# An Analysis of Illuminant Metamerism for Lithographic Substrates and Tone Reproduction

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## Abstract

Using metamerism index as a criterion variable representative of illuminant metamerism, the present research examines the potential effect of measurement condition (M1, M0), near-neutral patch type, and paper type on illuminant metamerism. Measurement condition and paper type are found to be relevant factors contributing to illuminant metamerism, while the near-neutral patch types are likely to have much less effect on the criterion variable here.


## Introduction

The commercial lithographic printing industry is currently impacted by a confluence of factors which have influenced process color workflows. These factors include a broadened reliance on industry specifications for process control aims, changes in standards for viewing conditions, and the increased availability of color measurement instruments that adhere to standardized measurement conditions developed to better address the increased use of optical brightening agents (OBAs) in printing substrates.

The manner in which these factors influence illuminant metamerism is the purpose of the present research. Using a metric known as metamerism index as the criterion variable representative of the condition of illuminant metamerism, the present research endeavors to provide useful information in the investigation of the potential presence of this condition via the measurement of various paper substrates that are appropriate for printed work using GRACoL 7 specifications.

Metamerism index is calculated for each utilized substrate using measurement conditions known as M0 and M1 as defined by ISO 13655-2009. The goals of the M0 and M1 measurement conditions are to provide tools to better the measure effect that OBAs have on measurement analyses. Further, metamerism index is calculated for the near-neutral cyan, magenta and yellow process color tonality patches as represented by the IDEAlliance ISO 12647-7 Digital Control Strip.

Therefore, the predictor variables here are paper substrate, measurement condition, and ISO 12647-7 patch type, as illustrated in Figure 1.

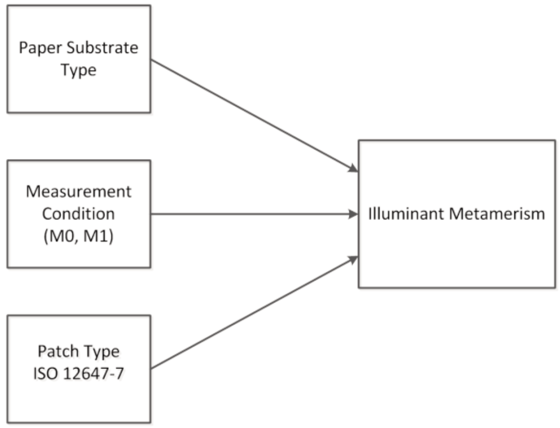


***Figure 1.*** *Criterion and predictor variables for the present research.*

## Method

One goal of the present study is to determine the relative degree of metamerism they can be expected with each examined paper using the metric metamerism index. Using substrates from various suppliers, digital halftone proofs using the Kodak Approval were made on six various paper stocks: the digital halftone proofs were produced to comply with GRACoL 7 specifications. The proofs included the ISO 12647-7 target as representative of the various near-neutral process color print patches specified by GRACoL 7 methodologies.

All measurements are taken using a single Minolta FD-7 45/0 Spectrophotometer capable of measuring M0 and M1 conditions as defined by ISO 13655:2009. A white ceramic tile was utilized as a backing material for all measurements. CIELAB colorimetric values derived from illuminants D50 and A2 were recorded, as were the spectral values of the samples using both M0 and M1 measurement conditions. The data collected for each patch selected from the ISO-12647-7 Digital Control Strip is illustrated in Table 1.

| | Measurement Condition M0 | | Measurement Condition M1 | |
|---|---|---|---|---|
| | D50 | A2 | D50 | A2 |
| Paper 1 | L* a* b* | L* a* b* | L* a* b* | L* a* b* |
| | λ 380 – 430 nm | λ 380 – 430 nm | λ 380 – 430 nm | λ 380 – 430 nm |
| Paper 2 | L* a* b* | L* a* b* | L* a* b* | L* a* b* |
| | λ 380 – 430 nm | λ 380 – 430 nm | λ 380 – 430 nm | λ 380 – 430 nm |
| Paper 3 | L* a* b* | L* a* b* | L* a* b* | L* a* b* |
| | λ 380 – 430 nm | λ 380 – 430 nm | λ 380 – 430 nm | λ 380 – 430 nm |
| Paper 4 | L* a* b* | L* a* b* | L* a* b* | L* a* b* |
| | λ 380 – 430 nm | λ 380 – 430 nm | λ 380 – 430 nm | λ 380 – 430 nm |
| Paper 5 | L* a* b* | L* a* b* | L* a* b* | L* a* b* |
| | λ 380 – 430 nm | λ 380 – 430 nm | λ 380 – 430 nm | λ 380 – 430 nm |
| Paper 6 | L* a* b* | L* a* b* | L* a* b* | L* a* b* |
| | λ 380 – 430 nm | λ 380 – 430 nm | λ 380 – 430 nm | λ 380 – 430 nm |

