Use of Ink Modeling and Volumetric Equations for Closed Loop Control of Optical Density in Coldset Newspaper Applications

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Abstract

This paper describes the development and use of ink models, volumetric equations, and machine translations to accurately control process color and black ink optical density in coldset newspaper application using three-color gray and solid black. It will also provide analysis and results from running data collected during actual production runs.

There are several enabling procedures and technologies that support the use of this methodology for ink density control. Specifically:

- Standardization of raw materials (ink, fountain, plates)
- Development of repeatable imaging to the plate substrate
- Development of digital controls for newspaper presses
- Development of repeatable water application within a tolerance with spray bars
- Development of accurate and repeatable metering of ink on a per column basis through the use of digital ink pumps
- Development of on-line and off-line scanning spectrodensitometer reading devices
- Development of linear curves to control ink and water

Use of optical density as the control feedback mechanism to the press controls and press operators keeps the operating environment on a common platform. There is no translation of the optical density readings as they are read using industry standard spectrodensitometer instruments and used as optical density readings. This provides for sufficient inter-instrument agreement between scanning and handheld instruments. Understanding of cyan, magenta, yellow, and black optical density is ubiquitous among press operators and this reduces the hurdle to accept the ink adjustment methodology.

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Use of this technology improves end-to-end quality performance available from coldset newspaper applications.

Introduction

As coldset newspaper presses are augmented or built new with additional or full process color capacity in multi-web configurations, development of on-line closed loop control of ink density provides a way to improve the quality and repeatability of product without adding to staffing requirements. The authors developed and applied this technology in off line proof of concept and closed loop on-line production applications across a network of 17 locations and 19 double-width 12 web newspaper presses.

Assumptions

There are several assumptions regarding necessary calibrations and enabling technologies that led to the development of the ink setting algorithm and defining the operating environment necessary to get the best results from an implementation.

- Specifications for Newsprint Advertising Production *(SNAP Committee 2009)*

  SNAP is a set of guidelines that is used to define the specifications of coldset printing on newsprint. These guidelines were used to define the parameters used in the print environment used to develop this technology including the density specifications (Table 1). In 2007, the SNAP printing process definition was legitimized through the Committee for Graphic Arts Technologies Standards (CGATS) and the publishing of the new ANSI standard: ANSI CGATS/SNAP TR 002-2007 *(CGATS 2007)*.

Color	Optical Density
Cyan	0.90
Magenta	0.90
Yellow	0.85
Black	1.05

  Table 1. *SNAP Solid Status T Optical Ink Density Targets.*

- Press Maintenance

  The operating environment assumes that the equipment is properly maintained and set up to manufacturer's specifications for impressions, roller durometer and stripes, tension system setup, and folder setup.

During the development of the ink control technology, nothing was assumed to be correct on the presses used to prove the concept. All equipment settings were recorded and checked against the manufacturer's specifications and corrected as required. All equipment corrections were recorded. It was necessary to ensure that the concept was proven on a “known” condition press.

All water and ink delivery systems were calibrated to deliver constant header pressure and constant pressure to device inlets. This proved to be difficult based on the systems that were installed at the beginning. Essentially, the ink and water systems as designed were not capable of delivering constant pressure regardless of demand. This poses a problem that must be corrected to get repeatable results from the printing system. The importance of this level of control will be discussed further later in this paper, suffice it to say that a digital system does not perform in a repeatable way when the feed pressure varies.

Ink and water delivery systems were redesigned to provide for constant ink pressure at device inlets regardless of demand. In both cases, it required the development of a smarter high-pressure header system using a system of pressure sensors, intelligent program controllers, volume boosters, and pumps to keep the headers at a constant pressure. Additional plumbing, full flow regulators, and gauges were installed to provide discrete regulated control to each device. Once this infrastructure was installed, it was calibrated to ensure constant header pressure and pressure at device inlets.

- Standardization of raw materials (ink, fountain, plates).

Coldset newspaper printing uses a variety of materials. The main consumables include film, plates, newsprint, fountain concentrate, water, and ink. On press, blankets and rubber rollers also have an impact on print reproduction.

Assuming that the materials are compatible with the process, it is important to standardize the materials used in the manufacturing to achieve repeatability and consistency of product. Furthermore, the ink-setting technology presented in this paper is not an adaptive technology. When implemented, it relies on the fact that consumables and the operating variables will remain consistent over time.

This is easily achieved in newspaper printing because the substrate doesn’t change, nor does the ink set, but it is critical to continuously work with manufacturers for consistent raw material shipments. To get the entire process under calibration, it is also necessary to ensure that the other essential materials used in the process are standardized and single sourced if possible from one manufacturer using one formula. Examples include the use of reverse osmosis processed water, a single fountain solution concentrate formula, a single set of ink formulas, a single plate substrate/chemistry system, a single film/chemistry system, etc.

Materials, staffing, and machine time are all consumed to calibrate the manufacturing systems. For manufacturing and print reproduction consistency and repeatability, it is important to reduce variables by standardizing materials and therefore avoiding the behavior of switching from product to product. Using this methodology, it’s possible to accurately repeat the results from press to press even if they are not in the same location. This methodology also allows easier and quicker troubleshooting of manufacturing issues.

- Repeatable imaging to the plate substrate.

  During the development of the technology, it was done using conventional film and plate workflow in prepress. Film imaging systems were calibrated to provide linear measured results on film using a calibrated transmission densitometer (i.e., 20% = 20%, 30% = 30% ... n% = n%). Plates were calibrated for exposure and vacuum using UGRA and FOGRA plate control gauges.

  The technology also works with plates made by computer-to-plate (CTP) imaging systems. CTP imaging systems are calibrated to provide linear measured results on rubbed back plates using the SNAP guideline for rubbing back and using a calibrated plate dot reader (i.e., 20% = 20%, 30% = 30% ... n% = n%) (SNAP Committee 2009).

