Repeatability of Ink Transfer and Color Management in Lithography:
Investigating the Performance of a Heidelberg Quickmaster DI-46 and Printmaster PM-74 against the ISO 12647-2:2004(E) criteria

Saleh Abdel Motaal and Mohammed Sikander

Undergraduate Students at the School of Graphic Communications Management, Ryerson University
350 Victoria Street, Toronto, Ontario M5B 2K3, Canada

sabdelmo@ryerson.ca, msikande@ryerson.ca.

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Abstract

The purpose of this research is to investigate the applicability of color management to lithography printing by exploring repeatability of ink transfer and its implications on thresholds and tolerances specified by the ISO 12647-2 and specifications like GRACoL 7. Two presses were investigated, a Heidelberg Quickmaster DI-46 and a Printmaster PM-74, using a special test form divided into 9 and 18 regions, for each press, respectively, to look at repeatability on the circumferential and axial dimensions. Densitometry and colorimetry measures were both explored, with focus on solid values, and all based on spectrophotometric data generated. This report is a continuation to a previous study (Abdel Motaal & Sikander, March, 2008) and adds the new dimension of comparison of the newly produced Printmaster data to the previous DI-46 set.

The Quickmaster DI46 4-color direct imaging waterless press was tested as a variant of a common impression cylinder to explore the potential for achieving the tight specifications and tolerances. The Printmaster's added width and conventional inking allows us to expand on the implications of circumferential and axial variations on the application of color management practices.

Based on a sample-set of 11 sheets from 100 consecutive good prints, we conclude that each press has unique ink transfer repeatability patterns that would impact the effectiveness and accuracy of color management at the calibration stage and during production. The Printmaster was susceptible to higher CIE L*a*b* variation values, as defined in the ISO 12647-2, with up to ΔE_{ab} of 5.44 in the CMY 3 color black patch. The DI press had more stable variability results yet has failed to meet the deviation tolerances for some primary colors and a number of secondary overprints.

1. Introduction

The practice of color management within the context of the recent ISO 12647-2 standards, GRACoL 7, the G7 Proof-to-press techniques place much emphasis on the role of CIE L*a*b* colorimetry, in view of tight deviation and variation tolerances.

Based on these new aims, presses now need to be more thoroughly tested to minimize any factors that result in variation of ink transfer, thus, increasing the repeatability of the process.

The objective of this research is to assess the implications of the repeatability of ink transfer, in certain press configurations, on the potential for application of color management practices, i.e. GRACoL, with reference to the criteria for variation as defined by the ISO 12647-2:2004 (E) specification. Subsequently, the test runs conducted for this study are designed to provide measurable colorimetric and densitometric values that may be comparable to those of the specifications and standards. However, additional consideration was taken in designing a test from that may provide added measurable data, to quantify in-sheet and cross-sheet variability, which is the focus of several recent works as a corner stone to color consistency in printing.

1.1. In-sheet Variability

A study conducted to investigate the "Spatial Uniformity of Offset Printing" (Sigg, 2007) using a custom test form that measures uniformity as a function of 19 axial and 14 circumferential bands has shown a strong correlation between spatial location and density variations. In fact, this research is largely inspired by the work and findings of this study and aims to further identify circumferential and axial implications on ink transfer variability.

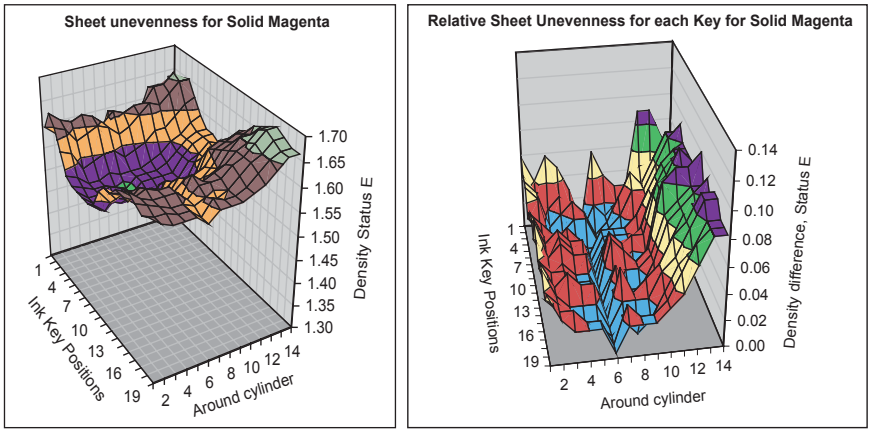


Figure 1 – Absolute and Relative Magenta Solid Unevenness (Sigg, 2007)

Figure 1, which is referenced from the work of the original author for demonstrational purposes, shows a 3D plot representation of the absolute and relative unevenness of the 266 solid magenta patches. The paper concluded that the "unevenness of inking around the cylinder [circumferentially] is around 0.08 density," a major factor when tolerance is often set at ±0.1 density.

Based on the visual assessments of this graph we have decided on recognizing that circumferential location may have implications, but also added that axial variability, regardless of the unevenness of the ink zone settings, may also be an important suspect to consider from a repeatability standpoint.

1.2. Axial Variation

While the setting of ink zones is a luxury in offset lithography that works to minimize the axial inaccuracy of the ink transfer, repeatability does not attain added control by this practice. Ink zone adjustments that are based on a trailing color control bar will allow for controlling the accuracy and evenness of the ink zone bands, however, differing levels of in-zone variations from the lead to trail edges can degrade repeatability (dispersion). The correlation between the trail edge and the length of the print may be affected by limited factors like the ink evenness along the length of the rollers through the revolution, the substrate's uniformity, as well as the image contained within each zone. In practice, printing work is often not designed based on the above constraints, for example, we do not layout the dimensions of a business card based on the width of the ink zones.

For this study, the placements of the targets were not designed to meet considerations for axial homogeneity allowing us to compare the "practical" potential for variation between axially imposed images. We have also recognized that we should not automatically attribute axial differences to ink zone settings, and comparisons like central tendencies are only valid within a given axial band. However, we were comfortable in comparing axial repeatability in terms of dispersion.

1.3. Circumferential Variation

Based on previous reasoning, we view circumferential ink transfer deviation as being heterogeneous by nature, and that the in-band variations might also be heterogeneous. This means that summaries of central tendencies are expected to differ from one circumferential band to the next, and that summaries of dispersion are also expected to differ. However, unlike the axial counterpart, the circumferential heterogeneity is a matter that is inherently uncontrollable, beyond the making the right selections for press design, maintenance and used materials, with no synonym to the axial ink keys.

For this study, we are able to compare maximum circumferential dispersion to emphasize repeatability. We can safely assume that the central tendency for each circumferential band across axial regions is in fact measuring the potential for even ink transfer across the circumferential length. Secondly, we can move forward on the premise that in-band variability can be quantified as the maximum and minimum axial dispersion values for each circumferential band.

2. Experimental Procedure

2.1. Inks

The formulation of the ink is key to the stability of the printing process. For each run, one set of inks, each from the same can, were used to increase consistency. On the DI-46 we used the Rycoline Waterless Process Inks Set and for the PM-74 we used the Hostmann-Steinberg Inkredible Reflecta Process set. The ink sets were evaluated against the ISO 12647-2:2004 (E) primary colors deviation tolerances during the run and were researched for compliance with ISO 2846-1 criteria (ISO, 2004). Our efforts failed to locate documentation on Rycoline series for the DI run, however, based on the manufacturers expert opinion, the newer Diamond series (within the same M 14700 – 700 family) of inks that use identical pigments and comparable formulation was tested against ISO 2846-1 and was approved by the GATF (Welfare, P., 2009, personal communication).

We have done these checks to exclude interference due to inks when comparing printing repeatability performances. Any amount of deviation (accuracy shift) may aggravate variation (repeatability), thus our caution was key to ensure valid assessments. In this effort, we have also minimized the impact of unpredictability of ink performance resulting from rheological and physical interactions, whereby we have ensured the inks have been designed and tested by the manufacturers to work together. We state this to provide the reader with emphasis on the importance of inks in achieving repeatability in printing.

