Colourimetric Values utilized by U.S. Ink Companies

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Abstract

Colourimetry is widely adopted in the printing industry, but the user-selected variables inherent in using the technologies are not widely standardized. In the present study, the current state of the adoption of particular colourimetric variables is examined in an U.S. ink companies. A quantitative, cross-sectional survey was distributed to ink companies inquiring about their selection of instrument geometry, colourimetric illuminant, standard observer and colour differencing method as part of their standard operating procedures. In addition, companies were asked about their choice for quality assurance software and preferred digital file format for colour communication.

1. Introduction

The widespread use of colourimetry has permeated the printing industry; colourimetric values are frequently utilized to manage and control both spot and process colour reproduction and are manifest in not only brand colour control initiatives, but also serve as the cornerstone of printing industry standards and specifications such as ISO/DIS 12647-2 (2012). When correctly implemented, the use of colourimetry enables the concise communication of colour values among stakeholders in the printing workflow, from concept to design to production. Colourimetry is applied in a wide-range of quality assurance applications from incoming materials inspection to process control applications. Clearly, one key goal in the adoption of colourimetry is to drive variance out of the printing workflow. Practitioners, however, must be wary of the myriad of variables inherent in the communication of colourimetric values, including illuminant, standard observer, and colour differencing method: unless properly managed, these variables could result in increasing variance in colour printing processes.

2. Need for the Study

Standards and specification committees for the printing industry reference selected colourimetric variables in their publications and mandates for relevant certifications. Many printers have moved from visual analysis and densitometry to colourimetric information for quality assurance applications in response directives from their customers. Print buyers and consumer brand owners increasingly demand consistent colour reproduction worldwide across a variety of substrates and media.

Ink companies in particular are widely regarded as being among the most influential users of colourimetry in printing workflows. The nature of the production of inks has practically mandated that manufacturers are early adopters of colourimetry to assure production consistency. Many ink companies pro-actively provide colourimetric data in reporting with ink shipments: some go as far as to print colourimetric information on the labels of their ink containers. As printers adopt colourimetric controls, they likely consult their respective ink company for assistance in establishing their own standard operating procedures (SOPs), which include the colourimetric variables examined in the present study.

While there are numerous examples of studies that compare various colour differencing methods (e.g.: Yu, 2014; Habekost, 2013; Chung & Chen, 2011) an extensive review of the literature revealed no published studies that examined which colourimetric variables are used by practitioners in this domain. In addition to an examination of which colourimetric variables are utilized, the present study also examines potential correlations that may contribute to a greater understanding here.

3. Research Questions

Utilizing a cross-sectional questionnaire instrument designed to examine the colourimetric variables utilized as standard operating procedures by ink companies in the United States is the primary focus of this study. Specifically, the following research questions frame the investigation:

RQ1. Which instrument geometry is utilized?
RQ2. Which illuminant is selected?
RQ3. Which standard observer is selected?
RQ4. Which colour differencing equation is utilized?
RQ5. Which, if any, software is utilized for quality assurance?
RQ6. Which, if any, digital file format is utilized for colourimetric communication?

In addition, the questionnaire inquires about the size of the responding company. The following hypotheses are tested regarding possible correlations among selected variables:

H1. The data indicate a correlation between size of company and quality assurance software utilized.

H2. The data suggest a correlation between software and colour differencing method.

H3. The data imply a correlation between software and file format utilized for the digital transfer of colourimetric variables.

Understanding the commonly used variables in this field and possible correlations can be relevant for a number of constituencies, including commercial printers and print buyers, industry manufacturers, educators, standards and specifications committees.

4. Literature Review

Literature germane to the present topic include published works that describe and define colourimetric variables, and those that compare and contrast those variables through psychophysical analysis.
A brief discussion of the variables examined in the present study is outlined below. Those interested in more detailed analyses here are encouraged to consult the cited sources for more information and specifics on the variables introduced.

