Print Quality Evaluation and Applied Colour Management in Coldset Offset Newspaper Print

Peter Nussbaum[*] and Jon Y. Hardeberg[*]

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Abstract

This paper aims to investigate print quality in newspaper print by considering the appropriate calibration standard and applying colour management. In particular it looks at the colorimetric properties of eight Norwegian newspaper printing presses in order to evaluate the relevant colour separation approach, either by applying custom separation profiles or by using an industry standard. The key method underlying the work described here relies on obtaining colour measurements to determine the repeatability of each participant in terms of colour differences. Furthermore the variation between the eight newspaper printing processes and the variation according to the colorimetric values of the ISO 12647-3:2005 standard are important parts of the quantitative evaluation. According to the colour measurements two custom ICC profiles were generated, The profile "NADA X" is calculated based on the obtained colour measurement data of the first test print run and "NADA Y" is computed on an average data set including colour measurement data of the first test print run and the measurement data set of ISOnewspaper26v4, along with the international standard profile "ISOnewspaper24v4.icc" which we here denote "NADA Z". The three profiles were applied to four test images, which were then printed by eight newspaper printing presses. A psychophysical experiment was carried out to determine pleasantness of the reproductions made according to the three profiles used. Finally the results of the study indicate the performance of the appropriate profile applying to the eight newspaper printing presses to obtain significant best print quality.

[*]The Norwegian Color Research Laboratory, Faculty of Computer Science and Media Technology, Gjøvik University College, P.O.Box 191, N-2802 Gjøvik

Introduction

Although process control for the production of half-tone colour separations, proof and production prints are clearly defined in ISO 12647-3:2005 often newspaper printing processes show major variations, which affect the appearance of print. Essentially, there are two different approaches considering printing press convention, namely optimized or standardized press behaviour. A fully optimized press is all about maximizing its capability in terms of lowest possible dot gain, highest ink densities and best contrast the individual printing press can achieve without regards to any external specifications or standards. Such individual parameters can create unique press condition, which requires custom ICC profiles to create the appropriate separations. Another approach is to make the press conform to a certain reference or standard such as ISO 12647-3:2005. By using the second approach and by standardising the behaviour of the press industry standard ICC profiles can be used.

In 1995, the Norwegian Newspaper Publishers' Association (NAL) founded its subsidiary NADA AS. NADA's primary goal has been to establish a standard for digital ad delivery in Norway, in order to simplify the process of creating and transmitting digital ads from producer to newspaper. Furthermore NADA has also been responsible for generating of three custom newspaper ICC profiles in the period of 2000 to 2004, which has been highly recommended by NADA to apply by the national newspapers printing process. However, these custom profiles have two common characteristics in terms of their parameters. The number of colour measurements for generating the profiles is very small and the degree of GCR (Grey Component replacement) is rather low considering newspaper print. Therefore the performance of the profiles and the corresponding print quality has been considered as not satisfactory and demonstrate the need for further revision.

Recently, NADA and eight of the largest Norwegian newspaper printing plants started a project to evaluate their common print quality and print control.

The aim of the presented work is to evaluate eight newspaper printing plants in terms of their conformance to specified values, in accordance with the requirements of ISO 12647-3:2005. Furthermore, the assessment of each individual printing press and the variation within the 8 participants are important parts of this study, in order to evaluate the appropriate colour separation approach, either by applying custom separation profiles or by using industry standard profile such as ISOnewspaper26v4.icc. In order to obtain the defined goals, NADA in collaboration with the Norwegian Color Research Laboratory has carried out this print quality project.

Experimental method

Various studies and research have been done in the field of print quality and repeatedly it has been concluded as a very complex issue. The subject has been discussed at various conferences (see e.g. Hardeberg and Skarsbø, 2002; Nussbaum *et al.*, 2004; Nussbaum and Hardeberg, 2006).
Principally there are two different approaches to assess image quality. The first approach is by measurement, using instruments to determine values for the various quality factors. The second method is based on observation, using psychophysical experiments to gather the judgement of human observers. For instance, the rank order method is a robust approach where observers are asked to rank the image samples in order, from best to worst, along an attribute defined by the instructions, such as pleasantness. This method is based on Thurstone's «law of comparative judgement» (Handley, 2001; Gescheider, 1985).
Considering the print quality evaluation in this study two approaches have been applied, using quantitative analyses based on colour measurements, and using psychophysical experiments (Figure 1).