The condition of the ink, including tack, dampening, temperature, and flow were optimized during makeready using consistent zone-based color control bar density testing and visual sheet quality assessments. Ink density deviations of ± 0.1 units for any color were flagged as out-of-tolerance and corrected. Dampening (for the PM-74) was metered during makeready to eliminate factors, including scum, while providing adequate operating buffer, 80-100 sheets between pulls, for the press condition to stabilize. The final printing unit conditions for inking, and dampening for the PM-74 press, were locked in following the last set of adjustments and 100 consecutive good sheets were pulled, after a buffer, to reflect the sampled population.

In view of the inks' influence on repeatability of ink flow, and based on the methodology above, we are expecting that variations caused by the ink in the final set of samples will be largely restricted to natural causes, practically unavoidable, (1) ink formulation- and printing unit condition- related factors affecting ink transfer, noted in solid density and dot gain (2) ink interactions, i.e. overprinting trap, noted in secondary and tertiary combinations; both will compare to real world settings where adequate process control is in effect.

2.2. Substrate

Substrates also play a major role in ink transfer. Evenness of surface and subliminal characteristics can contribute to ink transfer repeatability; in terms of (a) ink receptability, (b) effective printing squeeze (due to thickness), and (a) holdout (due to composition). Furthermore, the evenness of the colorimetric and visual properties can affect the observable image and measurements by shifting values of ink transfer that are derived through visual quantification methods like spectrophotometry. In a study of "The Effect of Certain Process Parameters on Inherent Color Variations on Press," MacPhee (2007) tested the implications of the "heterogeneity (fibers and fillers)" of the substrate by comparing CMYK density variations on paper substrates to those on a "impermeable and homogeneous" plastic counterpart at

quarter-tone intervals. Reportedly, the data has shown that the substrate is not a factor. However, to eliminate any speculation regarding the composition, we have used one stock for both tests, 100# Condat Supreme Gloss, leveling the potential for interference with ink transfer as well as any implications of the characteristics on colorimetric measurements. Secondly, we ensured that the substrate is comparable to a reference ISO stock, ISO 1: gloss-coated, wood-free (ISO, 2004), in terms of colorimetric value, to contribute to the accuracy of our data. Finally, emphasis was placed on reporting the localized values of substrate properties, where applicable. A non-printing patch for each region is used to measure visual variability, L*a*b* and Density values, and provide a reference to the subsequent validity of localized regional data.

Table 1 - Comparison of colorimetry of used substrate to ISO 1 reference (ISO, 2004, pp. 5 - Table 1)

	L*	***a****	***b****
ISO (1) *	93 (**95**) **±3.0**	0 (**0**) **±2.0**	-3 (**-2**) **±2.0**
PM-74	93.9 ±0.2	0.0 ±0.1	-0.1 ±0.3
DI-46	94.2 ±0.4	-0.4 ±0.1	-0.7 ±0.4

* Comparable white backing (informative) measurements in brackets.

Table 1 compares CIELAB colorimetry of the used substrate to the reference data with white backing, summarizing the data for each run for added comparability. As shown, the selected substrate has presented similar stability between both runs, and in the most part closely meets the specified ISO criteria. Should there be critical deviation (accuracy) assessments then measurements with black backing would be essential. This is also true when duplex printing is used. For the purposes of variation (dispersion) assessments, we chose to accept these results.

2.3. Selection of Samples

As previously stated, makeready was conducted to stabilize the process for each test run. Following the first good sheet and a buffer of around 100 sheets for the Printmaster and around 30 for the Quickmaster, 11 or more samples were taken for 100 consecutive prints, at constant settings, selected at random, for every ten sheets. An odd number of sheets (11) and circumferential bands (3) was chosen in the earlier research report (2009), for the Quickmaster press, and maintained here for consistency. Axial bands are also maintained at multiples of 3, with the ability to interpolate the data for comparison if necessary.

2.4. Test Form Design

To quantify the non-uniformity in ink transfer our test form was divided into identical grid regions across the axial and circumferential dimensions of the sheets. with each containing the IT8.7/3 color target for use with the i1 iSis. The IT8.7/3 target contains solid patches, two- and three-color overprints, as well as tint scales and number of other combinations. The design shown in Figure 2 was used for the Quickmaster DI-46 portrait press, with 3 by 3 regions on the sheet.



Figure 2 – i1 iSis Ready Test Form for Heidelberg DI-46

For the landscape Printmaster PM-74, the design was repurposed to the new sheet dimensions resulting in a 6 by 3 imposition layout.

2.5. Instrument and Measurement Considerations

For this research, we looked into colorimetric and densitometric data to compare ink transfer as quantifiable by both measures. The focus of our analysis is on variation (dispersion) between comparable values within a sample data set of sheets, divided into axial and circumferential subsections. All densitometric and colorimetric data used were computed from the 36-point spectra readings, with white backing, collected MeasureTool 5.02 (on Mac OS X) using an X-Rite i1-iSis automated spectrophotometer. The literature of the device indicates inter-instrument agreement at an average 0.4 DE*94 and short-term repeatability at 0.1 DE*94 (D50, 2°), on white backing. Thus, density and colorimetry were derived from a single source, eliminating instrument and/or methodical biases. Computations are suitable for comparisons of repeatability, as required. It should be emphasized that white backing measurements are comparable to the informative values in the ISO 12647-2:2004 (E) specification, allowing safe assessments of variation (repeatability) to the defined tolerances. However, we also emphasized that deviation (accuracy) should only be assessed using readings with black backing against the normative values, as intended.

2.6. Densitometry

Density measurements are a crucial parameter to the consistency of the data collected in our study. We have elected to use color control bar density to control the printing process for each run. We have used one instrument, the ATD 40 Auto-Tracking Densitometer (X-Rite, USA – S/N: 002127 M:ATS-40-00-01), and a comparable color control bar for each press. However, further from ensuring that we achieve density aim points and tolerances, all densitometric data used in our analysis are computed from the iSis spectra. Dry density computations are suited for valid repeatability comparisons.

Software functions were developed, building on the work published by the Colour Imaging Group at the London College of Communication (Green, 2003). The work defined the method of applying the density formula, as well as weighing functions based on those referenced by ANSI CGATS.5-1993 and the ISO 5-1993 for the Status T and Visual filters (Figure 3, data provided in Appendix 1. Weighing Functions).

$$D = -\log(Rc) \qquad (1)$$

with, *Rc*: Spectral reflectance as a product of the weighing function of a spectrally selective filter.

$$Rc = \sum(Rm * Rf) \div \sum(Rf) \qquad (2)$$

with, *Rf*: Filter response weighing spectra, and *Rm*: Measured reflectance spectra. Weighed by the scale of the reference *Rf* spectra to derive percentage values.

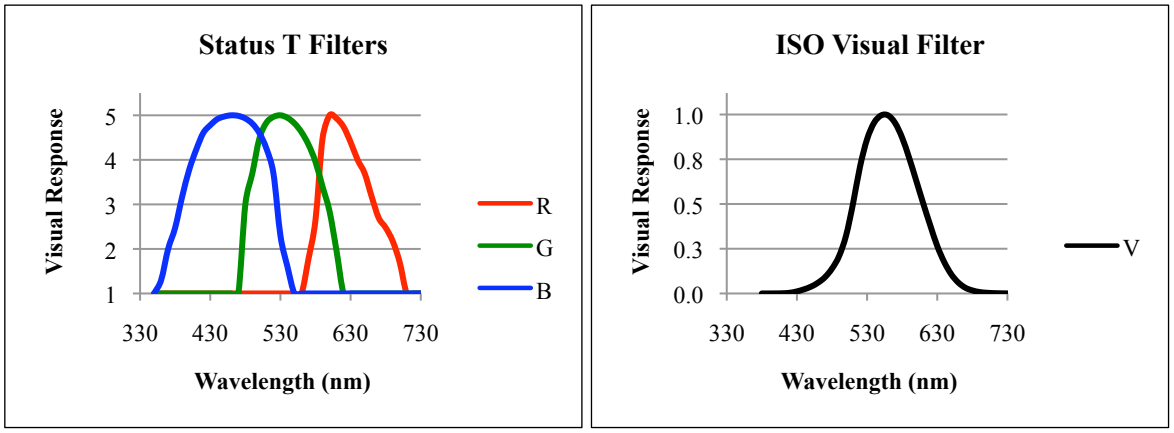


Figure 3 - Spectral Distribution Response Curves for Status T & ISO Visual Filters (Green, 2003)

In our complimentary journal report (2009), we have assessed the accuracy of the computed density against values measured through a traditional densitometer and found a maximum density error of ±0.10, affecting the measurement of black, with an overall mean of ±0.02 units and an overall standard deviation of ± 0.02 units. As such, we can guarantee the reliability of comparing computed densities, but emphasize that the data should not be compared to those generated using other methods.