4.1 Colourimetry, CIELAB, standard observer and standard illuminants

The process of quantifying the perception of colour is known as colourimetry. In industrial use, colourimetry is based on the work of the Commission internationale de l'éclairage, more commonly referred to as CIE, which is generally translated as the "International Commission on Illumination". Established in 1913, the CIE is recognized by the International Standards Organization (ISO) as an international standardization body (Schanda, 2007.)
CIELAB is an opponent colour system adopted by the CIE in 1976 as a colour model based upon a standard observer and standard illuminants (Berns, 2000). It is designed to be a device-independent, universal colour space representative of the range of colours perceptual to the 'average human' with normal colour vision. The CIE has defined two standard observers: a 1931 standard observer based on a testing individuals colour perception using a two degree angle of view, and a 1964 standard observer based upon testing using a ten degree angle of view (Schanda, 2007). Standard illuminants for colourimetry are representations of the spectral power distribution of light in numerical form; the CIE has defined several illuminants to represent particular light sources (Hunt & Pointer, 2011; Berns, 2000). These data are used to calculate the colourimetric values of a sample as it would appear under a light source that corresponds to the selected CIE illuminant.
When CIELAB values are derived from spectrophotometric readings, the standard observer, illuminant and spectral readings are factored to derive XYZ tristimulus values: the CIELAB values are based on those XYZ values (Berns, 2000). The instrument geometry from which the spectral data are derived is also a critically important factor in the use of colourimetry.

4.2 Instrument Geometry

Colour measurement instruments utilized by printing ink manufacturers measure the light reflectance of samples relative to a particular reference. Due to the surface characteristics of the samples measured and other factors, the instrument illumination condition and the incident angle of measurement are of critical importance. As detailed in Randall (1997), "Directional" geometry instruments measure directional light at 45 degrees incident to the light source, either illuminating at zero degrees and reading at 45 degrees (0°/45°) or illuminating at 45 degrees and measuring at zero degrees (45°/0°). "Spherical" instruments, otherwise known as d/8°, utilize diffuse lighting and measure at 8 degrees. These instruments generally enable users to read with the specular component of the light source included with, or excluded from, the colourimetric reading. Multi-angle instruments, sometimes called "gonio spectrophotometer" use directional lighting and measure at several angles, often simultaneously. Instruments that measure five angles are common multi-angle devices (Davis, 1996; Teunis, 1996).

4.3 Colour Differencing Equation, alternately known as colourimetric tolerancing method

The primary goal of a colourimetric differencing equation is to use objective, quantifiable measurements to replace more subjective visual analyses. Colour differencing equations reduce the colour difference between two samples to a single number. The CIE first published ΔE* (alternately known as ΔE*ab and ΔE76) in 1976 (Berns, 2000). This tolerancing method has been widely utilized in industry and by ISO procedures such as ISO12647-2 and ISO/DIS 15339 (Cheydleur, 2013; Warter, 2011).

In practical use, however, ΔE* proved to be limited as the CIELAB colour space is not visually uniform. In response to this condition, in 1986 The Colour Measurement Committee of the Society of Dyers and Colourists published an equation for determining colour difference, known as ΔEcmc (Hunt & Pointer 2011). The goal of the Committee was to develop a colour difference formula that better handled small colour differences. Later, the CIE created technical committees to examine the perceived limitations of ΔE* (Berns, 2000). Resultant equations of the CIE's work include ΔE94 (alternately known as ΔECIE1994) and ΔE00 (otherwise known as ΔECIE2000) (Hunt & Pointer, 2011; Luo, Chi & Rigg 2000; Wyszecki & Stiles 2000).

In addition to the technical literature, a number of psychophysical studies have been published that examine which colour differencing method best corresponds to human vision. Such research investigated samples with surface characteristics typical for the printing industry, and some have segregated trained and untrained observers in their analysis. These include several studies that have compared ΔE*ab to more current differencing methods in various contexts germane to the printing industry (e.g.: Yu, 2014; Habekost, 2013; Chung & Chen, 2011; Habekost, 2009). Generally, these studies conclude that in nearly all examined applications ΔE00 outperforms ΔE*, however in instances where ΔE00 is compared to other more current tolerancing methods (i.e.: ΔEcmc, ΔE94) results are generally less conclusive.

