

# **Inkjet Printing Efficiency Yield and the Customer Experience**

---

## Final Report Presentation: Group 3

*This information may not be publicly released without approval of an authorized representative of the HP program office or Spencer & Associates Publishing, Ltd.*

August 2006

**spencerLAB** DIGITAL COLOR LABORATORY

Catherine Fiasconaro, Director

Spencer & Associates Publishing, Ltd.

David R Spencer, President

---

New York, USA

<http://www.spencerlab.com>



Copyright ©2006 Spencer &  
Associates Publishing, Ltd.  
All rights reserved.

**spencerLAB**  
DIGITAL COLOR LABORATORY

# Project Objective and Scope

---

## Objective

Compare Levels of Printing Efficiency in Different Inkjet Printing Systems  
Gain Insight into Ink Efficiency of Various Inkjet Printing Systems in Typical Consumer Usage

*° Consumer usage is Intermittent; testing is usually based upon Continuous usage*

## Scope

Determine Impact on Yield of Intermittent versus Continuous Usage

- ° Measure Continuous Inkjet Cartridge Yields for each black and color cartridge*
- ° Measure Maintenance Ink used during cartridge changes*
- ° Determine Intermittent Inkjet Cartridge Yields*
  - Use SpencerLab Black/White and Color-only test documents in weighted ratio
    - Print as 2-page documents at a 70-page-per-month rate for 8-week test duration
  - Measure ink usage, correct for maintenance ink usage, and extrapolate yields
- ° Calculate impact as Printing Efficiency percentages*



# Some Definitions

---

## Consumer

- ° *A typical inkjet printer user normally printing mixed, general purpose documents*

## Continuous Inkjet Cartridge Yield

- ° *The average number of prints-per-cartridge through the entire life of a cartridge when printing continuously, with minimum interventions such as for paper jams, other color replenishment, etc.*

## Intermittent Inkjet Cartridge Yield

- ° *The average number of prints-per-cartridge through the entire life of a cartridge when printing only one or a few pages at a time, with significant time periods between print jobs*

## Effective Yield

- ° *The actual number of prints-per-cartridge available to the user in intermittent use — the Intermittent Inkjet Cartridge Yield*

## Maintenance Ink

- ° *Ink used for purposes other than page printing, such as to maintain printer functionality by keeping nozzles clear, removing air bubbles, etc.*

## Printing/Ink Efficiency

- ° *The percentage of ink actually used for printing in intermittent use, net of Maintenance Ink; equal to the ratio of Intermittent to Continuous Inkjet Cartridge Yield*



# Intermittent Usage Model

## Consumer Intermittent Usage

Consumers print a wide variety of documents, often with no consistent pattern

- ° *They may print black-only documents one day, web pages with color graphics the next, only black text a few days later, and some web pages later that day*

Consumers do not print continuously, start to finish of an ink cartridge

- ° *Although some high-end users may print very regularly, it would be highly unusual for any consumer to print continuously from ink cartridge insertion until it is depleted*

Typical consumer printing is intermittent, reflecting everyday starts and stops

- ° *Intervals may be fairly short, or may last for days*

## An Intermittent Usage Test Model

We can propose a typical consumer usage profile by assuming

- ° *The ratio of black/white to color*
- ° *The average document length*
- ° *The monthly page volume*

We applied the following estimates

- ° *Black/white to color ratio<sup>†</sup> = 2:1*
- ° *Document length<sup>†</sup> = 2 pages*
- ° *Prints per month\* = 70*

<sup>†</sup>SpencerLab estimate; your mileage may vary

\*Estimate based upon HP analysis of Lyra research, H1 2004 Bulk Ink Forecast, *including the installed bases of several vendors and involving the full range of home to office users*

Our test model is an estimate, but should allow insight into Effective Yield



# Printers and Inkjet Cartridges Tested

## Four-Color Inkjet Multi-Functional Printers

### HP Photosmart C3180 All-in-One

*Pre-release driver version: 2.26.2006, Firmware: R0618F \**

HP #92 Black, HP #93 Tri-Color  
and HP #94 Black, HP #95 Tri-Color†

### Epson Stylus CX4800 ‡

*Driver version: 5.5bA*

Black (T060120), Cyan (T060220),  
Magenta (T060320), Yellow (T060420)

### HP Photosmart C4180 All-in-One

*Pre-release driver version: 2.26.2006, Firmware: R0618F \**

HP #98 Black, HP #95 Tri-Color

### Epson Stylus DX3850 ‡

*Driver version: 5.5a*

Black (T061140), Cyan (T061240),  
Magenta (T061340), Yellow (T061440)

### Canon PIXMA MP170

*Driver version: 1.0 for Windows XP*

Black (PG-50 High Capacity), Color (CL-51 High Capacity)

### Epson Stylus DX4850 ‡

*Driver version: 5.5a*

Black (T061140), Cyan (T061240),  
Magenta (T061340), Yellow (T061440)

\*Comprehensive C3180 & C4180 tests utilized earlier firmware versions R0610R and R0610F, respectively; current firmware utilized for Continuous Ink Yield Tests and results applied to Intermittent Test analyses.

†HP PS C3180 tested both with ink sets available in US and Europe: US market: #92 Black & #93 Tri-Color, standard-capacity cartridges; European market: #94 Black and #95 Tri-Color, higher-capacity cartridges.

‡Epson Stylus printer models specific to geographic markets: Stylus CX4800 in US; Stylus DX3850 & Stylus DX4850 in Europe.