To quantity some print characteristics Preucil's Ink Trap and ANSI Tone Value formulas were used:

$$A = f\left(D_h, D_s, D_p\right) = 100 \times \left[\frac{1 - 10^{\left(D_h - D_p\right)}}{1 - 10^{\left(D_s - D_p\right)}}\right] \quad (3)$$

with A: Tonal Value (Percent), D_p: Status T density of substrate, D_s: Status T density of solid, D_h: Status T density of half-tone. (Comparable to Murray Davies) (ANSI, 2007)

$$\text{Preucil's Ink Trap } \% = 100 \times \left(\frac{D_{\text{Overprint}} - D_{\text{First Down}}}{D_{\text{Second Down}}}\right) \quad (4)$$

with D: Density of indicated solid patch using the complimentary filter for the second down ink.

2.7. Statistical Calculations

For the comparability of results, to ISO references and as per previous work (Seymour, 2007), calculations of standard deviation and central tendency are following CGATS/ISO 15790:2005 (ANSI, 2007). ISO defines CIELAB variation in ΔE_{ab} tolerances which are computed through the central tendency and a standard deviation, "analogous to a gaussian distribution," having an upper limit at 68 %.

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \quad (5)$$

$$s = \sqrt{\frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}{n-1}} \quad (6)$$

with n: Number of measurements, $\bar{x}$: Arithmetic mean of the n results considered, x_i: Result of the i^{th} measurement.

2.8. Colorimetry

Similar to the method of computing density, all CIE L*a*b* colorimetry values were calculated based on the CIE 1931 2º Standard Observer and the D50 reference illuminant, producing XYZ data. The resulting XYZ values were converted to CIELAB using built-in MatLab functions for converting "1931 CIE XYZ tristimulus values (2° observer)" to "1976 CIE L*a*b* values", referencing the "CIE illuminant D50, which is also the default illuminant specified in the International Color Consortium specifications ICC.1:2001-04 and ICC.1:2001-12" (MathWorks, 2009).

$$\Delta E^*_{ab} = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \quad (7)$$

with $\Delta L, a, b$: Difference between referenced and sample CIE L*a*b* values.

3. Results and Analysis

Table 2 – CEILAB Deviation for PM-74 (ISO, 2004, pp. 5 - Table 1)

	L*	a*	b*	L_{ISO}	a_{ISO}	b_{ISO}	ΔL	Δa	Δb	ΔE_{ab}
Paper	93.9	0.0	-0.1	95	0	-2	*-1.1 ≤±3*	*0 ≤±2*	*1.9 ≤±2*	2.2
Cyan	55.4	-34.8	-48.9	55	-37	-50	0.4	2.2	1.1	*2.5 ≤ 5*
Magenta	47.9	74.7	-1.1	48	74	-3	-0.1	0.7	1.9	*2.0 ≤ 5*
Yellow	87.8	-5.0	89.8	91	-5	93	-3.2	0	-3.2	*4.5 ≤ 5*
Black	20.1	1.2	2.0	16	0	0	4.1	1.2	2	*4.7 ≤ 5*
MY	47.8	68.8	46.2	49	69	52	-1.2	-0.2	-5.8	5.9
CY	49.3	-64.0	25.1	50	-68	33	-0.7	4	-7.9	8.9
CM	23.1	24.4	-45.7	20	25	-49	3.1	-0.6	3.3	4.6
CMY	21.6	3.1	-1.2	18	3	0	3.6	0.1	-1.2	3.8

Reference to white backing (informative) measurements from ISO 12647-2:200(E).

Table 2 summarizes the deviation for PM-74, based on the average for each colour in all 18 regions across all sheets, with reference to ISO. All deviation criteria were met for primary solids and the substrate. For secondary colours, ISO (2004) outlines that criteria such as those defined for primaries would not be sufficient due to the varying factors affecting over prints. Our goal of meeting, or falling close to the deviation tolerances is to level both runs in a standardized approach to increase the reliability and comparability of variation-related results.

Table 3 – CEILAB Deviation for DI-46 (ISO, 2004, pp. 5 - Table 1)

	L*	a*	b*	L_{ISO}	a_{ISO}	b_{ISO}	ΔL	Δa	Δb	ΔE_{ab}
Paper	94.2	-0.4	-0.7	95	0	-2	*-0.8 ≤±3*	*-0.4 ≤±2*	*1.3 ≤±2*	1.6
Cyan	55.4	-31.9	-50.8	55	-37	-50	0.4	5.1	-0.8	***5.2 ≤ 5***
Magenta	50.0	69.1	-3.2	48	74	-3	2	-4.9	-0.2	***5.3 ≤ 5***
Yellow	87.9	-4.2	92.2	91	-5	93	-3.1	0.8	-0.8	*3.3 ≤ 5*
Black	17.6	0.6	0.7	16	0	0	1.6	0.6	0.7	*1.8 ≤ 5*
MY	49.7	62.6	46.9	49	69	52	0.7	-6.4	-5.1	8.2
CY	48.9	-55.8	19.9	50	-68	33	-1.1	12.2	-13.1	17.9
CM	30.0	13.3	-45.9	20	25	-49	10	-11.7	3.1	15.7
CMY	28.6	-6.1	-2.7	18	3	0	10.6	-9.1	-2.7	14.2

Reference to white backing (informative) measurements from ISO 12647-2:200(E).

Table 3 shows the deviation for DI-46 press, based on the average for each colour in all 9 regions across all sheets. The data shown is a correction to those reported in the earlier journal report, where the white backing values were mistakenly omitted. When compared to the correctly published criteria for deviation, it is clear that the DI-46 data does not pass. With Cyan and Magenta going over the maximum ΔE_{ab} deviation by as much as 0.3. The previous incorrect data also flagged Magenta at ΔE 5.2, while Cyan was in tolerance, at 4.7. Both Yellow and Black remain within good deviation levels, with ΔE of 3.3 and 1.8, respectively.

As for overprints, the Quickmaster's waterless printing resulted in less trapping, with the DI benchmarked at 52, 71, and 61% for R, G, and B (Lind, 2003). Our measured values were at 62, 72, and 55%.