5. Research Design and Methodology

Using a self-reported mailed questionnaire instrument, managers at U.S. printing ink companies were identified using a list of such companies published by Ink World magazine (2014). Using methods suggested by Dillman, Smyth and Christian (2014), potential respondents were mailed an introductory letter, followed by a survey package consisting of a questionnaire instrument and postage-paid return envelope. In addition, a link to an Internet-based survey was provided as an alternative method of responding. Steps were taken to assure that all responses were anonymous. For example, the survey package also included a postage-paid return postcard, so that research subjects could indicate that they responded without revealing which response was theirs. Two weeks after the initial survey package was mailed a reminder was sent to non-respondents, and two weeks after the reminder mailing a second complete survey package was sent to those that did

not respond. Of the 127 U.S. ink companies identified from the sampling frame, four were no longer in business, and one self-disqualified. In total, 49 companies responded out of the potential 122; a response rate of 40%.

6. Limitations

As a quantitative, cross-sectional survey, the present study is not designed to uncover the reasons that underlie why ink companies make their particular variable selections. In addition, as the sampling frame was limited to those ink companies in the InkWorld listings, large ink companies with multiple locations were represented by one of their centralized locations. Therefore, a small, single location and perhaps highly specialized ink company has the same weight in the present analysis as did a large organization with numerous locations. Further, this study is limited to those ink companies conducting business in the U.S. In addition, to streamline the questionnaire instrument, variables such as user-defined parametric values inherent in some colour differencing methods (e.g.: the lightness to chroma ratio expressed in the DE_{cmc} equation) are not examined.

7. Findings, Data Analysis and Results

The demographic information regarding the respondents is replicated in table 1. Large and smaller companies were generally equally represented: if responding companies are divided among those that employ 50 or less versus 51 or more there was a nearly even split.

Size of company		
Number of employees	**N**	**%**
< 10	8	16.3
11 - 25	11	22.4
26 - 50	5	10.2
51 - 100	9	18.4
101 - 500	9	18.4
> 500	5	10.2
Don't know/Decline	2	4.1

Table 1: Companies in this study

Table 2 displays results pertaining to user standard operating procedures relevant to instruments and software: instrument geometry, quality assurance software and file format. In these instances, over 80% of users reported utilizing directional 0°/45° or 45°/0° measurement instruments. Four ink companies reported utilizing multi-angle instruments, while three reported using spherical instruments for their standard operating procedure. Turning to software, over 50% of the ink companies responding reported using X-RiteColour Master for their quality assurance needs. X-Rite iQC was the second most utilized software, with ten reported users and four reported using X-Rite ColourQuality as their standard. The only non-X-Rite software with more than one reported user was Datacolour Tools software, utilized by four of the respondents.

In terms of digital file format, the .mif format dominated with over 40% of users reported utilizing this particular type of file for transferring colourimetric information. This was followed by all versions of the .CxF file format with over 16% of users, and the standard file format for Microsoft Excel representing just over 8% of reported users. Of all of the variables examined here, file format resulted in the highest number of "Don't know," "Decline to answer," and questionnaires with no answer selected represented 35% of the returned surveys.

Instrument and Software Variable		
Instrument Geometry	**N**	**%**
0º/45º or 45º/0º	40	81.6
Sphere d/8º	3	6.1
Multi-angle/Gonio	4	8.2
None/Decline	2	4.1
Software		
ColourMaster	25	51
iQC	10	20.4
ColourQuality	4	8.2
Tools	3	6.1
Smart	1	2
BASF	1	2
MeasureColour	1	2
Other/None/Decline	4	8.2
File format		
.mif	20	40.8
.Cxf (any version)	8	16.3
.xls/.xlsx	4	8.2
None/Don't know/Decline	17	34.7

Table 2: Information on instruments, software and file formats

Table 3 displays responses from colourimetric variables, namely illuminant, standard observer and colour differencing methods preferred as SOP. The "daylight" illuminants of D50 and D65 dominated as SOPs for responding ink companies, accounting for over 90% of users. Over one half of the respondents reported using D50, and over 40% selected D65. In terms of standard observer, the ten degree (1964) standard observer was utilized by over 53% of respondents, with nearly 39% choosing the two degree (1931) standard observer.