- Digital controls for newspaper presses.

  Digital master and local controls for newspaper presses have become an enabler for doing complex math to preset ink, water, and other equipment settings needed to cold start the system within a nominal operating range that produces saleable copies quickly with a minimum of waste.

  The digital environment has provided a way to interface key components of the printing system together: presetting, press controls and auxiliary devices (such as spectrodensitometers, register systems, reporting systems, etc.)

Part of the technology requires that the ink coverage file generated for a page is accurately calculated during the RIPping process. This is achieved by RIPping known images that have mathematically known results for each ink key on the press. For instance, it is possible to create a page that has 20% total area coverage across the width of the page when checked manually using area calculations. The result from such a page through the workflow should result in an ink coverage file that has 20% ink coverage for each ink key on the page. Ink density calculations in the workflow were validated to ensure the test environment was accurate.

- Repeatable water application within a tolerance for spray bars.

  The spray bars used for the test environment delivers fountain water repeatable within ±10% for gross measured nozzle output and ±15% for distributed measured nozzle output across the bar using two-inch increments at the normal bar to roller distance. As was discussed, it was quickly discovered that more water pressure at the inlet to a spray bar yields more water output for the same on time for a spray nozzle. This pressure differential was eliminated by installing a redesigned water delivery system. A test stand is used to maintain the spray bars and balance the output within tolerance. For the test environment every spray bar was validated to be set to the standard specifications. Separate tests were performed to ensure repeatable and linear output results from calibrated spray bars.

  In addition, the curves controlling water were developed with the calibrated water system so that under nominal conditions, minimal water adjustments off of preset are necessary during a production run. This is an important point. The reality with spray bars is they pulse water at a relatively slow rate of one spray for every five to six folder cutoffs. This means the printing system always carries more water than is necessary to produce a clean lithographic image. Furthermore, there is web fan-out to control with four-color printing on newsprint. One method to control this fan-out is to always apply the same volume of water regardless of the print image or if a position has a blank plate. This is the methodology used to calibrate the water systems for the test and production environment. It does not pose a problem because newsprint is very absorbent and easily takes the water away in the printed copy.

  In order to control inking with mathematics, the water needs to be repeatable and controlled.

- Accurate and repeatable metering of ink on a per-column basis through the use of digital ink pumps.

  Newspaper presses in the United States tend to be equipped with ink pumps and rails versus conventional open fountain systems. The test environment was equipped with various solutions for digital metering of ink to each column through individual ink column pumps. The accuracy, repeatability, and linearity of the measured volume output from digital ink pumps were validated through independent testing. Again, it was quickly discovered that more ink pressure at the inlet to the ink pump yields more ink output for the same revolutions or on-time depending on the digital ink pump design. This pressure differential was eliminated by installing a redesigned ink delivery system.

  Analog newspaper inking systems such as open fountains and analog ink pumps can also use this ink adjustment technology; however, the results of the total system exhibit inherent inaccurate and non-repeatable results typically received from an analog system.

- Off-line and on-line scanning spectrodensitometer reading devices.

  In general, newspapers do not use a patterned bar for measuring ink density. Instead, a three-color gray bar built of screened process colors and sometimes a black bar is used. Pressmen can use handheld spectrodensitometers to read these bars. This is the primary means to ensure proper ink settings within specification on press.

  The proof of concept for the ink setting technology was done using optical density readings with handheld spectrodensitometers set to Status T response. The gray bar was designed to yield an optical density reading of 0.60 for cyan, magenta, and yellow. In addition, solid color bars and a solid black bar were initially used.

  As other devices became available, they were used in the production implementations of the technology. Initial installations were done using an off-line bar scanner. Printed pages were scanned and the ink density data was moved digitally to the press control system where the math was performed. Later, an on-web scanning system was used and the data from this system was captured from a semi-patterned gray bar with black solid patches.

- Linear curves to control ink and water.

  Once the process is under control by getting the previous variables under control, it becomes possible to use linear ink and water curves for control of the printing system (Charts 1 and 2). Essentially, more speed equals more ink and water, more ink coverage equals more ink; it can be described as a linear relationship within the press controls.

Chart 1. *Linear ink curve examples.*

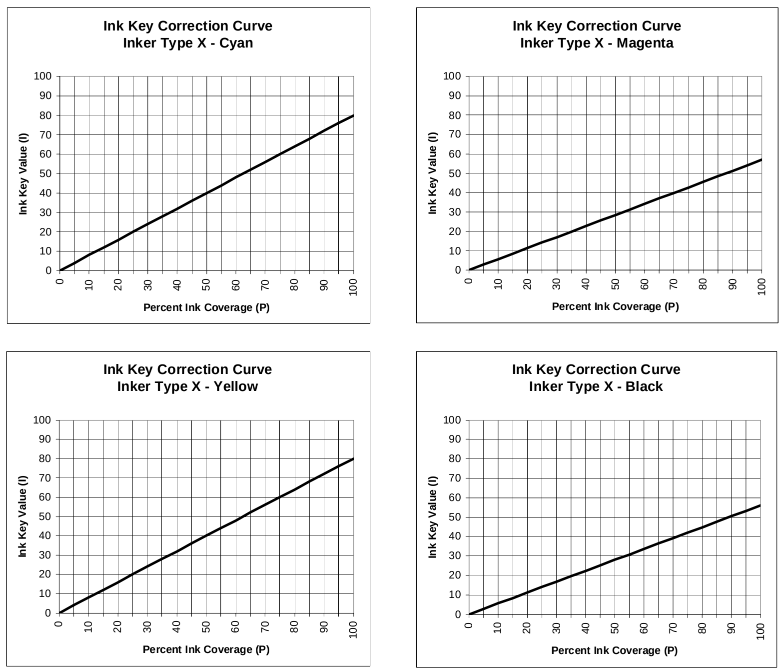
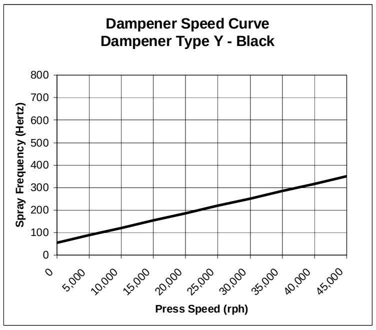
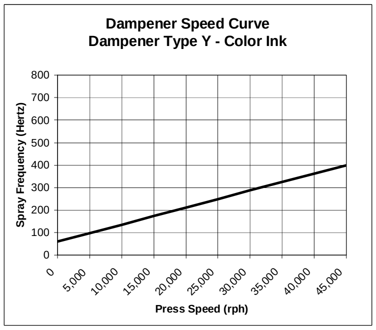