## Summary Findings

---

### HP Photosmart C3180 & HP Photosmart C4180 had the highest average Printing Efficiencies

HP products had the smallest percentage change from Continuous to Intermittent Inkjet Cartridge Yield

HP Photosmart C3180 and HP Photosmart C4180

- ° Both printers' Black and Tri-Color cartridges had the Highest Printing Efficiencies
- ° Both printers' Black and Tri-Color cartridges had the Smallest Yield Changes
- ° Both printers' Black and Tri-Color cartridges had the Lowest Total Ink Usages

### Printing Efficiency varies with Usage Profile

The consumer's usage profile and the efficiency of the printing system are significant factors in determining Effective Yield

Intermittent Inkjet Cartridge Yield, more reflective of typical consumer usage, may be very different than Continuous Yield, the most common method of measurement

Printing Efficiency varies significantly among vendors

### Ink usage varies greatly among vendors during Intermittent (consumer typical) printing

HP and Canon printers had the lowest Standard Deviation on ink usage

Epson printers had the highest Standard Deviation



# Summary Test Results

---

## Results are summarized in the following graphs

### Printing Efficiency

- ° *Black and color cartridge efficiencies are represented by vertical bars*
- ° *Height of bars represents the Printing Efficiency*
- ° *Weighted Average reflects the 2:1 ratio of black to color pages*

### Intermittent vs. Continuous Yield Change

- ° *Each black and color cartridge is represented by a vertical bar*
- ° *Total height represents Continuous Inkjet Cartridge Yield*
- ° *Darker portion represents Effective Yield*
- ° *Percentage difference represents Printing Efficiency*

### Ink Used in One Month of Intermittent Printing

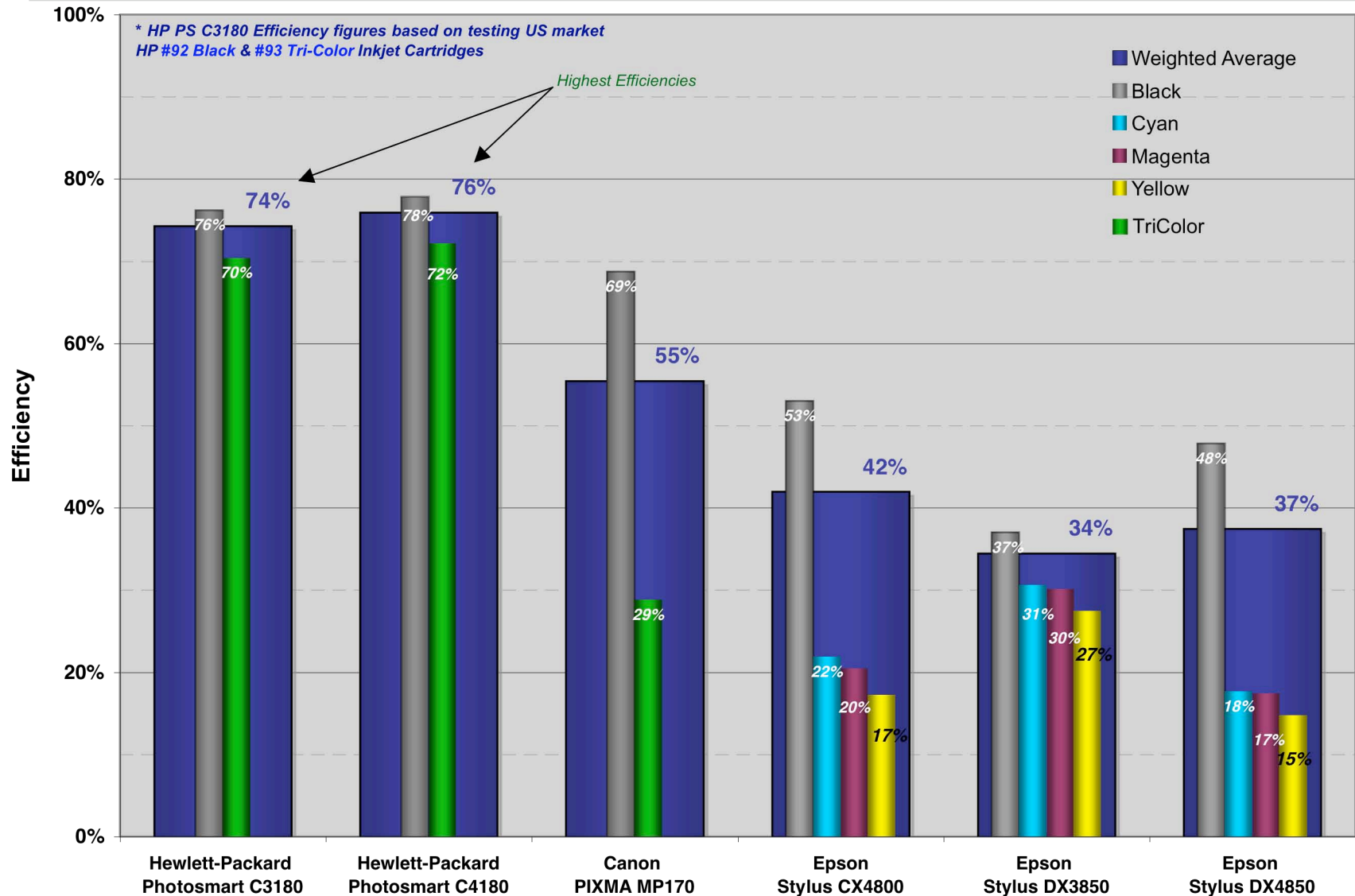
- ° *Usage rate of 70 pages-per-month, as tested*

### Standard Deviation of Ink Usage

- ° *Ink Usage Variation during Intermittent Testing*
- ° *Broken vertical bars represent standard deviation of black and color cartridges*

