

Printable Ink Efficiency: Measuring Coverage Reduction Across Common Worksheet Rendering Methods

A controlled experiment on 108 computer-generated worksheet pages, 36 rendering methods and 36 unseen holdout pages. It measures how much of each page a printer would be asked to cover, not how much ink or toner a printer uses.

MAIN FINDING

No single ink-saving setting performed best on every page. What a page can save depends on what covers it.

- Digital study complete
- Printer validation not yet run

PUBLISHED	VERSION	EVIDENCE
September 26, 2026	1.0	Estimated coverage and function checks on rendered pages

Canonical URL: <https://ultratextgen.com/research/printable-ink-efficiency-study/>
UltraTextGen Research · Version 1.0 · Published September 26, 2026

SUMMARY

What the study found

5 of 12

page types cover under 3% of the paper as designed

For handwriting sheets and photocopy masters, the best trade-off found was to leave the page unchanged.

● ESTIMATED COVERAGE

60 to 97%

less from removing decoration and lightening fills

On the poster, cut-card and decorated-worksheet designs, where backgrounds, borders or large color areas carry most of the coverage, removing decoration and lightening fills cut estimated coverage by about 60 to 97% on average per design (49 to 99% page by page). Text, lines and pictures still passed the checks, a result that is partly true by design because decoration was never a checked element.

ESTIMATED COVERAGE

FUNCTION CHECK

About 26%

less from fading the whole page to 75%

Page-wide fading cuts coverage in proportion to the fade (75% strength: about 26% less) and removes no mark. Page opacity already failed 12 of 108 pages at 75%.

ESTIMATED COVERAGE

FUNCTION CHECK

4% at most

less tone from dot patterns than a flat tint

As drawn in the browser, authored dot patterns never meaningfully beat an equally light flat color. Chromium's PDF export then stored them as 72 ppi images, so the file a user prints no longer carries the designed pattern.

ESTIMATED COVERAGE

CHROMIUM-SPECIFIC

NOT TESTED ON PRINTERS

What these numbers do not show yet

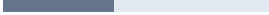
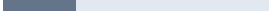
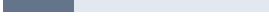
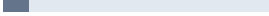
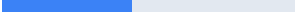
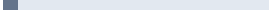
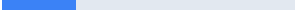
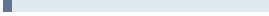
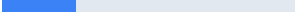
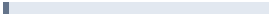
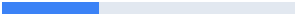
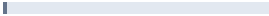
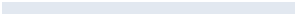
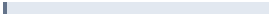
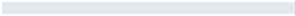
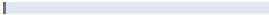
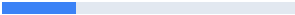
How to read the numbers. Every percentage on this page is **estimated printed coverage**, calculated from rendered pages. No ink or toner was weighed. Lower coverage is likely to need less ink or toner, but on laser printers the toner used per covered area is known to differ between solid areas, dot patterns and text edges, so a 30% cut in coverage is not necessarily a 30% cut in toner.

Physical printer validation has not been run, and the visual reviewers were AI models. Read the limitations

RESULTS

Best trade-off by page type

Pages that cover a quarter of the paper or more lost 48 to 98% of their estimated coverage under the best trade-off. Pages under 6% had 1.4 points or less to gain.

PAGE TYPE	COVERAGE AS DESIGNED	BEST TRADE-OFF FOUND	ESTIMATED CUT
COVERS A QUARTER OF THE PAGE OR MORE			
Poster	80% 	Eco Colour	61% 51.7 points 
Decorated worksheet	41.7% 	Remove decoration, then 75%	98% 40.9 points 
Color key	27.5% 	Eco Colour, text and lines at 75%	48% 13.2 points 
Cut-out cards	26.7% 	Decoration removal	62% 21.3 points 
COVERS ABOUT A TENTH OF THE PAGE			
Picture cards	9.6% 	Lighter fills and photos (55%)	44% 4.2 points 
COVERS UNDER 6% OF THE PAGE			
Word search	5.5% 	75% page opacity	25% 1.4 points 
Reading passage	3.1% 	75% page opacity	25% 0.8 points 
Table or schedule	2.8% 	Remove decoration, then 75%	36% 1.0 points 
Mixed worksheet	2.1% 	Eco Colour	33% 0.7 points 
Handwriting sheet	1.5% 	Leave unchanged	None 
Photocopy master	1.4% 	Leave unchanged	None 
Coloring page	1.1% 	75% page opacity	25% 0.3 points 

For each page type, the method with the largest cut on both coverage estimates among those that kept function on average over the type's 9 pages, kept at least 90% of the unchanged page's marks through simulated copies, were rated at least 4 out of 5 by the AI reviewers and did not inflate the PDF. Within 2 points, the simpler method won.

Points are percentage points of estimated coverage. Two picks depend on how "kept function" is applied: if every page, not the average, must score at least 0.90, cut-out cards move to lighter fills; at 0.95, cut-out cards move to leave unchanged and picture cards to 75% opacity. Where 75% opacity was picked, it more than halves text contrast (17.4:1 to 7.7:1 for near-black text, still above the 7:1 enhanced line) to save 0.3 to 1.4 points, so we would not use it for low-vision readers or long reading; no reader was tested. Rankings that compare faded text against removed fills are coverage rankings only; they need a physical test before they can be read as ink rankings.

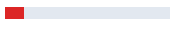
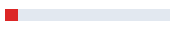
Printing worksheets yourself? **How to Save Printer Ink on Worksheets** turns these results into steps, and keeps what this study tested apart from general printing advice.

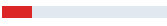
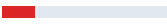
METHODS

What worked and what did not

Twelve of the 36 methods, across all 108 development pages: the mean cut in estimated coverage with its range from the lowest to the highest page, and how many pages failed the function check.

METHOD	MEAN CUT, 108 PAGES	PAGES FAILED	WHAT TO KNOW
CUT WHERE THERE IS COLOR TO REMOVE, WITH FEW OR NO FAILURES			
Eco Colour ECO_COLOUR	29.8% range 0 to 99%	0 of 108	Removes background and decoration, fills to 55%, photos to 80%, text and lines unchanged. It changed nothing on 45 of 108 pages, which have no fills or decoration.
Decoration removal DECOR_REMOVAL	11.4% range 0 to 88%	0 of 108	62% on cut-out cards; nothing to remove on pages without decoration.

