

# Delta E Based Regression Model

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**Abstract** - Color consistency is one of the main challenges in offset printing. It is affected by changes in ink flow, press dynamics, substrate behavior, and environmental factors. Operators usually make manual ink-key adjustments, which often lead to longer makeready times, waste, and inconsistent print quality. This review brings together research published from 2015 to 2025 that looks at the relationship between optical density, color difference ( $\Delta E$ ), and ink-control processes in offset printing. The findings show that keeping ink-film density within ISO-defined tolerance ranges greatly reduces color deviation ( $\Delta E$ ). Additionally, regression-based and machine learning methods have proven effective in predicting necessary ink adjustments and achieving uniform print results. The review points out the potential to create an integrated  $\Delta E$ -based regression model that uses historical press data, densitometric readings, and colorimetric targets to reach  $\Delta E$  values below 3. This could enhance production efficiency and print stability.

**Keywords:** Delta E, Optical Density, Ink Flow, Regression Model, Offset Printing, Process Control.

## 1. INTRODUCTION

In offset printing, keeping color consistent across production runs is essential for meeting quality standards and client expectations. However, several changing factors, such as ink-film thickness, roller mechanics, substrate absorption, and surrounding conditions, can affect printed color. The industry has traditionally relied on visual checks and densitometric measurements to manage ink film thickness and optical density. While managing density helps ensure consistent tone reproduction, it does not completely guarantee accurate perceived color, which is better measured using the CIE  $\Delta E$  color difference metric.

Recent developments in color science and computational modeling have led to predictive methods that combine densitometric and colorimetric data. These models seek to reduce color differences using data-driven predictions instead of manual adjustments. This review paper looks at research that explores the connections among density,  $\Delta E$ , and ink flow. It also identifies gaps in research that support the need for a  $\Delta E$ -based regression model for controlling the offset printing process.

## 2. LITERATURE REVIEW / RELATED WORK

Twelve key studies were reviewed to understand how process control methods have changed in offset printing. The focus was on density,  $\Delta E$ , and ink regulation.

### 1. An Experimental Investigation into the Effect of Density of Ink Film Thickness on Dot Area Changes on an Offset Press

- **Objective:** The main goal of the study was to investigate how ink film thickness, measured by optical density, affects dot area changes, or dot gain and loss, during an offset press run.
- **Methodology:** A controlled offset press experiment was conducted. Researchers printed 4,800 sheets across eight ink settings to create varying density levels. They used a reflection densitometer to take measurements, and they analyzed changes in dot area using 225X photomicrographs of the printed sheets.
- **Result:** The black dot tint curves, ranging from 10% to 50%, showed a sharp initial gain in dot area for the lighter settings. This gain tended to level off after the third or fourth ink test.

- **Conclusion:** The research found that ink film thickness is an important factor influencing dot area changes and overall print quality in the offset process. It suggested that medium ink settings provided the most stable and acceptable tonal reproduction.

## 2. Determination of the Deviations Tolerances of the Process-Colour Solids from the OK Print in Offset Printing Method

- **Objective:** To find the relationship between optical density ( $\Delta D$ ) and colour difference ( $\Delta E_{ab}$ ) for CMYK solids on different types of paper. The goal is to establish  $\Delta D$  tolerances that meet ISO  $\Delta E_{ab}$  standards.
- **Methodology:** A test form was printed on a sheet-fed offset machine using various paper types and control strips. Regression analysis modeled the relationship as  $\Delta E_{ab} = a\Delta D^2 + b\Delta D + c$ . The coefficients calculated from this model were used to determine the optimal  $\Delta D$  deviation tolerances that match ISO  $\Delta E_{ab}$  limits.
- **Result:** The optimal  $\Delta D$  tolerance limits varied significantly for each colour and paper type. Six out of eight models showed different tolerances in the positive and negative density directions.
- **Conclusion:** The study provided clear, experimentally-verified evidence of the  $\Delta D$  limits that ensure compliance with international  $\Delta E$  standards. It concluded that these limits need to be tailored for the specific combination of ink and paper used.

## 3. Validating A Model-Based Ink Key Presetting System

- **Objective:** The goal was to provide experimental validation for a previously developed model-based system for ink key presetting. This validation aimed to show its effectiveness in reducing make-ready time and connecting the digital prepress and pressroom workflow.
- **Methodology:** The system is based on a theoretical steady-state inking system model. It includes the dynamics of the roller train, vibrators, and the relationship between ink density and film thickness. Press tests were conducted using specific plate designs to calibrate and confirm the model's essential operational parameters.
- **Result:** The validation results showed that the system could achieve reasonable ink key presetting based on digital plate coverage data.
- **Conclusion:** The system offers a solid foundation for reducing setup time. However, its performance could improve by adding more detailed submodels to address complex factors such as dot gain and wet trapping.

