The Interaction Between Color Standards and Production Tolerances: A Mismatch of Metrics

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Keywords: Color, Color Management, Tolerances

Abstract

Color management is used throughout the industry for achieving predictable and consistent color. It has evolved over the years to become a standard process that can be used by many across the industry for different production processes, not simply by a few consultants. The process controls introduced show that the accuracy of these profiles stand the test of time through production. In many cases a color reference condition is chosen as the default color space, such as GRACoL 2013 CRPC6. The press profiles are developed using many different software solutions and in the case of the profile above, in North America, the TC1617 target will be used to generate the profile. When checking conformance against G7 colorspace the whole of the target will be measured, often using a high speed scanning spectrophotometer. This has a predefined set of metrics and tolerances. The goal of monitoring during production is to indicate if there has been a deviation from this target condition. However, in production different instruments may be used, as are different targets and the tolerances are then selected according to the target configuration. In these cases the same metrics are not being used and as such there can be a disconnect between the two sets of measurements, often passing in one case and failing in the other. The user is then unsure whether there prints are passing the standard. The differences between the multiple targets and tolerances are discussed in the paper and the differences between the results obtained from these targets is quantified.

Introduction

Color management takes on many different roles with the use of ICC profiles and device link profiles. From this, different color spaces are targeted, the most common in North America would be to one of the CRPC's that all have a neutral density built into the ICC profile. The scope of this paper is focused on investigating the

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situation when the user is targeting GRACoL 2013 CRPC 6. This is the standard target profile used for coated papers for offset and digital printing processes.

The typical profiling process carried out is outlined below, there will be some deviations dependent on the print process and the tools used, however the principles remain consistent.

- **Linearize the press.** This will ensure that the press is always in a known state for the color management to be applied. Dependent on the press this may also include a G7 grayscale (1D) linearization, which is beneficial when the process is far away from producing neutral prints in its native state. This is a critical step in the process and not enough effort is placed on this, which results in many profiles that are produced not being usable in the long term. If there is a problem with the press then it needs to be fixed, such as density balance across the sheet on a digital press, excessive circumferential density variation on an offset press, streaks or banding etc.
- **Print a profile target.** This needs to be printed in the native state of the press that has been achieved from the linearization and G7 grayscale linearization, if used. With a digital press this may also include the press calibration.
- **Measure using an instrument.** This can be an inline instrument, a scanning spectrophotometer or a hand held instrument. The target is often designed for the instrument, and may also be specific to the software that is used to create the profile. The measurement may be made in a third party app or directly into the profiling software.
- **Create a profile.** The ICC profile is created in the software package. This can be done from a single measurement or from multiple sheets and/or iterations dependent on the exact procedure.
- **Utilize the ICC profile.** The ICC profile is then added into the workflow, in a digital environment this will be at the digital front end, and in this case combined with any press calibration.

This is the point at which many users will stop the process, start printing with the profile that they have generated. Verification is the most important step in the process and one that should be completed after the profile has been generated and then at regular intervals.

- **Verification.** There are different levels of profile verification that can be used as well as different targets. The following summarize those commonly used in practice for GRACoL 2013 CRPC6.
    - o **Use TC1617.** This would be the ideal chart to use to check G7 colorspace conformance against GRACoL 2013 CRPC6. It has the correct number of patches and composition to accurately assess against the tolerance criteria. If G7 targeted or grayscale were to be

used then a P2P51 or G7 verifier would also be appropriate as they have the requisite patches.

- ✓ **Most accurate**

o Use the ISO 12647 two or three row strip. These targets have a selection of the colors in, but not the full range of patches to accurately verify against a G7 conformance level. In addition, the metrics that are used need to be carefully selected as often times different tolerance setts are used.

- ✖ **Can provide informative information**

o Look at the sheet. As shown in Figure 1 the user may choose to look at a verification sheet that has been output and visually assess whether the colors look good, sometimes this will include using a light booth, in other times not the case

- ✖ **Not recommended, but better than nothing!**

o Don't do anything. Unfortunately this is all too prevalent and there is no check on the validity of the profile to achieve the desired output. This can be due to a bad profile, the consumables, the press not being capable or the linearization being different.