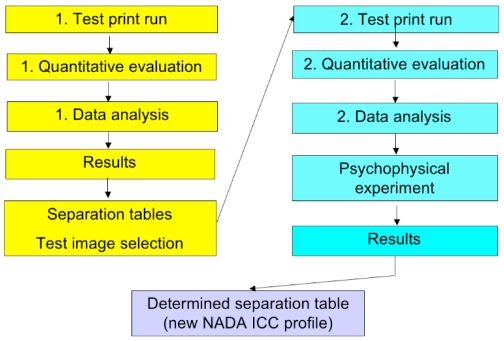


Figure 1: Overview of method.

Quantitative evaluation

The purpose of the following test is to determine the short and long term repeatability of each participant of the project. Furthermore the variation between the eight newspaper printing processes and the variation according to the colorimetric values of the ISO 12647-3:2005 are important parts of the quantitative evaluation. To compare the current printing parameters with the current Norwegian newspaper ICC profile and the ISOnewspaper26v4.icc the characterization test target ECI2002R CMYK.tif and the IT8.7-3 CMYK Target.tif were used in this work.

Furthermore the test document contained other colour charts and test images separated according to certain custom profiles and industry standard profile.
Considering the test print each printing plant was required to use the appropriate RIP settings according to the predefined Norwegian linearized newspaper production (equal RIP setting for each colour). Moreover, all participants used newspaper substrate (45g/m^2) and the density values were according to ISO 12647-3:2005. The colour measuring conditions were according to ISO 13655:2000, geometry 45/0, 2°observer, CIELAB system. For documentation all colorimetric measuring were made on white backing using Spectrolino. Considering colour difference calculations ΔE^*_{ab} values were computed between individual measurements and the "ISOnewspaper26v4" measurement data. Because the colorimetric variation tolerances in ISO 12647-3:2005 are defined in CIELAB ΔE^*_{ab} this colour difference metric only has been applied in this work. The arithmetic mean, standard deviation and maximum of the resulting colour difference distributions were then computed. The density measurements using SpectroEye were performed on black backing with DIN E and polarisation filter. The tolerance density deviation for densitometer measurements is ± 0.01 according to DIN 16536-2 (1995). We measured the 50% patch 10 times and the variation was less than 0.01 densities for all process colours.

Psychophysical Experiment

The aim of the psychophysical experiment was to determine pleasantness of the reproductions made according to different newspaper prints. Notice, two Test Print runs were carried out in this project with six months interval. According to the colour measurements of the first Test Print a number of ICC profiles with different separation settings were generated. An expert panel determined the two appropriate colour separations, which were used to carry out the psychophysical experiment according to the Test Prints of the second test run.
Two custom profiles and one process ICC profile (according to ICC-specifications) were applied to each test image (by using the relative colorimetric rendering intent) and printed in the eight newspaper printing plants. The three applied ICC profiles are:

- NADA X: ICC profile according to the average measurement values of seven (excluding Dagbladet) newspaper printing plants which results in 70 measurements (7x10 measurements), Profiling tool: GretagMacbeth, ProfileMaker 5.0.8, acromatic: MaxK, TIL: 240%, starting point: 5

- NADA Y: ICC profile according to the average measurement values of all eight newspaper printing plants (8x10 measurements) AND the measurement data of ISOnewspaper26v4, Profiling tool: GretagMacbeth, ProfileMaker 5.0.8, acromatic: MaxK, TIL: 240%, starting point: 5
- NADA Z: Based on the offset characterization table "FOGRA26.txt" valid for the following reference printing conditions relating to the international standard ISO/DIS 12647-3:2005

The images were simultaneously viewed side by side, as shown in Figure 2 and no anchor stimuli were used as a reference. The viewing set up was based on the standard condition of the graphic art industry ISO, 3664, vertical geometry 45°, background grey, light source D50 simulator, light intensity 100%. The images were viewed in a darkened room (lights off) and the images, approximately 10cm x 15cm in size, were viewed from a distance of approximately 65 cm.

Figure 2. Viewing arrangement for psychophysical experiment.

Four test images were chosen to contain a range of different types of pictorial content and tonal and chromatic variety as shown in Figure 3. The chosen images represent typical the type of images used in daily coldset offset newspapers.