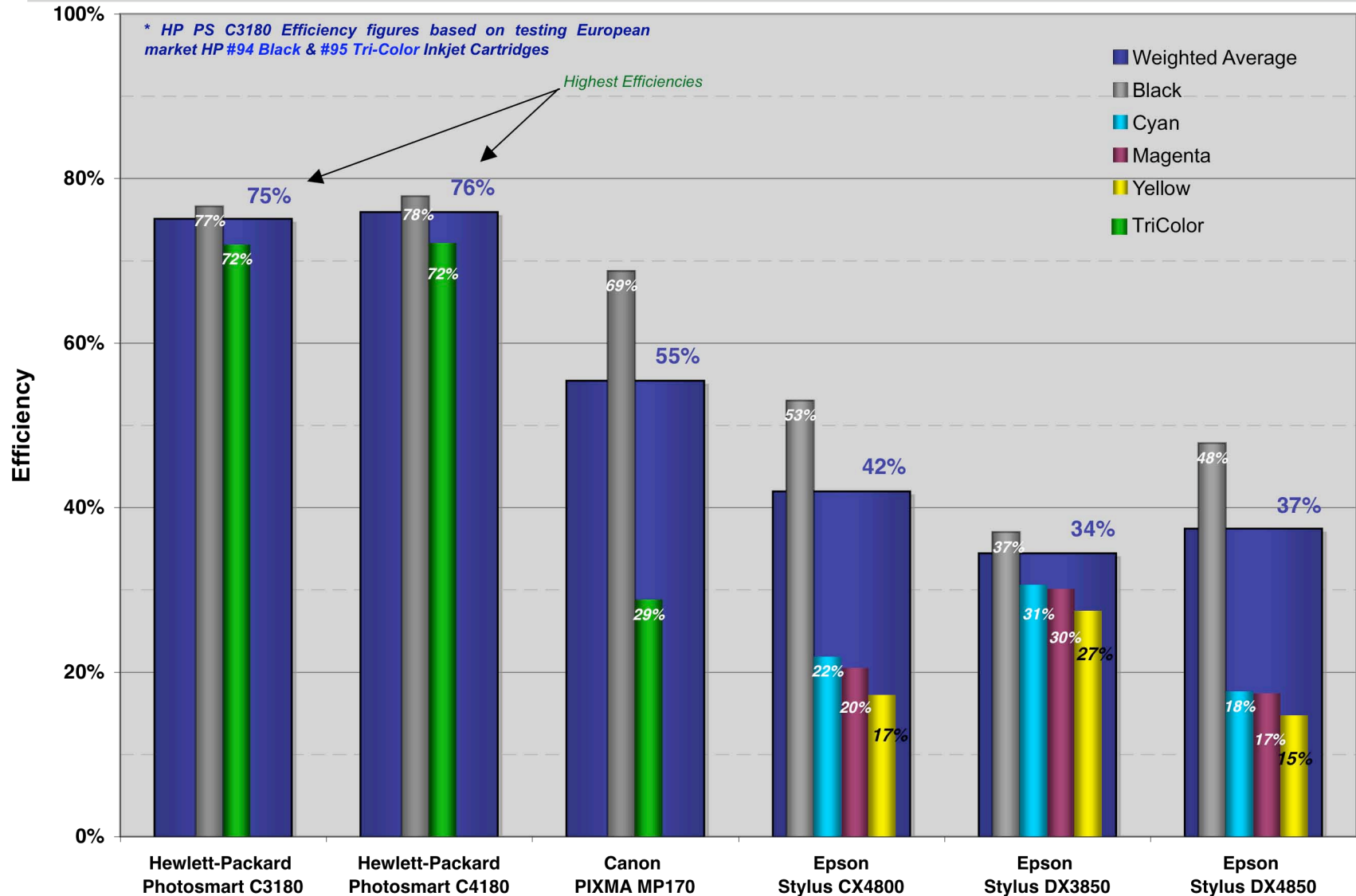


# Printing Efficiency

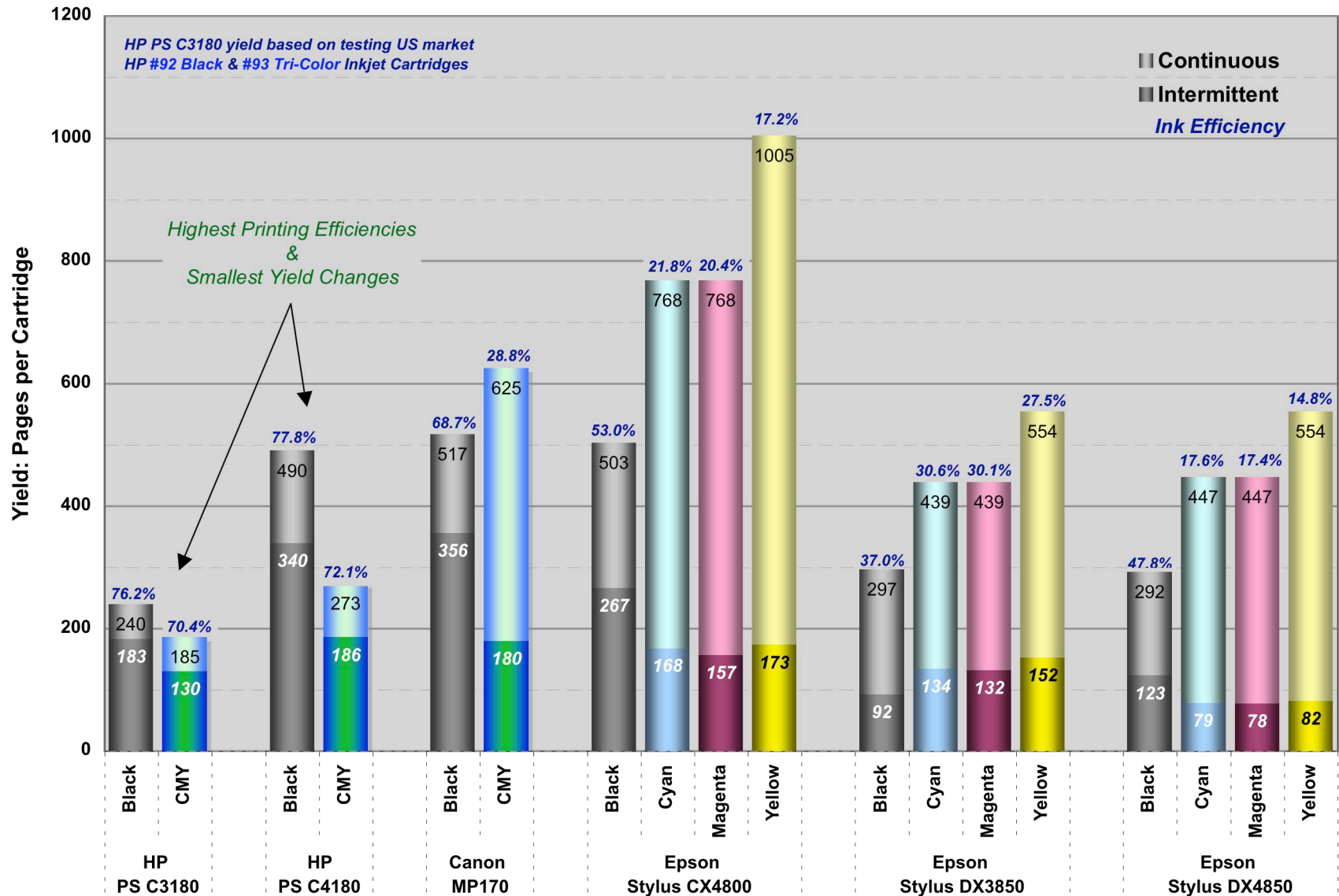




