Toner Yield of Electrophotographic Printing Devices in Consideration of Image Coverage

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Abstract

The most common toner yield measure for electrophotographic printing devices is the number of letter-sized pages that can be printed with a toner cartridge based on average image coverage of 5%. Average toner cartridge yield methodologies are codified in standards ISO/IEC 19752 and ISO/IEC 19798:2006 in accordance with a broad range of factors, including print job size, print quality mode, cartridge end-of-life determination, sample size and environmental conditions. The methodologies and results laid out in these standards are moreover based on average conditions which could be significantly different from the prevailing parameters of a specific job, the most significant of which are image coverage and the substrate being imaged.

The need for a more exacting method of quantifying toner yields, which takes specific production parameters into account, is further underscored by the fact that toner costs in relation to the overall cost of a printed product are considerably higher than ink is in relation to the overall printing cost in conventional printing processes.

In this research toner yield were determined as a function of the weight of toner consumed relative to the actual image coverage of four-color process images printed on synthetic paper by a Xerox DocuColor 7000 digital press. Total image area coverage for all colors was calculated from a PDF file using a Ghostscript interpreter and image coverage software.

The calculated yield predictions per toner cartridge were 33% higher than the manufacturer's yield projections, which demonstrates that toner yields can deviate significantly from the manufacturer's specification, which are based on average rather than specific job parameters.

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General Objectives and Overview of the Research

The objective of this research is to determine the amount of toner that is consumed when printing four-color process images on a digital press. The quantification of toner consumption will be based on the weight of toner consumed per unit square image area and the weight of toner waste produce per printing cycle. To this end test forms for cyan, magenta, yellow and black with known tonal values and square image areas were created. 30 sheets of each process color were printed and the weight of toner consumed by a contiguous (solid) image area measuring 1 $in.^2$ was extrapolated.

The calculated values were then used to determine their suitability as constants to predict toner consumption of a number of randomly chosen four-color process press runs, for which the total image area coverage was calculate by means of a software suite.

Rational for the Test Procedure

The main difficulty that a researcher faces when developing a reliable method of quantifying toner yields is the fact that the toner in commercial as oppose to consumer types of electrophotographic printing devices is not dispensed directly from the toner cartridge to the imaging system, but via a hopper. This technical design feature permits expired toner cartridges to be exchanged with new cartridges while the device is still running.

The most exacting method to quantify toner yields would be to weigh the toner consumed at the source, that is, determining the toner weight as a function of the toner cartridge weight before and after printing. This, however, is not possible on commercial types of electrophotographic printing devices because of their aforementioned indirect toner transfer via hoppers.

The only practical alternative is therefore to determine the weight of toner on the substrate, which in turn introduces a host of other problems. The moisture inherently contained in paper could constitute as much as 8% of its weight[1] and much of this moisture is driven off during the fusing phase where temperatures on the order of 300°F (150°C)[2] are used to fuse the toner particles to the surface of the paper. If this moisture loss is not accounted for there would be no way of telling which proportion of the printed paper's weight is due to any moisture lost or toner gained.

Further compounding the problem is the inherent hygroscopic nature of paper and its propensity to regain moisture lost subsequent to being heated in a printing device until a relative humidity equilibrium with ambient atmospheric conditions is reached.[3] Depending on the amount of moisture lost the regaining of a relative humidity equilibrium could take anywhere from a few hours to a few days[4] thus seriously impairing the accuracy of weight measurements if not taken in a controlled RH environment and at consistent time intervals (Figure 1).

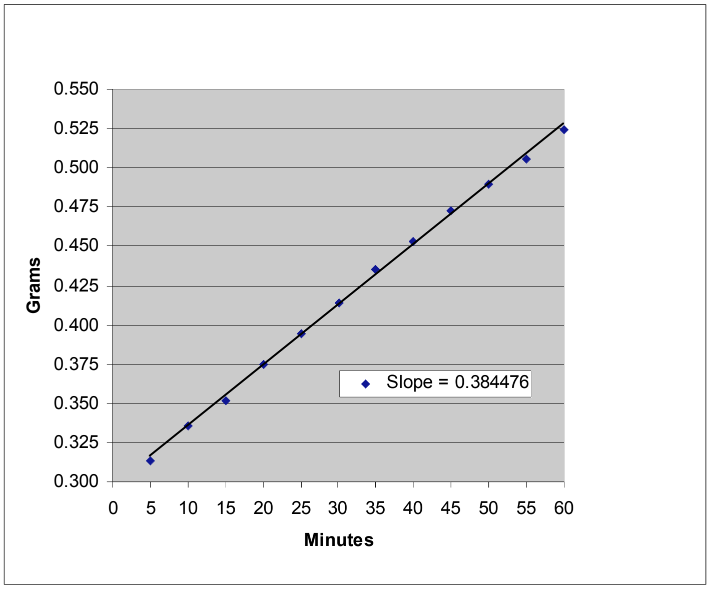


Figure 1. *Moisture gain in uncoated paper subsequent to printing (plus 137 grams).*