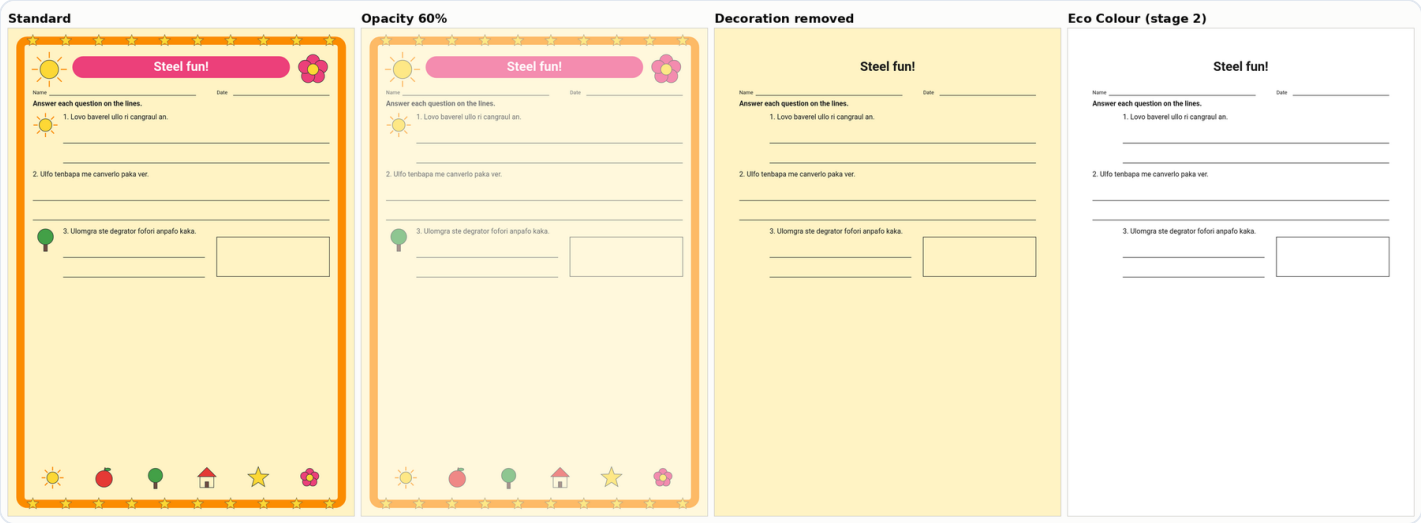
METHOD	MEAN CUT, 108 PAGES	PAGES FAILED	WHAT TO KNOW
Lighter fills (55%) TINT_FILL_55	20.0% range 0 to 50% 	2 of 108 	Fills and pictures only; text and lines unchanged. The best trade-off found for picture cards.
SMALL, EVEN CUT ON EVERY PAGE; FAILS WHERE TEXT SITS ON COLOR			
Page opacity 75% OPACITY_GROUP_75	26.1% range 25 to 30% 	12 of 108 	Removes no mark. Failed all 9 posters and 3 dense cut-card pages.
Lighter solid color 75% TINT_75	25.8% range 23 to 29% 	3 of 108 	Same coverage as page opacity, but re-colors white text dark when its fill lightens. Failed only 3 cut-card pages.
CUT MORE, AND BROKE MANY PAGES			
Page opacity 60% OPACITY_GROUP_60	41.4% range 40 to 46% 	46 of 108 	Failed every handwriting and cut-card page and 8 of 9 photocopy masters.
Lighter solid color 55% TINT_55	46.0% range 43 to 50% 	83 of 108 	Near-black text falls below the 4.5:1 line at 55% strength.
Page opacity 45% OPACITY_GROUP_45	56.3% range 55 to 60% 	108 of 108 	Failed every page.
Black and white, 1-bit threshold BW_THRESHOLD	33.7% range -11 to 92% 	62 of 108 	Thresholding the rendered page to 1-bit is unreliable.
NO REAL SAVING, OR A NEW PROBLEM			
Grayscale GRAYSCALE	27.3% four-color only; no tone removed 	8 of 108 	Removes no tone: the single-color darkness estimate moved 0.0%. The four-color figure falls only because color moves to black. Merged pastel color categories.

METHOD	MEAN CUT, 108 PAGES	PAGES FAILED	WHAT TO KNOW
Halftone dots, 30% area HALFTONE_M	26.4% range 0 to 74% 	19 of 108 	Never meaningfully beat an equally light flat tint. Chromium stored it as a 72 ppi image, and its PDFs were a median 21 times the size.
Outline, naive OUTLINE_NAIVE	28.8% range 0 to 99% 	21 of 108 	Does not re-color white text on fills: lost every word on all 9 posters.

A page fails below a function score of 0.80. The range bar runs from the lowest to the highest page, on a scale from -20% to 100%, and the tick marks the mean; a negative cut means the method added coverage. Values come from summary-by-mode.csv; all 36 methods are in the dot plot below.

 **CHROMIUM-SPECIFIC**

How a method is built changes the file. Grayscale or lightening applied as a CSS filter or an SVG filter exported the page as an image with no text layer; plain group opacity stayed vector. Chromium and PDF behavior



Decorated worksheet: Standard, 60% page opacity, decoration removed, and Eco Colour.

ABSTRACT

What the study asked and what it can conclude

Question	Which ways of rendering a printable page reduce how much of the page a printer is asked to cover, without damaging what the page is for?
----------	--

What was tested	36 rendering methods, compared with the unchanged page: page-wide fading, lighter solid color, lighter fills only, grayscale, two kinds of black and white, outline-only, background and decoration removal, halftone and dither patterns, high contrast, and ten methods built from the first round of results (five combined methods and five pairs that test how savings combine). Each was applied to 108 computer-generated pages (12 worksheet types, each at 3 fullness levels and 3 element sizes). 84 replicate pages, rendered with a reduced set of 14 methods, checked other content and US Letter paper, and 36 pages of 4 unseen types were held back to test the recommendations.
What was measured	Estimated printed coverage from the rendered pixels; whether each page's critical elements kept their visibility, text contrast and color separation; survival through a simulated photocopier; file size and render time; and what the exported PDF actually contains. The study produced 6,616 measurement rows.
What it can conclude	How much estimated coverage each method removes on each kind of page, and what each method breaks, in the tested conditions.
What it cannot conclude	How much ink or toner any method saves on a real printer, or how real readers judge the pages. Physical printer validation has not been run, and the visual reviewers were AI models.

How the study ran, and what is still to come

1 · BUILD

108 pages

12 worksheet types, 3 fullness levels, 3 element sizes, on A4

2 · RENDER

36 methods

Each compared with the unchanged Standard page in headless Chromium 141

3 · MEASURE

6,616 rows

Coverage, function checks, simulated copies, file size and PDF contents

4 · REPLICATE

84 pages

Other content seeds and US Letter, with 14 methods

5 · HOLD OUT

36 pages

4 unseen types, rendered after the routing rules were committed

6 · NOT YET RUN

Printers

Weighing ink and toner on inkjet, ink-tank, mono laser and color laser: designed, not executed

FINDINGS

Detailed findings

Each finding carries a tag for the kind of evidence behind it.

● ESTIMATED COVERAGE

measured from rendered pages

✓ FUNCTION CHECK

measured contrast, visibility or color separation against a stated threshold

◇ SIMULATED

produced by a model, not a real device

■ CHROMIUM-SPECIFIC

a property of the Chromium build used (141)

○ NOT TESTED ON PRINTERS

an open question for physical testing

● PHYSICAL PRINTER TEST

measured on a real printer: none in this version

Estimated coverage

● ESTIMATED COVERAGE

What covers the page decides what can be saved. As designed, five page types cover under 3% of the paper: coloring page 1.1%, photocopy master 1.4%, handwriting sheet 1.5%, mixed worksheet 2.1%, table 2.8%. The decorated worksheet averaged 41.7%, of which 40.7 points were decoration. Posters averaged 80%.

● ESTIMATED COVERAGE

Page opacity and an equally light solid color produce the same coverage.