Chart 2. *Linear water curve examples.*



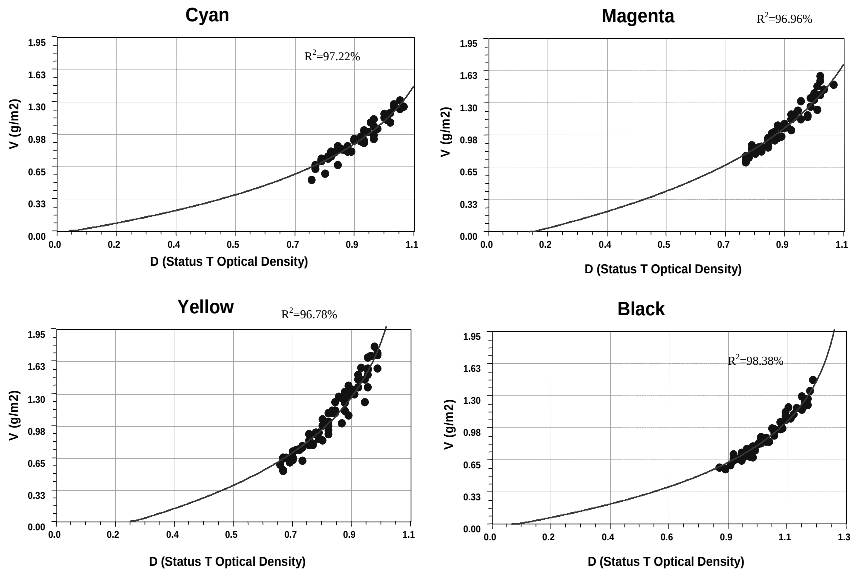


Ink Model

Standardizing on one set of ink formulas is necessary because the ink setting mathematics use an "ink model" which is created from the inks themselves. If the ink formulas keep changing, new ink models need to be established. This is not an issue and can be done but it is a time-consuming process.

The ink models were developed for each color using split samples and standard lab testing procedures on a PrufBau Printability Tester (Flint Group 2004). The following charts illustrate an actual scatter of data points from one of the tests (Chart 3, Appendix 1).

Chart 3. *Scatter of ink tests.*



As a separate study, blind samples were collected from the several ink manufacturing plants that supply the 17 plant infrastructure. It was discovered that one ink manufacturing plant exceeded the 0.5% specification and this data was excluded. The ink manufacturing process for that plant was corrected. It was important to know the tolerance of variability to determine if a national implementation of the new ink setting concept was actually possible.

Ink models are also known as ink mileage charts. They are created by running several samples of a fixed area with different ink film thicknesses on standard newsprint through the PrufBau Printability Tester. Samples are measured for ink density using a spectrodensitometer and weighed on a laboratory scale before and after printing. Then a calculation is made to determine how many grams per square meter create a specific optical density.

The data is collected and when it is complete, a curve fitting model is performed to determine the mathematical description of the ink model for each color. In the case of the data collected for this implementation, the best fit curve is more commonly known as an exponential growth curve (Equation 1 and Chart 4). This curve best describes the characteristics of ink on paper, with a rapid logarithmic increase in density as ink is applied to white paper that plateaus as the ink reaches the point of saturation or mass tone.

$$y = -c_t \ln (b_t - a_t x) \qquad \textbf{(Equation 1)}$$

Where: y = Volume (g/m^2)

x = Optical Density (Status T)

c_t, b_t, and a_t are constants

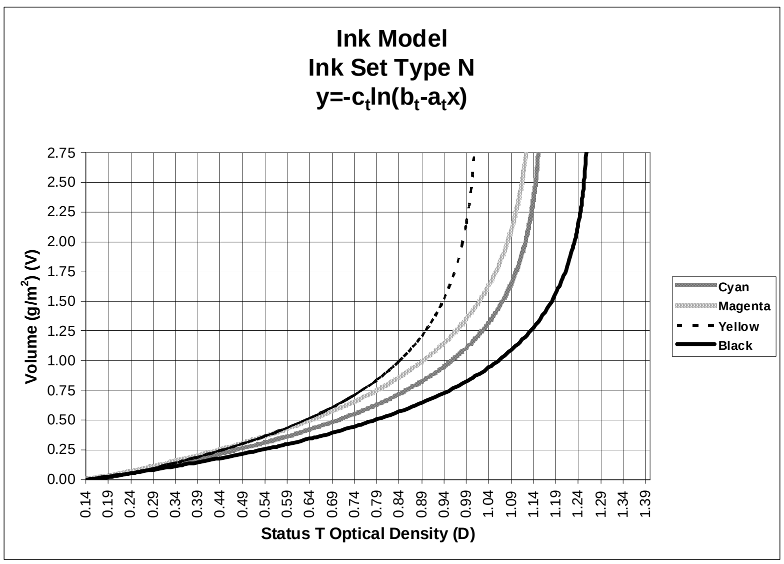
Cyan $y = -0.62051 \ln (1.12919 - 0.97131x)$

Magenta $y = -0.72525 \ln (1.14255 - 0.99719x)$

Yellow $y = -0.64337 \ln (1.20349 - 1.18002x)$

Black $y = -0.59309 \ln (1.12724 - 0.88777x)$

Chart 4. *Ink model.*



Ink Adjustment Algorithm

The ink adjustment algorithm uses the Linear Ink Preset Curves (Charts 1 and 2) and the Ink Models (Chart 4) as part of the calculations that are performed to determine the recommended ink adjustment.