- ✖ **Not recommended**

Figure 1: *Color verification*

However, once conformance has been confirmed after the profiling, the question is then how do you track that the press is staying in conformance. From a purely technical perspective for G7 colorspace this would be to measure the full TC1617 target, this can take between three and thirty minutes to complete dependent on the instrument used. In practice the measurement time is too long, and especially when multiple presses are involved it is overly onerous. In this case printers will use a much simpler target as they are not seeking in most cases to have a G7 pass but rather to see if the press has moved such that work needs to be done either with linearization or the development of a new profile.

This paper investigates this in further detail and looks at the potential errors that can arise when this is used in the verification process and then in the tracking process.

Potential issues

There are many different standards and specifications that are used around the world. Prior to looking at some of these in detail with respect to the pass / fail of a press to a G7 colorspace for GRACoL 2013 CRPC6 it is important to be aware of a number of potential issues with at the use of different standards and specifications. Three main primary issues are discussed below:

- In defining the specification there are three sub categories that are critical and can give rise to large discrepancies
    - *They have different color difference equations; some will use* ΔE *while the modern solutions all use* ΔE_{00}*. There is no easy way in which these can be correlated.*
    - *They have different tolerance criteria so that a metric that is used in one may not be used in another or it may use a weighting function etc.*
    - *They can have different tolerance numbers, even when the patches and metrics are exactly identical*
- They use different validation wedges to which the criteria described above are applied. This can give rise to sampling differences in the calculations, the number of patches used and also the part of the color space that is used for the analysis.
- The elephant in the room when discussing the use of tolerances and specifications is that there is also an inherent variation in the printing process, so this variation can give rise to different results either on a single sheet or between multiple sheets.

Standards and Specifications

When considering standards and specifications there are many that are in use and these continue to be developed as we understand more about the different printing processes, many of them are shown in Figure 2.

Figure 2: *Examples of different standards and tolerance sets*

Let us first consider the G7 tolerances that are used, they are split into three sections that build upon each other, namely grayscale, targeted and colorspace. As you increase the levels the tolerances from the previous levels apply, firstly conforming to grayscale, then the primaries and overprints and then finally the full collection of patches from a TC 1617 target. These are shown below;

- Grayscale, these are measured on the black and CMY color ramps and there are a predetermined number of specific patch combinations that are used.
    - *wΔL* avg K*
    - *wΔL* max K*
    - *wΔL* avg CMY*
    - *wΔL* max CMY*
    - *wΔCh avg CMY*
    - *wΔCh max CMY*

- Targeted adds in the color of the paper, primaries and overprints. It should be noted that a different number is used for the black tolerance and if Substrate-Corrected Colorimetric Aims (SCCA) are used then the paper color is taken into account and the difference calculated for the paper is zero.
    - *ΔE_{00} paper*
    - *ΔE_{00} K*
    - *ΔE_{00} CMY*
    - *ΔE_{00} RGB*

- Colorspace builds on the previous two metrics and add the average color difference for all color patches as well as the 95th percentile.
    - *ΔE_{00} avg all patches*
    - *ΔE_{00} 95% all patches*

The targets used for these are the G7 verifier, Figure 3 or P2P51, Figure 4, for grayscale and TC1617, Figure 5, for colorspace.