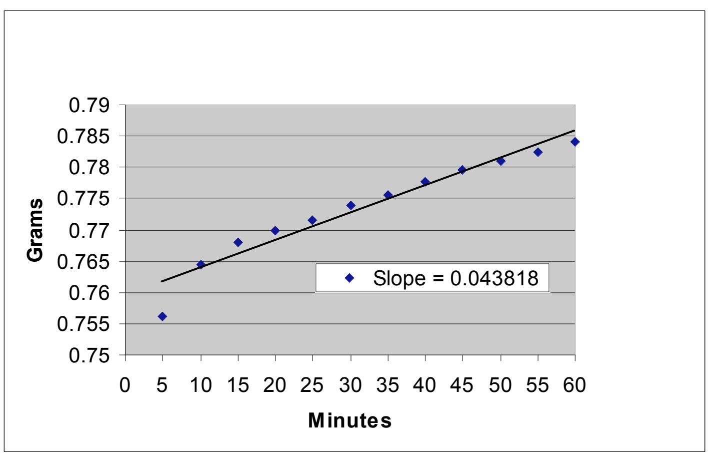


Figure 2. *Moisture gain in synthetic paper subsequent to printing (plus 239 grams).*

A trend analysis where the weight of 30 sheets of uncoated paper was tracked at 5-minute intervals subsequent to printing on a digital press, showed that the paper regained moisture, and by extension, weight amounting to 0.2107 grams over a 60-minute time period in a near linear progression (Figure 2).

To mitigate adverse effects of moisture exchanges it was decided to use synthetic paper for these tests because unlike paper they do not contain the fibrous material that is primarily responsible for its volatile reaction to moisture. It must be noted however that synthetic paper is also not inert to moisture, though to a much reduced degree than paper. The synthetic paper gained only 0.0278 grams over a time period of 60 minutes or 7.5 times less than the uncoated paper gained in the same time period. While an RH equilibrium was still not reached after 60 minutes had elapsed, the weight change was reduce to a negligible amount of 0.0015 grams as opposed to 0.0083 grams in the earliest 5 minute interval (Figure 2). A 60-minute time delay was therefore deemed to be a reasonable delay at which to determine the weight of the specimens, because weight changes due to moisture exchange with the ambient air slowed sufficiently to avoid significant errors that could be introduced by timing inconsistencies.

Toner Consumption Test Procedures and Conditions

All tests were conducted in a climate-controlled lab with RH values ranging from 31–33%. The test specimens were printed on a Xerox DocuColor 7000 digital press which is a electrophothographic printing device utilizing two component toner technology.

Thirty sheets were printed, the combined weight of which was safely within the maximum weight capacity of the analytical balance (315 grams) used to weigh the specimens. The synthetic paper printed was Xerox Digital Synthetic Paper (Polyester) caliper 0.0037, 8.5x11-in. This synthetic paper is specifically formulated to be compatible with the Xerox DocuColor 7000 digital press. The recommended printer settings for this synthetic paper coincided with regular coated paper 187–220 grams/m^2, thus all recommendations made in this research will be especially relevant for coated paper of similar grammage.

Each 30-sheet batch was cut down on a programmable cutter (Polar 68), to a size of 2.125x4.25 so that the test specimens would fit within the measuring chamber of the analytical balance. Exactly 60 minutes after printing the specimens were weighed on an analytical balance (see Appendix) and the weight of the printed sheets was recorded.

To determine the net toner weight consumed for a given print run of 30 sheets the weight of 30 unprinted sheets was subtracted from the weight of the printed sheets:

$$\textit{Net Toner Weight} = \textit{Weight of 30 Printed Sheets} - \textit{Weight of 30 Unprinted Sheets} \qquad (1)$$

But in order to cancel out the moisture content differences between the printed and the unprinted batches, the unprinted batch was likewise processed through the Xerox DocuColor 7000. The weight of this unprinted paper batch (237.0946 grams) was subsequently subtracted from all print runs to calculate their net toner weight.