Colourimetric Values		
Illuminant	**N**	**%**
D50	25	51
D65	20	40.8
F2	1	2
None/Don't know/Decline	3	6.2
Observer		
10º 1964	26	53.1
2º 1931	19	38.8
Other/None/Decline	4	8.1
Colour differencing method		
ΔE_{cmc}	22	44.9
ΔE^*_{ab}	12	24.5
ΔE^*_{00}	8	16.3
ΔE^*_{94}	2	4.1
ΔE^*_{ch}	1	2.0
None/Don't know/Decline	4	8.1

Table 3: Colourimetric Variables

When examining colour differencing method, ΔEcmc is the most widely used among U.S. ink companies with nearly 45% of respondents indicating this is their choice for colourimetric tolerancing, while over 24% of ink companies reported using ΔE*, and ΔE00 accounted for just over 16%.

Turning to potential correlations among selected variables, the analysis examined correlations between the size of the company and the quality assurance software utilized, between the quality assurance software and colour differencing method, and between the quality assurance software and the file format. Due to the relatively low number responses, to test for correlations the data were regrouped to reduce the number of categorical variables, as illustrated in Table 4:

Categorical Variables for Correlational Analysis	
	N
Size of company	
≤ 50 employees	24
> 50 employees	23
Quality Assurance Software	
ColourMaster	25
Other than ColourMaster	20
Colour Differencing Method	
ΔEcmc	22
Other than ΔEcmc	23
File format	
.mif	20
Other than .mif	12

Table 4: Categorical Variables for correctional analysis

In an examination of a potential correlation between size of company and quality assurance software selection, a chi-square test for association was conducted. All expected cell frequencies were greater than five. There was a statistically significant association noted between size of company and quality assurance software selection, $\chi 2(1) = 5.31$, $p = .021$. There was a moderately strong association between company size and software, $\varphi = 0.351$, $p < .05$. The data suggest that those companies with 50 employees or less are more likely to utilize X-RiteColour Master as their SOP for a quality assurance software.

In an examination of a potential correlation between quality assurance software selection and colour differencing method utilized, a chi-square test for association was again utilized. All expected cell frequencies were greater than five. There was no found statistically significant association between quality assurance software selection and colour differencing method, $\chi 2(1) = 1.96$, $p < 0.16$. As the data indicate no association, the null hypothesis here is retained and it is concluded that software choice and colour differencing method are not significantly correlated. Finally, turning to an examination of a correlation between quality assurance software and file format, one cell had an expected cell count as less than five. Therefore the results of the Fisher's Exact Test are reported: $p < .005$ (2-sided). This finding suggests that those companies utilizing X-RiteColour Master are more likely to utilize the .mif file format as their preferred method for communicating colourimetric data digitally.

8. Analysis

In an examination of the types of instruments utilized by U.S. ink companies, it is no surprise that directional 0°/45° and 45°/0° instruments are the most widely adopted, as it is likely that densitometry is commonly still utilized in addition to colourimetric data, and 0°/45° or 45°/ 0° geometry is mandated by standards bodies for ANSI status density readings (Brehm, 1999.) Further, such instruments are generally less expensive, easier to use and available with smaller measurement apertures than their spherical and multi-angle counterparts.

The usage of daylight illuminants is also to be expected, although some may find it interesting that the D50 illuminant only represented one-half of the respondents: this particular illuminant condition is widely utilized in the U.S. printing industry as referenced in ISO 13655:2009. Likewise, respondents reported adoption of the two degree (1931) standard observer at 38% versus 53% adopting the ten degree observer. This finding may also be curious to some, as standards committees in the printing industry generally utilize the two degree choice.