3.1. Repeatability of Ink Transfer: Solid Density Trends

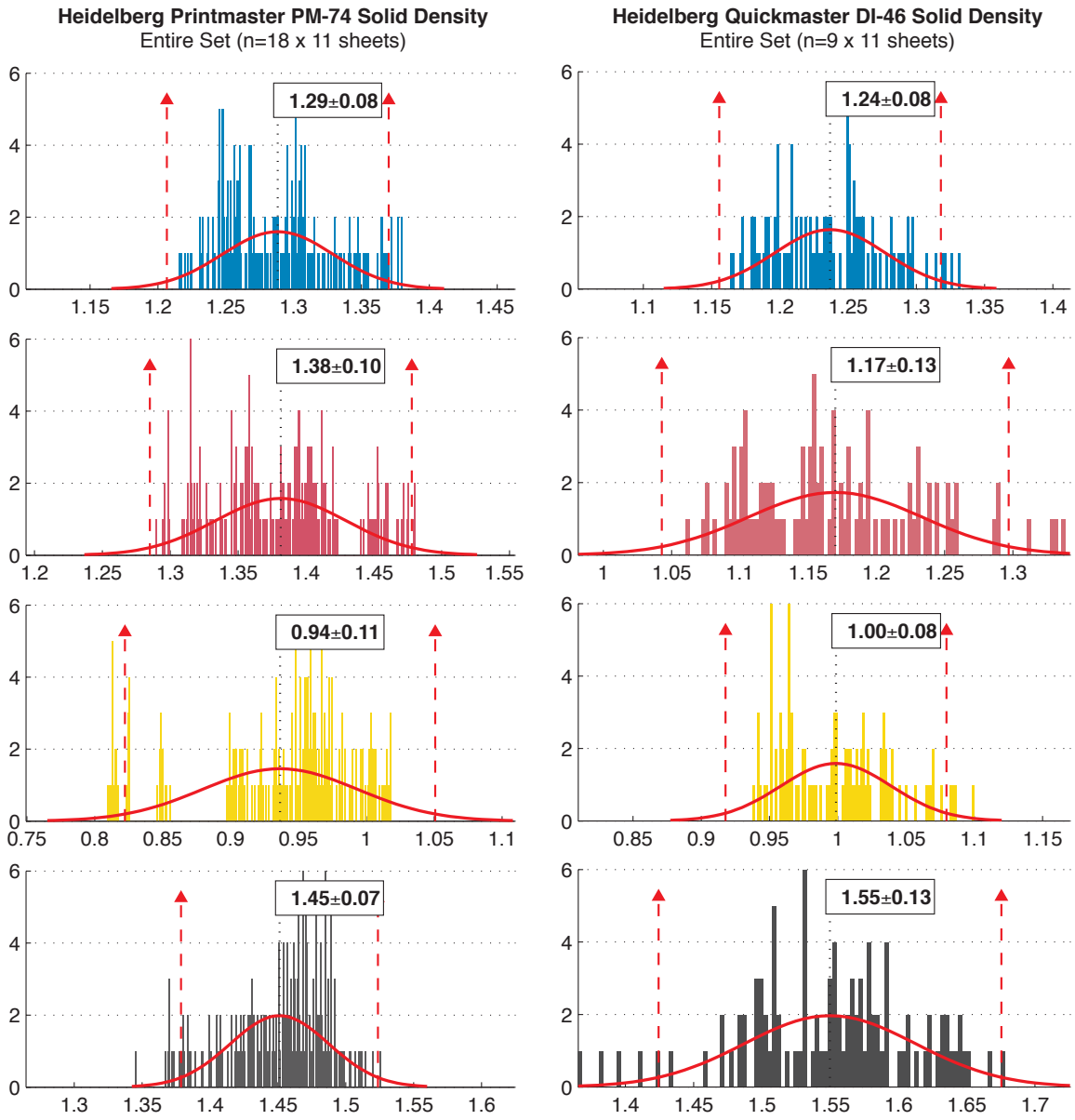


Figure 4 – Normal solid density distribution (k=2) histograms for PM-74 and DI-46 for the entire population

The distribution curves in Figure 4 are alarming at first glance, when comparing to traditional quality control data, since the densities extend over a wide range beyond the control limits of the probability density function (in red). However, the upper and lower bounds here are based on a factor of ±2 sigma, as the data contains a high degree of uncertainty (ANSI, 2007) regarding the underlying factors. The degree of uncertainty may be attached to (1) spatial variability relating to the repeatability of ink transfer, (2) spatial deviation relating to the accuracy of ink transfer, (3) conditional and material-related factors. These are suspects that may become exponentially visible when readings are collected over the entire sheet.

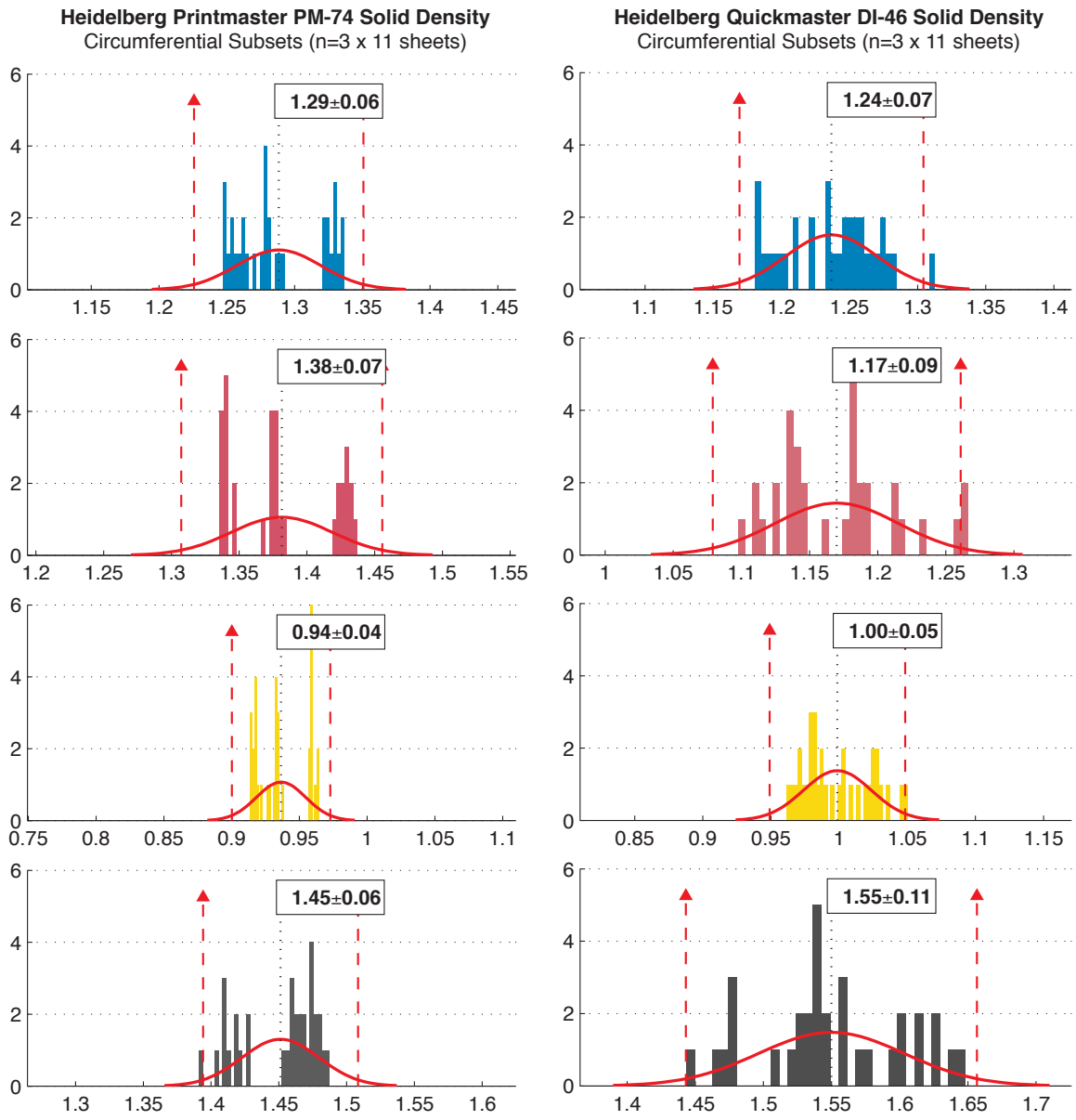


Figure 5 – Normal solid density distribution (k=2) histograms for PM-74 and DI-46 within circumferential subsets

When comparing to the dispersion of the entire population (Figure 4), the simple step of averaging axial values and summarizing the data into circumferential subsets has shown increasing stability, as shown in Figure 5, worthy of further discussion. This means that drawing conclusions about the presses from the entire dataset would clearly be an invalid approach if the data were taken at face value. The fact that the data here is more homogenous helps to further clarify implications of the (1) spatial variability and (2) deviation factors mentioned earlier. Differences between localized central tendencies (accuracy) and dispersion (repeatability) along the axial bands resulted in as much as added spread of 0.07 and 0.04 density, as the exponential effect of both shift and spread, for the PM and DI presses, respectively.