## 4. An approach to predict print density using scanner and regression models

- **Objective:** To present and validate a procedure for using a flatbed scanner as a densitometer to predict print density accurately. This offers a low-cost tool for quality assurance.
- **Methodology:** We calculated the density of printed patches using pixel intensity values from the scanned image. We then correlated this density with simultaneous measurements from a traditional densitometer and computed  $L^*$  values. Four regression algorithms modeled the scanner's behavior.
- **Result:** We successfully tested and validated the models for accuracy. The  $L^*$  values, used with the regression models, provided the most accurate prediction of print density.
- **Conclusion:** A conventional flatbed scanner, combined with the developed methodology that uses  $L^*$  values and regression models, can effectively serve as a densitometer for process control.

## 5. A Hybrid Model Approach for Achieving the Highest Level of Matching Between the "Print and Original" in the Sheet-Fed Offset Process

- **Objective:** To develop an optimized hybrid system that uses a dual measurement approach, Print Contrast and CIE  $L^*a^*b^*$ , to achieve the best and most acceptable match between the print and the original.
- **Methodology:** We took measurements with an X-Rite instrument under ISO specifications. The study also included a visual assessment component, where ten standard observers judged prints under a controlled Macbeth Lighting Booth.
- **Result:** Visual assessments showed that observers consistently preferred the print with a higher contrast value, even when a print with lower contrast had a numerically superior (smaller)  $\Delta E$  value.

- **Conclusion:** Single-parameter quality control methods are not enough. The "Hybrid System" approach, which combines CIE Lab, Contrast, and visual perception, provides the most convincing, measurable, and acceptable method for matching print to original.

#### 6. How Many $\Delta E$ 's Are There in a $\Delta D$ ?

- **Objective:** To analyze the relationship between density tolerance ( $\Delta D$ ) and colorimetric tolerance ( $\Delta E$ ) and determine if  $\Delta D$  control assures  $\Delta E$  control during a press run. We also investigated if single-channel density is sufficient for proof-to-print matching.
- **Methodology:** We analyzed data from three press tests (web and sheetfed) across thirty printing stocks and two ink formulations. We performed a separate analysis on hardcopy proofs from twenty-one proofing system vendors.
- **Result:** The study found that controlling density tolerance ( $\Delta D$ ) within a press run successfully ensures a colorimetric tolerance ( $\Delta E$ ). However, single-channel density cannot guarantee a colorimetric match between a proof and a press sheet.
- **Conclusion:** Density measurement is a valid and effective stand-in for color control in press process control. However, a complete colorimetric approach is needed for the important task of proof-to-print matching.

#### 7. Interaction Between Offset Ink And Coated Paper - A Review Of The Present Understanding

- **Objective:** This review aims to summarize the current understanding of the complex interaction between offset ink and coated paper, focusing mainly on sheet-fed offset printing.
- **Methodology:** A detailed literature review was conducted, examining the properties of coatings and offset inks, the mechanics of ink film thickness, and how ink sets (oil penetration into the coating) and influences quality defects.
- **Result:** The review found that factors like coating topography, uniformity of the coating layer, and ink film thickness are key factors in print gloss and mottle. Mottle tendency is particularly related to inconsistencies in the coating structure and ink setting.
- **Conclusion:** Despite extensive research, a complete understanding of the inkpaper interaction remains uncertain. Poor interaction often leads to runnability problems, such as picking and blocking, as well as defects in the final print quality.

#### 8. Model-Based Ink Key Presetting for Offset Presses

- **Objective:** This project aims to create an analytical ink key presetting system based on a physical model of the printing process to estimate ink key openings and significantly reduce make-ready time. This paper serves as the theoretical foundation for the validation paper, #3.
- **Methodology:** A steady-state ink system model was built mathematically. This model brings together the physical components, including the roller train, vibrator motion, overall system gain, and the key relationship between density and ink film thickness. The system uses digital plate coverage as the main input.
- **Result:** The summary outlines the successful creation of the model and its intended implementation through an electronic interface for automatic key setting.
- **Conclusion:** The developed model offers a solid analytical framework for ink key presetting. It can function as an independent tool or provide accurate starting settings for future closed-loop color control systems.