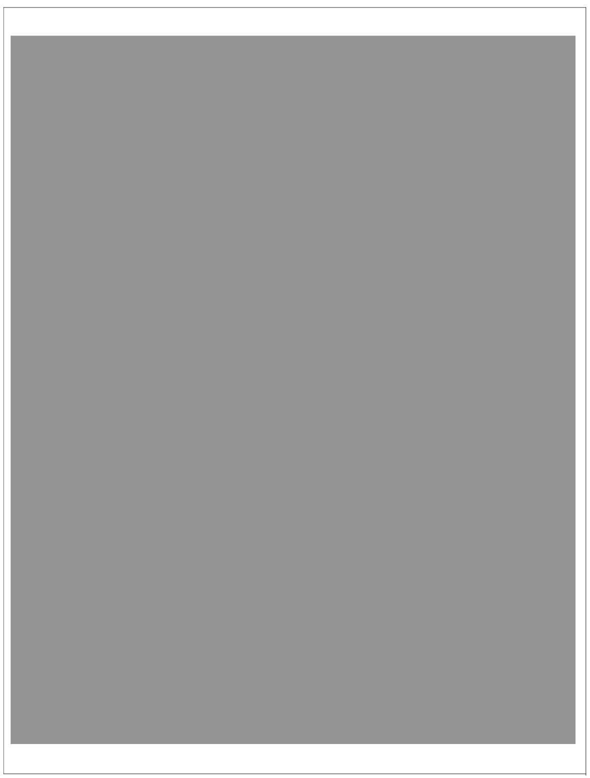


Figure 3. *Test form, 50% tint, 8x10 image area to determine toner consumption.*

The first order of business was to determine the toner consumption for each of the process colors CMYK. For this purpose a test form was designed in

CorelDraw. The test form consisted of an 8x10-in. rectangular 50% mid-tone image area and was identical for all four process colors (Figure 3). A 50% tint rather than a solid image area was selected in order to be able to capture the enlargement of image areas due to dot gain or tone value increase, which could have an significant effect on toner consumption. Also, since average halftone reproductions consist predominantly of tonal values other than solids, a 50% halftone dot appears to be the best compromise among the available options. The net toner weight results for the cyan, magenta, yellow and black test runs are shown in Table 1:

Cyan	3.7566 grams
Magenta	3.6903 grams
Yellow	2.1765 grams
Black	3.7625 grams

Table 1. *Net toner weight for CMYK test runs (30 sheets).*

The final objective is to calculate the weight of toner per unit contiguous image area, where unit contiguous image area is defined as a solid image area having a square area of 1 $in.^2$. This is done by first converting a given halftone percentage/image coverage combination and then converting it to its equivalent contiguous image area using the following equation:

$$\text{Contiguous Image Area1} = \text{Ratio of Image to Non-Image Areas} \times \text{Square Image Area} \qquad (2)$$

For example applying equation (2) to the 8x10 in, 50% halftone area of the test form used for this method results in $0.5 \times (8 \times 10) = 40\ in^2$ of contiguous image area.

Toner consumption per unit contiguous image area can now be calculated by the following equation:

$$\text{Toner consumption per unit contiguous image area} = \frac{NTW}{CIA \times NSP} \qquad (3)$$

Where NTW = Net Toner Weight (of a print run)
CIA = Contiguous Image Area
NSP = Number of Sheets Printed

Equation (3) was then used to calculate the Toner Consumption per Unit Contiguous Image Area for cyan, magenta, yellow and black print runs (Table 2). These values are intended to be used as toner constants to calculate and predict toner consumption of four-color process jobs printed on coated paper.

Cyan	0.0031305 gram/in^2
Magenta	0.0030752 gram/in^2
Yellow	0.0018137 gram/in^2
Black	0.0031354 gram/in^2

Table 2. CMYK toner consumption per unit contiguous image area measuring 1 in^2, (toner constants).

It should be noted here that in order to maintain the integrity of original digital files all color management including gray component replacement functions of the printing device were disabled. The final print-ready PDF format was created, either from jpeg, or CorelDraw files.

Testing the Accuracy of the Image Area Calculation Software Used

As it is not possible to determine the image coverage of pictorial four-color process image files by manual measurement methods and calculations a combination of computer programs consisting of a software package called APFill and Ghostscript (henceforth called Image Calculation Software) was used to determine the relative proportions of CMYK image areas of a PDF file. To verify the accuracy of this method a test form consisting of CMYK halftone wedges was created in CorelDraw and converted to a PDF file (Figure 4). Because all image elements of this test form have known rectangular shapes, sizes and halftone values it is possible to mathematically derive the contiguous CMYK image areas for this image file, against which the Image Calculation Software results could then be compared. The CMYK halftone wedges are composed of ten halftone steps increasing incrementally from 10–100%, where every step has a dimension of 1.5x0.8 in. or 1.2 in^2. In this case, because there are multiple halftone values to be considered, the contiguous image square area is calculated with equation (4):

$$\text{Contiguous Image Area2} = \sum (\text{Ratio of Image to Non-Image Areas x Square Image Areas}) \quad (4)$$

Mathematically derived contiguous image area

Applying equation (4) to one of the halftone wedges of the test form gives:

$0.1 \times 1.2 = 0.12$
$0.2 \times 1.2 = 0.24$
$0.3 \times 1.2 = 0.36$
$0.4 \times 1.2 = 0.48$
$0.5 \times 1.2 = 0.60$
$0.6 \times 1.2 = 0.72$
$0.7 \times 1.2 = 0.84$
$0.8 \times 1.2 = 0.96$
$0.9 \times 1.2 = 1.08$
$\underline{1.0 \times 1.2 = 1.20}$
$\Sigma = 6.60$

Thus the contiguous image area of the test form is 6.6 $in.^2$ for each of the four process colors.