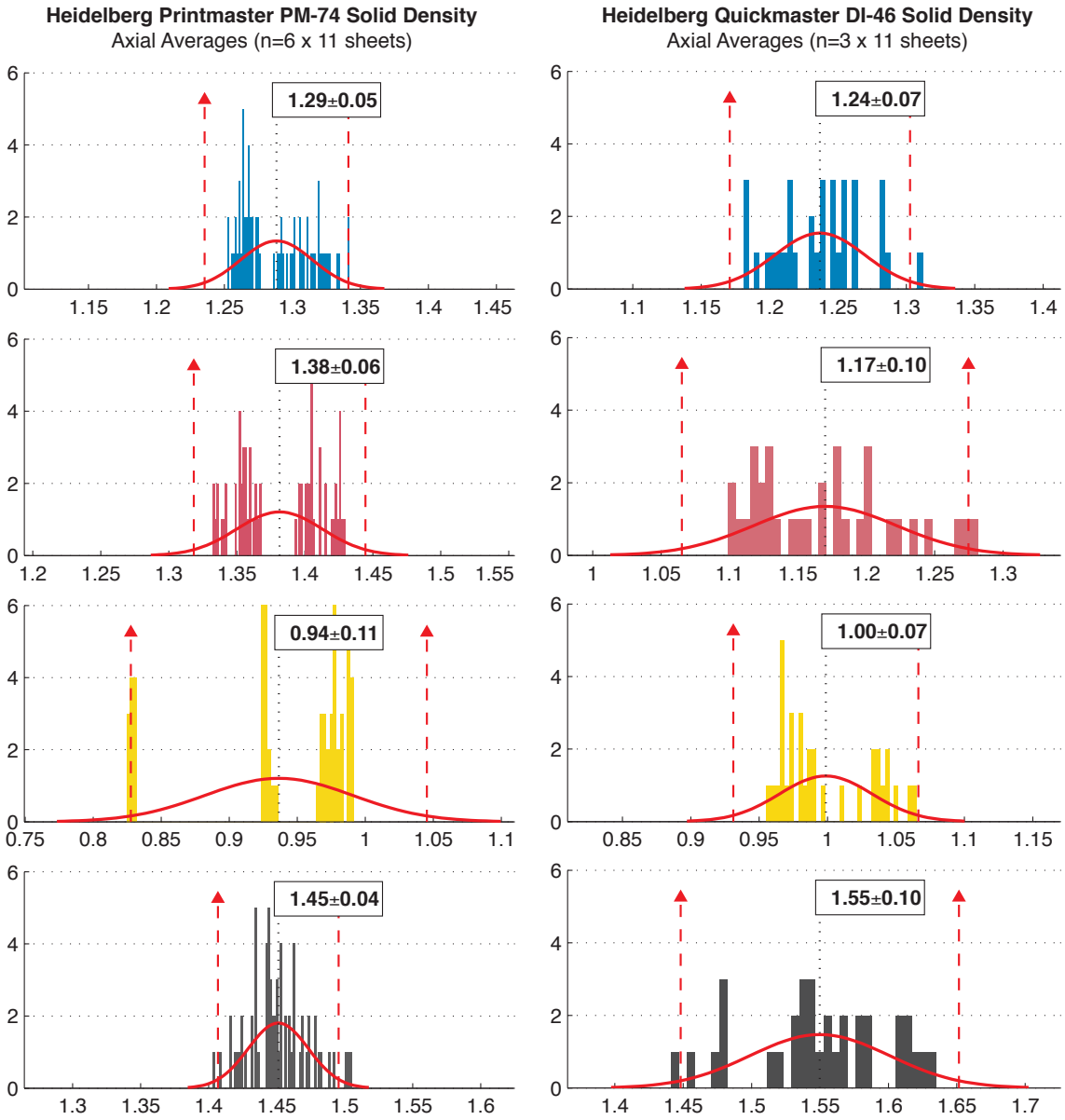


Figure 6 – Normal solid density distribution (k=2) histograms for PM-74 and DI-46 within axial subsets

At this point, we have achieved acceptable fit in the distribution of solid density in both the circumferential subsets (Figure 5) and axial subsets (Figure 6) and can safely conclude that factors of spatial variability and deviation have a notable impact on the repeatability of the ink transfer. Axial spread can be awarded some latitude on a printing unit basis as the settings of the ink keys may produce some anomalies (i.e. the Yellow). The first relationship that can be identified across both presses is the fact that each press design and condition hold unique tendency by which circumferential and axial shifts will affect either or both the accuracy and repeatability of ink transfer at various magnitudes for every given printer unit as demonstrated by the uneven changes in distributions for both press, units and across both subsets.

3.2. Cross-Sheet Variability

Testing for the effects of ink keys is not part of this research design, and as such, axial assessments and conclusions will be limited. However, through the summary of axial band data, on a sheet-by sheet basis we can look closer into circumferential variations that contributed to the differences in the dispersion of the data. In Figure 7, it is clear that each press has unique repeatability patterns. The DI was largely unstable across sheets, while the Printmaster had distinct and consistent accuracy shifts, circumferentially.

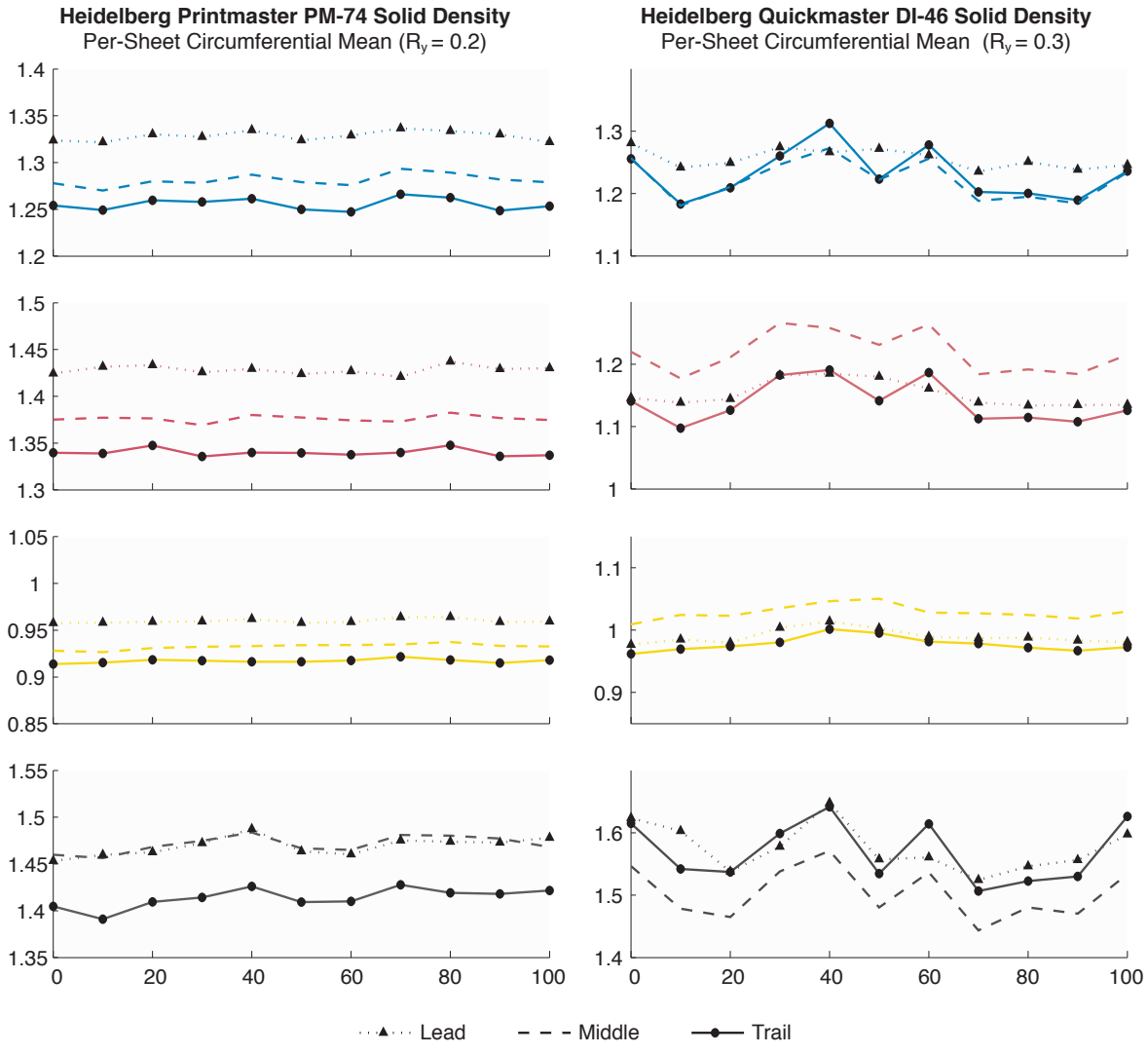


Figure 7 – Circumferential mean solid density for 11 sample sheets for both PM-74 and DI-46.