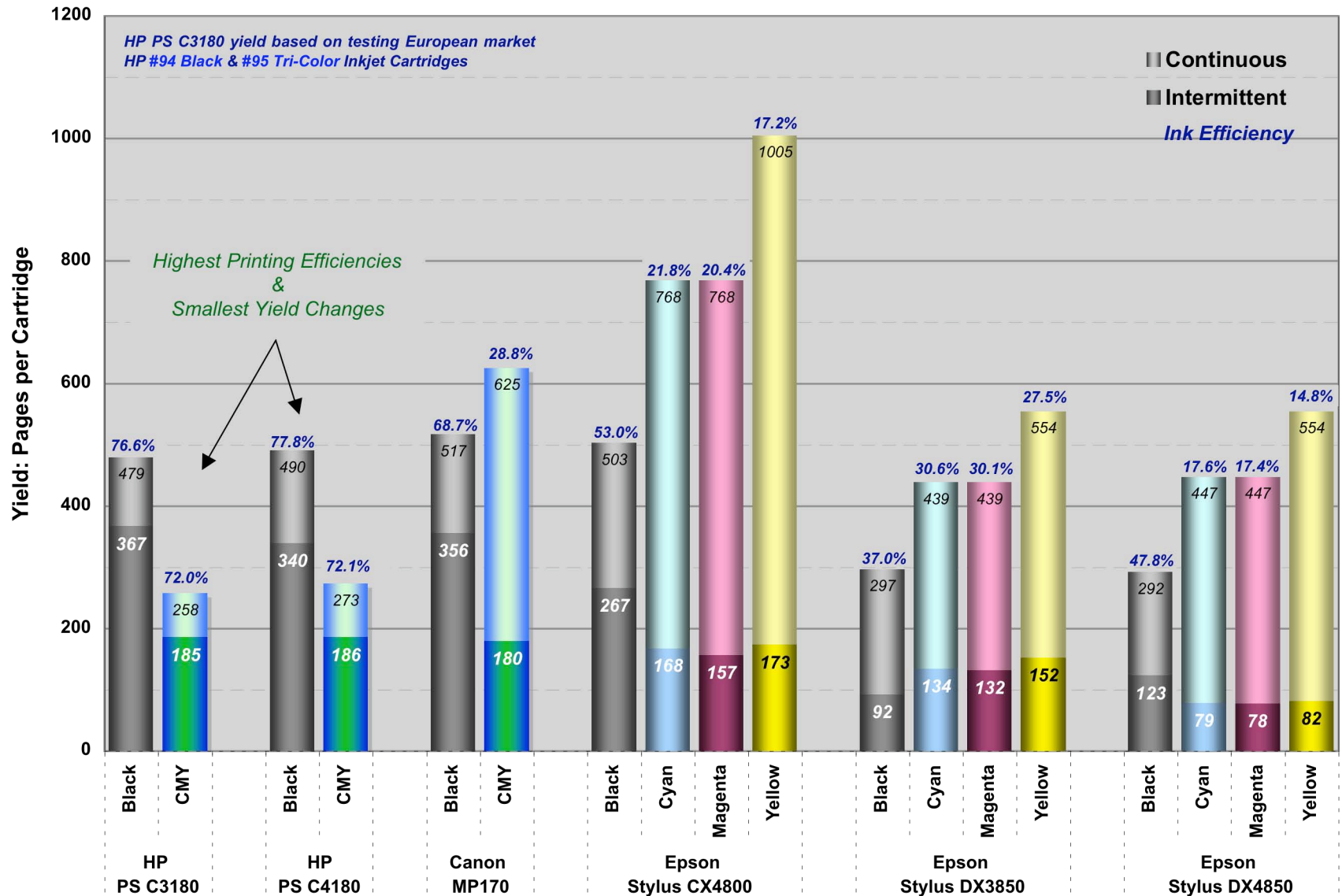
# Printing Efficiency



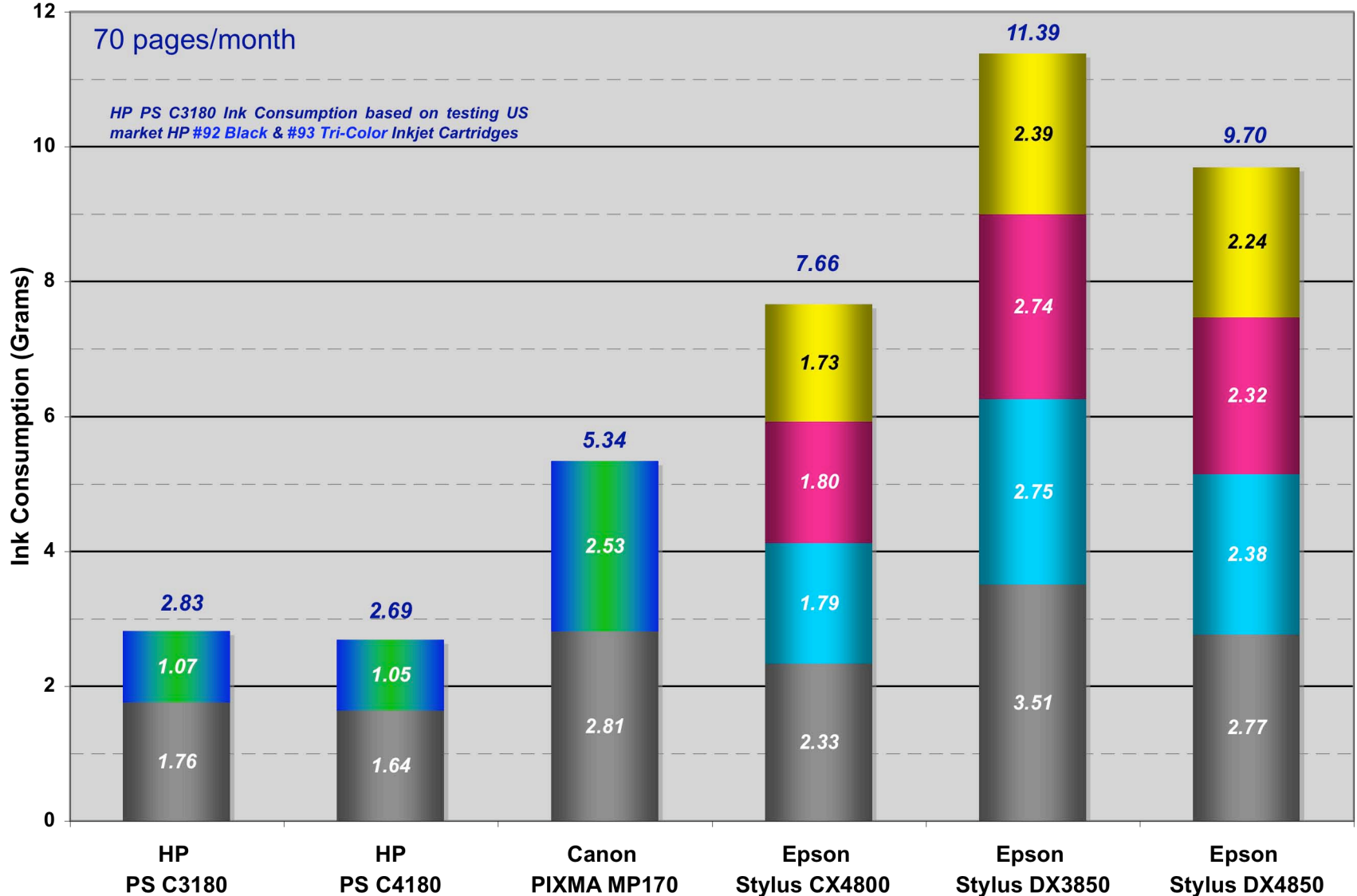