Image Calculation Software derived contiguous image area

The Image Calculation Software can be used at image resolutions ranging from 72 dpi to 600 dpi; the latter of which was used because it results in the highest degree of accuracy.

As the Image Calculation Software reports contiguous image areas as a percentage of the press sheet area, absolute contiguous image areas were calculate using the following equation:

$$\textit{Contiguous Image Square Area} = \textit{Contiguous Image Area Ratio} \times \textit{Substrate Square Area} \quad (5)$$

The Image Calculation Software yielded 7.11% contiguous image area ratios for each process color and applying equation (5) gives:
$0.0711 \times (8.5 \times 11) = 6.64785\ in.^2$ contiguous image area per process color halftone wedge.

This constitutes 0.04785 $in.^2$ more than the mathematically derived square image area for this test form, or 0.0725% more than an absolutely correct result.

An error of less than 1% was deemed to be insignificant.

Figure 4. *Test form with known CMYK image square areas.*

Predicting Toner Consumption of Six Randomly Selected Images

The CMYK toner consumption constants in Table 2 were then tested as to their suitability to predict toner consumption of six different four-color process print runs of 30 sheets.

All images are four-color process reproductions with various proportions of cyan, magenta, yellow and black. The images printed (Figures 5–10) were randomly selected to simulate the incoming orders that a typical printing house might receive and the combined weight of cyan, magenta, yellow and black toner weight was calculated using equation (1).

Cyan, magenta, yellow and black image area percentages relative to a 8.5x11-in. sheet was determined by the Image Calculation software which were subsequently converted to contiguous image square areas using equation (5). The results are shown beside each image.

The predicted toner weight for cyan, magenta, yellow and black was calculated using the following equation:

Predicted Toner Weight on Paper =
Contiguous Image Square Area
x Toner Constant
x Number of Sheets Printed (6)

Where Toner Constant = 0.0031305 for Cyan
0.0030752 for Magenta
0.0018137 for Yellow
0.0031354 for Black

Image Calculations
C: *31.62%*
0.3162 x (8.5x11) = 29.5647 in^2
M: *13.75%*
0.1375 x (8.5x11) =12.856225 in^2
Y: *3.09%*
0.0309 x (8.5x11) = 2.88915 in^2
K: *0.54%*
0.0054 x (8.5x11) = 0.5049 in^2

Figure 5. *Dock.*

Predicted Toner Weight (30 Sheets)

C: *29.5647 x 0.0031305 x 30 =*	*2.776566 g*
M: 12.856225 x 0.0030752 x 30 =	1.186065 g
Y: *2.88915 x 0.0018137 x 30 =*	*0.1572 g*
K: *0.5049 x 0.0031354 x 30 =*	*0.04749 g*
Total:	***4.167321 g***

Image Calculations
C: *20.06%*
0.2006 x (8.5x11) = 18.7561 in^2
M: 23.93%
0.2393 x (8 x11) = 22.37455 in^2
Y: *35.12%*
0.3512 x (8.5x11) = 32.8372 in^2
K: *7.24%*
0.0724 x (8.5x11) = 6.7694 in^2

Figure 6. *Fall.*

Predicted Toner Weight (30 Sheets)

C: *18.756 x 0.0031305 x 30 =*	*1.761477 g*
M: *22.37455 x 0.0030752 x 30 =*	*2.064186 g*
Y: *32.8372 x 0.0018137 x 30 =*	*1.786704 g*
K: *6.794 x 0.0031354 x 30 =*	*0.636741 g*
Total:	***6.249108 g***

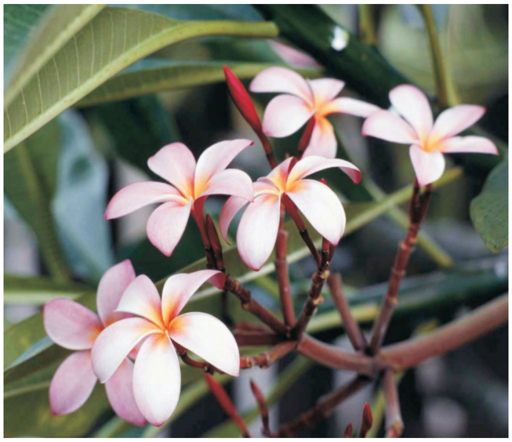


Image Calculations
C: *27.21%*
0.2721 x (8.5x11) = 25.44135 in^2
M: *24.02%*
0.2402 x (8.5x11) = 22.4587 in^2
Y: *28.37%*
0.2837 x (8.5x11) = 26.52595 in^2
K: *10.13%*
0.1013 x (8.5x11) = 9.47155 in^2