3.3. In-Sheet Variability

While it is possible to mathematically investigating the tendency for correlation between circumferential accuracy and/or dispersion, that would remain something for future work. Since we only have data for two presses under unique conditions, any conclusions cannot be checked for their validity regarding other presses. The second limiting aspect is that our data for any given patch may only be interpolated from 9 or 18 points for each sheet, that is measuring the solid cyan from the same solid cyan patch across the regional targets, for the DI and PM presses, respectively. However, with reference to the work of Sigg (2007), "looking at the spatial variability around the cylinder […] there is a systematic pattern," and for the solid density, the supplied graph identifies similarity between the lead and tail edges, as with our DI cross-sheet circumferential solid density charts in Figure 7. Sigg's study was conducted on a Heidelberg Speedmaster 74, which raise the following questions for future investigation:

1. Why do the circumferential densities for the PM-74 gradually increase from the lead to trail, while the comparable Speedmaster 74 had the lighter density in the centre of the cylinder length?
2. Why are the circumferential values for each band distinctly categorized for the PM-74, while those for the DI-46 tend to cross path and do not maintain a distinct pattern?
3. How much of the observable circumferential patterns for each press may be attributed to circumferential factors, as well as for axial factors?

The latter question regarding the implications of axial factors on circumferential trends is crucial, as the relationship between the XY position on the sheet and density variations still remains a product of the variability of both dimensions.

3.4. Circumferential Trends

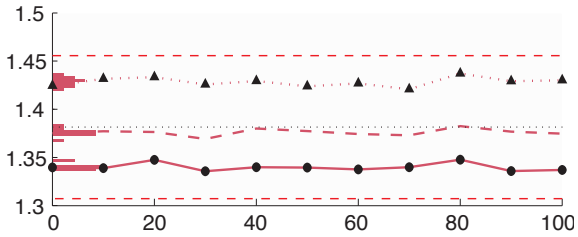


Figure 8 – Cross-sheet circumferential mean solid density for Magenta against histogram for PM-74.

It is interesting to note that in a very unique relationship that occurred during our tests, a very concrete observation was recognized that highlights the heterogeneity of circumferential density for the PM-74. A strong distinction was very clear for the circumferential segments of Magenta, which closely resembled the categorical distribution of Figure 5, shown here on the y-axis of Figure 8. The important aspect to note here is the fact the due to the evident heterogeneity of the central densities across the three circumferential bands, and due to a levelness in the overall axial (zonal) values the conditions have presented this clearly. However, further tests to reproduce and control this condition are necessary for any clarification.

3.5. Density Variation and Published Standards

Table 4 – Solid density distribution results for PM-74 and DI-46 compared to GRACoL reference

	GRACoL 2007		**Approximate Density**	**Tolerance**
		Cyan	1.45	±0.10
		Magenta	1.45	±0.10
		Yellow	1.00	±0.07
		Black	1.70	+0.20 -0.05

	$\bar{x}$	$2s$		$\bar{x}$	$2s$
Entire Dataset	*PM-74*	*n=198*		*DI-46*	*n=99*
Cyan	1.29	±0.08		1.24	±0.08
Magenta	1.38	±0.10	←A	1.17	±0.13
Yellow	0.94	±0.11	←B	1.00	±0.08
Black	1.45	±0.07		1.55	±0.13
Circumferential Subsets	*PM-74*	*n=33*		*DI-46*	*n=33*
Cyan	1.29	±0.06		1.24	±0.07
Magenta	1.38	±0.07	←A	1.17	±0.09
Yellow	0.94	±0.04	←B	1.00	±0.05
Black	1.45	±0.06		1.55	±0.11
Axial Subsets	*PM-74*	*n=66*		*DI-46*	*n=33*
Cyan	1.29	±0.05		1.24	±0.07
Magenta	1.38	±0.06	←A	1.17	±0.10
Yellow	0.94	±0.11	←B	1.00	±0.07
Black	1.45	±0.04		1.55	±0.10

95% Confidence; "For graphic technology applications, a coverage factor of 2 generally should be used in comparing the uncertainty in measured data values with specific application requirements." (ANSI, 2007). "Densities are Suggested, L*a*b* takes precedent" (IDEAlliance, 2007)

From Table 4, we can objectively compare both the DI-46 and PM-74 presses, as well as further recognize matters relating to location and configuration. In terms of falling within tolerance compared to the GRACoL (2007) references, the combined variation along the axial and circumferential lengths of the sheet have greatly aggravated the dispersion of the data. However, when the thresholds are weighed with two sigma (95%) as specified in the CGATS/ISO 15790:2005 (ANSI, 2007) for uncertainty and reflection and transmission metrology, the PM-74 values, aside for yellow (marked with B), are still within the variation tolerances. In terms of deviation tolerances, the current practices, recognizing the relationship between substrate, process, and density, give precedence to the conformance of the CIE L*a*b* deviation over density. As for the DI-46, the numbers are still comparable, with yellow having tighter variations, yet, still beyond the tolerance. When comparing the contribution of dispersion from each subset to the entire sheet, we are not able to recognize a clear distinction between the magnitudes of dispersion, with circumferential and axial factors having different, as shown in the histograms, yet largely equal contributions to variation.

3.6. CIE L*a*b* Variation and Published Standards

According to the previous findings regarding the repeatability and density, we have assumed that in-process variations that will occur naturally are explicit only for the circumferential dimension. Axial variations, on the other hand, lend themselves to the adjustment of ink zone settings and are not as definitive for being inherent causes. In order to assess the CIE L*a*b* variations, as described by ISO (2004), we are only going to focus in identifying the axial bands, as subsets of circumferential variations, which attained the least and most variance for the solid primaries, overprints, and 3 color black patches. An overall 'mean' variance is also provided for comparison across the presses, although we maintain that ink zone effects make for a degree of unevenness in that sense.

*Table 5 – CIE L*a*b* variation results for PM-74 compared to ISO reference*

Printmaster PM-74		s_L	s_a	s_b	$\Delta E`$	$s_{\Delta E}$	ΔE_v	$Tolerance_{ISO}$	**Result**
Least Variance	Paper	0.08	0.04	0.10	0.11	0.06	0.17	—	—
Axial Band #4/6	Cyan	0.54	0.16	0.61	0.73	0.37	1.10	4	√
	Magenta	0.45	0.48	0.83	0.91	0.51	1.42	4	√
	Yellow	0.13	0.22	1.09	0.99	0.50	1.48	4	√
	Black	0.63	0.06	0.12	0.55	0.32	0.87	5	√
	MY	0.38	0.47	0.68	0.82	0.37	1.19	—	—
	CY	0.79	0.69	0.62	1.14	0.36	1.51	—	—
	CM	0.75	0.27	0.18	0.73	0.35	1.08	—	—
	CMY	0.67	0.38	0.46	0.86	0.20	1.07	—	—
Most Variance	Paper	0.07	0.04	0.08	0.11	0.05	0.16	—	—
Axial Band #2/6	Cyan	0.43	0.17	0.49	0.60	0.27	0.87	4	√
	Magenta	0.42	0.43	0.82	0.87	0.50	1.37	4	√
	Yellow	0.14	0.21	1.11	1.00	0.51	1.51	4	√
	Black	1.36	0.11	0.20	1.24	0.56	1.81	5	√
	MY	0.38	0.48	0.86	0.93	0.48	1.41	—	—
	CY	0.75	0.69	0.71	1.12	0.51	1.62	—	—
	CM	0.89	0.36	0.17	0.86	0.43	1.29	—	—
	CMY	0.74	0.32	0.49	0.90	0.23	1.13	—	—
Mean Variance	Paper	0.08	0.05	0.10	0.12	0.06	0.18	—	—
Overall	Cyan	0.73	0.24	0.71	0.92	0.48	1.40	4	√
	Magenta	0.56	0.65	1.18	1.22	0.79	2.01	4	√
	Yellow	0.23	0.49	3.67	2.91	2.29	5.21	4	X
	Black	1.01	0.09	0.23	0.85	0.59	1.44	5	√
	MY	0.50	0.66	2.98	2.52	1.79	4.31	—	—
	CY	0.86	0.85	4.29	3.69	2.48	6.17	—	—
	CM	0.99	1.40	0.78	1.74	0.71	2.46	—	—
	CMY	0.84	1.28	3.66	3.37	2.08	5.44	—	—