# Intermittent vs. Continuous Yield Change



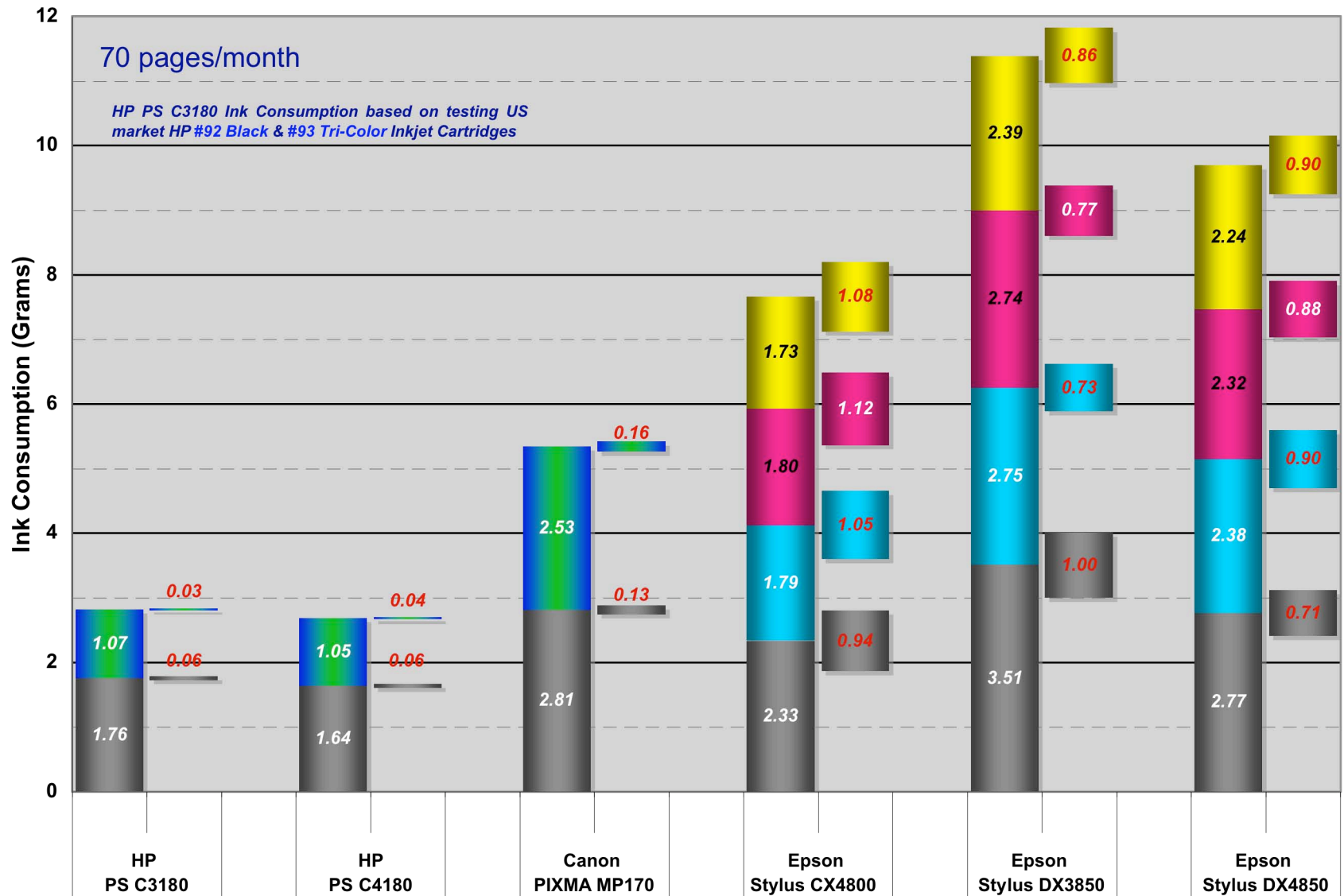
# Intermittent vs. Continuous Yield Change



