included in the page yield calculation. Consequently, the reported page yield numbers are not based on the ISO/IEC 24711 standard since ISO/IEC 24711 requires that defective cartridges are excluded from the page yield calculation.

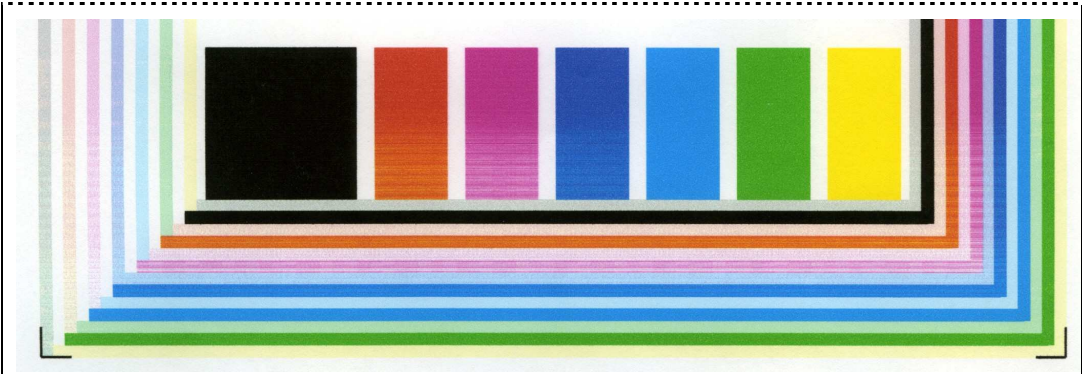
The test methodology for this reliability and page yield comparison study was developed by Hewlett-Packard and implemented by INNOVATIONSTECHNIK.

Appendix 2: ISO/IEC 24712 Test Page Suite

Test suite page 1
Business LetterTest suite page 2
SpreadsheetTest suite page 3
NewsletterTest suite page 4
SlideTest suite page 5
Diagnostic

Appendix 3: Definitions

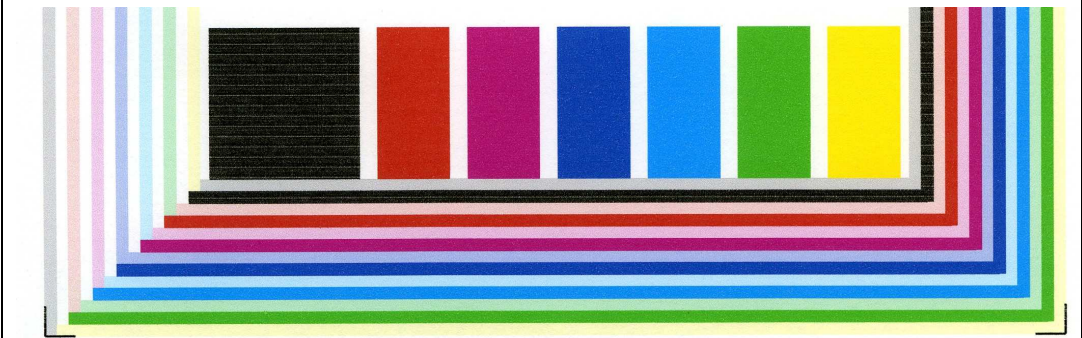
Test Project Terminology	Definition
Substantial Ink Leakage	- Ink visibly spilled in the plastic bag containing the cartridge. - Ink visibly spilled in the interior of the cartridge packaging. - Ink visibly spilled over the print head nozzles.
	
	Black ink cartridge in a pool of ink Colour cartridge ink spilled in plastic bag
End-of-Life (EOL)	A condition determined by one of three mechanisms: 1. Fade has occurred on diagnostic page. 2. Streak removal operation steps have been exhausted. 3. Cartridge is Dead-on-Arrival (DOA).
Fade	A significant decrease in density on the bands or blocks of the diagnostic page. This decrease in density does not have to occur completely across the page to be considered fade. For a comparison to determine if fade is occurring, reference the 10 th page printed by that printer.
	
Excerpt from Diagnostic Page – Decrease in the density of black ink	



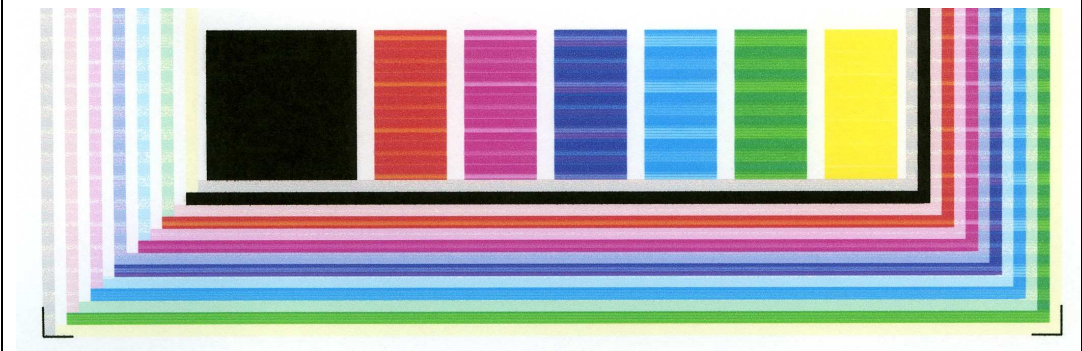
Excerpt from Diagnostic Page – Decrease in the density of magenta ink