Figure 7. *Flowers.*

Predicted Toner Weight (30 Sheets)

C: *25.44135 x 0.0031305 x 30 =*	*2.389323 g*
M: *22.4587 x 0.0030752 x 30 =*	*2.071947 g*
Y: *26.52595 x 0.0018137 x 30 =*	*1.443303 g*
K: *9.47155 x 0.0031354 x 30 =*	*0.890910 g*
Total:	***6.795483 g***

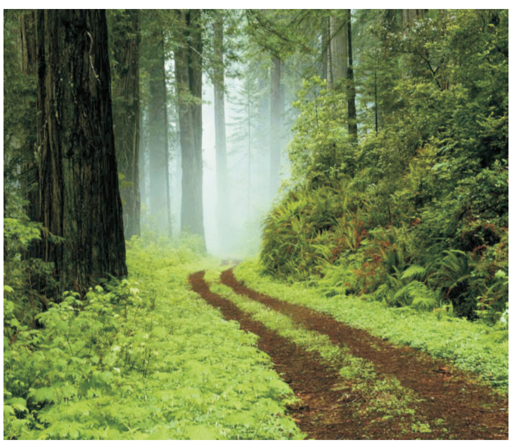


Image Calculations
C: *26.83%*
0.2683 x (8.5x11) = 25.08605 in^2
M: *18.22%*
0.1822 x (8.5x11) =17.0357 in^2
Y: *36.67%*
0.3667 x (8.5x11) = 34.28645 in^2
K: *8.54%*
0.854 x (8.5x11) = 7.9849 in^2

Figure 8. *Forest.*

Predicted Toner Weight (30 Sheets)

C: *25.08605 x 0.0031305 x 30 =*	*2.355954 g*
M: *17.0375 x 0.0030752 x 30 =*	*1.571811 g*
Y: *34.28645 x 0.0018137 x 30 =*	*1.865559 g*
K: *7.9849 x 0.0031354 x 30 =*	*0.751074 g*
Total:	***6.544398 g***

Image Calculations
C: *29.15%*
$0.2915 \times (8.5 \times 11) = 27.25525\ in^2$
M: *18.87%*
$0.1887 \times (8.5 \times 11) = 17.64345\ in^2$
Y: *31.46%*
$0.3146 \times (8.5 \times 11) = 29.4151\ in^2$
K: *5.08%*
$0.0508 \times (8.5 \times 11) = 4.7498\ in^2$

Figure 9. *Bird.*

Predicted Toner Calculations (30 Sheets)
C: *27.25525 x 0.0031305 x 30 = 2.559675 g*
M: *17.64345 x 0.0030752 x 30 = 1.627713 g*
Y: *29.4151 x 0.0018137 x 30 = 1.600503 g*
K: *4.7498 x 0.0031354 x 30 = 0.446775 g*
Total: ***6.234666 g***

Image Calculations
C: *23.45%*
$0.2345 \times (8.5 \times 11) = 21.92575\ in^2$
M: *19.52%*
$0.1952 \times (8.5 \times 11) = 18.2512\ in^2$
Y: *32.14%*
$0.3214 \times (8.5 \times 11) = 30.0509\ in^2$
K: *6.02%*
$0.0602 \times (8.5 \times 11) = 5.6287\ in^2$

Figure 10. *Waterfall.*

Predicted Toner Weight (30Sheets)
C: 21.92575 x 0.0031305 x 30 = 2.059155 g
M: 18.2512 x 0.0030752 x 30 = 1.68378 g
Y: 30.0509 x 0.0018137 x 30 = 1.635099 g
K: 5.6287 x 0.0031354 x 30 = 0.529446 g
Total: **5.90748 g**

Verifying the Accuracy of Toner Consumption Predictions

First the actual toner consumption has to be calculated using equation (1).