Figure 3. Four test images: camera, car, portrait and flag. The images "camera" and "portrait" are reproduced with the permission of Ole Jakob Bøe Skattum. The images "car"and "flag" are reproduced with the permission of Verdens Gang (VG).

A total of 25 observers (14 experts and 11 naïve) with normal colour vision and ages from 20 to 58 took part in the experiment. Each observer was required to assess four different images. Each image is reproduced by three different separation algorithms and printed in eight different printing plants. Note that the assessments were carried within each individual coldest offset newspaper press. The law of comparative judgement was applied and the method used was rank order (Engeldrum, 2000).
The observer's task was to rank the three prints in the viewing cabinet in order, from best to worst, in terms of preferred pleasantness. In a study by Morovic (2002) pleasantness is defined as the reproduction's correspondence with preconceived ideas of how a given image should look according to an individual in terms of contrast, colour, sharpness, etc.

Results and discussion

Firstly the results of the quantitative evaluation will be presented. The Color Research Laboratory received 20 Test Prints (printed on one side only) from all eight participants and measured a total of ten test charts (IT8.7-3 CMYK Target) from each participant to evaluate their colorimetric properties. The selected test charts have been considered according to density control on solid CMYK bars. 5 density measurements have been performed with the settings DIN E and polarisation filter on a black background on solids across the paper width (Figure 4).

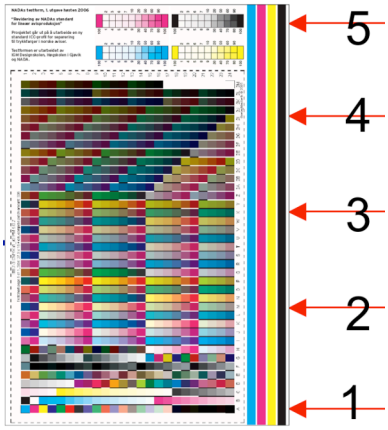


Figure 4. Test chart IT8.7-3 CMYK including solid bars across the paper width to perform density control.

The 5 densities across the paper width from all 20-test prints in each colour have been averaged. Table 1 shows the density values from each participant on Test Print 1 (column 1) and Test Print 2 (column 2). The reflection densities of the process colour solids on newsprints according to the ISO 12647-3:2005 are specified cyan 0.90, magenta 0.90, yellow 0.90 and black 1.10. The density tolerances are ±0.1. It can be seen that in Test Print 1 all participants performed excellent within the ISO tolerance ±0.1 (except for "Stavanger Aftenblad" in yellow 0.77 density). However, except for "Dagbladet", "Stavanger Aftenblad" and "Halden Arbeiderblad" the density performance in Test Print 2 looks rather poor and the density values for some of the colours are outside the ISO tolerance. Notice, the high density value in black for "Fædrelandsvennen".

Participants	Cyan		Magenta		Yellow		Black	
	1.TP	2.TP	1.TP	2.TP	1.TP	2.TP	1.TP	2.TP
Dagblad	0,93	0.88	0,98	0.89	0,95	1,0	1,17	1.16
Aftenposten/VG	0,97	0.75	0,92	0.85	0,89	0.7	1,12	0.99
Nr1 Trykk	0,86	0.75	0,97	0.94	0,94	0.75	1,11	1.04
Fædrelandsvennen	0,90	0.92	0,93	0.76	0,88	0.88	1,19	1.49
AdresseTrykk	0,83	0.7	0,89	0.76	0,94	0.71	1,05	1.17
Bergens Tidende	0,96	0.97	0,93	1.01	0,98	1,0	1,10	1.18
Stavanger Aftenblad	0,87	0.89	0,88	0.83	0,77	0.89	1,10	1.07
Halden Arbeiderblad	0,81	0.8	0,81	0.81	0,86	0.86	1,20	1.13

Table 1. Density performance from each participant in Test Print 1 (1.TP) and Test Print 2 (2.TP). The yellow marked densities are outside the ISO tolerance values.

Considering the solid ink uniformity across the paper width Figure 5 shows the cyan ink variations on Test Print 1 and Test Print 2 for all participants. Although the solid ink uniformity in test print 1 measured 5 times across the paper width are within the ISO tolerance the variations in test print 2 are much larger and partly outside the ISO tolerance. For almost all participants it can be seen a correlation between the large variations and the average density in test print 2.