The variables defined for the ink setting algorithm are as follows:

- D_c = Current Status T Optical Density Value

  This data is provided by taking actual optical density readings from printed samples using a spectrodensitometer. The data range is 0.000 to 1.300. A spectrodensitometer provides values for gray bar and solid ink density; the default is graybar for cyan, magenta, yellow and solid ink density for black.

- D_t = Target Ink Density Value Setting

  SNAP density targets were used for solid bars and a 0.60 gray bar is also used. The values used in the testing are as follows:

Color:	**Graybar Density Target**	**Solid Ink Density Target**
Cyan	0.60	0.90
Magenta	0.60	0.90
Yellow	0.60	0.85
Black	0.60	1.05

- A = Calculated Ink Volume Adjustment Factor (Equation 2)

  The basis for this adjustment factor is derived from the ink model (Chart 4).

$$A = ((V_t - V_c)/V_c) \times 100$$ **(E**

Where:

V_c = Current Volume of Ink (g/m^2) given D_c

V_t = Target Volume of Ink (g/m^2) given D_t

Example 1:

Assume Current Black Ink density (D_c) is 0.90.

Black Ink Model

y = –0.59309 ln (1.12724 – 0.88777x)

Calculate Current Volume:

substitute Current Volume and Target Density

V_c = –0.59309 ln (1.12724 – 0.88777(D_c))

V_c = –0.59309 ln (1.12724 – 0.88777(0.80))

V_c = 0.66

Assume Target Black Ink density (D_t) is 1.00.

Calculate Target Volume:

substitute Target Volume and Target Density

V_t = –0.59309 ln (1.12724 – 0.88777(D_t))

V_t = –0.59309 ln (1.12724 – 0.88777(0.80))

V_t = 0.85

Calculate the ink volume adjustment factor:

A = ((V_t - V_c)/V_c) × 100

A = ((0.85 – 0.66)/0.66 × 100

A = 28.7%

Example 2:

Assume Current Black Ink density (D_c) is 1.07.

Black Ink Model

$y = -0.59309 \ln (1.12724 - 0.88777x)$

Calculate Current Volume:

substitute Current Volume and Target Density

$V_c = -0.59309 \ln (1.12724 - 0.88777(D_c))$

$V_c = -0.59309 \ln (1.12724 - 0.88777(0.80))$

$V_c = 1.03$

Assume Target Black Ink density (D_t) is 1.00.

Calculate Target Volume:

substitute Target Volume and Target Density

$V_t = -0.59309 \ln (1.12724 - 0.88777(D_t))$

$V_t = -0.59309 \ln (1.12724 - 0.88777(0.80))$

$V_t = 0.85$

Calculate the ink volume adjustment factor:

$A = ((V_t - V_c)/V_c) \times 100$

$A = ((0.85 - 1.03)/1.03 \times 100$

$A = -17.5\%$

- I_c = Current Ink Key Value Setting

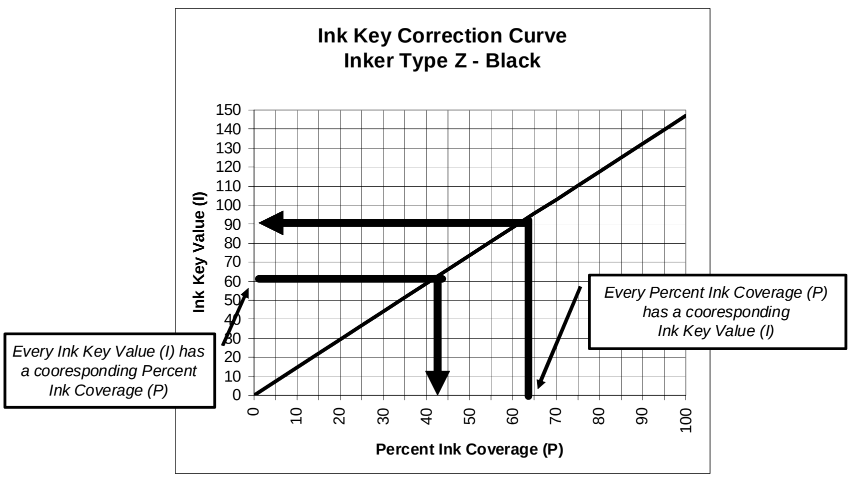
  This is the current active ink key value for a column. With digital ink pumps, this is specific number that will range depending on the design of the digital inking system. Because the ink preset curve is used in the calculations, this allows for supporting multiple inking systems on the same press.

- I_n = New Calculated Ink Key Value Setting

Not all inkers have the same ink key correction curve. To make the final calculation on how to adjust each ink key, it is a four-step process.