From Table 5, we can see that the Printmaster has great stability, when localized color targets are measured in accordance with the ISO tolerance and G7 characterization practices. This is the conclusion we can draw from the least and most variances for localized axial bands. However, when it comes to the core of this study, where we are looking into repeatability for the entire sheet size, we find from the overall mean that the Yellow, which was identified earlier as to possibly relate to ink zone settings, and the secondary colors, including the 3 color black are varying widely. This last value is of special

importance, since: (1) we are more sensitive to variations in neutrals, and, (2) gray balance is the cornerstone of the recent calibration processes, such as G7 proof-to-press, which rely on concepts like Neutral print density curves. That is a relationship curve "between the measured neutral density points of a printed tonal range that describes the neutral reproduction curve and its contrast." (IDEAlliance, 2007)

Based on this new approach, in place of the practice of controlling individual TVI values for CMY to adjust the neutrality of the output, GRACoL and SWOP now rely on NPDC. The aims are no longer based on density readings with the process being entirely driven through colorimetric data. (IDEAlliance, 2007) The alarming concern is that when looking at localized variation for the Printmaster, the CMY black was stable, where in fact the variation for the entire sheet measured up to ΔE of 5.44. While the standards may not highlight a definite tolerance, it stands to common reason that ΔE 5.44 within 100 consecutive sheets may be problematic to a job with neutral grays. Finally, the ability to find the right place on the sheet that falls in the centre of the variation (limiting it to 5.44) now becomes a matter of concern when targets are measured for the NPDC calibrations.

*Table 6 – CIE L*a*b* variation results for DI-46 compared to ISO reference*

Quickmaster DI-46		**s_L**	**s_a**	**s_b**	**ΔE`**	**$s_{\Delta E}$**	**ΔE_v**	**$Tolerance_{ISO}$**	**Result**
Least Variance	Paper	0.13	0.03	0.11	0.16	0.07	0.23	—	—
Axial Band #1/3	Cyan	0.42	0.43	0.53	0.69	0.40	1.08	4	√
	Magenta	0.64	1.09	0.58	1.20	0.66	1.86	4	√
	Yellow	0.13	0.15	1.54	1.36	0.72	2.07	4	√
	Black	1.13	0.12	0.24	0.97	0.63	1.60	5	√
	MY	0.36	0.63	0.54	0.75	0.47	1.23	—	—
	CY	0.38	0.68	0.91	1.09	0.46	1.55	—	—
	CM	0.50	0.80	0.37	0.92	0.40	1.32	—	—
	CMY	0.53	0.87	0.93	1.30	0.42	1.71	—	—
Most Variance	Paper	0.15	0.03	0.12	0.16	0.11	0.27	—	—
Axial Band #3/3	Cyan	0.61	0.40	0.75	0.95	0.43	1.38	4	√
	Magenta	0.73	1.12	0.89	1.38	0.78	2.16	4	√
	Yellow	0.19	0.28	1.46	1.25	0.80	2.05	4	√
	Black	1.86	0.15	0.25	1.51	1.10	2.61	5	√
	MY	0.41	0.60	0.57	0.81	0.41	1.22	—	—
	CY	0.60	0.91	1.31	1.57	0.58	2.16	—	—
	CM	0.58	1.24	0.77	1.43	0.60	2.03	—	—
	CMY	0.63	1.46	1.00	1.75	0.59	2.35	—	—
Mean Variance	Paper	0.14	0.05	0.12	0.16	0.10	0.27	—	—
Overall	Cyan	0.61	0.43	0.72	0.92	0.47	1.39	4	√
	Magenta	0.92	1.58	1.53	2.06	1.19	3.24	4	√
	Yellow	0.20	0.33	2.35	2.01	1.26	3.27	4	√
	Black	1.64	0.14	0.26	1.34	0.99	2.33	5	√
	MY	0.71	1.48	1.12	1.83	0.78	2.60	—	—
	CY	0.78	0.84	1.69	1.86	0.83	2.68	—	—
	CM	1.29	1.63	0.93	1.99	1.10	3.08	—	—
	CMY	1.29	1.82	1.09	2.16	1.21	3.37	—	—

For the Quickmaster, Table 6, the results are notably stable. As such, these tolerances are achievable under the right conditions, and would require added care with the newer colorimetry-based trends.

4. Conclusion

In comparison of the variation results, we have identified some key factors that might have contributed to the differing overall ISO CIE L*a*b* variance thresholds.

1. The Quickmaster is a smaller size portrait press, with half the size of the data used in the Printmaster calculations for the overall mean variances.
2. The common impression cylinder for the DI may result in more stable sheet travel between the units and at the printing nips.
3. As a waterless press, possible variation due to ink-water balance is eliminated.

However, the waterless aspect of the DI also comes with some attached considerations. According to our findings, the inaccuracy, as deviation from the standard value of the solid overprints was substantially high in comparison (Table 3), largely due to trapping limitations and higher ink tack values.

Circumferential and axial variations are inherent to printing, but emphasis should still be placed on investigating the factors that result in circumferential trends and press-specific mechanics, as well as the configuration and maintenance may provide some solution options.

Density is becoming the second-rank choice for color control, with the main role of ensuring that the pre-established process aims, defined using colorimetry. However, based on the work conducted during this research and the findings, we maintain that density is also important when testing the press for its repeatability as it provides information that the operator can easily translate into machine-related knowledge.

In evaluating both the Quickmaster and the Printmaster presses, we conclude that each has very unique ink transfer repeatability patterns that would impact the effectiveness and accuracy of color management at the calibration stage and during production. In terms of calibration, we have found that the most stable subsection for measuring characterization is in the centre of the sheet as it had the smallest range for variation. For the Printmaster, the circumferential centre and the operator side was consistently more stable.

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Appendices

Note: - The amount of data generated during this research makes it impossible to attach to the report. The full MatLab functions, data files, and source measurements will be made available to the reader's request.

1. Weighing Functions: ANSI Filter and CIE Observer

Band (nm)	Status T (Rf Red)	Status T (Rf Green)	Status T (Rf Blue)	ISO Visual (Rf Neutral)	CIE 1931 2º (x)	CIE 1931 2º (y)	CIE 1931 2º (z)	D50 (I)
380	10.0000	10.0000	299.9163	0.0000	0.0014	0.0000	0.0065	24.4900
390	10.0000	10.0000	1499.6848	0.0001	0.0042	0.0001	0.0201	29.8700
400	10.0000	10.0000	5997.9108	0.0004	0.0143	0.0004	0.0679	49.3100
410	10.0000	10.0000	16982.4365	0.0012	0.0435	0.0012	0.2074	56.5100
420	10.0000	10.0000	39994.4750	0.0040	0.1344	0.0040	0.6456	60.0300
430	10.0000	10.0000	59979.1076	0.0116	0.2839	0.0116	1.3856	57.8200
440	10.0000	10.0000	82035.1544	0.0230	0.3483	0.0230	1.7471	74.8200
450	10.0000	10.0000	93972.3311	0.0380	0.3362	0.0380	1.7721	87.2500
460	10.0000	10.0000	100000.0000	0.0600	0.2908	0.0600	1.6692	90.6100
470	10.0000	10.0000	97050.9967	0.0910	0.1954	0.0910	1.2876	91.3700
480	10.0000	1000.0000	84918.0475	0.1390	0.0956	0.1390	0.8130	95.1100
490	10.0000	5000.3454	65012.9690	0.2080	0.0320	0.2080	0.4652	91.9600
500	10.0000	29991.6252	39994.4750	0.3230	0.0049	0.3230	0.2720	95.7200
510	10.0000	68076.9359	17988.7092	0.5030	0.0093	0.5030	0.1582	96.6100
520	10.0000	92044.9572	5000.3454	0.7100	0.0633	0.7100	0.0782	97.1300
530	10.0000	100000.0000	199.9862	0.8620	0.1655	0.8620	0.0422	102.1000
540	10.0000	87902.2517	39.9945	0.9540	0.2904	0.9540	0.0203	100.7500
550	10.0000	66069.3448	10.0000	0.9950	0.4334	0.9950	0.0087	102.3200
560	10.0000	41975.8984	10.0000	0.9950	0.5945	0.9950	0.0039	100.0000
570	59.9791	21978.5987	10.0000	0.9520	0.7621	0.9520	0.0021	97.7400
580	449.7799	8994.9758	10.0000	0.8700	0.9163	0.8700	0.0017	98.9200
590	29991.6252	2500.3454	10.0000	0.7570	1.0263	0.7570	0.0011	93.5000
600	100000.0000	699.8420	10.0000	0.6310	1.0622	0.6310	0.0008	97.6900
610	84918.0475	89.9498	10.0000	0.5030	1.0026	0.5030	0.0003	99.2700
620	54954.09	10.00	10.00	0.38	0.8544	0.3810	0.0002	99.0400
630	25003.45	10.00	10.00	0.27	0.6424	0.2650	0.0001	95.7200
640	10000.00	10.00	10.00	0.18	0.4479	0.1750	0.0000	98.8600
650	5000.35	10.00	10.00	0.11	0.2835	0.1070	0.0000	95.6700
660	1499.68	10.00	10.00	0.06	0.1649	0.0610	0.0000	98.1900
670	500.03	10.00	10.00	0.03	0.0874	0.0320	0.0000	103.0000
680	299.92	10.00	10.00	0.02	0.0468	0.0170	0.0000	99.1300
690	149.97	10.00	10.00	0.01	0.0227	0.0082	0.0000	87.3800
700	50.00	10.00	10.00	0.00	0.0114	0.0041	0.0000	91.6000
710	10.00	10.00	10.00	0.00	0.0058	0.0021	0.0000	92.8900
720	10.00	10.00	10.00	0.00	0.0029	0.0010	0.0000	76.8500
730	10.00	10.00	10.00	0.00	0.0014	0.0005	0.0000	86.5100