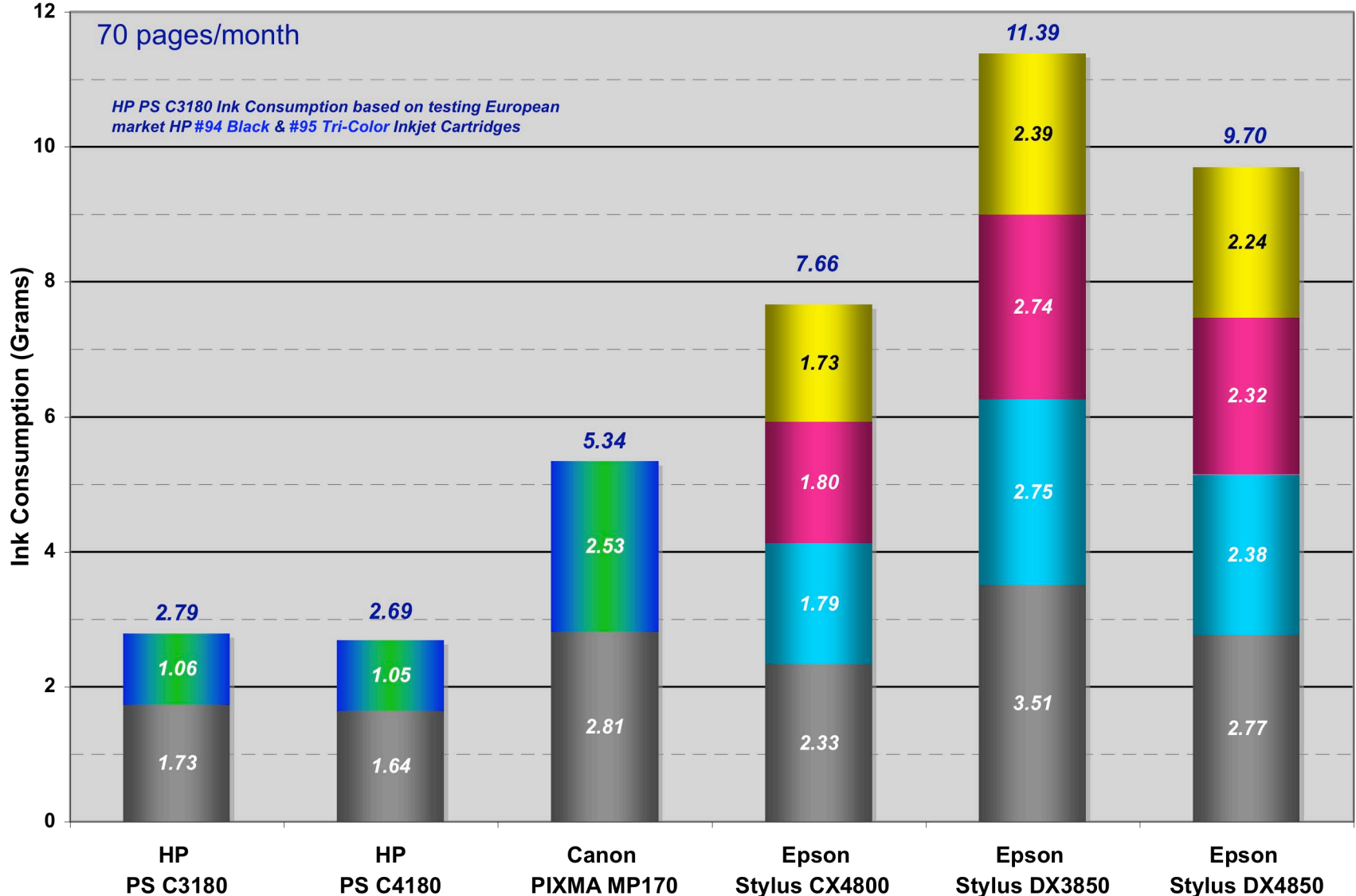
# Ink Used in One Month (70 pages) of Intermittent Printing