The Ink Key Correction curves (Chart 1) have two axes, one is the Ink Key Value Setting (I) and the other is the Percent Ink Coverage (P). For each Ink Key value, there is a corresponding Percent Ink Coverage (Chart 5):

Chart 5. *Corresponding ink key values and percent ink coverage.*



When:	I_c = Current Ink Key Value Setting
Then:	P_c = Current Percent Ink Coverage
When:	I_n = New Calculated Ink Key Value Setting
Then:	P_n = New Calculated Percent Ink Coverage

The first step is to translate the Current Ink Key Setting (I_c) into a Current Percent Ink Coverage (P_c) using the appropriate Ink Key Correction curves (Chart 1).

Second, use the Current Percent Ink Coverage (P_c) and the Calculated Ink Key Adjustment Factor (A) to produce the New Calculated Percent Ink Coverage (P_n) (Equation 3):

$$P_n = (P_c) + (P_c \text{ x } A)$$

Third, translate the New Calculated Percent Ink Coverage (P_n) into a New Calculated Ink Key Value Setting (I_n) using the appropriate Ink Key Correction curves (Chart 5).

Fourth, apply the New Calculated Ink Key Value Setting (I_n) to the ink column on press.

<u>Example 1a (Chart 6):</u>

Assume Current Black Ink density (D_c) is 1.07.

Assume Target Black Ink density (D_t) is 1.00.

Assume that the black inker Current Ink Key Value Setting (I_c) of 25 has a corresponding Current Percent Ink Coverage (P_c) of 17.

Assuming the 28.7% calculated ink volume adjustment factor (A) from Example 1:

The New Calculated Percent Ink Coverage (P_n) is calculated:

$$P_n = (P_c) + (P_c \times A)$$

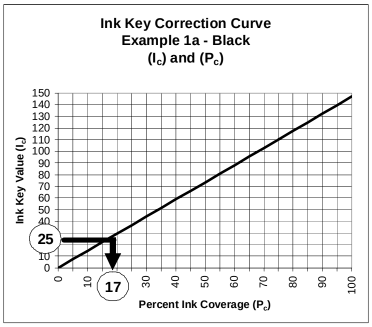
$$P_n = 17 + (17 \times 28.7\%)$$

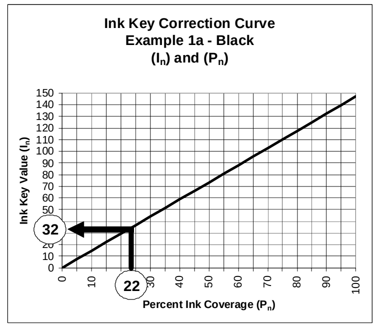
$$P_n = 22$$

Translate the New Calculated Percent Ink Coverage (P_n) into a New Calculated Ink Key Value Setting (I_n) using the appropriate Ink Key Correction curves (Chart 1). In this case, the corresponding New Calculated Ink Key Value Setting (I_n) is 32.

The ink key is adjusted on press to a setting of 32.

Chart 6. *Example 1a.*





Example 2a:

Assume Current Black Ink density (D_c) is 0.90.

Assume Target Black Ink density (D_t) is 1.00.

Assume that the black inker Current Ink Key Value Setting (I_c) of 39 has a corresponding Current Percent Ink Coverage (P_c) of 27.

Assuming the –17.5% calculated ink volume adjustment factor (A) from Example 2:

The New Calculated Percent Ink Coverage (P_n) is calculated:

$$P_n = (P_c) + (P_c \times A)$$

$$P_n = 27 + (27 \times -17.5\%)$$

$$P_n = 22$$

Translate the New Calculated Percent Ink Coverage (P_n) into a New Calculated Ink Key Value Setting (I_n) using the appropriate Ink Key Correction curves (Chart 1). In this case, the corresponding New Calculated Ink Key Value Setting (I_n) is 32.

The ink key is adjusted on press to a setting of 32.

System Implementations

Once the proof of concept was developed using handheld devices, there were two types of production implementations installed using this ink adjustment algorithm.

The first implementation uses gray bars as the control pattern, and an off-line scanning spectrodensitometer is used to take density readings of cyan, magenta, and yellow. These readings are provided through an interface to the press control system where the algorithm is used to perform automatic ink key corrections. This has been installed and running successfully for over five years across a network of 17 locations and 19 double-width newspaper presses.

The second implementation uses a patterned gray bar with solid black boxes. It uses different spectrodensitometer scanning system mounted on the press itself—it measures optical ink density on the running web providing readings for cyan, magenta, yellow, and black. These readings are provided through an interface to the press control system where the algorithm is used to perform automatic ink key corrections. This has been installed and run successfully on one web of one press for a couple of months to prove out the automated concept. Due to the ability to collect data easily from this setup, this will be used to analyze how effective the algorithm can be for controlling ink density.

Data Analysis

As mentioned earlier in the previous paragraph, during the second implementation, a spectrodensitometer scanning system was mounted on the press. To measure the effectiveness of the algorithm, the system was set up in two modes: Manual Mode and Closed Loop or Automatic Mode. 1,146 data points per color were used for this analysis for the Manual Mode and 629 data points for the Automatic Mode. The data was collected over 13 printing days.

During the Manual Mode, the scanning system only captures and records the ink adjustments made by the operators, but it does not perform automatic ink adjustments. The data collected during this mode is used as the baseline data.

The Closed Loop Mode allows the scanning system to adjust ink automatically using the algorithm defined as the Ink Model. The essential step in Closed Loop Mode is to determine the scan frequency and therefore the frequency of the ink adjustments. If scan frequency is set incorrectly, it causes ink fluctuations and unstable inking. During the implementation, the system was set to scan every 2,500 folder cutoffs. Due to changes required to press control system, black ink density was not controlled and measured during testing. The system only allowed ink adjustments for cyan, magenta, and yellow.

Once the data is collected, the analysis was conducted for each color. Manual Mode and Closed Loop Mode were tested for equal means, equal variances, and proportions (Pyzdek, 2000).