***Table 1.*** *Data collected for each of the 11 patches from the ISO-12647-7 digital control strip.*

## Illuminant Metamerism

Metamerism is described by Berns has a ″Phenomenon in which spectrally different stimuli matched to a given observer″ (p.14).″ Illuminant metamerism is further defined by Berns as a condition in which:

″… Pairs of colors with different spectral reflectance curves could match under one set of viewing and illuminating conditions, but fail to match under another. They are called metameric pairs or metamers. When mismatch occurs due to a change in illumination, the phenomenon is called illuminant metamerism ″ (p. 28).

Therefore, materials of different spectral properties can provide the stimuli necessary for color matching when viewed using a specific illuminant. Stated another way, it could be said that illuminant metamerism is exhibited when two samples produced under differing conditions can produce the visual stimuli wherein they match when viewed using one light source and yet not when these same samples are viewed using another light source.

## Metamerism Index

Developed as a single number index, metamerism index purports to demonstrate how well to objects that match when viewed using one illuminant will match under a second, different illuminant. The index is described in CIE Publication 15.2 (1986) Section 5.2, as illustrated in Equation 1.

$$\text{Metamerism index} = \sqrt{(\Delta L_{n1} - \Delta L_{n2})^2 + (\Delta a_{n1} - \Delta a_{n2})^2 + (\Delta b_{n1} - \Delta b_{n2})^2} \quad (1)$$

*Where n1 is the first, reference illuminant, n2 is the second illuminant, and Δ is the difference between the standard and sample.*

It is important to recognize that the most commonly used colorimetric information, such as CIELAB and Delta-E, need to be expressed in terms of a single illuminant. This yields little information about the potential presence of illuminant metamerism. Delta-E alone, therefore, is an inadequate metric for the present analysis. The present research calculates Metamerism Index using measurement conditions M0 and M1 as defined by ISO 13655-2009.

## Measurement Condition

The increased use of optical brightening agents (OBAs) in the manufacture of printing substrates is well documented. OBAs serve to enhance the brightness of the substrate through the phenomenon of fluorescence: they absorb ultra-violet (UV) radiation of wavelengths below 400 nanometers (400nm) and emit light in the 400-460nm ″blue″ range of the visible spectrum. The degree of the effect is therefore based on the amount of UV light present in the illuminant. When viewed with an illuminant with a large component of UV light, substrates containing

OBAs appear brightened; this effect is mitigated with illuminants exhibiting little or no UV component. As reflective color measurement instruments necessarily contain illuminants, measurement conditions need to be carefully defined in regard to the illuminant and respective UV component.

### Instrument Measurement Conditions ISO 13655:2009 M0, M1

In 2009, ISO published standard 13655 with specifies measurement conditions labeled M0, M1, M2 and M3: one goal of this particular standard is to further specify the illuminants contained in reflective color measurement instrumentation with respect to the UV component. A brief overview of the measurement conditions defined by ISO-13655 is provided.

### Measurement condition M0

Measurement condition M0 is a measurement condition applicable to a vast array of legacy instrumentation which generally utilizes unfiltered tungsten light, and does not specify the UV content of the instrument light source. Therefore, ISO 13655 indicates that M0 is not to be utilized when measurements exhibit the phenomenon of fluorescence and measurement data is exchanged among relevant stakeholders. Measurement condition M0 also specifies that the readings are not influenced by polarizing or UV-blocking filtration.