Streaks

Very thin lines of colour or the lack of colour where it should be, in the blocks surrounding the edge of the diagnostic page. Streaks differ from fade in the width and severity of the reduction in density. Streaks can appear due to a number of reasons, including thermal issues and clogged nozzles.

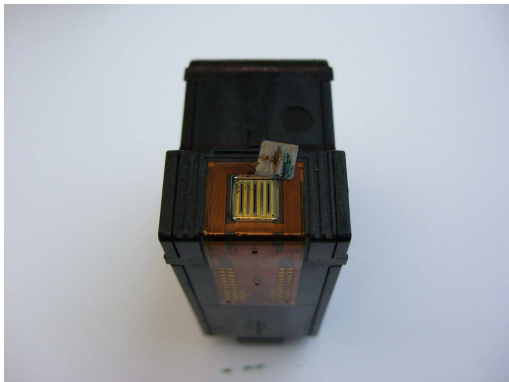
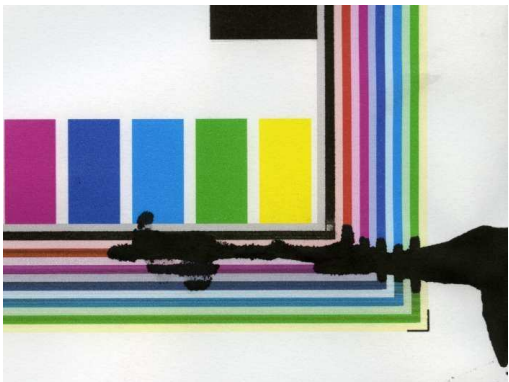


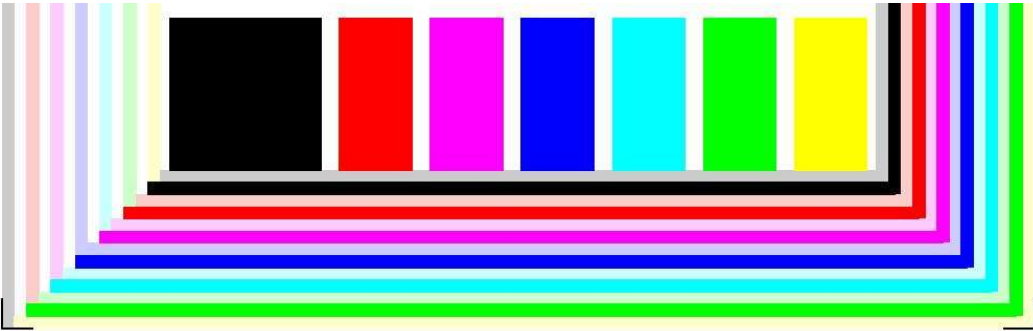
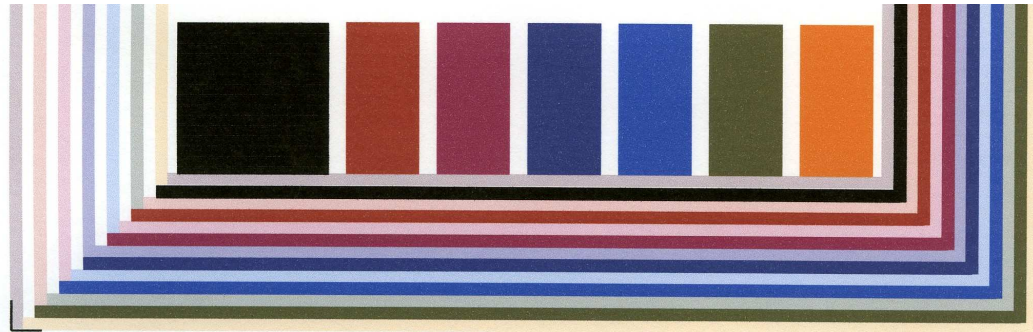
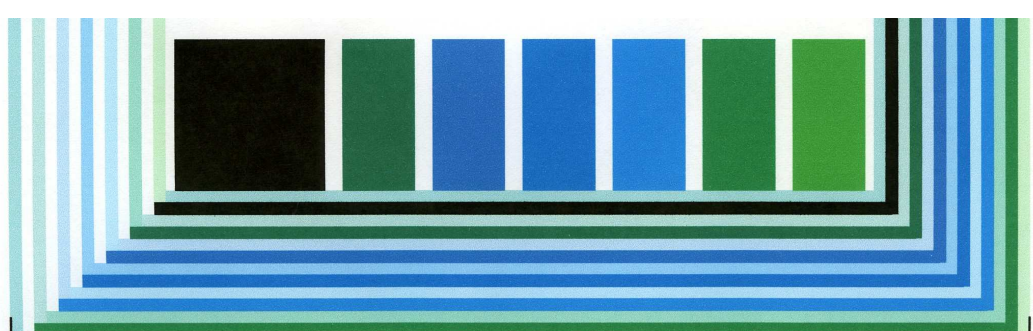
Excerpt from Diagnostic Page – Thin horizontal lines extending the width of the print