Controlling Cyan Ink Density

In Manual Mode, 15.88% of samples did not meet ink density specification. With closed loop inking, this was reduced to 10.81%. There were minimal changes to average ink density from Manual to Closed Loop Mode, average ink densities at 0.609 and 0.605 respectively. During manual process, the samples that did not meet ink density specifications were mostly set on the higher end. During closed loop ink control, the cyan ink density was centered and variation was reduced (Chart 6).

Controlling Magenta Ink Density

When ink adjustments were made manually by the operators, 19.37% of magenta ink densities were out of specification. With Closed Loop Mode using the algorithm, more copies meet density specification, the variation is smaller and the mean is centered to the target (Chart 6).

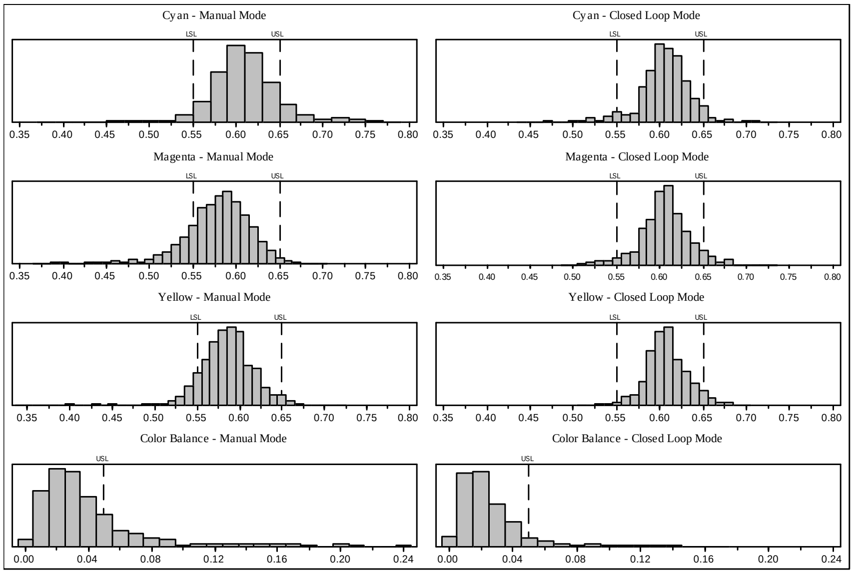
Controlling Yellow Ink Density

When ink adjustments were made manually by the operators, yellow ink density average was 0.584 with 13% of copies out of ink density specification. During closed loop ink density control, average yellow ink density was 0.608 with reduced variation and only 5.56% of copies did not meet ink density specification (Chart 6).

Controlling Color Balance

Color balance has shown the most significant improvement with the use of ink adjustment algorithm. The statistical findings are consistent with color ink density findings. From manual process to closed loop inking 14.71% more copies met color balance specification and the average color balance moved from 0.042 to 0.026 (Chart 6).

Chart 6. *Ink density and color balance comparison (manual vs. closed loop).*



Based on this study of 7,100 sample points, we are 95% confident that (Table 2, Appendices 6, 7, 8, 9):

1. The Closed Loop Mode and Manual Mode have statistically different means and Closed Loop Mode using the ink adjustment algorithm was closer to meeting optical ink density specifications for the gray bar *(target is 0.60 optical ink density for cyan, magenta and yellow).*
2. The Closed Loop Mode has a smaller variance than the manual process variance. The data is centered on the target for each color and color balance.
3. The percent compliance for Closed Loop Mode is greater than the Manual Mode for optical ink density and color balance.

Table 2. *Summary of statistics.*

Color	Test Phase	N	% Compliant	Mean	StDev	SE Mean	95% CI
Cyan	Manual	1146	84.12%	0.609	0.0410	0.00121	(0.60660, 0.61136)
	Closed Loop (Auto)	629	89.19%	0.605	0.0334	0.00133	(0.60201, 0.60724)
Magenta	Manual	1146	80.63%	0.576	0.0405	0.00120	(0.57412, 0.57881)
	Closed Loop (Auto)	629	90.78%	0.606	0.0296	0.00118	(0.60328, 0.60791)
Yellow	Manual	1146	87.00%	0.584	0.0348	0.00103	(0.58213, 0.58617)
	Closed Loop (Auto)	629	94.44%	0.608	0.0243	0.00097	(0.605910, 0.609721)
Color Balance	Manual	1146	76.70%	0.042	0.0398	0.00118	(0.03982, 0.04444)
	Closed Loop (Auto)	629	91.41%	0.026	0.0220	0.00088	(0.023950, 0.027395)

Conclusions

Use of optical density as the control feedback mechanism to the press controls and press operators keeps the operating environment on a common platform. There is no translation of the optical density readings as they are read using industry standard spectrodensitometer instruments and used as optical density readings. This provides for sufficient inter-instrument agreement between scanning and handheld instruments. Understanding of cyan, magenta, yellow, and black optical density is ubiquitous among press operators, and this reduces the hurdle to accept the ink adjustment methodology.

Use of closed loop control with an algorithm based on ink modeling and volumetric equations reduces variation and centers the data on optical ink density targets. As a result of this technology, more copies are printed within specification of optical ink density and color balance.

Use of this technology improves end-to-end quality performance available from coldset newspaper applications.

Acknowledgments

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Selected Bibliography

Committee for Graphic Arts Technologies Standards (CGATS), 2007, “CGATS TR002.”

Flint Group, 2004, “Mileage/Receptivity – Newsink (PR-T150.0).”

Pyzdek, Thomas, 2000, “Quality Engineering Handbook,” pp 287–291.

SNAP Committee, 2009, “Specifications for Newsprint Advertising Production," August 2009.