Across 108 pages they differed by 0.02 points on average and 0.11 at most. At 75% strength, page opacity cut estimated coverage by 26.1% and lighter solid color by 25.8%. At 60% opacity the cut was 41.4%.

● ESTIMATED COVERAGE

Fading removes no mark. The share of the page carrying any mark fell 0.1% under 75% opacity, against 16 to 35% under decoration removal, Eco Colour or outline conversion.

● ESTIMATED COVERAGE

Removing decoration is the largest lever where decoration exists. Removing background and decoration cut 97% on the decorated worksheet (the tinted background alone, 59%), 62% on cut-out cards and 94 to 98% on the unseen certificates. This saving equals the share of each page the designs gave to decoration, so it describes these designs, not real worksheets.

ESTIMATED COVERAGE

Eco Colour (remove background and decoration, fills to 55% strength, photos to 80%, text and lines unchanged) cut 61% on posters, 97% on the decorated worksheet, 76% on cut-out cards, 47% on the color key, 33% on the mixed worksheet and 28% on picture cards. It changed nothing on 45 of 108 pages, which have no fills or decoration.

ESTIMATED COVERAGE

Grayscale removes no tone. The single-color darkness estimate moved 0.0% on average (−0.8% to +0.8% by page). The four-color estimate fell 27.3% only because color moved to black; if a device built grays from color inks, the fall would be 2.6%.

ESTIMATED COVERAGE

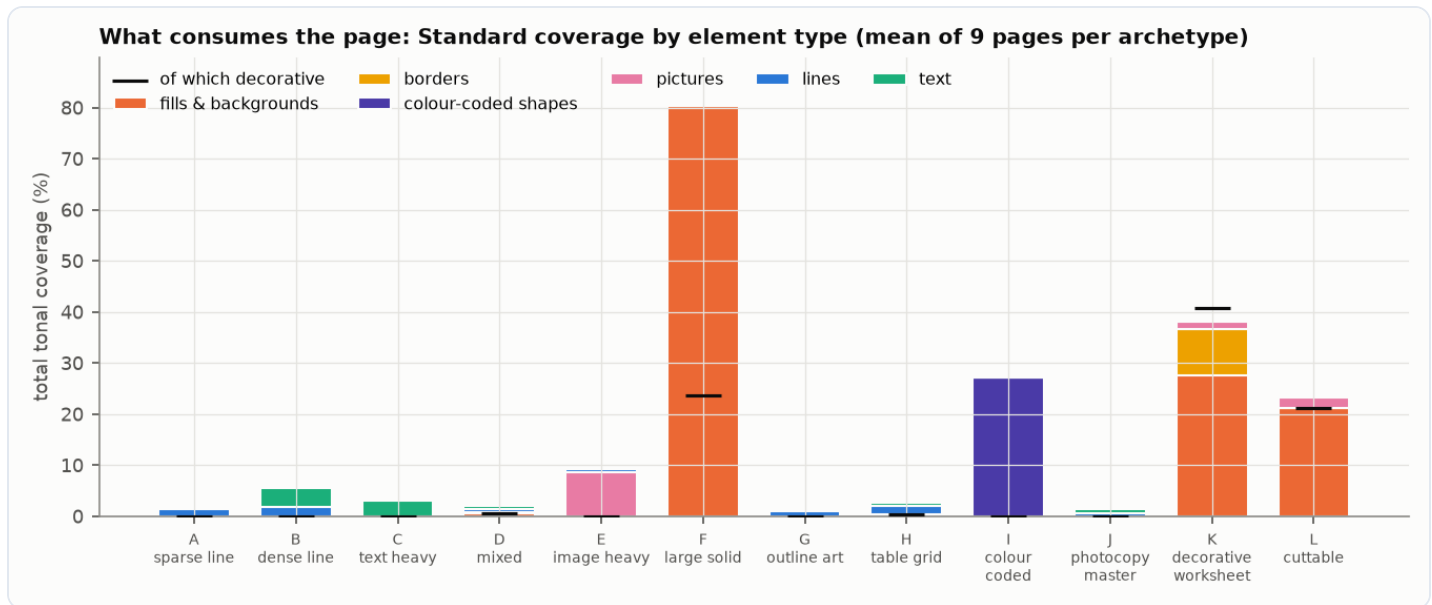
Dot patterns never meaningfully beat a flat tint. Against an equally light flat color, halftone and dither patches measured at most 4% less and up to 19% more total tone (median ratio 1.03; single-color darkness within 5%).

ESTIMATED COVERAGE

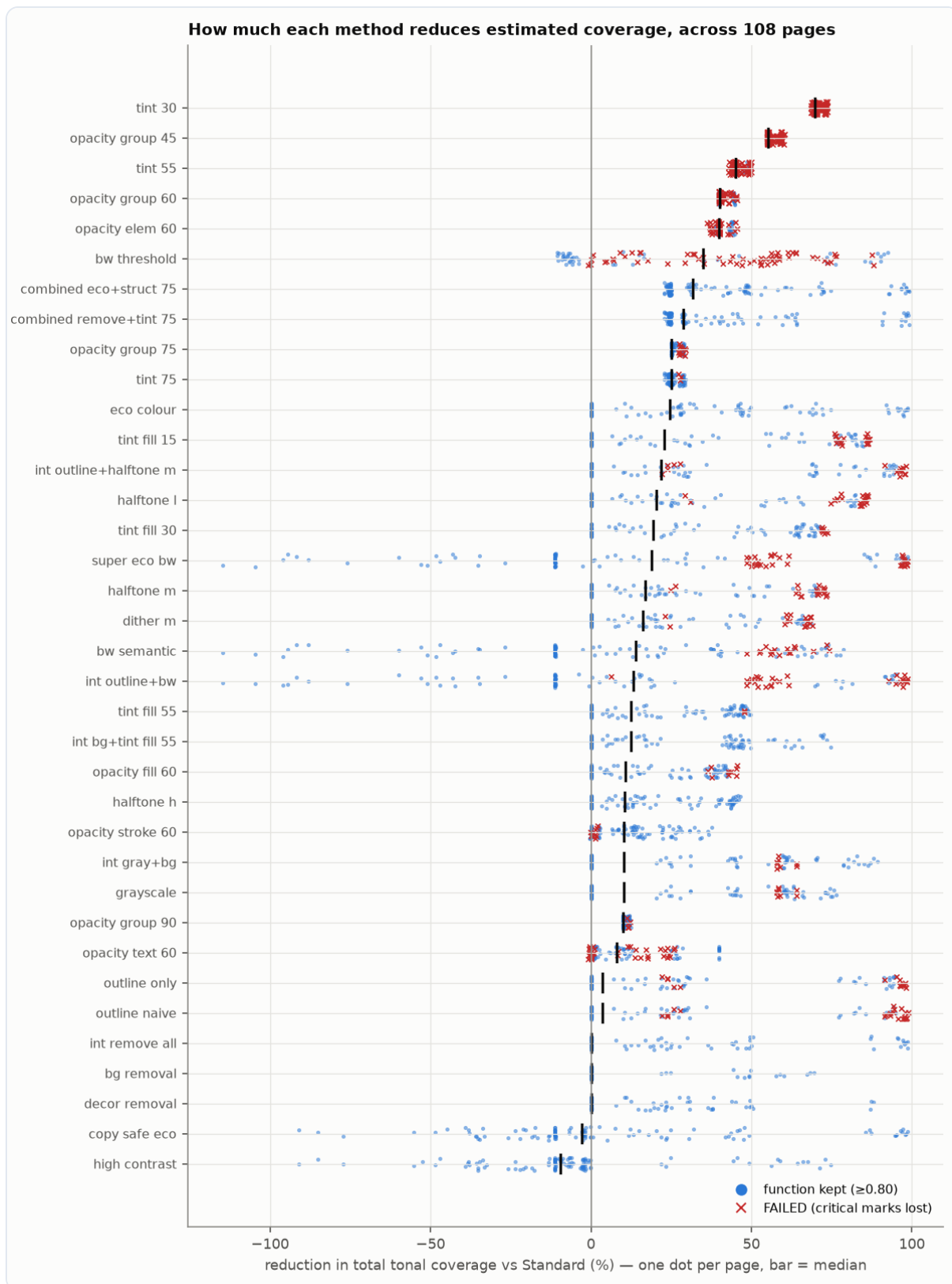
Combined methods multiply, not add. On posters, background removal plus lighter fills saved 51.7 points, against 62.4 by adding the two and 51.1 by multiplying their remaining shares. Across all pairs the multiplicative prediction was 0.5 points off on average; single pages were up to 13.4 points off.