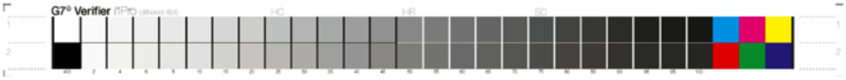

Figure 3: *G7 Verifier*

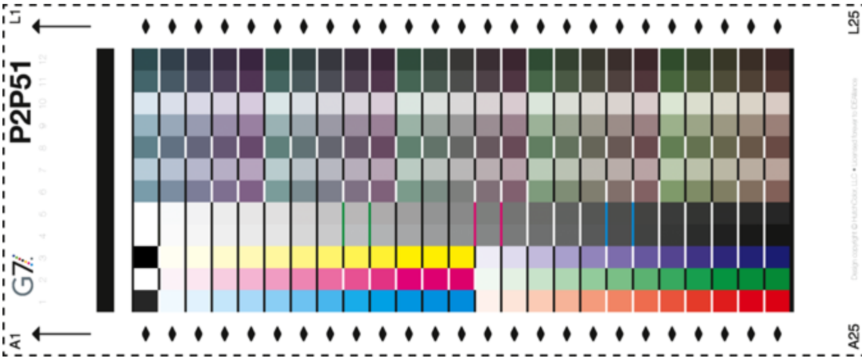

Figure 4: *P2P51*

Figure 5: *TC1617*

One of the other test wedges that is used is the Idealliance ISO 12647-7 Control Wedge 2013, Figure 6. This is also the control wedge that is printed on the EFI Fiery Color Profiler Suite Test Page, as seen in Figure 1. This has a wide range of colors and in certain cases can be used to check against conformance to G7 with certain limitations, notable that there are fewer patches for the K and CMY ramps, five in each that correspond to those in the specification, This will give rise to potential issues with the individual passes as well as the weighted average values. Finally for the colorspace criteria, there is much less sampling (only 5%) of the colorspace, down from 1617 to 84 patches.

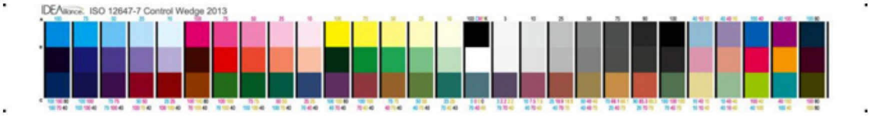

Figure 6: *Idealliance ISO 12647-7 Control Wedge 2013*

This is often used an give an indication if the press has deviated away from conformance when used with G7 tolerances. However, many times when using this strip the tolerances that are used are those for either the ISO 12467-7 Color Bar, ISO 12467-7:2016 Color Bar or the ISO 12467-8 Validation Print Color Bar, all of which are shown below.

- ISO 12467-7 Color Bar
    - ΔE *paper*
    - ΔE *avg all patches*
    - ΔE *max all patches*
    - ΔE *max primaries (CMYK)*
    - ΔH *max, primaries (CMYK)*
    - ΔCh *avg CMY Gray*

- ISO 12467-7:2016 Color Bar
    - ΔE_{00} *paper*
    - ΔE_{00} *avg all patches*
    - ΔE_{00} *max all patches*
    - ΔE_{00} *max primaries (CMYK)*
    - ΔH *max, CMY*
    - ΔCh *avg CMY Gray*
    - ΔCh *max CMY Gray*

- ISO 12467-8 Validation Print Color Bar
    - ΔE_{00} *paper*
    - ΔE_{00} *avg all patches*
    - ΔE_{00} *max all patches*
    - ΔH *max, CMYRGB patches*
    - ΔCh *avg CMY Gray*

Firstly, the ISO 12467-7 Color Bar uses ΔE with the other two using ΔE_{00}. Comparing the other two sets of tolerances with those from G7 Colorspace we discussed there are less factors which are used for the assessment but significantly only two of the factors *ΔE_{00} paper* and *ΔE_{00} avg all patches* occur in both sets of data. The *ΔCh avg CMY Gray* while appearing to be similar is not weighted as in the G7 grayscale definition.

The tolerances for ISO 15311 PSD 2016 media relative and ISO 15311 PSD 2011 media relative, again showing a disparity with those used for the G7 conformance.

- ISO 15311 PSD 2016 media relative
    - *ΔE_{00} avg all patches*
    - *ΔE_{00} 95% all patches*
    - *ΔCh max CMY Gray*

- ISO 15311 PSD 2011 media relative
    - *ΔE_{00} avg all patches*
    - *ΔE_{00} 95% all patches*

In assessing the different tolerance sets used it is evident that there is little similarity between them, Table 1. The only metric that appears consistently is *ΔE_{00} avg all patches*. This gives rise to potential issues when evaluating conformances to GRACoL 2013 when using these other tolerance sets irrespective of the target used.