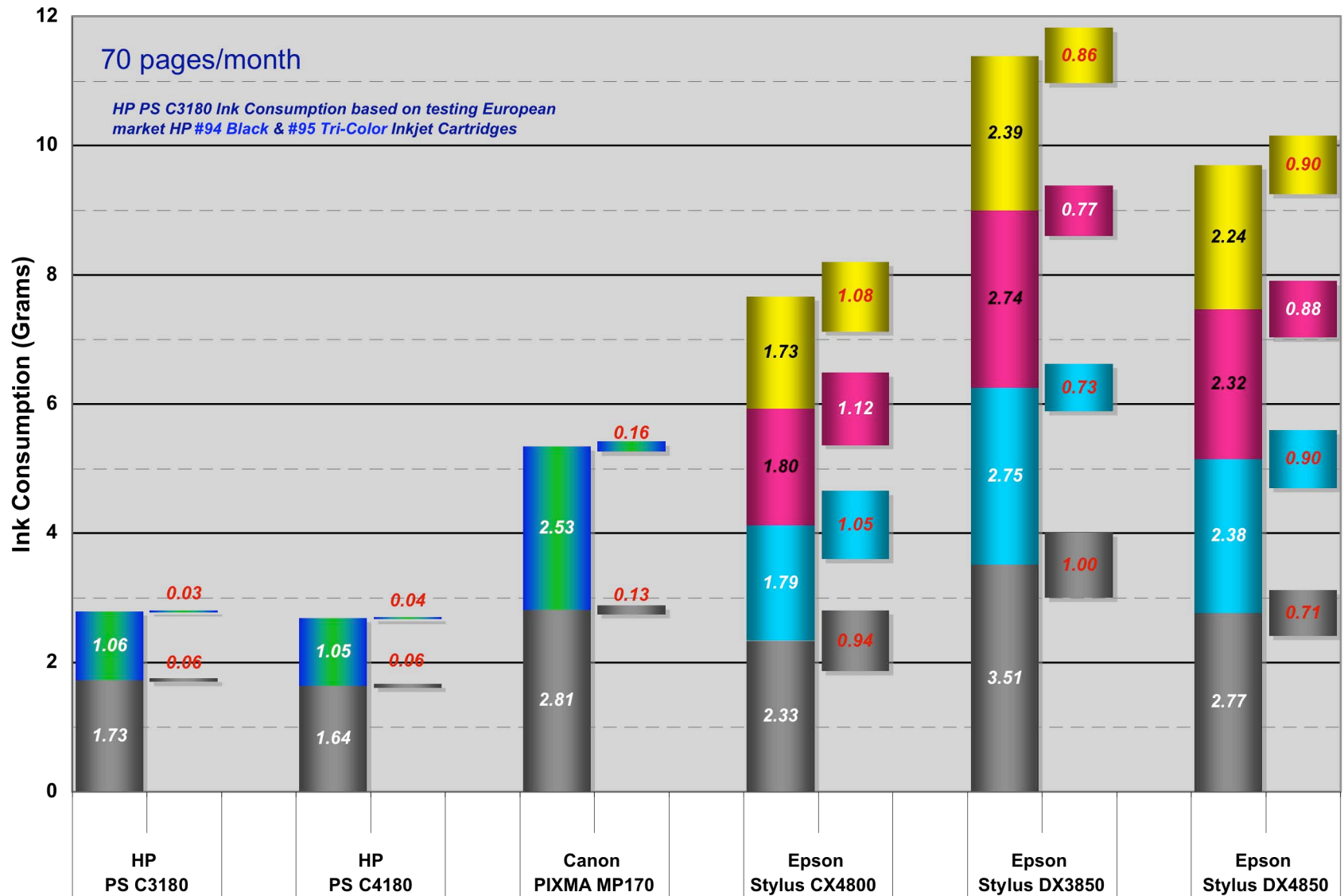
# Standard Deviation of Ink Usage



# Ink Used in One Month (70 pages) of Intermittent Printing



# Standard Deviation of Ink Usage





## General Observations

---

### Tested Epson printers experienced Print Quality issues during intermittent testing

Nearly half of all tested Epson printers required user intervention maintenance cycles, due to printhead clogging and ink drying issues

- ° 4 out of 10 Epson CX4800 printers required user-initiated printhead cleanings
- ° 5 out of 10 Epson DX3850 printers required user-initiated printhead cleanings
- ° 5 out of 10 Epson DX4850 printers required user-initiated printhead cleanings

Multiple printhead cleanings were sometimes required on these Epson printers (a maximum of 3 per incident) in order to produce acceptable print quality

One Epson DX3850 printer was re-started one week into the testing due to overage of printhead cleanings required to solve printhead issues; subsequent 8-week re-test ran successfully within maximum cleaning parameters

### Tested HP and Canon printers required no user-initiated maintenance cycles during testing

### Ink Usage of HP Photosmart C3180 and Photosmart C4180 offered Lower Standard Deviation than tested Canon and Epson printers

Lower Standard Deviation = more consistent ink output yield among tested cartridges  
Standard Deviation of Ink Usage from the Mean was least for tested HP printers





# Methodology

---

## Three Test Types Performed and Analyzed

### Continuous Inkjet Ink Usage

- ° *Count good pages printed during continuous printing and measure ink used*

### New Cartridge Installation/Supply Change Ink Usage

- ° *Measure amount of ink used by all cartridges when any cartridge is replaced*

### Intermittent Inkjet Ink Usage

- ° *Measure amount of ink used over 8 weeks during intermittent printing*



# Methodology (continued)

---

## Controls

Test printers and ink cartridges sourced from various retailers, where possible

- ° *HP All-in-One printers supplied by HP, prior to commercial release*
  - HP ink cartridges sourced from retailers
- ° *OEM cartridges were used; high capacity where available*
- ° *Paper and ink cartridges acclimatized for at least 8 hours prior to testing*

Print Modes: Default on Plain paper

- ° *White copy paper, 20lb, 92 brightness*

Ink weight measured with calibrated 1-milligram precision

One of each printer model was tested simultaneously from a single computer to ensure a standardized systems environment

- ° *Printers connected via High-Speed USB 2.0 to Intel Pentium 4 class, Windows XP platforms*

Continuous testing included 9 of each cartridge type

- ° *Three cartridges tested on each of three printers of each model*

New Cartridge Installation testing included 3 of each cartridge type

- ° *One cartridge tested on each of three printers of each model*
- ° *Individual color cartridges were tested on one printer each, per error analysis*

Intermittent testing included 10 cartridges of each type

- ° *Ten printers of each model were tested in parallel for eight weeks*
- ° *Spares were utilized to assure at least nine cartridges of each type survived the long test*

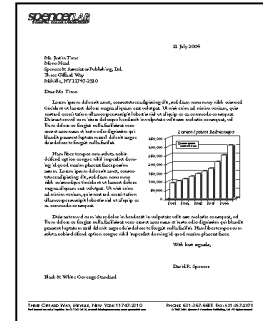


# Methodology (continued)

## SpencerLab Test Files

### Black Text

- Modeled after a black-and-white business letter
- Included a small graph without grayscale
- Digital coverage was below 5%
  - Allowed for nominal dot gain of about 20%



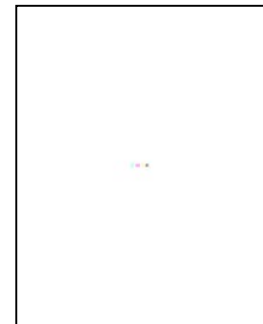
### Color Slide

- Modeled after a simple presentation slide
- Included simple graphics and bullet text
- Created in RGB with only primary and secondary colors
- Digital coverage was below 5% per color, nominally equal
  - Allowed for nominal dot gain of about 20%



### “Nominal” CMYK Page

- Designed to use minimum amounts of ink
- Coverage is less than 1/1000th of Black Text or Color Slide test page coverage



### Full Coverage page

- Designed to use maximum amounts of one ink
- Black, Cyan, Magenta, or Yellow



# Continuous Inkjet Cartridge Yield

---

## Test Methodology

Measure ink used by each cartridge through test duration

- ° *Black Text and Color Slide files tested individually*
- ° *Print continuously, pausing for paper replenishment, jam clearance, and overnight*

Test files printed until *End-of-Life*--the earlier of *Ink Out* or *Visible Fade*