ESTIMATED COVERAGE

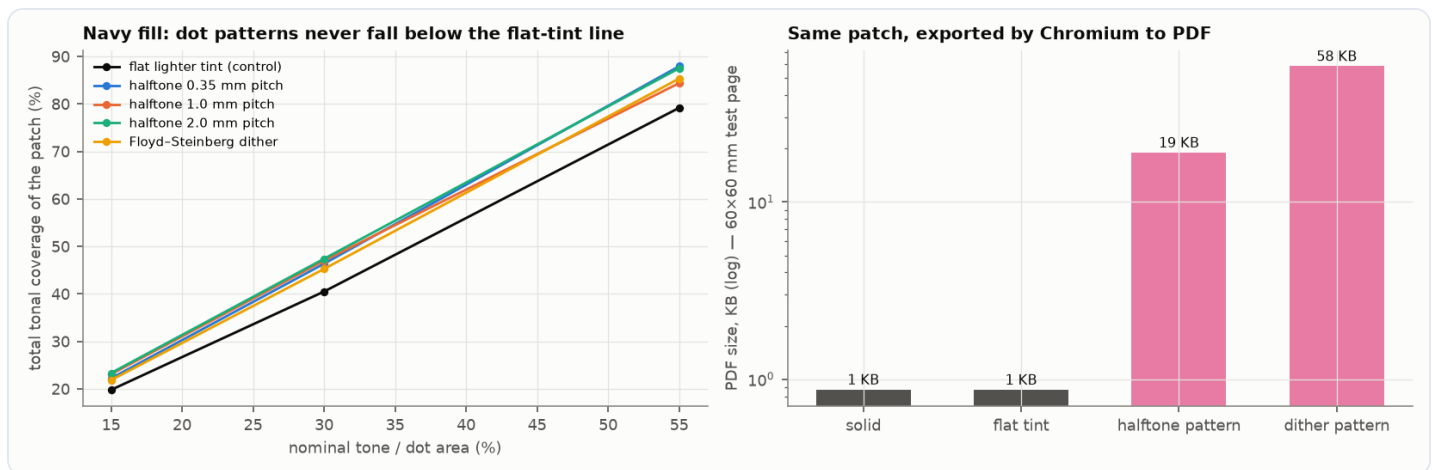
Absolute savings shrink with coverage. For 75% page opacity, no page under 3% coverage gained a full point with its function kept; the lowest-coverage page that did started at 4.4%.



What covers each page type as designed: mean of 9 pages per type, split by element group. Groups are measured by removing each one in turn, so they need not add up exactly to the total.



Reduction in estimated coverage for every method on every development page. One dot per page; the bar is the median; red crosses failed the function check (below 0.80). The figure's legend calls every other page "function kept"; elsewhere on this page that term means 0.95 or above. Method names are the identifiers used in the data files.



Navy test patch at 600 dpi: halftones and a dither against the equally light flat tint (left), and the median size of all 60 × 60 mm test patches, every color, tone and dot spacing, as Chromium PDFs (right).

Function checks

✓ FUNCTION CHECK

Page opacity fails first where text sits on color. At 75% opacity, 12 of 108 pages failed: all 9 posters, where white 12 pt labels, already below the 4.5:1 line as designed (2.4:1), fell to 1.9:1 against their fills, and 3 dense cut-card pages, where dark labels on pink card fills fell from 4.63:1 to 2.76:1. The lighter-color version re-colors white text dark when its fill lightens; it passed the posters and failed only those 3 cut-card pages.

✓ FUNCTION CHECK

Near-black text crosses the 4.5:1 line between 60% and 55% strength.

#1a1a1a text on white measures 7.69:1 at 75%, 4.54:1 at 60% and 3.90:1 at 55%. Text that starts as dark gray crosses much earlier. On the decorated worksheet the white banner title (large text, 3:1 line) fell to 2.79:1 at 75%; dark text on its pale yellow background held 7.10:1 at 75% and fell to 4.26:1 at 60%.

✓ FUNCTION CHECK

Stronger fading fails many pages, and every page by 45%. 60% page opacity failed 46 of 108 pages, including every handwriting and cut-card page and 8 of 9 photocopy masters; 55% lighter color failed 83; 45% opacity and 30% lighter color failed all 108.

✓ FUNCTION CHECK

Hard black and white is unreliable. Thresholding the rendered page to 1-bit failed 62 of 108 pages. A per-element conversion kept text and lines but turned gray tracing letters solid black (+86% coverage on handwriting pages); the automated check missed this, and the AI reviewers scored it 2 out of 5 (their brief had listed this defect as an example).