Note that the appropriate density and ink uniformity is an issue of calibration and will determine the print quality.

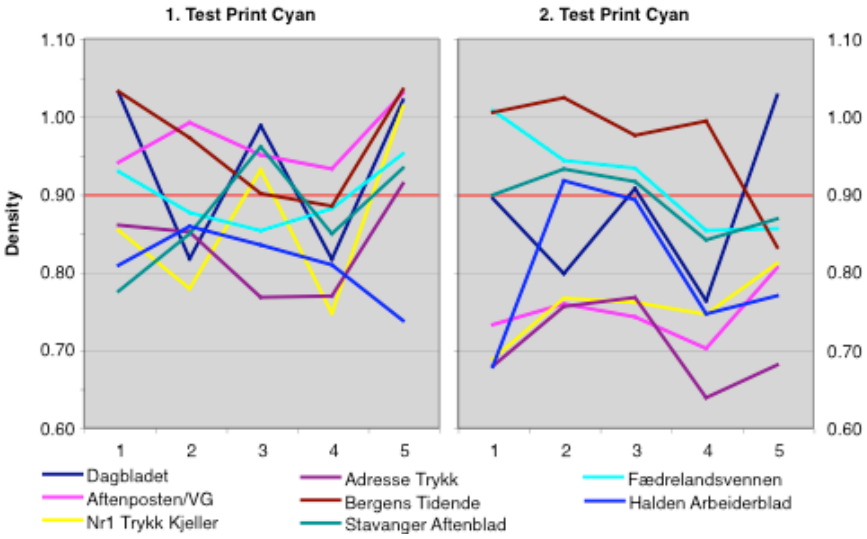


Figure 5. Solid cyan ink uniformity in test print 1 (left column) and test print 2 (right column) measured 5 times across the paper width

To determine the variation in terms of colour stability over time the quality factor repeatability is required (Morovic and Nussbaum, 2003). Figure 6 shows the performance of the short-term repeatability of each participant according to Test Print 1. The colour differences were calculated between the average of the ten measurements and each individual measurement. Although some of the participants show larger variations the results of all participants are still within an acceptable tolerance (Mean $\Delta E^*_{ab} < 1.0$ units).

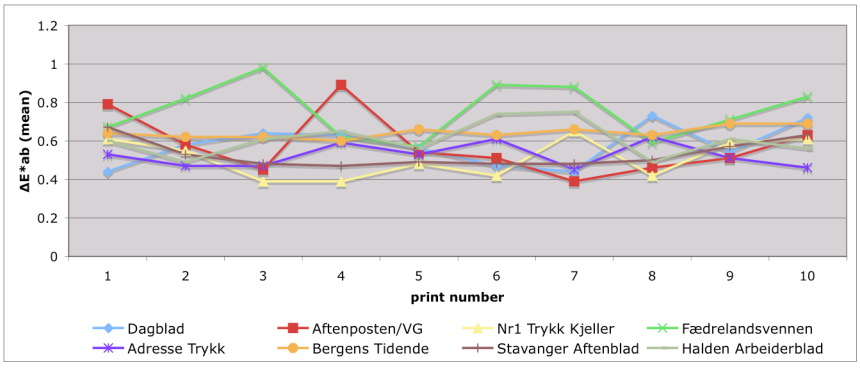


Figure 6. Short-term repeatability performance of each participant in Test Print 1.

Another property of evaluating the performance of a printing process is by analysing the long-term repeatability (six months interval). Figure 7 shows the variations between Test Print 1 and Test Print 2 from each participant. The colour differences were calculated between the average of the ten measurements (Test Print 1) and the average of the two measurements of Test Print 2. It can be seen that "Dagbladet" indicates the largest colour difference in terms of mean (despite similar density performance in Test Print 1 and Test Print 2). This is due to different RIP (Raster Image Processor) settings between Test Print 1 and Test Print 2 (Therefore the colour measurement data (Test Print 1) from "Dagbladet" has been excluded and not been taken into account for the generation of the "NADA X" ICC profile). Due to the excellent density performance between Test Print 1 and Test Print 2 it is not unexpected that "Halden Arbeiderblad" shows a rather low colour difference (mean ΔE^*_{ab} 2.38 units) between the two test prints.