Thus:

Forest	*244.7337 g*
Paper	*–237.0946 g*
Actual Toner Weight = 7.6391 g	

Dock	*241.2291 g*
Paper	*–237.0946 g*
Actual Toner Weight = 4.1345 g	

Waterfall	*244.0955 g*
Paper	*–237.0946 g*
Actual Toner Weight = 7.0009 g	

Bird	*243.3380 g*
Paper	*–237.0946 g*
Actual Toner Weight = 6.2434 g	

Flowers	*244.0888 g*
Paper	*–237.0946 g*
Actual Toner Weight = 6.9942 g	

Fall	*243.1685 g*
Paper	*–237.0946 g*
Actual Toner Weight = 6.0739 g	

Finally, the difference or Δ between the total predicted toner weights and the actual total toner weight can be calculated using the following equation:

$$\Delta = \text{Predicted Toner Weight} - \text{Actual Toner Weight} \quad (7)$$

Thus:

Forest:

Predicted	*6.544398 g*
Actual	*–7.6391 g*
	Δ = –1.094702 g

Dock:

Predicted	*4.167321 g*
Actual	*–4.1345 g*
	Δ = 0.032821 g

Waterfall:

Predicted	*5.90748 g*
Actual	*–7.0009 g*
	Δ = –1.09342 g

Bird:

Predicted	*6.234666 g*
Actual	*–6.2434 g*
	Δ = –0.008734 g

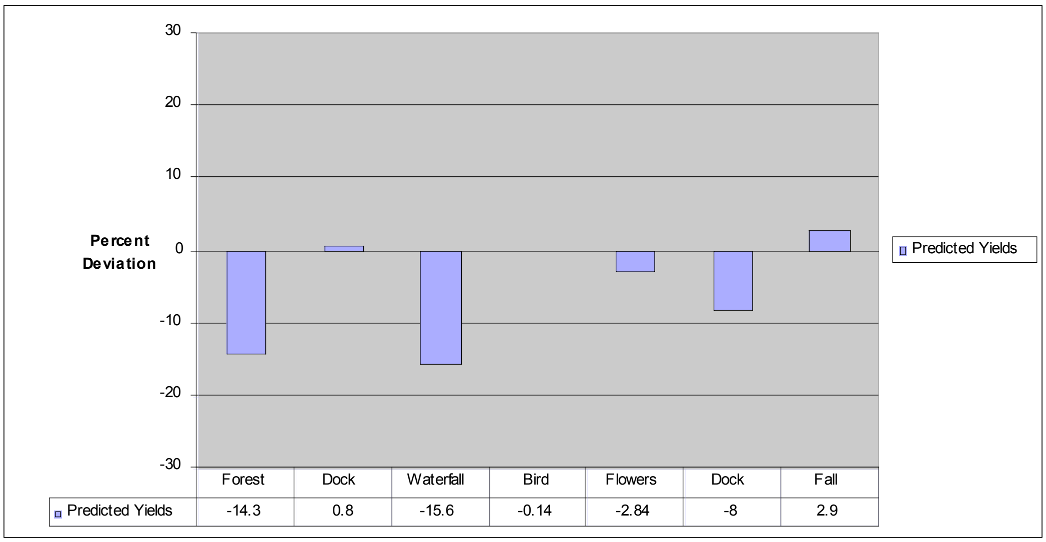
Flowers:

Predicted	*6.795483 g*
Actual	*–6.9942 g*
	Δ = –0.198717 g

Fall:

Predicted	*6.249108 g*
Actual	*–6.0739 g*
	Δ = 0.175208 g

Expressed as a percentage the deviations of predicted from actual toner consumptions are shown in Figure 11.



	Forest	Dock	Waterfall	Bird	Flowers	Dock	Fall
Predicted Yields	-14.3	0.8	-15.6	-0.14	-2.84	-8	2.9

Figure 11. *Percent deviation from actual tonal consumption.*

In order to ready electrophotographic printing systems for subsequent printing cycles the photoconductor surface has to be cleaned of toner particles that were not transferred to the substrate, with the practical implication of these remaining toner particles winding up in the waste container of the systems. Since the efficiency with which toners are transferred could be as low as 80%,[5] as much as 20% of the toner consumed is not accounted for in the foregoing calculations, because up to this point only toner particles that settled on the substrate were considered.

According to the published specifications of this device (Xerox DocuColor 7000) the toner waste bottle fills with approximately 50,000 prints. Since the aggregate weight of CMYK toner particles in the waste bottle was found to weigh 3.47 kg, it follows that the weight of toner wasted for every individual sheet printed is 3470 ÷ 50,000 = *0.0694* grams. As 0.00694 grams represents the waste toner aggregate for all four process colors, toner waste per individual process color is 0.0694 ÷ 4 = 0.01735 grams.

Total toner consumption is thus comprised of the toner weight on the substrate plus wasted toner weight, which can be expressed in the following equation:

Predicted Total Toner Weight of a Print Run =
Contiguous Image Square Area x Toner Constant x Number of Sheets Printed
+(0.01735 x Number of Sheets Printed) (8)

Where:

Toner Constant =0.0031305 for Cyan
0.0030752 for Magenta
0.0018137 for Yellow
0.0031354 for Black

Waste Constant = 0.01735

Shown in Table 3 below are the yield projections as stated by the manufacturer of the device, against which the calculated predicted yields can now be compared.