#### 9. Random Forest-Based Prediction of the Optimal Solid Ink Density in Offset Lithography

- **Objective:** This project seeks to increase the efficiency and precision of determining the optimal Solid Ink Density (SID) in offset lithography using a machine-learning algorithm.
- **Methodology:** The Random Forest algorithm was utilized to create a prediction model. It was trained with the  $L^*a^*b^*$  colorimetric values of the printed CMY process solids as input features. The model's effectiveness was compared with other common regression algorithms.
- **Result:** The Random Forest model showed better performance, achieving a high predictive accuracy with an  $R^2$  value of 0.969.
- **Conclusion:** The Random Forest algorithm has proven to be an effective and efficient method for accurately predicting the optimal SID in offset printing, offering a data-driven tool for setting ink targets.

### 10. Ink flow control by multiple models in an offset lithographic printing process

- **Objective:** This study aims to develop a reliable technique for controlling ink flow in offset printing by using a multiple model approach to handle the process's inherent noise and non-linear features during production.
- **Methodology:** Experiments were carried out during regular production runs. The control system used a multiple model approach, incorporating a linear general model to stabilize operations. A noise-filtering criterion was established based on the standard deviation of the measured ink amount to avoid oscillatory control actions.
- **Result:** The standard deviation of the measured ink amount was found to be 2. The controller effectively adjusted ink keys to maintain the desired ink amount under varying conditions, such as changes in printing speed, temperature, and ink demand.
- **Conclusion:** The multiple model control technique is a practical solution for achieving precise ink flow control in the dynamic and noisy environment of offset lithographic production.

### 11. Closed loop color control in the work

- **Objective:** This paper introduces the next generation of closed-loop color control systems designed to manage color based on measurements of the printed image itself (Color Control In the Work - CCIW), which removes the dependence on traditional color bars.
- **Methodology:** This paper describes how the technology has evolved, contrasting earlier closed-loop systems that adjusted ink keys based on color bar patches with the new CCIW architecture, which is flexible enough to measure and control the actual image content.
- **Result:** The summary highlights that technological advancements have recently made these image-based systems both technically and financially viable.
- **Conclusion:** The future of color control in offset printing shifts from managing control strips to measuring the image itself. The new CCIW systems represent an important advancement for more accurate and flexible color management integrated within the printed product.

### 12. Determination of the Deviations and Variations Tolerances of the Process Colour Solids from the OK Print in Offset Printing Method

- **Objective:** This study seeks to define the relationship between optical density deviation ( $\Delta D$ ) and color difference ( $\Delta E_{ab}$ ) for CMYK solids on two different paper types, establishing  $\Delta D$  tolerances that comply with ISO  $\Delta E_{ab}$  standards. This builds on research presented in paper 2.
- **Methodology:** A test form was printed on a four-color sheet-fed offset press. Regression analysis helped create the quadratic model:  $\Delta E_{ab} = a\Delta D^2 + b\Delta D + c$ . The goal was to identify which  $\Delta D$  limit values align with the defined ISO  $\Delta E_{ab}$  limits for each color and paper type.
- **Result:** The experimentally obtained coefficients differed for the various paper/ink combinations, necessitating unique limits for  $\Delta D$ . The results showed the need to establish custom  $\Delta D$  limits for process control.
- **Conclusion:** The study delivered crucial evidence for the  $\Delta D$  limits that ensure colorimetric compliance ( $\Delta E$ ) for different ink-paper combinations, supporting the practical process control approach when limits are carefully defined.

## 3. CRITICAL ANALYSIS / DISCUSSION

The reviewed literature shows how control in the offset printing process has evolved from traditional densitometric monitoring to intelligent, adaptive color management systems. Three main trends stand out: (1) analytical regression models that establish relationships between optical density and color deviation; (2) model-based and hybrid control systems that combine prepress and pressroom parameters; and (3) data-driven machine learning models that optimize ink flow predictively.

### 3.1 Analysis of Existing Methods and Emerging Trends

Early studies, like those by Spiridonov & Kachin (2013), developed quadratic regression equations, such as  $\Delta E_{ab} = a\Delta D^2 + b\Delta D + c$ . These equations quantify how density deviation ( $\Delta D$ ) affects color difference ( $\Delta E$ ). They showed strong correlations ( $R^2$  values

usually above 0.90) in limited material sets, proving that controlling optical density can keep color difference within ISO limits ( $\Delta E \leq 5$ ). However, these static models relied heavily on manual calibration and did not adapt to real-time changes in the press.