### Measurement condition M1

One impetus driving the need for measurement condition M1 results from instances where colorimetric and spectral data need to be communicated in an absolute manner, and where the presence of OBAs in substrates results in the condition of fluorescence. For optically brightened substrates, ISO 13655 permits an illuminant compensation method utilized together with a controlled amount of the Ultra-Violet (UV) component applied in the measurement instrument.

### Measurement conditions M2 and M3

Measurement condition M2 specifies measurement for non-polarized illuminants with the UV component filtered, and measurement condition M3 specifies polarized illuminants with the UV component filtered. These conditions are not commonly utilized for spot readings of colorimetric data in the United States, and therefore the present research is limited to utilizing measurement conditions M0 and M1 as independent variables.

**Process Color Near Neutral Patches: ISO-12647-7 Digital Control Strip 2009**

In process color printing, the ability to reproduce near neutrals using various percentages of three chromatic colors is the foundations of many process control efforts, including IDEAlliance GRACoL 7 methodologies, System Brunner, and procedures advanced by the Printing Industries of America. The widespread use of process color near neutrals as a foundation for process control efforts is due to the realization that small shifts in process variables, such as tone value increase, will be readily noticeable in near-neutral patches comprised of cyan, magenta and yellow tints. The same amount of process variation that produces a color shift in a process color near neutral may not be as noticeable in other types of images. Therefore it is recognized that in color reproduction, process control is image dependent: the amount of visually noticeable color shift is due, in part, to the images being reproduced. As process color near-neutrals likely represent the smallest latitude for process variation resulting in visually noticeable color shift, known percentages of cyan, magenta and yellow that should produce a visual near-neutral are used for process control applications. The IDEAlliance ISO12647-7 Digital Control Strip includes seven process color near neutral patches, as well as a patch for paper. These patches, along with the cyan, magenta and yellow solids are evaluated to determine their possible contribution to illuminant metamerism The patches chosen for analysis in the present research are reproduced in Table 2.

| | | | Patch Detail | | | |
|---|---|---|---|---|---|---|
| | ISO 12647-7 | Descriptor | % Cyan | % Magenta | % Yellow | % Black |
| 1. | 0000 | "Paper" | 0 | 0 | 0 | 0 |
| 2. | 3.12.22.2 | | 3.1 | 2.2 | 2.2 | 0 |
| 3. | 10.27.47.4 | | 10.2 | 7.4 | 7.4 | 0 |
| 4. | 251919 | "Highlight Contrast" | 29 | 19 | 19 | 0 |
| 5. | 504040 | "Highlight Range" | 50 | 40 | 40 | 0 |
| 6. | 756666 | "Shadow Contrast" | 75 | 66 | 66 | 0 |
| 7. | 100100100 | | 100 | 100 | 100 | 0 |
| 8. | 807070100 | | 80 | 70 | 70 | 100 |
| 9. | 100 | "Cyan" | 100 | 0 | 0 | 0 |
| 10. | 100 | "Magenta" | 0 | 100 | 0 | 0 |
| 11. | 100 | "Yellow" | 0 | 0 | 100 | 0 |

***Table 2.*** *Details of the ISO12647-7 digital control strip patches utilized.*

## Procedure

To calculate Metamerism Index, the difference between measured colorimetric values and a respective standard need to be calculated for two different illuminants. Therefore, for the present study standards need to be developed for each patch using the respective measuring condition (M0, M1) and each illuminant (D50, A2). For each chosen patch, the respective colorimetric standards are developed as an arithmetic mean of all of the utilized papers using the pertinent measuring conditions and illuminants. As such, the standards used were "virtual" and did not represent a physical standard, but rather the mean of the respective samples.

In order to properly choose an appropriate statistical test, the data were tested for the potential presence of normal distribution using Shapiro-Wilk's test. For measurement conditions M0 and M1, it is ascertained that the metamerism index scores were not normally distributed ($p < .05$). Therefore, a Mann-Whitney test was utilized as a non-parametric test to determine if there exists a statistically significant difference between measurement condition as a dichotomous predictor variable and the continuous criterion variable represented by metamerism index.