The manufacturer's yield projections shown are expressed as the number of impressions that can be obtained from toner cartridges holding 2,12 kg, 2.12 kg, 1.76 kg, and 1.86 kg for the cyan, magenta, yellow and black toner cartridges respectively.

30% Total Area Coverage (7.5% per color)	45% Total Area Coverage (11.25% per color)	60% Total Area Coverage (15% per color)
Black: 36,000	Black: 25,000	Black: 19,000
Cyan: 58,000	Cyan: 39,000	Cyan: 29,000
Yellow: 58,00	Yellow: 39,000	Yellow: 29,000
Magenta: 58,00	Magenta: 39,000	Magenta: 29,000

Table 3. *Manufacturer's toner yield projections.*

Because the yield projections shown in Table 3 are proportionally identical to each other it is immaterial which total area coverage will be compared to the calculated predicted yields. Thus all further discussion will be based on the 60% or 15% per color total area coverage.

Using the CMYK toner constants from Table 2 and a toner waste constant of 0.01735 the predicted total toner weight for one printed sheet for each color having a given total area coverage will be calculate by first determining that 1 in^2 represents 1.06951% of an 8.5x11 press sheet and then applying the following equation:

Total toner weight for one sheet with given total area coverage =

$$\left(\frac{TCxTAC}{1.06951}\right)+0.01735 \qquad (9)$$

Where TC = Cyan Toner Constant 0.0031305
Magenta Toner Constant 0.0030752
Yellow Toner Constant 0.0018137
Black Toner Constant 0.0031354

TAC = Total Area Coverage

Thus for 15% total area coverage in each of cyan, magenta yellow and black we calculate:

<u>Cyan</u>

$\left(\frac{0.003105x15}{1.06951}\right)+0.01735$ = 0.0612556 total toner weight at 15% total area coverage

<u>Magenta</u>

$\left(\frac{0.0030752x15}{1.06951}\right)+0.01735$ = 0.06048 total toner weight at 15% total area coverage

<u>Yellow</u>

$\left(\frac{0.0018137x15}{1.06951}\right)+0.01735$ = 0.0427873 total toner weight at 15% total area coverage

<u>Black</u>

$\left(\frac{0.0031354x15}{1.06951}\right)+0.01735$ = 0.0613243 total toner weight at 15% total area coverage

Dividing these toner weights per sheet into the weight that individual toner cartridges hold gives the yield per toner cartridge:

<u>Cyan</u>
2120 ÷ 0.0612556 = **34,609** sheets (8.5x11) can be printed from one toner cartridge

<u>Magenta</u>
2120 ÷ 0.06048 = **35,052** sheets (8.5x11) can be printed from one toner cartridge

<u>Yellow</u>
1760 ÷ 0.0427873 = **41,133** sheets (8.5x11) can be printed from one toner cartridge

<u>Black</u>
1860 ÷ 0.0613243 = **30,330** sheets (8.5x11) can be printed from one toner cartridge

Figure 12 shows that the predicted yields are clearly higher than the manufacturer's yield projections. An addendum to the manufacturer's own yield projections states that actual yield projections could vary greatly depending on color intensity, area coverage, paper stock and mode selection.[6] Specifically, the manufacturer identifies *Xerox Digital Color Xpression +* (90 g/m^2) and *Xerox Digital Color Gloss Coated Text* (120g/m^2) for uncoated and coated paper stocks respectively as so called "centerline papers" on which performance projections are based (ibid., 3). Toner yield differences could thus in part have been caused by substrate dissimilarities, as the paper used in this research is the equivalent of 187–220 g/m^2 coated stock.