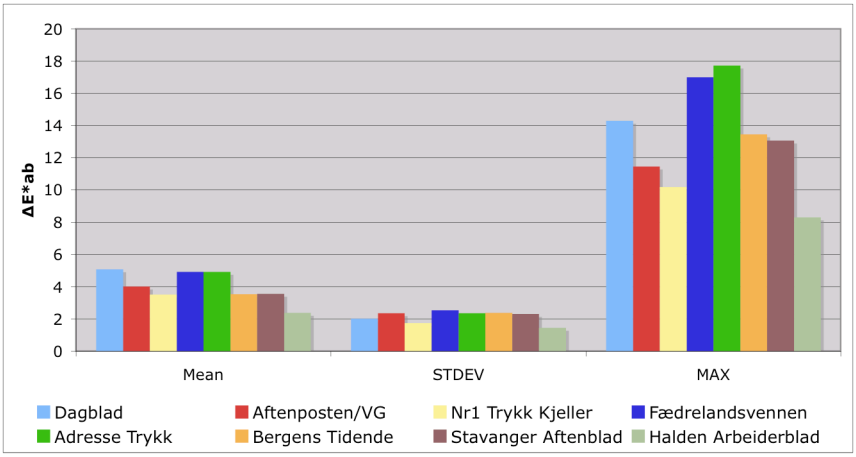


Figure 7. Long-term repeatability performance of each participant (six months interval).

A further approach to assess the colorimetric properties is to analyse the variations between the eight newspaper printing processes. Figure 8 presents the colour difference between the average measurements of all eight newspaper printing plants and each individual participant in Test Print 2. Notice, that participant "Fædrelandsvennen" shows the largest difference (mean $\Delta E^*_{ab} > 4.8$ units). Furthermore the max difference has been calculated for the solid black as expected due to the tremendous high density value (black density 1.49). Participant "Dagbladet" illustrates the smallest difference (mean ΔE^*_{ab} 2.1 units).

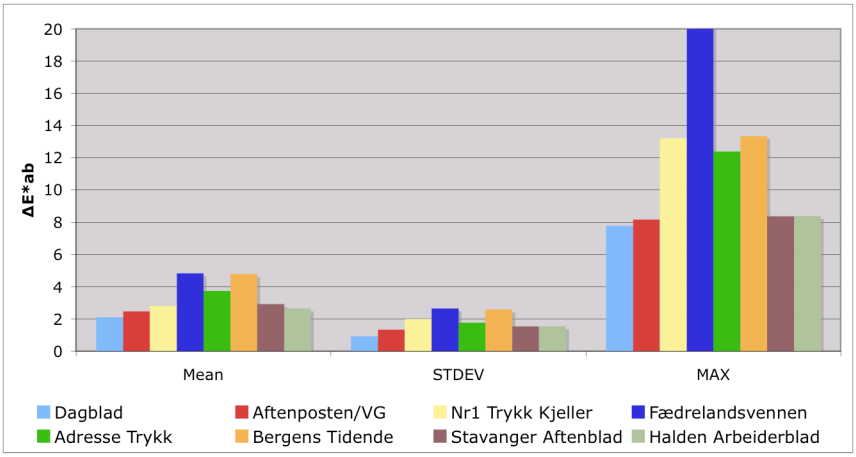


Figure 8: Variations between the eight participants according to test print 2.

The size of the halftone dots increase during the printing process. This is called dot gain. It is important to know the dot gain characteristics to achieve high print quality. E.g ISO 12647-3:2005 has defined a tone value increase curve for 26%. Table 2 shows tone value increase for the 50% control patch measured on paper substrate with DIN E with polarisation filter on a black background for Test Print 1 and Test Print 2. Note that the measurement results demonstrate a rather large variation in terms of tone value both within the colours cyan, magenta, yellow and black and within the participants. As mentioned previously each printing plant was required to use the appropriate RIP settings according to the predefined Norwegian linearized newspaper production (equal setting for each colour). However, in order to obtain a common specified dot gain (e.g. 26%) in all printing plants the RIP setting has to be adjusted individually for each participant and for each colour.