For the six different paper types and 11 different patches analyzed, the Shapiro-Wilk's test for normality was again utilized. In these instances, all of the predictor variables indicated a non-normal distribution as assessed by a Shapiro-Wilk's test ($p < .05$), with the limited exceptions noted in Table 3. Of the 17 different combinations of paper type and patch type, only four could be described as representative a normal distribution using the Shapiro-Wilk's test. Due to the relatively small sample sizes, the non-parametric Kruskal-Wallis H test was used to analyze the respective categorical predictor variables consisting of three or more groups (paper type and patch type) and the continuous criterion variable (metamerism index).

| | Shapiro-Wilk | | |
|---|---|---|---|
| Paper Type | Statistic | df | Sig. |
| 2 | 0.918 | 22 | 0.068 |
| 3 | 0.942 | 22 | 0.22 |
| 6 | 0.921 | 22 | 0.081 |
| Patch Type | | | |
| Paper | 0.882 | 12 | 0.093 |

***Table 3.*** *Paper and Patch Types representative of normal distributions per Shapiro-Wilk's test*

## Discussion

The results obtained in the present research indicate that in regard to illuminant metamerism measurement condition and that paper type can have influence. The type of patch, however, exhibits less effect on the criterion variable.

## Measurement Condition

Metamerism index values were statistically significantly different between measurement conditions M1 and M0, $U = 1,737$, $z = -2.01$, $p < 0.05$. A comparison of the respective distributions is illustrated in Figure 2, where an assessment of the visual inspection of the histograms indicates approximately equal shapes of the distributions.

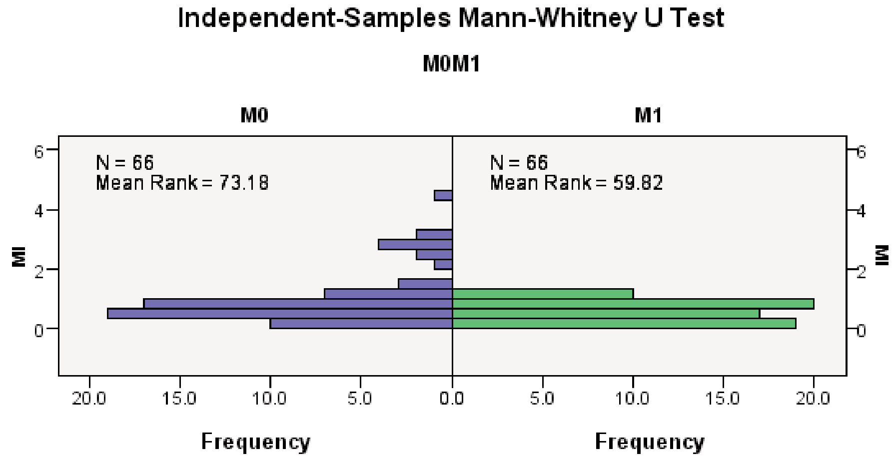


***Figure 2.*** *Histogram of metamerism index for measurement condition*

Further, a visual inspection of the histograms for measurement condition as illustrated in Figure 2 indicates that measurement condition M0 is more subject to outliers, and therefore can be subject to more variation, versus measurements resulting from condition M1.

## Paper Type

Analysis of paper type using the Kruskal-Wallis H test indicates a statistically significant difference between the various paper types analyzed, $X2(5) = 84.43$, $p < 0.01$. A visual inspection of the boxplots in Figure 3 indicates that the shapes of the distributions are not extremely dissimilar with the possible exception of the variance noted in paper type 5. The small sample sizes complicate the visual inspection efforts here, however.

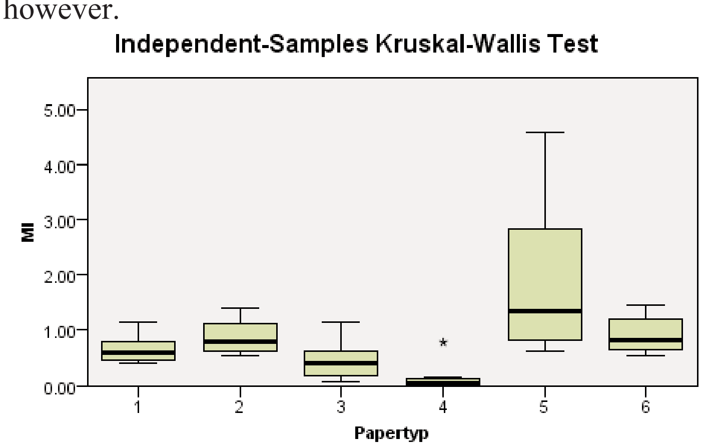


***Figure 3.*** *Boxplots of metamerism index for paper type.*

A closer examination of the various paper types that exhibited statistically significant differences from other paper types is displayed in Table 4: here, it is noted that paper type 4 differs the most from the others, followed by paper types 3 and 5.