✓ FUNCTION CHECK

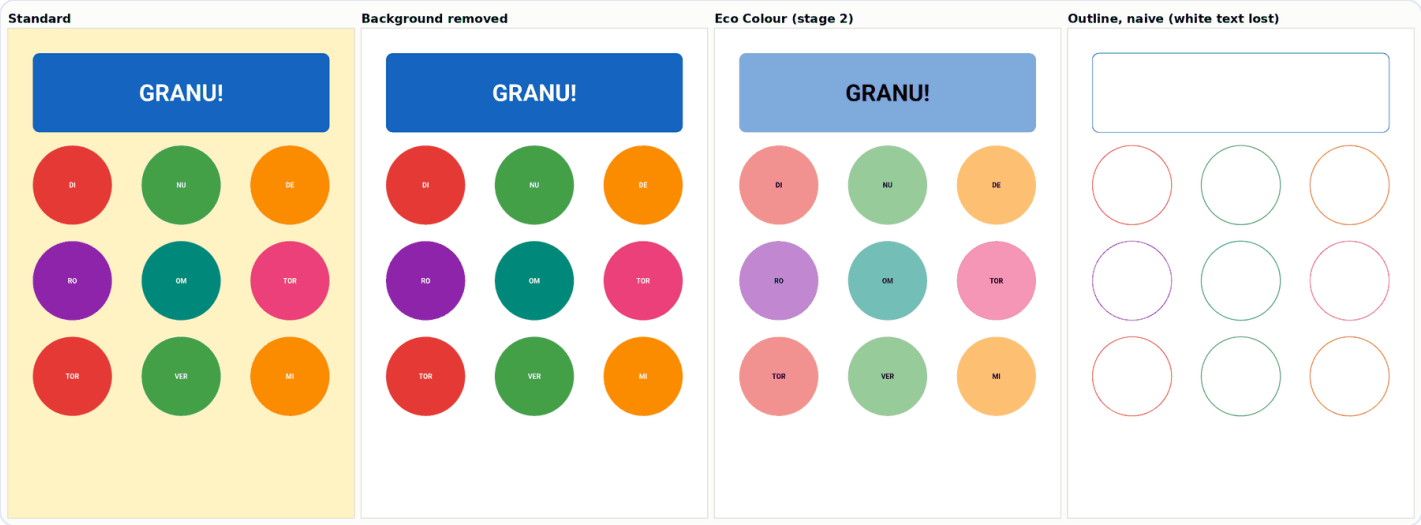
Knockout text is the implementation trap. Removing or outlining fills without re-coloring the white text on them lost every word on all 9 posters.

✓ FUNCTION CHECK

Color categories. Grayscale reduced four pastel categories to a color difference of 0.2 (CIEDE2000; 10 was the distinguishable line) and failed 6 of 9 color-key pages. Lightening fills to 55% kept saturated categories apart for normal color vision. In a deuteranopia simulation, the key's weakest red and green pair, already below the distinguishable line of 10 as designed (5.2), fell to 2.9.

◇ SIMULATED

Copies suffer before the original. In the simulated copier, the worst-hit lines or text at 75% opacity kept 81% as many visible marks as the unchanged page's own copies on medium-size pages and 62% on small-element pages; at 60%, 67% and 36%. Two simulated copies erased pale flat tints outright.



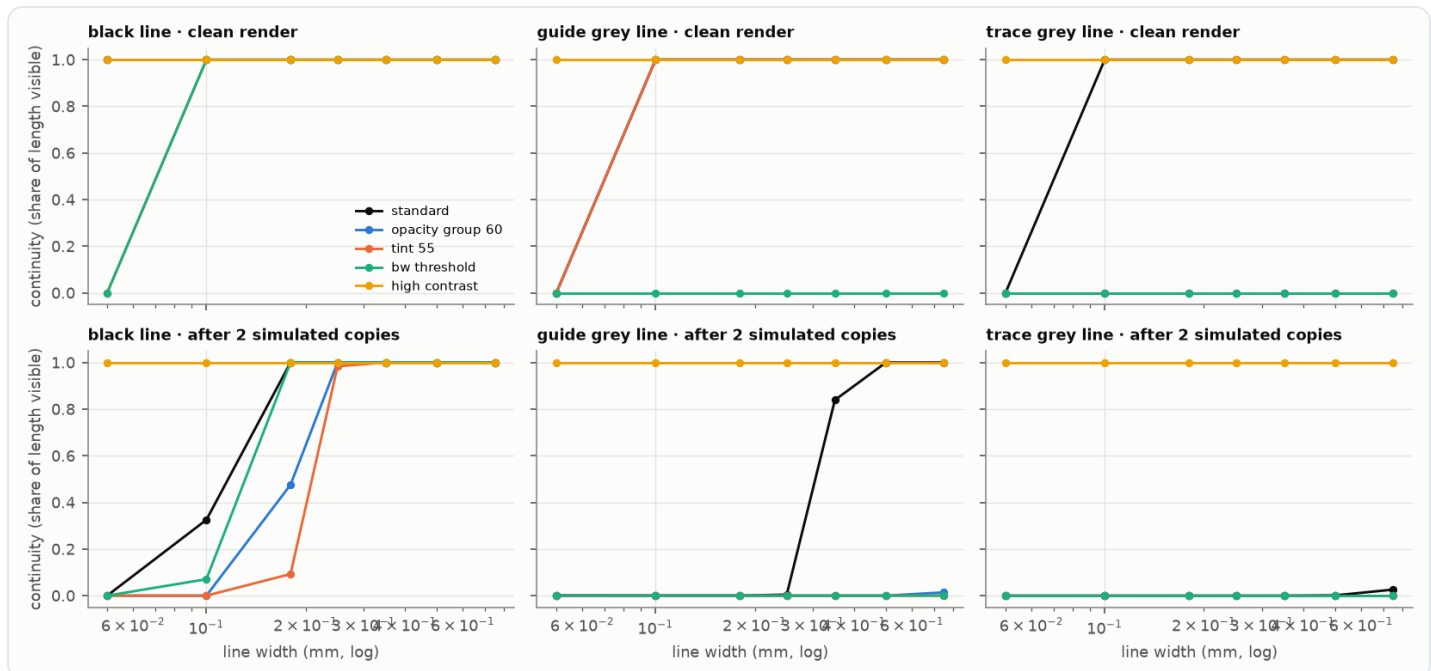
Poster: the naive outline version loses every white label, because the fill it stood out against is gone.

Standard	Opacity 75%	Opacity 60%	High contrast
Nutenbri practice Name _____ Date _____ nu me veris	Nutenbri practice Name _____ Date _____ nu me veris	Nutenbri practice Name _____ Date _____ nu me veris	Nutenbri practice Name _____ Date _____ nu me veris
after 2 simulated copies Nutenbri practice Name _____ Date _____ nu me veris	after 2 simulated copies Nutenbri practice Name _____ Date _____ nu me veris	after 2 simulated copies Nutenbri practice Name _____ Date _____ nu me veris	after 2 simulated copies Nutenbri practice Name _____ Date _____ nu me veris

Handwriting sheet, clean and after two simulated copies. Gray guides and tracing letters are the first marks lost.

Standard	Fills 45% lighter	Grayscale	Black & white
Colour key Count the circles of each colour and write the totals. ka = yo = mi = lo = fo = 	Colour key Count the circles of each colour and write the totals. ka = yo = mi = lo = fo = 	Grayscale Colour key Count the circles of each colour and write the totals. ka = yo = mi = lo = fo = 	Black & white Colour key Count the circles of each colour and write the totals. ka = yo = mi = lo = fo =

Color key: lighter fills keep the categories apart; grayscale and black and white merge them.



Controlled line test at 300 dpi: share of each line still visible, clean (top) and after two simulated copies (bottom). Only high contrast kept the tracing gray through the simulated copies.

Chromium and PDF behavior

CHROMIUM-SPECIFIC

Chromium's PDF export does not keep dot patterns. Every pattern-filled shape was written as its own full-page 72 ppi image with an alpha mask, not as vector dots. At 0.35 to 0.5 mm spacing the PDF holds a flat, lighter tone; at 1 to 2 mm, blocky aliased dots. Flat tints stay vector. So the halftone results above describe the pattern as drawn in the browser, not the file a user would print.