Appendix

1. Raw Data for Creating Ink Model (next page)

Cyan

g/m^2	Density
1.225	1.05
1.1875	1.02
1.025	0.98
0.8875	0.94
0.85	0.89
0.7875	0.85
0.7	0.81
1.0875	1.02
0.925	0.97
0.9125	0.94
0.8	0.9
0.6625	0.86
0.575	0.82
0.5125	0.78
1.1125	1.01
0.9625	0.97
0.95	0.93
0.8	0.89
0.75	0.84
0.725	0.81
1.25	1.03
1.1375	1
1	0.95
0.925	0.91
0.825	0.87
0.725	0.83
0.625	0.79
1.25	1.06
1.125	1.01
1.05	0.97
0.9	0.93
0.8125	0.88
0.7875	0.84
0.7125	0.81
1.3125	1.05
1.175	1
1.0875	0.96
0.9	0.93
0.825	0.89
0.8	0.84
0.7125	0.81
1.275	1.03
1.125	0.97
1.0125	0.94
0.9125	0.91
0.85	0.86
0.75	0.83
0.6625	0.79

Magenta

g/m^2	Density
1.6625	1.11
1.4875	1.06
1.3875	1.02
1.175	0.98
1.025	0.93
0.9625	0.9
0.875	0.86
0.7875	0.82
0.7375	0.79
1.575	1.02
1.35	0.99
1.1875	0.94
1.05	0.91
1.0125	0.88
0.8625	0.84
0.8375	0.81
1.2375	1.01
1.1625	0.98
1.1375	0.93
0.95	0.89
0.85	0.86
0.8	0.81
1.525	1.02
1.4	1
1.225	0.95
1.0875	0.91
1	0.87
0.8375	0.83
0.7625	0.79
1.475	1.01
1.2625	0.99
1.1625	0.94
1.05	0.9
0.925	0.86
0.85	0.83
0.7	0.79
1.4	1
1.325	0.96
1.1875	0.93
1.075	0.89
0.95	0.86
0.875	0.81
1.4375	1.03
1.3375	1
1.1375	0.96
1.0625	0.92
0.925	0.88
0.8125	0.84
0.75	0.8

Yellow

g/m^2	Density
1.675	0.97
1.4375	0.95
1.3375	0.91
1.25	0.88
1.125	0.85
0.925	0.84
0.8875	0.8
0.75	0.76
0.65	0.73
0.6375	0.7
1.55	0.99
1.3625	0.96
1.2125	0.95
1.075	0.9
1	0.88
0.8875	0.84
0.825	0.82
0.7875	0.79
0.6125	0.76
0.6	0.72
0.5125	0.7
1.55	0.96
1.4375	0.93
1.275	0.9
1.1	0.86
0.975	0.84
0.9	0.8
0.775	0.79
0.725	0.75
0.6	0.72
0.575	0.69
1.7125	0.99
1.5625	0.94
1.375	0.9
1.2625	0.87
1.1	0.85
1.0375	0.82
0.8875	0.78
0.7625	0.76
0.7	0.73
0.65	0.7
1.775	0.98
1.6625	0.96
1.4875	0.93
1.3125	0.89
1.2125	0.86
1.1	0.84
0.975	0.82
0.8875	0.78
0.75	0.76
0.7125	0.73
0.65	0.7
1.4875	0.96
1.2875	0.92
1.25	0.89
1.125	0.89
1.125	0.86
1.0125	0.84
0.9	0.81
0.825	0.78
0.7375	0.75
0.625	0.73
0.5225	0.7
1.6875	0.99
1.5375	0.96
1.3625	0.93
1.2	0.89
1.125	0.86
0.975	0.82
0.8375	0.81
0.775	0.78
0.725	0.74
0.65	0.71

Black

g/m^2	Density
1.35	1.16
1.1625	1.13
1.075	1.07
0.925	1.03
0.8625	0.98
0.7625	0.93
0.7125	0.88
1.275	1.15
1.1125	1.1
0.9625	1.05
0.8375	1.01
0.75	0.96
0.725	0.91
0.6	0.87
1.175	1.11
1.0625	1.07
0.9375	1.03
0.8125	0.97
0.6875	0.92
0.65	0.88
1.2125	1.14
1.075	1.09
1.0375	1.05
0.8375	1
0.675	0.95
0.6625	0.9
0.575	0.83
1.2	1.14
1.1375	1.07
0.9	1.03
0.825	0.98
0.7375	0.93
0.65	0.88
1.2125	1.15
1.075	1.09
0.975	1.06
0.875	1
0.7875	0.95
0.65	0.91
0.5625	0.85
1.25	1.14
1.1	1.07
0.9625	1.03
0.8625	0.99
0.6875	0.94
0.6625	0.89
1.4625	1.17
1.3	1.13
1.1875	1.08
0.975	1.02
0.8875	0.98
0.7375	0.94
0.6625	0.88

2. Statistical Analysis Results Cyan

Two-Sample T-Test and CI: C_Manual, C_Auto

```
Two-sample T for C_Manual vs C_Auto

             N    Mean   StDev  SE Mean
C_Manual  1146  0.6090  0.0410   0.0012
C_Auto     629  0.6046  0.0334   0.0013

Difference = mu (C_Manual) - mu (C_Auto)
Estimate for difference:  0.00436
95% CI for difference:  (0.00083, 0.00789)
T-Test of difference = 0 (vs not =): T-Value = 2.42
P-Value = 0.016  DF = 1524
```

Test for Equal Variances: C_Manual, C_Auto

```
95% Bonferroni confidence intervals for standard
deviations

             N      Lower      StDev      Upper
C_Manual  1146  0.0391611  0.0409979  0.0430088
  C_Auto   629  0.0314119  0.0334022  0.0356514

F-Test (Normal Distribution)
Test statistic = 1.51, p-value = 0.000

Levene's Test (Any Continuous Distribution)
Test statistic = 21.59, p-value = 0.000
```