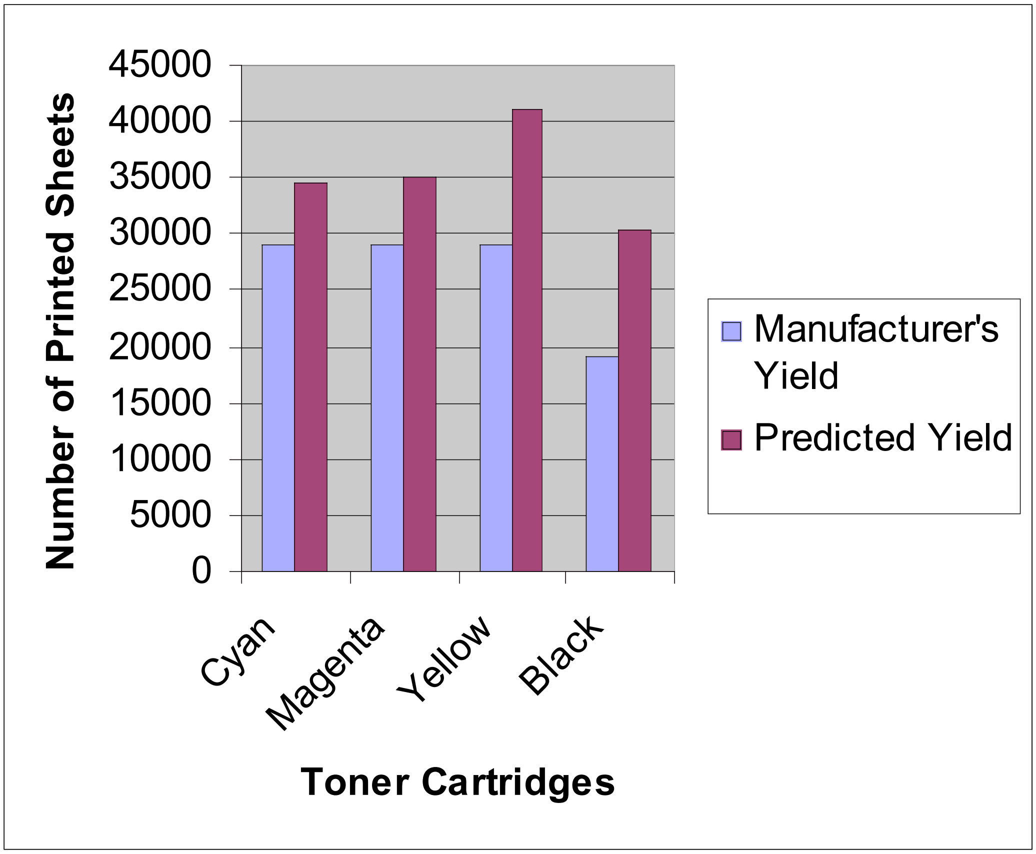


Figure 12. *Manufacturer's vs. predicted yields at 60% total area coverage (15% per color).*

According to the manufacturer's yield projections, the sum of all pages that can be printed from four CMYK full toner cartridges amounts to 106,000, whereas the calculated predicted yields come to 141,122 pages or a difference of 35,122 pages. Expressed as a percentage it can therefore be stated that the calculated predicted values yield 33% more pages than the manufacturer's projections.

Conclusion

The accuracy of the described method to predict toner weights on paper ranged from more than 99% to 84.4%. While it is encouraging to note that in four out of six test runs the predictions came within 92% accuracy there were two outliers with 85.7% and 84.4% predictions rates respectively. The majority of calculated weight predictions were somewhat lower than the actual weights. Possible reasons for the variability in these test results include the dynamic changes that paper is subjected to because of relative humidity fluctuations, minuscule press sheet size variations, and the variability of the printing device itself.

When waste toner is included, the calculated yield predictions were 33% higher than the manufacturer's yield projections, which demonstrates that toner yields can deviate significantly from the manufacturer's specification, which are based on average rather than specific job parameters.

One of the first estimating principles is to know the cost of job. A 33% overestimate of toner consumption will lead to inflated cost estimates and could consequently put a printer in an uncompetitive position.

The proposed constants to predict toner yields can only be used when identical production parameters exist, short of which, the constants used in this study must be recalculated. For digital presses other than the one used for this research it will probably be necessary to adopt the procedures described here to arrive at customized values that are reflective of a printing device's technical peculiarities.

The recommended toner consumptions per square inch of solid image area printed with a Xerox DocuColor 7000 digital press on Xerox Digital Synthetic Paper or coated paper weighing 187–220g/m^2 is:

Cyan,	0.0031305 gram/in^2
Magenta,	0.0030752 gram/in^2
Yellow,	0.0018137 gram/in^2
Black,	0.0031354 gram/in^2

The amount of toner waste per printed sheet was determined to be 0.01735 grams.

Further research, using the proposed methods to estimate toner consumption, will be conducted for other digital printing processes. With regard to drop on demand ink jet printing, the possibility to weigh toner consumed at the source exists, which should eliminate some of the problems introduced when quantifying toner weights on the printed substrate.

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Appendix

<u>Instrumentation</u>

Precision Analytical Balance
Pinnacle, Model PI-314
Denver Instruments

Capacity:	310 grams
Readability:	0.1 mg
Repeatability:	0.1 mg
Linearity:	0.3 mg
Pan Size:	3.1 in. dia

<u>Printing Device</u>

Xerox DocuColor 7000 Digital Press
Electrophotography

Resolution:	2400x2400x1 dpi
Imageable Area:	12.4x18.9 in
Paper weight range:	60–300g/m^2

<u>Paper</u>

Xerox Polyester Paper, 3.7 mil
Equivalent of 187–220 g/m^2, coated 2 sides, gloss, smooth

<u>Software</u>

APFill Ink & Toner coverage meter v4.4.4009
Ghostscript v8.61

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