CHROMIUM-SPECIFIC

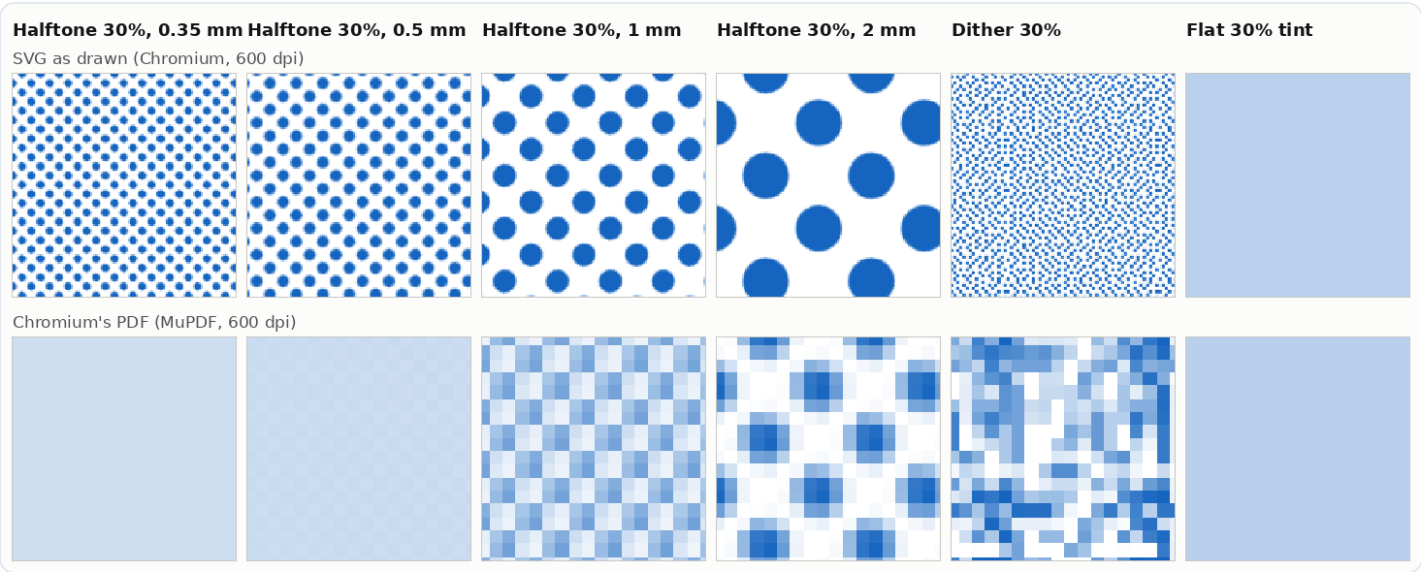
Chromium's PDF of a fine pattern is lighter than the design. MuPDF and PDFium showed 0.35 to 0.5 mm halftones 8 to 39% lighter than Chromium's own raster of the same design, while agreeing with each other within 6%. Flat methods agreed within 1 to 5% across all four renderers.

CHROMIUM-SPECIFIC

Pattern files are large and slow. Page PDFs with patterns were a median 19 to 21 times (halftone) and 28 times (dither) the size of the unchanged page, up to 148 MB and 198 MB for one A4 page, and the slowest single export took 723 seconds (timings are upper bounds: the machine was not idle for part of the run). Flat methods rendered and exported within a few percent of the unchanged page, except per-element and text-only opacity, whose PDFs were a median 1.5 and 1.1 times larger (up to about 12 times).

CHROMIUM-SPECIFIC

Filter-based implementations rasterize the whole page. Grayscale or lightening applied as a CSS filter or an SVG filter exported the page as an image with no text layer; plain group opacity stayed vector.



A 30% pattern as drawn (top) and inside Chromium's PDF (bottom). Fine screens flatten to a lighter tone and coarse ones to blocky squares; the flat tint is unchanged.

Not yet validated on physical printers

- NOT TESTED ON PRINTERS

Whether any cut in estimated coverage becomes a matching cut in ink or toner, for each method and printer type.
- NOT TESTED ON PRINTERS

Whether grayscale saves anything on a given printer; several manufacturers say grayscale modes can still use color ink.
- NOT TESTED ON PRINTERS

Whether faded text and gray guides survive a printer's own dot screening. Every contrast figure here assumes a lighter color prints as a flat tone.
- NOT TESTED ON PRINTERS

Real copier behavior. The copier is a model with chosen settings, and the finding that pale tints vanish while coarse dots survive comes from those settings.
- NOT TESTED ON PRINTERS

The simulated printer screen gave halftones a median 1.31 times, and dithers 1.24 times, the dot area of the equal flat tint.

◇ SIMULATED

HOLDOUT

How the recommendations held on unseen pages

The routing rules were written down and committed before four held-back page types (a certificate, a maze, a month planner and a labeled diagram, 36 pages) were rendered.

 Not exercised	Every holdout page was routed to the same method, Eco Colour, so the rules for pictures, sparse pages and text-and-line pages were not exercised.
 Held	Function was kept on all 36 pages for normal color vision, which mostly confirms that Eco Colour leaves text and lines alone.
 Held	The decoration rule's coverage prediction held: certificates lost 94 to 98% of their estimated coverage, 99% of the best available. Whether a certificate still works as an award without its frame was not assessed.
 Failed	The color rule failed. Planners and diagrams saved 47 to 65%, but a more aggressive fill lightening saved more on every one. On the maze, color meaning is two small start and finish dots while the coverage is black walls: Eco Colour saved 1 to 7% where 45% was available. Routing by what covers the page, not by page type or feature, is the lesson; that rule itself has not yet been tested on unseen pages.

METHOD

How the study was run

Pages

Every page was generated from code, so one property could change at a time. Twelve development types were each built at three fullness levels (30%, 60% and 92% of the usable area populated) and three element sizes (for example 16, 12 and 9 pt body text; 0.40, 0.25 and 0.15 mm guide lines) on A4 with 15 mm margins: 108 pages. Replicates rebuilt each type's typical page with four more content seeds (48 pages) and its three medium-size pages on US Letter (36 pages), with a reduced set of 14 methods; seeds change words and picture choice, not layout. Text is pseudo-words; pictures are simple vector clip art and procedural photographs.

The 12 page types and their critical elements

PAGE TYPE	STANDS IN FOR	CRITICAL ELEMENTS
Sparse lines	Handwriting practice, tracing	Ruled lines, guides, tracing letters
Dense lines	Word searches, grids	Grid, letters
Text heavy	Reading passages	Text
Mixed	Everyday worksheets	Text, answer lines, pictures
Image heavy	Picture cards	Pictures, words
Large solid color	Posters	Titles, color fills
Outline art	Coloring pages	Outlines
Table or grid	Schedules, forms	Grid, small text
Color coded	Color keys, sorting tasks	Color categories, labels
Photocopy master	Quizzes for copying	Small text, boxes, lines, guides
Decorative worksheet	Worksheets with borders and clip art	Questions, answer lines
Cutable	Flashcards, cut-out cards	Cut lines, pictures, words

Rendering methods

36 methods were compared with the unchanged Standard rendering. The first 26 were defined before the main measurements; the 10 in the Derived and Pairs rows were built afterwards from those results.