Participants:	**Tone value %**				**Tone value %**			
	Test print 1				**Test print 2**			
	C	**M**	**Y**	**K**	C	**M**	**Y**	**K**
Dagbladet	31	28	22	29	25	25	23	27
Aftenposten/VG	17	18	14	4	23	26	19	10
Nr1 Trykk Kjeller	11	22	9	17	16	8	9	10
Fædrelandsvennen	20	15	17	10	20	14	18	26
Adresse Trykk	17	13	14	8	8	6	10	14
Bergens Tidende	18	18	13	15	12	14	14	9
Stavanger Aftenblad	10	8	8	12	11	10	14	13
Halden Arbeiderblad	13	10	15	12	21	16	21	8

NADA_avis_vjanu2004	16	19	16	8	16	19	16	8
ISO 12647-3:2005	26	26	26	26	26	26	26	26

Table 2: Tone value increase for the 50% control patch measured on paper substrate with DIN E with polarisation filter on a black background

A further important part of the evaluation is to analyse the variation between all eight participants and the colorimetric values of the "ISOnewspaper26v4" ICC profile. According to the results given in Table 3, the participant "Dagbladet" shows the closest match (mean ΔE^*_{ab} < 4.12 units) and participant "Adresse Trykk" presents the largest difference (mean ΔE^*_{ab} > 7.67 units). This result corresponds with the tone value increase for 50% value seen in Table 2 (Test Print 2) which have shown a very close match between "Dagbladet" and ISO 12647-3:2005 and a rather large difference between "Adresse Trykk" and ISO12647-3:2005 respectively.

ΔE^*_{ab}	**Mean**	**STDEV**	**MAX**
Dagblad	4.12	1.49	10.97
Aftenposten/VG	5.23	1.48	10.66
Nr1Trykk Kjeller	6.29	2.29	13.18
Fædrelandsvennen	5.34	2.37	14.44
Adresse Trykk	7.67	2.93	19.57
Bergens Tidende	6.85	2.86	17.00
Stavanger Aftenblad	7.32	2.92	16.03
Halden Arbeiderblad	6.53	2.6	15.66

Table 3. Colorimetric colour differences between each newspaper printing plant and ISOnewspaper26v4 values.

Looking at the CIELAB values for the primary colours cyan, magenta, yellow and black specified in ISO 12647-3:2005, the differences between the actual values and the nominal values must not exceed the tolerances shown in Table 5. Table 4 presents the CIELAB values for the primary colours from all eight participants, ISO 12647-3:2005 and "NADA average 2007" (Test Print 2). Moreover the Table shows colour differences calculated between the participants and ISO 12647-3:2005. The green marked values indicate that the colour differences are within the ISO tolerance of ΔE^*_{ab} 5 units. The violet marked values are outside the ISO tolerance. It is interesting to note that according to Test Print 1 almost all participants show colour differences within the ISO tolerance. On the other hand it can be noticed that except for "Dagbladet" and Halden Arbeiderblad" the colour difference in Test Print 2 exceed the ISO tolerance for most of the participants due to the inappropriate density values (Table 1).