G7 Grayscale	G7 Targeted	G7 Colorspace	ISO 12467-7:2016 Color Bar	ISO 12467-8 Validation Print Bar	ISO 15311 PSD 2016 media relative	ISO 15311 PSD 2011 media relative	GRACoL Digital Press	JPMA 2018
wΔL* avg K	wΔL* avg K	wΔL* avg K						
wΔL* max K	wΔL* max K	wΔL* max K						
wΔL* avg CMY	wΔL* avg CMY	wΔL* avg CMY						
wΔL* max CMY	wΔL* max CMY	wΔL* max CMY						
wΔCh avg CMY	wΔCh avg CMY	wΔCh avg CMY						
wΔCh maxCMY	wΔCh maxCMY	wΔCh maxCMY						
	ΔE_{00} paper	ΔE_{00} paper	ΔE_{00} paper	ΔE_{00} paper				
	ΔE_{00} K	ΔE_{00} K						
	ΔE_{00} CMY	ΔE_{00} CMY						
	ΔE_{00} RGB	ΔE_{00} RGB						
		ΔE_{00} avg all patches	ΔE_{00} avg all patches	ΔE_{00} avg all patches	ΔE_{00} avg all patches	ΔE_{00} avg all patches	ΔE_{00} avg all patches	ΔE_{00} avg all patches
		ΔE_{00} 95% all patches			ΔE_{00} 95% all patches	ΔE_{00} 95% all patches		
			ΔE_{00} max all patches	ΔE_{00} max all patches			ΔE_{00} max all patches	ΔE_{00} max all patches
			ΔE_{00} max primaries (CMYK)					
			ΔH max, CMY					
				ΔH max, CMYRGB patches			ΔH max, CMYRGB patches	
			ΔCh avg CMY Gray	ΔCh avg CMY Gray			ΔCh avg CMY Gray	
			ΔCh max CMY Gray		ΔCh max CMY Gray			

Table 1: *Comparison of the tolerance sets for different systems*

Analysis and discussion

To evaluate the impact of these metrics a number of print tests were carried out to quantify the impact of the changing conformance guidelines and their impact on the ability for the press to pass or fail. This is one of the main criteria that users will leverage to see if they need to carry out work on the press or call in service. Many tools are available for this analysis; in this case AccurioPro Cloud Eye has been utilized for the analysis.

The reports produced include the information regarding the specifics of the analysis, Figure 7, followed then by the pass fail characteristics, the TVI data, G7 analysis and then pass/fail on every patch in the validation wedge. For this paper we have focused on the pass-fail criteria for each of the different tolerance set / patch combinations.

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Report

Details

Job ID:	18452	Date / Time:	3/6/2020 10:08:35 AM
User name:	Mark Bohan	Target config.:	GATF Test Wedge 12647-7
Meas. device:	Konica Minolta FD-9 USB 10001579	Target Profile:	GRACoL2013 CRPC6
Printer:	Tolerance Evaluation	Tolerance:	G7 Colorspace (Press)
Averaging:	OFF	Substrate:	Relative
Meas. conditions:	Observer: 2° Observer, Illuminant: D50, Mode: M1, Filter: None		

Figure 7: *Job and measurement information*

Firstly evaluating the ISO 12647-7 Control Wedge 2013 for G7 Colorspace tolerances, Figure 8 and ISO 12647-7:2016 Control bar tolerances, Figure 9 there are a number of areas that should be highlighted which are summarized below;

- It can be see that the press passes to G7 colorspace, while it fails the ISO 12647-7:2016 Control bar tolerances. This situation occurs often in practice leading printers to believe the press is out of conformance or that the profile they generated was bad.
- The average of all colors is one ΔE_{00} tighter for the ISO 12647-7:2016 Control bar tolerances. Again this will often give rise to different pass and fail messages.
    - o In addition, they use different metrics for the defining the high limit; the G7 Colorspace uses the 95th percentile of all patches while the ISO 12647-7:2016 Control bar uses the maximum value.
- The average and max *ΔCh CMY Gray* not only have different tolerance values but also are not weighted in the ISO 12647-7:2016 Control bar tolerances. This places then a greater emphasis on the shadow regions whose impact is minimized by the weighting functions in the G7 tolerances.