All 36 methods and their data identifiers

FAMILY	METHODS (DATA IDENTIFIERS)	WHAT IT DOES
Page opacity	OPACITY_GROUP_90/75/60/45 , OPACITY_ELEM_60	Fades the whole page, or each element separately
Partial opacity	OPACITY_FILL_60 , OPACITY_STROKE_60 , OPACITY_TEXT_60	Fades only fills, strokes or text
Lighter solid color	TINT_75/55/30	Moves every color toward white, fully opaque

FAMILY	METHODS (DATA IDENTIFIERS)	WHAT IT DOES
Lighter fills	TINT_FILL_55/30/15	Fills and pictures only; text and lines unchanged
Grayscale	GRAYSCALE	Each color to its gray of equal lightness
Black and white	BW_THRESHOLD , BW_SEMANTIC	1-bit threshold of the page, or per-element black and white
Outline	OUTLINE_ONLY , OUTLINE_NAIVE	Fills become outlines; the naive version does not re-color white text
Removal	BG_REMOVAL , DECOR_REMOVAL	Deletes the page background, or decorative art, borders and non-essential fills
Patterns	HALFTONE_H/M/L , DITHER_M	Fills become 1 mm dot screens (55, 30, 15% area) or a 30% dither
High contrast	HIGH_CONTRAST	Background off, black structure, strokes at least 0.3 mm, darker guides
Derived	ECO_COLOUR , SUPER_ECO_BW , COPY_SAFE_ECO , COMBINED_REMOVE+TINT_75 , COMBINED_ECO+STRUCT_75	Removal combined with lighter fills, black and white, high contrast or 75% strength
Pairs	INT_BG+TINT_FILL_55 , INT_REMOVE_ALL , INT_OUTLINE+BW , INT_GRAY+BG , INT_OUTLINE+HALFTONE_M	Two methods together, to test how savings combine

Coverage estimates

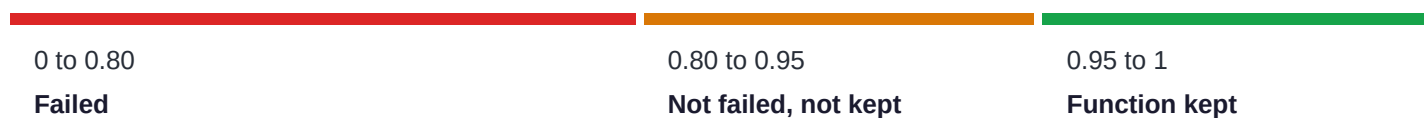
Pages were rendered in headless Chromium 141 at 150 dpi (controlled tests at 300 and 600 dpi) and composited on white. From the sRGB pixels: **total tonal coverage** (the headline figure) uses a naive four-color split, $K = 1 - \max(R, G, B)$ and $C = (\max - R) / \max$ with M and Y alike, summed per pixel and averaged over the page; **single-color darkness** is the mean of $1 - \text{luma}$ (Rec. 709); **marked area** is the share of pixels carrying any mark. The

four-color split is not a color-managed conversion; it sends every gray to black only and counts a saturated two-ink color as about 200%, so points are not comparable across page types. A composite estimate (every gray built from color inks) is reported alongside. Each element group's share was measured by removing it and re-measuring.

Function checks

Each page type declares its critical elements, and a page scores the minimum over them, so it is only as usable as its most damaged element. Text contrast is measured against the fills actually beneath it, at 4.5:1 for normal text and 3:1 for large text (at least 18 pt, or 14 pt bold), and lines at 3:1; these WCAG 2.2 thresholds are a screen standard used as a print proxy. A mark counts as visible when it differs from what lies beneath it by at least a 15% tone step. Color categories count as distinguishable at a CIEDE2000 difference of 10. Pictures are compared by edge structure at pixel and reading-distance scales. A page fails below 0.80 and keeps function at 0.95 or above.

Function score of a page: the lowest score among its critical elements



Simulated photocopying

Each copy generation applies a 0.10 mm optical blur, maps anything lighter than 0.90 luma (Rec. 709) to paper and anything darker than 0.10 to solid black, and adds noise; three generations were run. Survival is compared with the unchanged page's own copies, per critical element, after the first and second copy. The settings were chosen to reproduce documented copier behavior and were not fitted to any machine.

Classification

On each page, a method was marked failed below the function line; dominated when another tested method was at least as good on both coverage estimates, function, copy survival and complexity, and strictly better on one (this includes "no effect on this page"); needing physical validation when its saving depends on device behavior (patterns, colors pushed into a faint band, or color moved to black); promising when it cut at least 15% and a full point with function and copies kept; and conditional otherwise.

Cross-checks and review

- **Renderers.** Chromium's rasters were compared with resvg 0.48.1, and Chromium's PDFs were rasterized with MuPDF (PyMuPDF 1.28.2) and PDFium (pypdfium2 5.13.0). Firefox and WebKit were not available.

- **Robustness.** Statuses were stable in 167 of 168 content-seed cells and in 99% of 504 A4 versus US Letter comparisons. Failure counts were re-run at alternative thresholds and criteria.
- **Visual review.** Two independent AI vision reviewers scored 21 methods on each type's typical page from coded images, without method names or coverage figures (86.5% identical usability scores, all within one point; Cohen's kappa 0.74, weighted 0.92). A third re-scored the poster and decorated worksheet after a bug fix. Raters and the automated check agreed only moderately (rank correlation 0.61): the check was stricter on contrast, failing 29 renderings the raters scored usable with defects, and laxer on guide hierarchy and pale colors.
- **Independent review.** Seven AI agents, each reviewing from one professional perspective, and an adversarial claim check reviewed the results against the data and code before publication. They found three measurement errors and the PDF export behavior above; the errors and figures were corrected in this version, and what re-analysis could not fix is listed under Limitations.

LIMITATIONS

What the study cannot tell you

1. **No ink or toner was measured.** Every figure is estimated coverage. Ink, toner, cartridge yield and cost need physical tests, and toner per covered area differs between solid areas, dots and text edges on laser printers.
2. **Physical printer validation has not been run.** A weighing protocol for inkjet, ink-tank, mono laser and color laser printers is designed, not executed.
3. **Contrast assumes flat tones.** A printer prints a lighter color as dots, so faded text and thin guides may perform worse on paper than here.
4. **The four-color estimate is a naive proxy.** No color-managed separation with an ink limit was run, and near-black colors with a slight tint count much higher than pure black.
5. **Chromium PDF behavior.** Pattern fills export as 72 ppi images and filters rasterize the whole page in this build; other PDF producers were not tested, and only one browser engine was available.
6. **The simplicity ranking assumes screen implementations.** Lighter color and grayscale were rated the simplest methods, but applied as a CSS or SVG filter they rasterize the PDF in this Chromium build.
7. **Halftone results describe the pattern as drawn,** not the image stored in the PDF, and pattern savings on the 150 dpi grid move by up to 3.9 points with resolution.
8. **The copier is simulated.** Its settings were not fitted to a device and drive the copy findings.
9. **Coverage was measured on the master, not on copies.** The simulated copier already drops the decorated worksheet's pale background on the first copy, so when a class set is photocopied, removing it saves coverage on the master only.