Test and CI for Two Proportions: C_Manual, C_Auto

```
Event = Pass

Variable    X     N  Sample p
C_Manual  964  1146  0.841187
  C_Auto  561   629  0.891892

Difference = p (C_Manual) - p (C_Auto)
Estimate for difference:  -0.0507052
95% CI for difference:  (-0.0829026, -0.0185078)
Test for difference = 0 (vs not = 0):  Z = -3.09  P-
Value = 0.002

Fisher's exact test: P-Value = 0.003
```

3. Statistical Analysis Results Magenta

Two-Sample T-Test and CI: M_Manual, M_Auto

```
Two-sample T for M_Manual vs M_Auto

             N    Mean   StDev  SE Mean
M_Manual  1146  0.5765  0.0405   0.0012
M_Auto     629  0.6056  0.0296   0.0012


Difference = mu (M_Manual) - mu (M_Auto)
Estimate for difference:  -0.02913
95% CI for difference:  (-0.03242, -0.02583)
T-Test of difference = 0 (vs not =): T-Value = -17.34
P-Value = 0.000  DF = 1636
```

Test for Equal Variances: M_Manual, M_Auto

```
95% Bonferroni confidence intervals for standard
deviations

             N      Lower      StDev      Upper
M_Manual  1146  0.0387121  0.0405279  0.0425157
  M_Auto   629  0.0278015  0.0295630  0.0315537

F-Test (Normal Distribution)
Test statistic = 1.88, p-value = 0.000

Levene's Test (Any Continuous Distribution)
Test statistic = 37.37, p-value = 0.000
```

Test and CI for Two Proportions: M_Manual_1, M_Auto_1

```
Event = Pass

Variable      X     N  Sample p
M_Manual_1  924  1146  0.806283
M_Auto_1    571   629  0.907790

Difference = p (M_Manual_1) - p (M_Auto_1)
Estimate for difference:  -0.101507
95% CI for difference:  (-0.133675, -0.0693394)
Test for difference = 0 (vs not = 0):  Z = -6.18  P-
Value = 0.000

Fisher's exact test: P-Value = 0.000
```

4. Statistical Analysis Results Yellow

Two-Sample T-Test and CI: Y_Manual, Y_Auto

```
Two-sample T for Y_Manual vs Y_Auto

             N    Mean   StDev  SE Mean
Y_Manual  1146  0.5841  0.0348   0.0010
Y_Auto     629  0.6078  0.0243  0.00097

Difference = mu (Y_Manual) - mu (Y_Auto)
Estimate for difference:  -0.02367
95% CI for difference:  (-0.02644, -0.02089)
T-Test of difference = 0 (vs not =): T-Value = -16.73
P-Value = 0.000  DF = 1673
```

Test for Equal Variances: Y_Manual, Y_Auto

```
95% Bonferroni confidence intervals for standard
deviations

             N      Lower      StDev      Upper
Y_Manual  1146  0.0332703  0.0348308  0.0365392
  Y_Auto   629  0.0228904  0.0243408  0.0259799

F-Test (Normal Distribution)
Test statistic = 2.05, p-value = 0.000

Levene's Test (Any Continuous Distribution)
Test statistic = 30.90, p-value = 0.000
```

Test and CI for Two Proportions: Y_Manual_1, Y_Auto_1

```
Event = Pass

Variable      X     N  Sample p
Y_Manual_1  997  1146  0.869983
Y_Auto_1    594   629  0.944356

Difference = p (Y_Manual_1) - p (Y_Auto_1)
Estimate for difference:  -0.0743736
95% CI for difference:  (-0.100833, -0.0479145)
Test for difference = 0 (vs not = 0):  Z = -5.51  P-
Value = 0.000

Fisher's exact test: P-Value = 0.000
```

5. Statistical Analysis Results Color Balance

Two-Sample T-Test and CI: ColorBalance_Manual, ColorBalance_Auto

```
Two-sample T for ColorBalance_Manual vs
ColorBalance_Auto

                        N    Mean   StDev  SE Mean
ColorBalance_Manual  1146  0.0421  0.0398   0.0012
ColorBalance_Auto     629  0.0257  0.0220  0.00088

Difference = mu (ColorBalance_Manual) - mu
(ColorBalance_Auto)
Estimate for difference:  0.01646
95% CI for difference:  (0.01358, 0.01934)
T-Test of difference = 0 (vs not =): T-Value = 11.22
P-Value = 0.000  DF = 1772
```

Test for Equal Variances: ColorBalance_Manual, ColorBalance_Auto

```
95% Bonferroni confidence intervals for standard
deviations

                        N      Lower      StDev
Upper
ColorBalance_Manual  1146  0.0380508  0.0398356
0.0417895
  ColorBalance_Auto   629  0.0206831  0.0219936
0.0234746

F-Test (Normal Distribution)
Test statistic = 3.28, p-value = 0.000

Levene's Test (Any Continuous Distribution)
Test statistic = 49.03, p-value = 0.000
```

Test and CI for Two Proportions: ColorBalance_Manual_1, ColorBalance_Auto_1

```
Event = Pass

Variable                 X     N  Sample p
ColorBalance_Manual_1  879  1146  0.767016
ColorBalance_Auto_1    575   629  0.914149

Difference = p (ColorBalance_Manual_1) - p
(ColorBalance_Auto_1)
Estimate for difference:  -0.147134
95% CI for difference:  (-0.179972, -0.114296)
```

```
Test for difference = 0 (vs not = 0):  Z = -8.78  P-
Value = 0.000

Fisher's exact test: P-Value = 0.000
```