| Paper Combinations | | Test Statistic | Standard Error | Adjusted Sig. |
|---|---|---|---|---|
| 4 | 1 | 45.64 | 11.53 | < 0.01 |
| 4 | 2 | 68.41 | 11.53 | < 0.01 |
| 4 | 6 | -73.00 | 11.53 | < 0.01 |
| 4 | 5 | -92.41 | 11.53 | < 0.01 |
| 3 | 2 | 39.41 | 11.53 | < 0.01 |
| 3 | 6 | -44.00 | 11.53 | < 0.01 |
| 3 | 5 | -63.41 | 11.53 | < 0.01 |
| 1 | 5 | -46.77 | 11.53 | < 0.01 |

***Table 4.*** *Paper combinations exhibiting significant differences in metamerism index.*

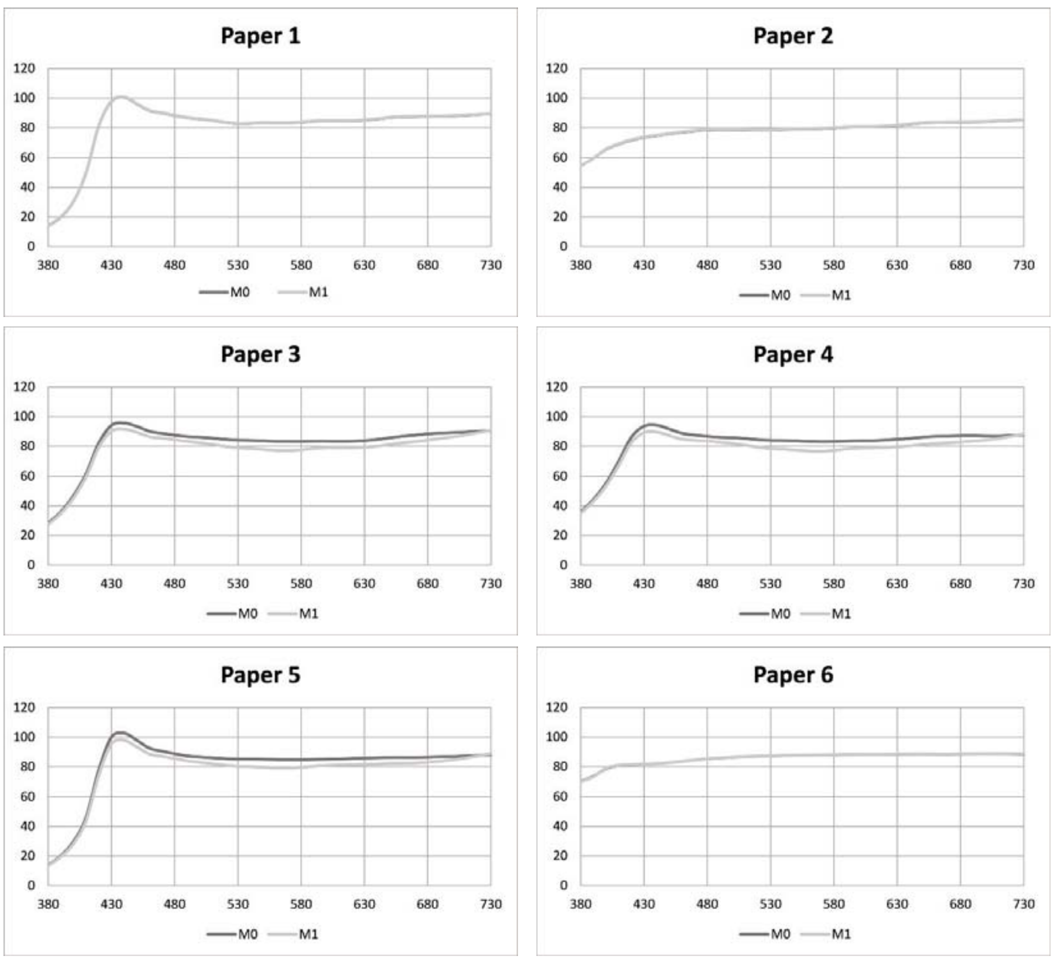


***Figure 4.*** *Spectral curves of paper types.*

Figure 4 illustrates the spectral curves of the paper types analyzed: among these papers it is noted that paper types 3, 4 and 5 display the effect of OBAs as indicated by the increased spectral reflection in the 400-440 nm range.

Turning to the predictor variable patch type, the Kurskal-Wallis H test indicates a statistically significant difference between the various patch types analyzed with regard to illuminant metamerism: X2(10) = 22.84, $p < 0.05$. A visual inspection of the boxplots in Figure 5 illustrates that the distributions are not especially dissimilar in shape.

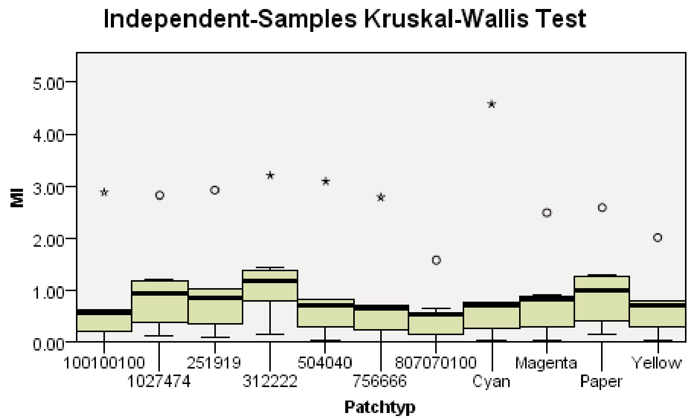


***Figure 5.*** *Boxplots of metamerism index for patch type.*

A closer look at the interactions of the various patch types, however, demonstrates a single statistically significant interaction between the 80-70-70-100 patch and the 3.1, 2.2, 2.2 patch (p =0.027). It is suggested here that this particular finding is not especially meaningful; especially when it is considered that among the patches analyzed there are 55 different sample pair combinations. Therefore, further investigation here was not conducted.

## Summary

The present research underscores the importance of defining the measurement condition (e.g.: M0, M1) when communicating colorimetric data. When communicating colorimetric numbers, users need to add measurement condition to an already robust list of relevant attributes, including illuminant, observer, and other metrological conditions. The need for communicating measurement condition does not escape users who communicated spectral data: these users were previously largely immune to need to note illuminant and observer information but now need to add measurement condition to instrument geometry and spectral data when spectral measurement data is communicated.