The information for the weighing functions is based on the work published by the Colour Imaging Group at the London College of Communication (Green, 2003). For industry standard reference the ANSI CGATS.5-2003 and ISO 5-1993 should be consulted.

2. Material & Equipment Details

Materials Used

- Heidelberg Quickmaster DI-46 Ink-set
  - Process Cyan, Waterless (Rycoline – S/N: M14704, B/N: 11765)
  - Process Magenta, Waterless (Rycoline – S/N: M14703, B/N: 1692)
  - Process Yellow, Waterless (Rycoline – S/N: M14700, B/N: 11764)
  - Process Black, Waterless (Rycoline – S/N: M14705, B/N: 9481)
- Heidelberg Printmaster PM-74 Ink-set
  - Process Cyan, Waterless (Rycoline – S/N: M14704, B/N: 11765)
  - Process Magenta, Waterless (Rycoline – S/N: M14703, B/N: 1692)
  - Process Yellow, Waterless (Rycoline – S/N: M14700, B/N: 11764)
  - Process Black, Waterless (Rycoline – S/N: M14705, B/N: 9481)
- 100# Condat Supreme Gloss — 28”× 40” 236M (Spicers, CA – S/N: SC0162vmast)
  - Press Sheet: 13½” × 18⅛”

Equipment

- Heidelberg Quickmaster DI 46-4, 4/c CI Press
- Heidelberg Printmaster PM74-4, 4/c
- ATD 40, Scanning Densitometer (X-Rite, USA)
- X-Rite ATD Software — Windows 2000
- i1 iSis - Scanning Spectrophotometer (X-Rite, USA)
- GretagMacbeth MeasureTool & ProfileMaker 5.02 — Mac OS X 10.4.11
- X-Rite 530 - Reflection Spectrodensitometer (X-Rite, USA)
- IHARA R710, Reflection Densitometer (IHARA, JP – S/N: 071701)

Additional Software

- Adobe Illustrator CS3 — Mac OS X
- ColorThink 3.0 Pro — Mac OS X
- MatLab R2007b & R2008b — Mac OS X

3. Sample Data for Converting 36-Spectra to Density

	K			C			M			Y		
Step	*IHARA*	*iSis*	*ΔD*	*IHARA*	*iSis*	*ΔD*	*IHARA*	*iSis*	*ΔD*	*IHARA*	*iSis*	*ΔD*
100	1.67	1.57	0.10	1.40	1.38	0.02	1.37	1.29	0.08	1.13	1.11	0.02
90	1.40	1.33	0.07	1.09	1.08	0.01	1.15	1.09	0.06	1.04	1.00	0.04
80	1.11	1.04	0.07	0.95	0.95	0.00	0.95	0.91	0.04	1.01	0.98	0.03
70	0.93	0.90	0.03	0.84	0.82	0.02	0.75	0.72	0.03	0.95	0.92	0.03
60	0.78	0.76	0.02	0.73	0.71	0.02	0.64	0.61	0.03	0.77	0.75	0.02
50	0.55	0.53	0.02	0.56	0.54	0.02	0.55	0.52	0.03	0.58	0.55	0.03
40	0.43	0.40	0.03	0.42	0.41	0.01	0.46	0.42	0.04	0.48	0.46	0.02
30	0.35	0.32	0.03	0.31	0.30	0.01	0.36	0.31	0.05	0.33	0.33	0.00
25	0.30	0.28	0.02	0.26	0.26	0.00	0.30	0.26	0.04	0.27	0.26	0.01
20	0.25	0.23	0.02	0.24	0.23	0.01	0.26	0.23	0.03	0.22	0.22	0.00
15	0.20	0.19	0.01	0.20	0.21	0.01	0.22	0.19	0.03	0.17	0.18	0.01
10	0.18	0.17	0.01	0.15	0.15	0.00	0.19	0.16	0.03	0.09	0.13	0.04
7	0.16	0.15	0.01	0.13	0.13	0.00	0.16	0.13	0.03	0.08	0.11	0.03
3	0.13	0.12	0.01	0.09	0.09	0.00	0.11	0.09	0.02	0.07	0.07	0.00
Mean			0.03			0.01			0.04			0.02
Min			0.01			0.00			0.02			0.00
Max			0.10			0.02			0.08			0.04
StDev			0.03			0.01			0.02			0.01

4. MatLab code for Converting 36-Spectra to Density & XYZ

```
function [ output_args ] = pspd2D( sample , filterRGB )
%pspd2D Summary of this function goes here
%   Works  on CASRPC-->(P:C)

    if (size(sample,2) == 36)
        %=-LOG(SUMPRODUCT('Status T'!E$3:E$41,'Reflectance
        %range'!$B$3:$B$41)/SUM('Status T'!E$3:E$41))
        fR = double(filterRGB(1,1:36));
        fG = double(filterRGB(2,1:36));
        fB = double(filterRGB(3,1:36));
        fV = double(filterRGB(4,1:36));

        for ismp =1:size(sample,1)
            vsmp = double(sample(ismp,1:36))*100;

            CMYKDensityMatrix(ismp,1,1) = -log10(sum(vsmp.*fR)/100/sum(fR));
            CMYKDensityMatrix(ismp,1,2) = -log10(sum(vsmp.*fG)/100/sum(fG));
            CMYKDensityMatrix(ismp,1,3) = -log10(sum(vsmp.*fB)/100/sum(fB));
            CMYKDensityMatrix(ismp,1,4) = -log10(sum(vsmp.*fV)/100/sum(fV));
        end
        output_args = CMYKDensityMatrix;
    else
        output_args = zeros(size(sample,1),36);
    end
end

function [ output_args ] = pspd2XYZ( sample ,d50spectral, cmfCIE1931_2  )
    [x,y,z] = size(sample);
    if (size(sample,2) == 36)
        % Refer to Sharma, p. 87
        vilu = double(d50spectral);
        cmx = double(cmfCIE1931_2(1,1:36));
        cmy = double(cmfCIE1931_2(2,1:36));
        cmz = double(cmfCIE1931_2(3,1:36));
        %Normalizing Constant D50Spectral(nm) times cmf|y(nm)
        NC = vilu.*cmy;
        SNC = sum(NC);
        for ismp =1:size(sample,1)
            vsmp = double(sample(ismp,1:36))*100;

            X(ismp,1) = sum(vsmp.*vilu.*cmx)/SNC;
            Y(ismp,1) = sum(vsmp.*vilu.*cmy)/SNC;
            Z(ismp,1) = sum(vsmp.*vilu.*cmz)/SNC;
        end
        XYZ(:,:,1) = X; %reshape(X,14,13);
        XYZ(:,:,2) = Y; %reshape(Y,14,13);
        XYZ(:,:,3) = Z; %reshape(Z,14,13);
        output_args = XYZ;
    else
        output_args = zeros(size(sample,1),1,3);
    end
end
```

5. Print Characteristics of the DI-46 from the same Dataset (for reference)