Colors				
Summary	**Patch**	**dE2000**	**Tolerance**	**Result**
Paper white	B16	0.00	3	Pass
Average		1.24	3.5	Pass
Max. 95% quantile		2.63	5	Pass
dE max. CMY	A11	2.02	3.5	Pass
dE K (Black)	A23	2.31	5	Pass
dE max. RGB	B7	2.10	4.2	Pass
wdL Ø CMY gray		0.15	1.5	Pass
wdL max. CMY gray	B22	0.42	3	Pass
wdL Ø K (Black)		0.31	1.5	Pass
wdL max. K (Black)	A22	1.43	3	Pass
wdCh Ø CMY gray		0.46	1.5	Pass
wdCh max. CMY gray	B20	1.33	3	Pass

Figure 8: *ISO 12647-7 Control Wedge 2013, G7 Colorspace tolerances*

Colors				
Summary	**Patch**	**dE2000**	**Tolerance**	**Result**
Paper white	B16	1.36	3	Pass
Average		1.53	2.5	Pass
Maximum	B1	3.74	5	Pass
Primary colors	A1	2.26	3	Pass
dCh Ø CMY gray		1.65	2	Pass
dCh max. CMY gray	B17	2.17	3.5	Pass
dH max. CMY	A11	2.98	2.5	Fail

Figure 9: *ISO 12647-7 Control Wedge 2013, ISO 12647-7:2016 Control bar tolerances*

Analyzing the data from the TC1617 target, Figure 10, which is the primary target for assessing colorspace it can be seen that in this case it is a pass. This is a separate print and the patches are located in different positions on the sheet. In addition, there are many more patches in this target. There are a number of items that can be summarized below;

- In this case, there is a small difference between the average color deviation from target and the 95th percentile, but this is relatively small.
- The primaries and solids are similar, the deviation due to the change in location on the sheet and from measurements on different sheets.
- There is reasonable agreement with the grayscale numbers; this is in part due to the evenness of the prints, location of the patches and the number of the patches in the ramps used for the analysis.

Colors

Summary	Patch	dE2000	Tolerance	Result
Paper white	B2	0.00	3	Pass
Average		1.44	3.5	Pass
Max. 95% quantile		2.88	5	Pass
dE max. CMY	E5	2.61	3.5	Pass
dE K (Black)	B1	2.39	5	Pass
dE max. RGB	F6	2.61	4.2	Pass
wdL Ø CMY gray		0.42	1.5	Pass
wdL max. CMY gray	A8	1.00	3	Pass
wdL Ø K (Black)		0.82	1.5	Pass
wdL max. K (Black)	A35	1.52	3	Pass
wdCh Ø CMY gray		0.50	1.5	Pass
wdCh max. CMY gray	A16	1.43	3	Pass

Figure 10: *TC1617, Colorspace tolerances*

The data from the P2P51, Figure 11 and G7 verifier, Figure 12 both show good agreement with the results from the full TC1617, between each other and also with regard to those from the ISO 12647-7 wedge with the G7 Colorspace tolerances applied.

Colors

Summary	Patch	dE2000	Tolerance	Result
Paper white	E1	0.14	3	Pass
Average		1.00	3.5	Pass
Max. 95% quantile		2.11	5	Pass
dE max. CMY	C13	2.40	3.5	Pass
dE K (Black)	D25	2.11	5	Pass
dE max. RGB	A25	3.50	4.2	Pass
wdL Ø CMY gray		0.35	1.5	Pass
wdL max. CMY gray	E9	0.99	3	Pass
wdL Ø K (Black)		0.64	1.5	Pass
wdL max. K (Black)	D11	1.28	3	Pass
wdCh Ø CMY gray		0.45	1.5	Pass
wdCh max. CMY gray	E11	0.94	3	Pass

Figure 11: *P2P51, G7 Colorspace tolerances*

Colors

Summary	Patch	dE2000	Tolerance	Result
dE max. CMY	2D1	2.23	3.5	Pass
dE K (Black)	2A1	2.12	5	Pass
dE max. RGB	2C2	2.20	4.2	Pass
wdL Ø CMY gray		0.22	1.5	Pass
wdL max. CMY gray	C2	0.63	3	Pass
wdL Ø K (Black)		0.46	1.5	Pass
wdL max. K (Black)	V1	1.04	3	Pass
wdCh Ø CMY gray		0.64	1.5	Pass
wdCh max. CMY gray	K2	1.58	3	Pass

Figure 12: *G7 Verifier, G7 Colorspace tolerances*

To further investigate the impact of the tolerance sets and verification target a series of twenty print samples were analyzed to obtain a practical observation of what would be observed in a typical digital press environment. These were taken from multiple presses and included sample sheets that were within conformance and those that were outside. On the first sheet a P2P51, ISO 12647-7 and G7 Verifier targets were located, on a second sheet a full TC1617. These were then all measured and analyzed for G7 conformance and the results are shown in Table 2. In all cases, when the press sheet passed G7 Conformance using the TC1617 a fail was reported by the ISO 12647-7 verification wedge using the ISO 12647-7:2016 Control bar tolerances.

