

Journal of

INDUSTRIAL TECHNOLOGY

Volume 21, Number 1 - January 2005 through March 2005

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Peer-Refereed Article

KEYWORD SEARCH

**Packaging
Printing
Quality
Quality Control
Research**

The Official Electronic Publication of the National Association of Industrial Technology • www.nait.org

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Color Quality Assurance for Package Printing

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Introduction

To remain competitive in the marketplace, today's Industrial Technology practitioners are under intense pressure to employ techniques that will help them maintain quality in manufacturing processes and to effectively quantify and communicate quality to customers. Industrial Technology educators are charged with preparing graduates that understand process control and quality assurance within their respective specializations. This study is an investigation of the utilization of colorimetric measurement and printing process control to develop a system whereby the color appearance of packages can be quantified, controlled, and communicated.

A case study research methodology was used, whereby the implementation of a color quality assurance system for a major company was planned, tracked and documented. Theoretical background is presented to establish a foundation for understanding color measurement systems and the standards applied. Industrial Technology practitioners in the field can use this information to develop or modify their own quality assurance initiatives. Industrial Technology educators, particularly those in graphic communications-related specialties, can use this information as a practical application to support their teaching of colorimetric theory and practice, printing process control, and color quality assurance.

Quality assurance is a process of ensuring that a manufactured product conforms to the customer's quality specifications (Field, 1996, Rizzo, 1997). The factors that define quality specifications and acceptance levels are largely implied by the intent of the printed product within a given market. For example, printed newspapers have less stringent paper quality require-

ments than do marketing brochures. Likewise, paperback books require less stringent image-positioning precision than do hardcover case bound books. In the food packaging market, color fidelity and consistency will likely be considered to be of utmost importance to the customer.

While it is intuitive to imply that color quality and consistency for commercial packaging will have a positive affect at the point of purchase, a review of literature yields little empirical research suggesting that consumer decision is influenced by physical appearance. Bone and France (2001) carried out the only empirical study on the topic found in the PsycINFO database, and that study does suggest that the selection of color will have a significant effect on consumer decisions. However, no studies were found examining package-to-package color consistency the effects on consumer behavior. Young (2002) discusses the urgent need for more quantitative data to strengthen an understanding of the relationship between package design and consumer decisions. Regardless, packaging printers must meet the quality demands of packaging customers who demand a high degree of color accuracy and consistency.

On the issue of quality assurance for color, it is common practice in the printing industry for the customer to approve a color proof produced by some means before the pressrun begins. This practice is loosely defined in the *Best Business Practices for the Printing Industry* (2002), a set of industry customs recently written by a National Association of Printing Leadership (NAPL) and Printing Industries of America (PIA) appointed committee. During the pressrun, the press operator attempts to match the proof in some consistent manner, in some cases

by visual, non-objective means. The outcome of acceptable color quality falls on the customers' acceptance of the work. In many cases the customer's assessment of a visual match between the press sheet to the proof is subjective, which may lead to disagreements. Therefore, in color critical environments it becomes essential for both customer and printer to have a basis for evaluating and assuring color quality by empirical means that are understood and agreed upon by both parties.

This study suggests that package printers will benefit from implementing colorimetry during production and as a means of quantifying color for quality assurance. By employing colorimeters and calculating Delta E values within a system of process control, color reproduction quality can be tracked and hue errors documented objectively. This practice will assure that those involved in the quality chain have a scientific basis from which to communicate color-related issues.

Theoretical Background

Colorimetry

Colorimetry is a means of measuring a specific color under a standard light source and assigning that color a numerical value by placing it in one or another color models based on human color vision. Colorimetry values are based on international standards established by the Commission Internationale de l'Eclairage (CIE). The official CIE recommendations on colorimetry are published in ISO 10526/CIE 5005 (1999). These color standards are based on empirical data collected through experiments on a number of subjects with normal color vision, first carried out in the 1930s. The CIE experiments involved asking subjects (referred to as "observers") to view a color test patch under a standard illuminant in a 2 degree field and match it to a color created by combining three primary colors emitting electromagnetic radiation at 444.4 nm (blue), 526.3 nm (green), and 645.2 nm (red), respectively. The three lights were independently adjusted in intensity (referred to as chromaticity

values) to match a series of test colors selected from the visible spectrum. The results form the basis for a three-dimensional space that represents human color perception (Wyszecki & Stiles, 2000). The original color space developed is called CIE XYZ, with X (red), Y (green), and Z (blue) intensity values converted into two chromaticity coordinates through the formulas:

$$x = X/X + Y + Z$$

$$y = Y/X + Y + Z$$

The values for x and y can be plotted on a chromaticity diagram, thus representing coordinate system within a 2-dimensional space (see Figure 1).