° *End-of-Life by Ink Out signal on control panel or in driver:*

- Epson Stylus CX4800, Epson Stylus DX3850, and Epson Stylus DX4850

° *End-of-Life by Visible Fade attributed to ink supply:*

- HP Photosmart C3180, HP Photosmart C4180, and Canon PIXMA MP170

Each cartridge weighed immediately before test start and at *End-of-Life*

° *Difference between weights is Total Ink Available*

- Includes new cartridge installation priming usage

## Analysis

Count *Pages-per-Cartridge*, averaged for each cartridge type

Note *Total Ink Available*, averaged for each cartridge type

- Continuous printing measurement assumed to remain valid when printing intermittently



# New Cartridge Installation/Supply Change Ink Usage

---

## Test Methodology

Measure Ink change of each cartridge due to Insertion Priming, and Maintenance when replacing other ink cartridges

- ° *Weigh and install a set of ink cartridges*
- ° *Print high-coverage pages until Control Panel/Printer Driver indicates Ink Low, preparing printer for a new ink cartridge*
  - High-coverage Black pages printed when measuring impact on color cartridges
  - High-coverage Cyan, Magenta, or Yellow pages printed when measuring impact on black cartridges
- ° *Print one copy of Nominal CMYK page*
  - All colors will be printed, but in negligible quantities
- ° *Wait five minutes to allow for any automatic post-printing maintenance cycles*
- ° *Remove and weigh each ink cartridge*
- ° *Weigh and install a new cartridge for the one color that showed Ink Low; re-install all other cartridges*
- ° *Wait five minutes; print Nominal CMYK page; wait five minutes*
- ° *Remove and weigh each ink cartridge*



# New Cartridge Installation Ink Usage (continued)

---

## Analysis

Difference between weights of each cartridge is *New Cartridge Installation Ink*

° *When black cartridge is replaced*

- *Maintenance Ink* used on each black and color cartridge due to black cartridge change

° *When color cartridge is replaced*

- *Maintenance Ink* used on each black and color cartridge due to color cartridge change



# Intermittent Inkjet Cartridge Yield

---

## Test Methodology

Measure ink used by each cartridge over Intermittent test duration

- ° *Insert a new priming set of ink cartridges, such as those provided with the printer*
- ° *Print high-coverage pages until Control Panel/Printer Driver indicates Ink Low, preparing printer for new cartridge*
  - High-coverage Black pages printed on all ten printers; then
  - High-coverage Cyan, Magenta, or Yellow pages printed on three, three and four printers, respectively
- ° *Weigh and install all new ink test cartridges*
- ° *Print Black Text file as a 2-page print job; wait one-half day*
- ° *Print Black Text file as a 2-page print job; wait one-half day*
- ° *Print Color Slide file as a 2-page print job; wait one-half day*
- ° *Repeat 4 days each week for 8 weeks – a rate of 70 pages-per-month*
  - The four-day business week takes holidays into account
  - 84 Black Text Pages and 42 Color Slide pages printed
- ° *Maintenance cycles performed as required*
  - If print quality was unacceptable, head cleanings and nozzle checks were performed as necessary; pages were re-printed. Maximum of three consecutive cleaning cycles.
  - Power Save Mode left at factory defaults, printers not powered off during test
- ° *Remove and weigh each ink cartridge*
  - Difference between weights, averaged for each cartridge type, is *Test Intermittent Ink*





## Intermittent Inkjet Cartridge Yield (continued)

### Analysis: Calculate *Intermittent Inkjet Cartridge Yield* for each cartridge

*Total Ink Available* is the sum of its *New Cartridge Installation Ink*, *Intermittent Printing Ink*, and the probable impact of other color *New Cartridge Installation Inks*

- ° *The first two terms have been measured (p20-22)*
- ° *Intermittent Printing Ink is the Test Intermittent Ink (p23) less its New Cartridge Installation Ink, together normalized by the ratio of its Intermittent Inkjet Cartridge Yield to its number of Test Pages Printed*
- ° *New Cartridge Installation Ink (p22) for any other cartridges that may be changed during its life must be multiplied by that probability, the ratio of Cartridge Yields divided by the ratio of the number of Test Pages Printed*

Calculate per equations for each color cartridge; e.g. for black:

$$\text{Total Ink Available}_K = \text{New Cartridge Installation Ink}_K + \text{Intermittent Printing Ink} + \text{Prob}(\text{New Cartridge Installation Ink}_{K/\text{Color}})$$

$$\text{where Intermittent Printing Ink} = (\text{Test Intermittent Ink}_K - \text{New Cartridge Installation Ink}_K) \times \frac{\text{Yield}_K}{\text{Test Pages Printed}_K}$$

$$\text{and Prob}(\text{New Cartridge Installation Ink}_{K/\text{Color}}) = \left( \frac{\text{Yield}_K}{\text{Yield}_{\text{Color}}} \times \frac{N_{\text{Color}}}{N_K} \right) \times \text{New Cartridge Installation Ink}_{K/\text{Color}}$$

Calculate Yields from these  $n$  simultaneous equations with  $n$  Yield unknowns

### Calculate Printing Efficiency and Yield Change

*Printing Efficiency*: the Ratio of Intermittent to Continuous Inkjet Cartridge Yield, expressed as a percentage

*Yield Change*: the Difference between Printing Efficiency and 100%





# Thank You — The *SpencerLab* Project Team

---

## Project Leader

Catherine Fiasconaro, director of *spencerLAB*

## Associate Project Leader

David R Spencer, president

## Project Administrator

Jennifer Piano, manager

## Project Testing & Analysis

Vikaas Gupta, color engineer

Jesse Glacken, lab technician

## Support Team

Vishal Sahay, laboratory engineer

Marc Spencer, associate

Copyright ©2006 Spencer & Associates Publishing, Ltd. *Independent testing, commissioned by Hewlett-Packard Company.* Results and analyses in this report are based upon testing procedures developed and implemented by the *SpencerLab* Digital Color Laboratory in our continuing commitment to accuracy and integrity, and are based upon our best knowledge at the time of testing. Usage of derivative works require prior permission from Spencer & Associates Publishing, Ltd.