10. **Some thresholds were not varied:** the color-difference line (10), the dominance tolerance, the 0.95 function line, the 0.90 copy line, the complexity scale and the copier settings. Function is a pass/fail line, so failure counts depend on where it sits. With a 0.90 failure line, Eco Colour fails 3 dense cut-card pages; under the first, stricter picture check it would fail 9 mixed worksheets; with deuteranopia in the color check it fails all 9 color-key pages.
11. **Decoration results are partly true by design.** Decoration was never a critical element, so removing it could only fail by damaging something else, and the saving equals the decoration share the designs gave each page. Layout, visual hierarchy and appeal were not measured.
12. **Only one color-vision deficiency was simulated** (deuteranopia). Some standard pages already fall below accessibility thresholds, and function is scored relative to them.
13. **The reviewers were AI models.** They saw small images of typical pages only, and their brief named two example defects they later found. No teacher, child or low-vision reader rated a page.
14. **The holdout tested one method,** and the holdout pages were built by the same author as the methods.
15. **Page-type exceptions.** The handwriting sheet's tracing letters are solid gray rather than dotted, and the photocopy master's pale tracing does not survive two simulated copies even unchanged.
16. **The pages are synthetic.** Averages across page types describe this mix of 12 designs, not real worksheets; use the per-type results.

RECORD

Corrections made before publication

Version 1.0 September 26, 2026: first published version

Review found and fixed these before version 1.0: text contrast had been measured against white instead of the fills beneath it (75% page opacity went from 0 failures to 12); copy survival had missed guides the unchanged page already lost by the second copy (handwriting sheets and photocopy masters went from "fade to 90%" to "leave unchanged"); one combined method had the wrong complexity; the PDF check had missed images stored inside patterns; and one contrast figure first attributed to text on a tint belonged to a banner title. Superseded wording does not appear on this page.

DATA

Data, samples and reproducibility

Full study, version 1.0

PDF · 1.5 MB

The same text as this page, with title, version and canonical URL on every page.

coverage-results.csv

CSV · 3.0 MB

Every measurement: one row per page and rendering.

summary-by-mode.csv

CSV · 7 KB

Start here: per-method means, ranges and failure counts.

The full study is available as a PDF generated from this page: Printable Ink Efficiency study, version 1.0 (PDF, 1.5 MB). The measurement data are CSV files with one header row; coverage values are fractions of the page (0.25 = 25%), and total tonal coverage can exceed 1 because a saturated two-ink color counts about 2.

FILE	CONTENTS	SIZE
coverage-results.csv	All 6,616 rows: one per page and rendering, with every coverage estimate, function score, copy result, contrast result, file size and status	3.0 MB
page-definitions.json	Every generated page: type, fullness, size, paper, seed, critical elements and standard coverage	280 KB
summary-by-mode.csv	Per-method means, medians, ranges and status counts over the 108 development pages	7 KB
effect-by-archetype.csv	Per-method results for each page type	33 KB
combined-optimal.csv	The best trade-off selection by page type	1 KB
holdout-summary.csv	Holdout pages, routed methods and outcomes	20 KB
sensitivity.csv	Failure and status counts under alternative thresholds and criteria	17 KB
contrast-backing-aware.csv	Text and line contrast against the actual background, per page and rendering	295 KB
interactions.csv	Observed, additive and multiplicative predictions for method pairs	108 KB

FILE	CONTENTS	SIZE
line-survival.csv, text-survival.csv, colour-survival.csv	Controlled line-width, small-text and color-category tests	150, 38 and 2 KB
halftone-dither.csv	Halftone, dither and flat-tint patches: coverage, simulated device screen, copies, file sizes, renderer readings	17 KB
pdf-pattern-structure.csv, pdf-filter-check.csv	What Chromium's PDFs contain for each pattern, and whether filter implementations stay vector	5 KB and 379 bytes
renderer-consistency.csv, resolution-sensitivity.csv	Chromium, resvg, MuPDF and PDFium compared; 100, 150 and 300 dpi compared	10 and 4 KB
performance-results.csv	Load, raster and PDF export times, DOM size and PDF size per method (times are upper bounds: the machine was not idle for part of the run; the layout_s and style_s columns were not recorded and are 0 on every row)	56 KB
visual-quality-results.csv	The AI reviewers' scores and defect notes, decoded	44 KB

Sample PDFs from the pattern test (30% navy fill, 60 × 60 mm): halftone, 0.35 mm, halftone, 1 mm, dither and flat tint.

Software: Chromium 141.0.7390.37 driven by Playwright 1.56, Python 3.11, numpy 2.4, Pillow 12.3, pandas 3.0, resvg 0.48.1, PyMuPDF 1.28.2, pypdfium2 5.13.0; fonts Roboto 3.015 and Liberation Serif 2.1. The rendering is deterministic, so the same software reproduces the same pixels. The measurement code is not published with this version.

CITE

How to cite this study

UltraTextGen Research. "Printable Ink Efficiency: Measuring Coverage Reduction Across Common Worksheet Rendering Methods." Version 1.0, September 26, 2026.

<https://ultratextgen.com/research/printable-ink-efficiency-study/>

Please cite the version number. A later version will keep this address and state what changed.

SOURCES

External sources

That laser toner use per covered area differs between solid areas, halftones and text is reported by K. Wong, Estimation of Toner Usage in Xerographic Printing

(<https://www.imaging.org/common/uploaded%20files/pdfs/Papers/2008/ICISH-0-909/42852.pdf>) (IS&T, 2008), and by Gao, Ju,

Nelson, Prenn and Allebach, Toner Usage Prediction for Laser Electrophotographic Printers

(<https://library.imaging.org/admin/apis/public/api/ist/website/downloadArticle/ei/28/20/art00028>) (IS&T Electronic Imaging, 2016),

whose model needed pixel neighborhoods rather than raw pixel counts to predict toner weighed per page.

The contrast thresholds of 4.5:1 for normal text and 3:1 for large text and graphical objects come from the W3C's Web Content Accessibility Guidelines 2.2 (<https://www.w3.org/TR/WCAG22/>), a screen standard used here as a proxy for print.

That grayscale printing can still use color ink is stated in Epson's Black Ink Only and Grayscale FAQ

(https://www.epson.co.uk/en_GB/faq/KA-01055/contents?loc=en-us), Canon's guide to printing a color document in

monochrome (https://ij.manual.canon/ij/webmanual/PrinterDriver/W/MG3000%20series/1.0/EN/PPG/dg-c_monochrome.html) and HP's Ink Usage in Inkjet Printers (<http://www.hp.com/pageyield/en-150/articles/howInkIsUsed.html>).

Copier background suppression, the behavior the simulated copier imitates, is described in Xerox's support article on automatically suppressing background variation (<https://www.support.xerox.com/en-us/article/KB0138689>).