CIE Lab

The original CIE color model was designed to measure colored light sources rather than colored objects. The system has been modified several times over the years to include various

iterations, most of which are designed to measure reflection of color. One of these is the CIE Lab color space, also known as CIE 1976, which has become the most commonly used CIE model in the printing industry. The goal of the CIE Lab space is to make each numerical step from one coordinate to the next represent an equal shift in color, a quality lacking in the original CIE XYZ color space. The CIE Lab system is a 3-dimensional space, within which all colors visible to the human eye can be plotted. The color coordinates in this system are:

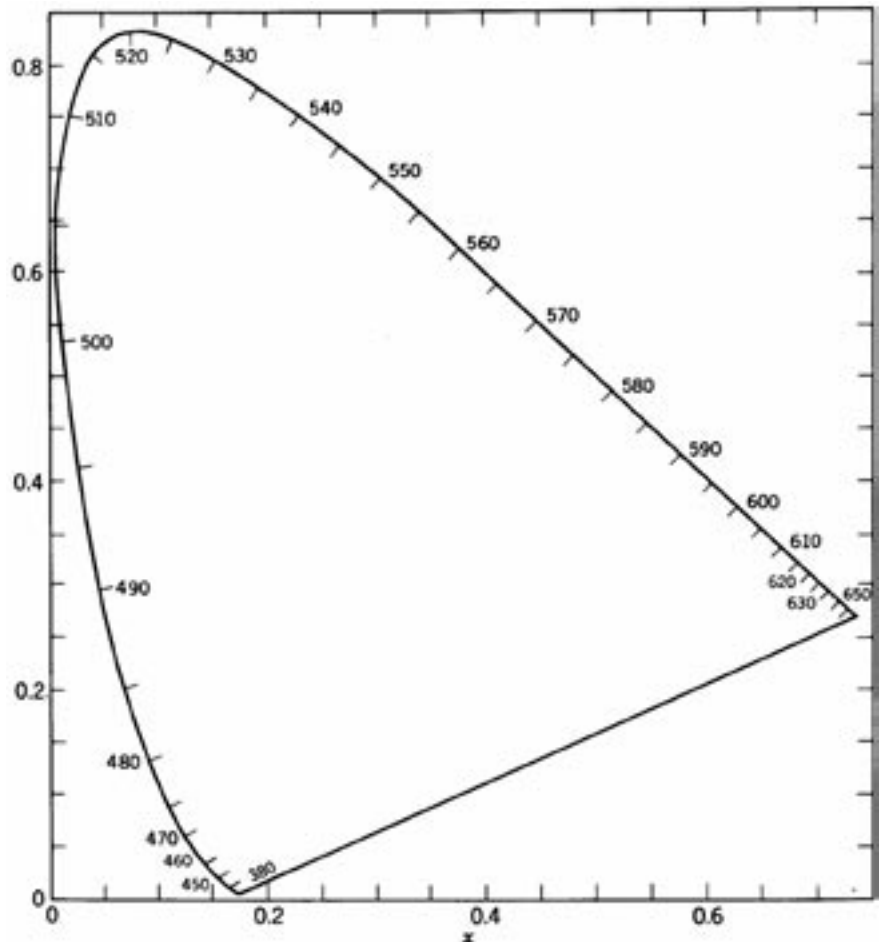
L* - the lightness coordinate.

a* - the red/green coordinate, with +a* indicating red, and -a* indicating green.

b* - the yellow/blue coordinate, with +b* indicating yellow, and -b* indicating blue.

(see Figure 2 on next page).

Figure 1. The CIE 1931 chromaticity diagram representing a 2-dimensional numerical model of human color vision



Colorimeters

A colorimeter is a device that measures and assigns a numerical value to a color. A comprehensive background on the function and use of colorimeters can be found in Hunter & Harold's text *Colorimetry: The Measurement of Appearance* (1987). The device works by measuring the spectral characteristics of a color under a specific illuminant. The spectral response is converted to the color-matching functions of any of several CIE standard colorimetric spaces. The type of illuminant used is defined in color temperature, which is a measurement system that relates the light source to the spectral distribution radiated from a theoretical black body heated to a specific temperature measured on the Kelvin scale.