The reported preferred use of ΔEcmc as a colour differencing equation by many ink companies is of particular note as ΔEcmc is not recognized by graphic arts standards and specifications committees to the extent of ΔE* and ΔE00 (Cheydleur 2013, Warter 2011. The second most widely used colour differencing method in this study is ΔE* and the more current ΔE00 represents the third most popular choice among responding ink companies. It is noteworthy that the data indicate if the number of ink companies using ΔE* and ΔE00 are combined, they still do not equal the nearly 45% of companies adopting ΔEcmc

as a part of their standard colourimetric operating procedure.

In the examination of quality assurance software, clearly the X-Rite products enjoy the majority of the market share with U.S. ink companies, three of their software products are adopted by nearly 80% respondents. X-RiteColour Master is the most widely utilized, and is most likely the choice of smaller companies. The prevalence of the .mif digital file format may speak to the dominance of X-RiteColour Master as a software choice for quality assurance use as the format been a default selection of Colour Master users for many years.

9. Conclusions & Implications

In 1986, Fred Davis published a technology acceptance model for empirically testing new end-user information systems: theory and results, where he posited that perceived ease of use and perceived usefulness were direct antecedents to technology adoption. It is suggested here that the technology acceptance model (TAM) is an appropriate lens to view the implications of the present study. Clearly, the sheer diversity of colourimetric variables reported as SOPs by U.S. ink companies represents an interesting condition for the commercial printing industry: stakeholders who desire more homogeneity among the colourimetric variables utilized by industry are advised to build the case for the usefulness of selected methods to overcome the inconvenience of the incumbent changing their current SOP. For example, the present study indicates that a large percentage of responding ink companies prefer to utilize DEcmc. This particular tolerancing method is not recognized in ISO12647-2 (2013) which references ΔE* as a normative parameter with ΔE_{00} as the informative parameter (Cheydleur, 2013). Psychophysical colour differencing research that limits comparisons of ΔE* to ΔE00 could be leaving out wide swaths of the industry; users of DEcmc would be understandably unfazed by such studies. If DEcmc is meeting the needs of such companies, the moves of standards committees may hold little sway, especially if unsupported by convincing psychophysical evidence of the superiority of one colour differencing method over another. Restated in the view of Davis' TAM (1986), the perceived usefulness one colourimetric tolerancing method versus another may not be sufficiently significant to warrant a change.

This finding further suggests that the recent adoption of the file CxF3 file as an ISO standard format (ISO 17972-1: 2015) may not have an immediate impact on what U.S. ink companies continue to use: especially if this case is similar to the persistent use of DEcmc by many. It is reasonable to conclude that if ink companies and their constituents are utilizing file formats other than CxF3, and their selected formats perform well in their workflows, they will likely see little reason to switch unless a case for the superiority of CxF3 can be clearly and empirically supported. As with colour differencing methods, the recognition of standards bodies may be of little consequence to contented users of other formats.

10. Future research

Future researchers could adopt a more qualitative approach to print providers and buyers to obtain a richer understanding of the salient factors driving the choices that ink companies make in regard to colourimetric variables. Further, as this research is limited to U.S. ink companies, researchers may choose to examine ink companies outside of the U.S.

In addition, the present study potentially builds upon a rich tradition of technology adoption studies conducted since the seminal Rogers' Diffusion of Innovations was first published in the early 1960's (Rogers, 2003). As such, a point of reference for future potential researchers examining U.S. ink companies use of colourimetry and the respective variables is provided. Subsequent researchers may choose to re-examine ink companies in the future to better ascertain the stage of adoption of the variables examined here, as well as the relative influence of standards committees and software vendors on these variables.
Finally, researchers may wish to replicate this study with actual printers to better ascertain which vari-

ables such companies choose to select as part of their standard operating procedures: such studies could result in noteworthy comparisons to the present work.

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