Excerpt from Diagnostic Page – Thin horizontal lines extending the width of the print

Streak Removal Procedures	This is the cartridge cleaning procedure (servicing) used to restore print performance. If streaks are observed on three consecutive diagnostic pages, a streak removal procedure should be implemented. Streak removal operations should be conducted according to the HP printer manual documentation. If there were additional cleaning steps advised for the non-HP cartridges, they were included within the cleaning process. Use of a “light” and “strong” cleaning procedure counts as one cartridge cleaning operation. Cleaning is verified by reprinting the test page suite. If streaks are still present on the diagnostic page, the clean procedure is repeated. Any pages printed during the cleaning operation are not counted in the yield calculation. Due to the significant amount of ink that is used for cleaning, the maximum permissible number of times that the streak removal operation can be used on a given cartridge is three times. Cartridges which require a fourth service are considered to be at EOL.
Individual Cartridge Yield	Individual cartridge yield is calculated by counting the number of diagnostic pages printed between cartridge installation and EOL, then multiplying by five. The diagnostic page is the last plot printed in the test suite.
Average Cartridge Page Yield	Average cartridge yield for a given cartridge type: $\bar{X} = \sum_{i=1}^n \frac{x_i}{n}$ Where x_i = the individual cartridge yield. n = is the sample size i.e. (17 for example), excluding cartridges identified as “Dead-on-Arrival” as per definition above. This average cartridge page yield number is solely used for the purposes of calculating premature failures.
90% Lower Confidence Bound Page Yield	Calculated as: $\bar{X} - (t_{\alpha, n-1}) * \frac{s}{\sqrt{n}}$ Where “s” is the Sample Standard Deviation for a given cartridge brand: $s = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{X})^2}{(n-1)}}$

	Where x_i = the individual cartridge yield. n = n is the sample size i.e. (17 for example), including cartridges identified as “Dead-on-Arrival” as per definition above. And where $t_{\alpha, n-1}$ can be found on a Students’ t-Distribution Table with $n-1$ degrees of freedom (df or ‘v’) and an α of 0.1. This provides a 2-tailed confidence interval with 90% confidence. A different sample size and/or different confidence interval will yield a different $t_{\alpha, n-1}$. The 90% lower confidence bound value means that one can be 90% confident that the true mean page yield is equal to or greater than the value of the lower bound of the confidence interval. The page yield values used for this calculation include cartridges identified as dead-on-arrival (as defined above) and premature failure (as defined below).
Dead-on-Arrival (DOA)	A condition determined by one of three mechanisms: 1. Cartridge found to have substantial leakage (as defined above) at start or during testing. 2. 50 or less pages printed by a cartridge. 3. Colour mix (as defined below) has occurred and incorrect colours printed on 10 consecutive pages – colour cartridge failure mechanism only.
 Colour cartridge nozzle plate loose	 Excerpt from Diagnostic Page – Leaking black ink
Premature Failure	A cartridge that has a page yield of less than 75% of the average page yield (as defined above) for that cartridge brand.
Problem Cartridge	Cartridges identified as dead-on-arrival and cartridges identified as premature failures (as defined above).
Process Failure	A process failure occurs when an empty cartridge that is handed in for refilling is rejected by the refiller station sales representative during the refilling process as the refiller station personnel is not in a position to successfully refill the cartridge.

Colour Mix	Defined as a colour cartridge that cannot print the correct Cyan, Magenta and Yellow colours as shown on the diagnostic page 5 of the page yield test suite. Ink has mixed in an unintended manner inside the cartridge and has caused a discolouring of the ink. An example of correct colours in comparison to colour mix is provided below.
 Excerpt from Diagnostic Page – Correct colours	
 Excerpt from Diagnostic Page – Colour Mix	
 Excerpt from Diagnostic Page – Colour Mix	
Waiting Time	The time between dropping of the empty cartridges at the refiller station to be refilled and being instructed to pick them up.

Appendix 4: Photos of the Test Lab Environment



Photo 1: Panoramic view of the printing lab



Photo 2: Top view of the printing lab



Photo 3: Test engineer inspecting prints



Photo 4: Some of the paper used stabilizing in boxes



Photo 5: Temperature acclimation of various cartridges