A change in the color temperature of a light source used to illuminate an object will result in changes in color appearance. Therefore light sources for measuring colors with a colorimeter are standardized. ISO 10526/CIE 5005 (1999) defines standard illuminants for colorimetry. The D65 standard, indicating a color temperature of 6500 degrees Kelvin, and the D50 standard, indicating a color temperature of 5000 degrees Kelvin are both common standards for colorimetric measurement used in the printing industry.

Color Tolerances

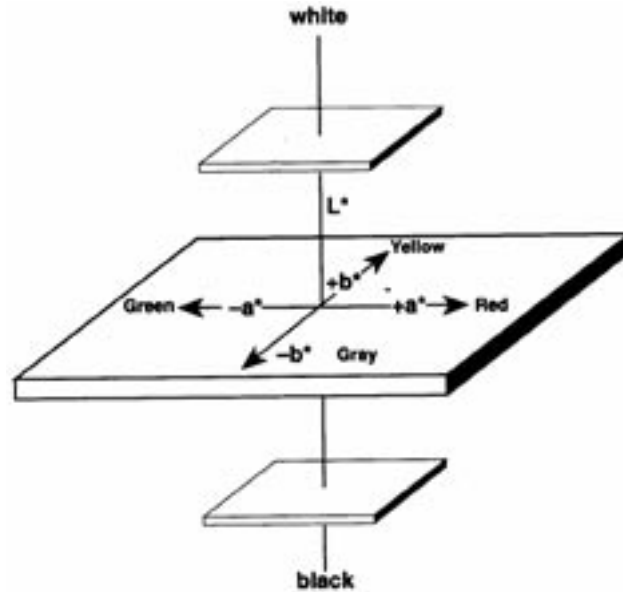
When comparing an agreed upon standard color to a reproduction of the color, a colorimeter can be used to determine a difference error. Using a colorimeter, a given color standard can be measured to yield a CIE Lab value, representing the exact point for that color within the color space. Delta E is calculated by averaging the differences among the L, a, and b values of the color standard to be matched, with the L, a, and b values of the actual measured ink film. CIELAB color difference, between any two colors in CIE Lab color space, is the distance between the color locations. This distance is typically expressed as ΔE^* , where:

ΔL^* being the lightness difference.

Δa^* being the red/green difference.

Δb^* being the yellow/blue difference

Figure 2. The CIE Lab (CIE 1976) color space based on reflective color.



CIE Lab color space is approximately uniform for the perception of small color differences. Thus, CIE $L^*a^*b^*$ color difference (ΔE^*) is an equally weighted combination of the coordinate (L^*, a^*, b^*) differences.

$$\Delta E = [(\Delta L^2) + (\Delta a^2) + (\Delta b^2)]^{1/2}$$

A drawback to using CIE $L^*a^*b^*$ in tolerancing systems is that the rectangular acceptability volumes do not conform well with human color perception. The foundation of empirical research on measuring the just-perceptible color difference was done by MacAdam in a series of studies reported in 1942. His color perception research involved the development and deployment of a device that required an observer to view a color through a 2-degree field and to match a surround color. This was done by turning a control knob to vary the color in tiny increments along a straight line in the CIE XYZ chromaticity diagram. This was done for colors throughout the color space. Results suggested that the ability to discriminate colors is not uniform, but vary throughout the color model. Further, the just perceptible differences are in the shape of ellipsoids, with less tolerance for acceptance for shifts of lightness and less acute differentiation possible for colors of high saturation.

(see Figure 3 on next page). Much research has further refined MacAdam's findings (Wyszecki & Stiles, 2000), with Robertson (1977) the first to plot the just-perceptible color differences in CIE Lab space.

Research built upon these findings formed the basis for the development of the Color Measurement Committee (CMC) tolerancing system, established by the Society of Dyes and Colourists in Great Britain and standardized for the textile industry in ISO 105 J03 (Luo, et al, 2002), (McDonald & Smith, 1995). The CMC color tolerancing equations take into account the non-linear relationships that have been established through research and weighs each according to its location in the color space. Further, unlike a Delta E measurement in CIE Lab space, in CMC a Delta E of 1.0 represents a consistent color difference, regardless of what area of color space the target and sample are in. This permits the use of a single number for acceptance or rejection decisions anywhere within the color space.