	TC1617	P2P51	G7 Verifier	12647-7 Tol G7	12647-7 Tol Strip
1	Pass	Pass	Pass	Pass	Fail
2	Pass	Pass	Pass	Fail	Fail
3	Fail	Pass	Fail	Fail	Fail
4	Fail	Fail	Fail	Pass	Fail
5	Pass	Fail	Fail	Pass	Fail
6	Pass	Pass	Pass	Pass	Fail
7	Fail	Fail	Fail	Fail	Fail
8	Pass	Pass	Pass	Pass	Fail
9	Fail	Fail	Fail	Fail	Fail
10	Fail	Fail	Fail	Fail	Fail
11	Fail	Fail	Fail	Fail	Fail
12	Fail	Fail	Fail	Fail	Fail
13	Pass	Pass	Fail	Pass	Fail
14	Fail	Fail	Fail	Fail	Fail
15	Pass	Pass	Pass	Pass	Fail
16	Pass	Pass	Pass	Pass	Fail
17	Fail	Pass	Pass	Pass	Fail
18	Fail	Fail	Fail	Fail	Fail
19	Pass	Pass	Fail	Fail	Fail
20	Pass	Pass	Pass	Fail	Fail

Table 2: *Pass / fail results from different press runs*

Evaluating the agreement between the four verification wedges using G7 colorspace tolerances there has been reasonable agreement with all four producing the same result, be it a pass or a fail. There were a number however that did show a difference in the pass/fail criteria and this was typically with one of the target results being different to the other three. Assessment of the prints, Table 3, that failed showed that half of them were on the limits of a pass/fail (generally 10% or less away from the tolerance value), so any small variation in print was causing the difference. Of the remaining two showed a lack of uniformity, something that is seen when the press has not been optimized prior to the prints being produced. The last 10% of failures were due to there not being the correct amount of patches on the ISO 12647 target to get a accurate representation of the black and CMY ramps.

Factor	Agreement	Uniformity	Not enough patches	Close to tolerance limit
Total	12	2	2	4
1	1	0	0	0
2	0	1	0	0
3	0	0	0	1
4	0	0	1	0
5	0	0	0	1
6	1	0	0	0
7	1	0	0	0
8	1	0	0	0
9	1	0	0	0
10	1	0	0	0
11	1	0	0	0
12	1	0	0	0
13	0	0	0	1
14	1	0	0	0
15	1	0	0	0
16	1	0	0	0
17	0	0	0	1
18	1	0	0	0
19	0	1	0	0
20	0	0	1	0

Table 3: *Agreement with all verification wedges*

Conclusions

The use of the TC1617 target provides the most accurate method to verify that a press is in conformance with G7 colorspace and should always be used once a profile has been generated initially to check that it is a good profile.

However, once production has started it is often the goal of the analysis to see if the press has drifted significantly away from this position and remedial work needs to be completed. To do this it is often not practical to measure the full TC1617 chart due to the time it takes to be measured. Smaller targets are then used in its place.

Critically, when evaluating if the press has shifted it is imperative that the same tolerance sets are used. This paper has clearly demonstrated that using the wrong tolerance sets will result in the press failing when in fact the press is within tolerances, or in other cases never going out of tolerance.

A simplified method is needed and the proposal is to use a universal target with the G7 colorspace tolerances used for that. The ISO 12647-7 three row target would provide a wider range of colors than existing G7 targets that are designed for G7 targeted. There are only limited situations that this would give rise to false results, at a lower value than those caused by sheet uniformity. In setting the tolerance values it may be necessary to increase the tolerance levels by 25% or 50% so that actions are only carried out when a significant change has occurred, this may well be dependent on both the color criticality of the printer and the print process used.