In addition, this research indicates that the tonal patch type is not a particularly meaningful contributing factor to illuminant metamerism to the extent that substrate and measurement condition can be. From the present analysis, tonality, as represented by overprinted screen tints of near-neutral chromatic process colors, did not contribute to illuminant metamerism when comparisons among halftone-based off-press proofs are considered using various substrates and measurement conditions.

While illuminant metamerism should never be ignored in color critical workflows, any data indicating that neutrals produced from overprinted screen tints of process colors are not especially subject to metameric conditions could be welcome information to color professionals already exasperated by the maximal process control efforts required to achieve and maintain these neutrals. This finding adds to previous research on proof to press match using process colors, where cyan and black were found to exhibit more illuminant metamerism than did yellow or magenta.

Further, a potentially important boundary condition for metamerism index is noted for future research using this metric where standards are created based on a mean of all relevant samples, as was the case in the present study. Such methodologies should recognize the sensitivity of outliers in using metamerism index as a measure of illuminant metamerism if this method is utilized.

The results of the present research do, however, emphasize the importance of those working in color critical workflows to be sensitive to the effect of illuminant metamerism. In addition, the present study calls attention to the fundamental need to remain vigilant about standardized viewing conditions to ensure the valid assessment of color. Further, the present study aspires to help to promote the adoption of the use of metamerism index into the standard operating procedures as a tool for quality assurance and communication purposes.

## Acknowledgements

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