Background of the Problem

One business focus of the Eureka Paperbox Company, headquartered in Williamsport, Pennsylvania, is to manufacture printed candy packages

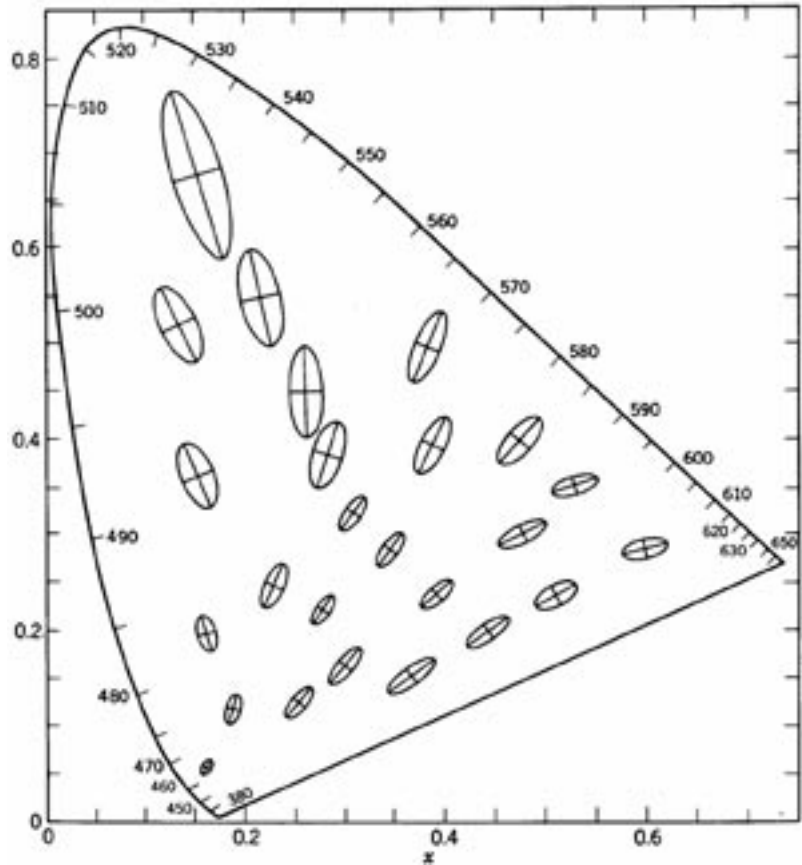
for the Just Born Candy Company using the offset lithographic printing process. Recognizable products commonly sold in retail stores include Mike n' Ike ® and "Hot Tamales ®" brand name candy. The package designs incorporate the heavy use of a single, dominant specialty spot color. The Just Born Company requires that packages for these products must be printed with a great deal of accuracy and consistency. However, no specific color quality benchmarks had been established. New management at Eureka Paperbox Company found that on many occasions, color issues were raised and that there was no means of objectively documenting color numerically. The Eureka Paperbox Company's initiative was to develop a means of color communication that would assure their customers of color consistency with a minimal level of perceptible color differentiation among printed packages. The system would also provide feedback on the success of process control measures.

The lead author was invited to implement a quality assurance system that would guarantee customers of color fidelity and consistency. The approach required several phases including (1) identifying variables and establishing process control tolerances, (2) implementing the use of colorimetry in the pressroom, and (3) establishing sampling procedures and acceptable color tolerances. The overall desired result was to minimize factors that contribute to color variation in the manufacturing process and to enable precise communication of color among those involved in design, purchasing, and printing of the packages.

Process Control Variables

A color's hue, chroma, and luminance will shift slightly during print production. Problems leading to color shifts in print production are well explained the current technical literature (Wilson 2003, Rizzo, 1997). Color shifts on press can be minimized through a program of process control, designed to minimize variables. Each of the press variables below was identified for measurement and process control.

Figure 3. MacAdams' ellipsoids representing boundaries of just perceptible color differences in the CIE XYZ color space. Ellipsoids are magnified 10X their actual size in this diagram.



Cylinder Pressures. The pressure between press cylinders is controlled by placing thin sheets of paper or Mylar material behind the printing plate and blanket to achieve contact and compression, called squeeze. The amount that the plate and blanket compress against each other is typically measured in thousands of an inch.