Later work by Chu & Seymour (2005) and Chu & Sharma (2010) introduced model-based ink-key setting systems based on the steady-state dynamics of the inking unit. These techniques converted digital plate coverage into predictive ink-key positions, reducing make-ready time significantly—by as much as 40%. Despite this advancement, these models could not make real-time corrections once the press run started.

Recent studies indicate a shift toward data-driven adaptive control. Li et al. (2022) applied Random Forest regression to predict Solid Ink Density (SID) using CIE  $L^*a^*b^*$  data, achieving an  $R^2$  of 0.969 and a mean  $\Delta E_{00}$  under 2.8. This exceeded the performance of both Artificial Neural Networks (ANN) and Support Vector Regression (SVR). Similarly, Zhang et al. (2019) developed multiple-model controllers that could switch among various models depending on press speed and ink demand, ensuring stable density control even amid production noise. Closed-loop color control systems, like Müller's CCIW (2021), now directly measure color from printed images instead of using side color bars, marking a major shift toward systems that use real-image feedback.

### 3.2 Comparative Evaluation of Techniques

Analytical regression models are simple, clear, and easy to understand. They work well in controlled settings or during lab calibrations. However, their reliance on specific press conditions limits their broader use. On the other hand, machine learning approaches offer flexibility across different materials and operating conditions but need a lot of computational power. For example, Random Forest and Gradient Boosting regression methods exceed the accuracy of traditional polynomial models (reducing  $\Delta E$  error by 15–25%), but they require extensive, high-quality datasets for training.

Hybrid methods seek to combine the advantages of both approaches. For instance, combining densitometric feedback with  $\Delta E$ -based color correction creates a dual-layer control method. Density ensures tonal balance, while  $\Delta E$  correction maintains perceptual accuracy. In practice, these hybrid systems have reduced total color deviation by about 30–40% compared to systems that rely solely on densitometry. Still, full integration with ink-key actuators and roller dynamics is limited in open academic research, with most applications found only in proprietary systems.

### 3.3 Gaps and Challenges in Current Research

Despite notable progress, there are still significant gaps in research:

- **Fragmented modeling approaches:** Current models either focus on colorimetric prediction ( $\Delta E$ -based) or mechanical ink flow, with no frameworks that connect both.
- **Limited generalization:** Most models need recalibration whenever there is a change in press setup, substrate, or ink formulation, which restricts their use across different presses.
- **Data and infrastructure barriers:** The application of machine learning is constrained by the lack of standardized, open-access datasets that include synchronized density,  $\Delta E$ , and ink-key data.
- **Real-time adaptability:** Many regression and control models function offline or semi-offline, lacking the ability to make ongoing predictive adjustments during active production.
- **Proprietary restrictions:** Advanced closed-loop systems like CCIW are commercial secrets, limiting their study and improvement in academic and industrial research.

### 3.4 Author's Interpretation and Future Direction

From an analytical standpoint, merging  $\Delta E$ -based regression into an adaptive, hybrid control framework is a logical step toward smart color management. Traditional density control maintains tonal stability but does not ensure perceptual uniformity. In contrast, machine-learning systems can capture complex non-linear links between ink-film thickness,  $\Delta E$ , and density, although they might lack physical clarity. Combining both empirical knowledge and computational intelligence could lead to models that not only predict but also actively correct deviations during print runs.

The proposed  $\Delta E$ -Based Regression Model builds on these ideas. By using historical press data (ink key positions, optical density, and  $\Delta E$  records), the model learns the specific behavior of the press and can predict optimal ink adjustments to keep  $\Delta E \leq 3$ . Integrating regression analysis with feedback from inline spectrophotometers will allow the system to self-calibrate and adapt to various conditions. This model could bridge the gap between theoretical research and real-world practice, moving offset printing closer to fully automatic, precision-driven production with minimal operator involvement.

#### 4. CONCLUSION

This review brings together important developments in controlling color consistency in offset printing. It highlights the measurable link between optical density and  $\Delta E$ . Research shows that  $\Delta E$  rises significantly with changes in ink density. Methods based on regression and machine learning have been useful for predicting and managing color variations. However, combining these methods with physical press control is still lacking.

The suggested  $\Delta E$ -based regression model aims to use past press data along with densitometric and colorimetric information to suggest automatic ink changes. This method can shorten setup time, cut down on material waste, and achieve ISO-compliant color stability. Future research should aim to incorporate these models into real-time closed-loop systems and expand their use across different presses and materials through adaptive learning.

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