Roller Hardness and Pressures. The surface quality of press inking rollers can have a dramatic effect on ink film consistency, and thus color consistency. Ink solvents, paper coatings, and ozone can all contribute to a hardening of the resilient rubber surface of press rollers. A durometer is used to measure the hardness of press rollers. The pressure from one roller to the next is also critical for consistent ink transfer.

Plate Type and Processing. Depending upon their surface characteristics, printing plates may vary in ink receptivity

and length of press life. Establishing a consistent type and brand of plate, as well as plate exposure procedures with the goal of minimizing the effects of exposure variations on ink film thickness.

Dampening Solution Conductivity.

The condition of dampening solution can have an effect on color quality in a variety of ways. Over time, dampening solution will pick up ink pigment particles and actually appear to have a tint. This tint can contaminate non-image areas of the sheet as well as the color of the ink film being printed. Changes in the dampening solution can also affect emulsification rates. This refers to the speed at which ink takes on and mixes with water, creating an emulsion. Improper emulsification will lead to ink film thickness and color variation problems. A conductivity meter is used to measure and monitor the quality of the dampening solution.

Figure 4. A process control chart developed for Eureka Paperbox Company.

Process Control Form: Eureka Paper Box

| Instrument | Measurement and range | Frequency | | |
|---------------------------|-----------------------|--------------------------------------|---------------------|----------------|
| Prepress Variables | | | | |
| Film base density | densitometer | 4.3 +- .10 | upon receipt | Film 50% patch |
| 50%, +- 1% | upon receipt | | | |
| Platemaking | grayscale | Step 6 | once per month | |
| | | Drawdown 60 seconds | every plate | |
| Press Variables | | | | |
| Blankets Specs | bench micrometer | .077 Caliper four corners +- .001 | when installing | |
| Plate packing | bench micrometer | .015 | | |
| Blanket packing | bench micrometer | .012 | | |
| Squeeze specs | packing gauge | .006 plate over bearers | | |
| | | .010 blanket over bearers | weekly | |
| | | .004 back cylinder pressure | | |
| Fountain solution | calculate | pH: 4.2 +- .1 | each shift | |
| | pH meter | 2100 micromhos +- 200 | each shift | |
| | conductivity meter | Forms 25 - 35 | every two weeks | |
| Roller Hardness | shore A durometer | | | |
| Distributors 35 - 45 | | | | |
| Ink form to plate | visual stripes | 3/8 " | every new press run | |
| Ink form to oscillator | visual stripes | 3/8" | every new press run | |
| Water form to plate | visual stripes | 1/2" | every new press run | |
| Press Sheet | | | | |
| solid patches | densitometer | + - .05 to ink swatch | throughout run | |
| 50% tint | densitometer | + - 3% | throughout run | |
| Line colors | spectrophotometer | Delta E (tolerance to be determined) | throughout run | |

Ink System Wash-up Procedures. When changing the ink system from one color of ink to another, any ink residue left from the previous press run can contaminate the new color. To assure a thorough ink wash-up, clean, resilient rubber wash-up blades must be used in the wash-up tray to squeegee the ink and solvent from the press rollers. Inspection and replacement schedules for this was established by the plant operations manager. Additionally, multi-stage wash-up solvents and procedures were established to assure thorough clean-ups.

Paper. Paper brightness, surface quality, and neutrality (deviance from color cast) all have a dramatic effect on how color inks will appear printed on their surface. Because of cost concerns, management may be tempted to switch to a different paper brand, without realizing the effects that this will have on color. Paper specifications were established to assure consistency.

Ink. Establishing an ink type and brand is essential to assuring consistent color results. There are many ink manufacturing variables that can affect color

quality, including ink pigment size and concentration, vehicle type, viscosity, and tack. Choosing a single ink type and brand helps assure that the ink will not impact color variation.

Forms were developed to track these variables and assure that maintenance schedules were met. Once the control and measurement of these variables were established, color consistency could be measured with more confidence in minimal variation. Additionally, pinpointing color shift problems became easier to troubleshoot in that records could now be consulted. (Figure 4)

The Quality Assurance System

Implementing Sampling Procedures

The International Standards Organization established sampling procedures published in ISO/DIS-2859-1, originally developed for government procurement, but now widely used across nearly all manufacturing industries (Field, 1994). The details of the system are covered well by the Printing Industries Quality Assurance Council (PIQAC) (1992). This publication was

produced for printing companies moving toward ISO 9002 certification. The sampling system described in ISO/DIS-2859 (1989) defines three levels of inspection. The higher the inspection level, the tighter the sampling procedures and the more samples required for a given batch size. Level I sampling is recommended for situations where processes and results are established and deemed to be very reliable. Level II sampling is the normal scheme used in most sampling situations. Level III may be employed where the customer is very discriminating or where quality is highly suspect.

Level II sampling was selected for the Eureka Paperbox Quality Assurance Program. As a point of reference, average production runs at Eureka are for 20,000 pieces. Following a Level II inspection requires that 125 samples be measured for the batch. According to the system, a rejection level of 0.10 (1%) rejects the batch if only one sample is found to be out of tolerance.

Defining Color Variability

Before establishing color tolerances, it is critical to determine what amount

of color variance is reasonable given the unique production process. This requires testing under conditions that assure that variables are held constant to a reasonable degree over the course of the production run. To test the degree of color variability within the system, all process control variables were measured and assured to be within tolerance. The press was set up for a normal production run and a test form was reproduced in a 20,000-impression production run—the typical run length. Sampling at a Level II was done according to ISO/DIS-2859-1 procedures, pulling a total of 125 samples and measuring Delta E against a test color swatch.

Of the 125 samples tested for variability, the minimum Delta E recorded was 0.22, and the maximum 3.01, with a mean of 1.786 and a standard deviation of 0.7853. To assure customer approval of packages with the maximum color variance, the color standard and the printed package with a Delta E of 3.01 were forwarded for customer approval as acceptable variation.

Discussion

The overall variance of the Delta E values provides insight into how well system variables are being maintained within the press system. Variance is an increasingly important concept in quality control. Attempting to decrease the variance to improve quality may not be desirable given the additional costs required to do so. This micro-economic concept can be referred to as 'quality elasticity'. For example, improving the color consistency by lowering the Delta E raises one major micro-economic question: What 'input' would it take to lower the maximum acceptable Delta E value? In this case, inputs (ultimately expressed in money units) might include newer equipment and controls, increased maintenance intervals, or increased training of staff. Given the additional costs, would the resulting reduction in Delta E variance (output) be economically feasible? This decision would have to be made on a management level and depends largely on the nature of the product and on customer

demands and willingness to pay. Further insights into quality might be analyzed within this quality assurance model. The sample presented above to determine variance was taken from a single production run, within a single shift, done by the same crew, and using the same printing press. This was done to determine system variance under normal conditions. During the course of this quality assurance initiative, additional data was obtained to compare Delta E averages from different shifts and production crews. Data was also analyzed for production runs over time, to determine trends in Delta E changes. The data collected over time and among different shifts did not provide any statistically significant differences, which indicates that the quality system implemented is working well over the gamut of production.

Another discussion point emerging from the research is that some colors allow a wider variance in Delta E than others. Research on just-perceptible-differences has shown, for example, that differences in saturated green colors are more difficult to detect than a saturated orange, which would thus require a lower Delta E variance to be deemed acceptable. What follows is that different standards may be required for different colors. From a management perspective, a printed color for which delta E values must be tightened may require one press over another or one crew over another. This understanding may also lead package designers to consider certain colors over others, as a color that is easily detected for color difference may ultimately require a higher cost of production.

Summary

The use of colorimetry in the pressroom can have tremendous benefits for assuring quality and for analyzing quality issues. To implement a system of color error measurement, a total quality control system should be in place in the pressroom that includes identifying and controlling variables that affect print quality. Once established, Delta E values can be used to assure customers of color consistency. Then, disputes over

color inaccuracy can be objectively settled. What's more, this data can be used to analyze the success of process control systems, the effectiveness of production personnel, and to aid in the decision making process that leads to investments to improve quality. This research attempted to synthesize theoretical information on color science and human color perception and apply these concepts to a practical color quality initiative in industry. The information herein presented provides Industrial Technology practitioners with a foundation for employing colorimetric data for process control and quality assurance. Furthermore, This research could help Industrial Technology practitioners develop better techniques for communicating color quality to customers while further developing or refining their own quality programs. Graduates of Industrial Technology programs must put quality measurement and control theory into practice. This case study should provide a framework for Industrial Technology educators looking to tie together the relationship between color theory in the classroom and practical process control techniques in industry.

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