		1. TP	ΔEab	2. TP	ΔEab	1. TP	ΔEab	2. TP	ΔEab	1. TP	ΔEab	2. TP	ΔEab	1. TP	ΔEab	2. TP	ΔEab
		Cyan				Mag				Yellow				Black			
Dagblad	L*	55.7		59.7		54.3		55.7		80.2		80.1		34.5		35.8	
	a*	-24		-24.6		50.9		48.4		0.3		0.3		1.7		1.6	
	b*	-32.2	6.1	-27.3	1.1	1.9	4.82	0	1.4	62.5	1.97	64.9	3.62	4.9	2.08	5.3	1.1
Aftenposten/	L*	57.6		62.8		55		58.4		79.4		80.4		39.4		39.6	
VG	a*	-24		-23		48.2		43.2		0		-2		1.6		1.8	
	b*	-29.6	3.0	-24.1	5.2	1.5	2.63	-0.6	4.8	64	3.01	52.8	9.03	5.1	2.98	5.3	3.24
Nr1 Trykk	L*	59.3		65.1		55.3		57.2		81.5		80.6		38.2		39.1	
Kjeller	a*	-25.4		-23.7		50.9		46.4		-1.4		-0.8		1.9		1.9	
	b*	-30	3.2	-22.6	7.77	0.3	3.89	-1.4	1.7	62.2	0.72	58.2	3.66	5.7	2.17	6.3	3.22
Fædrelands-	L*	58		58.1		55.2		55		78.7		76.7		32.7		27.4	
vennen	a*	-26.1		-25.8		45.6		44.6		-0.3		0		1.2		0.8	
	b*	-26.6	1.6	-24.9	2.4	0.4	2.09	-0.1	2.8	62.6	2.59	61.7	4.43	4	3.83	2.1	9.42
Adresse	L*	58.6		63.7		54.6		59.8		79.1		80.6		39		37.8	
Trykk	a*	-23.3		-23.4		46.3		38.9		-0.7		-3		1.8		1.5	
	b*	-27.4	1.5	-19.8	8.8	1.7	2.92	-3	9.5	64.2	3.08	46.7	15.2	5.6	2.78	5.2	1.49
Bergens	L*	56.6		58.6		53.9		49.7		79.4		77.3		35.3		38.5	
Tidende	a*	-24.5		-23.5		49.8		50.8		0.9		1.4		1.6		1.7	
	b*	-30.8	4.4	-27.3	1.3	2.4	4.54	5.8	9.7	65.8	4.85	66.3	6.41	4.9	1.3	5.4	2.23
Stavanger	L*	59.6		59.3		55.3		56.3		78.6		79.7		37.5		39.1	
Aftenblad	a*	-22.3		-24.3		45		47.1		-1.6		-1		1.6		1.6	
	b*	-26.2	2.7	-28.0	1.3	0.7	2.71	-0.5	0.6	53	9.1	59.9	2.28	5	1.16	5.5	2.8
Halden	L*	60.4		58.4		58		57.2		79.5		79.3		36		35.6	
Arbeiderblad	a*	-24.8		-24.8		43.2		44.7		-0.7		-0.3		1.4		1.4	
	b*	-27.6	1.8	-27.6	0.8	-3.4	5.25	-1.7	3	59.3	2.95	60.9	2.14	4.2	0.59	4.4	0.91
NADA	L*	58.3		60.8		55		56.3		79.7		79.3		36.7		36.9	
average 2007	a*	-24.5		-24.1		47.5		45.3		0.4		-0.7		1.6		1.6	
	b*	-28.8	2.0	-25.1	2.8	0.9	1.9	-0.4	2	62.5	2.27	58.4	3.82	4.9	0.54	5.1	0.78
ISOnewspaper26v4	L*	58.7				55.8				80.9				36.5			
ISO 12647-3	a*	-24.7				47.2				-1.4				1.3			
2004	b*	-26.9				-0.8				61.8				4.5			

Table 4: CIELAB coordinates for newspaper according to measurements on white backing (ISO 12647-3:2005).

	Cyan	Magenta	Yellow	Black
Deviation Tolerances	5	5	5	5

Table 5: CIELAB tolerances (ΔE^*_{ab}) for the solid tones of primaries according to ISO 12647-3:2005.

Notice, that all participants have used substrates, which meet the tolerances for the colour of the print substrate (ISO 12647-3:2005). Figure 9 shows the average colour gamut projection of the Test Print 1 and Test Print 2 and the ICC profile "ISOnewspaper26v4" onto the a*b*-plane according to the level of lightness L*=50.

The data used in this task are based on colorimetric measurements, which have been analysed and visualised by the icc3d application (Farup *et al.*, 2002). It can be seen that the average measurement of the Test Print 1 has the largest colour gamut. On the other hand the average measurement of all the 8 printing presses in Test Print 2 result in a smaller colour gamut. The measurement data of the "ISOnewspaper26v4" profile lies between the two test prints.

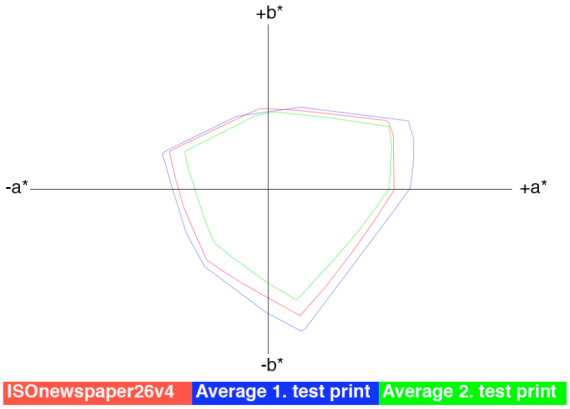


Figure 9. 2D colour gamuts comparison of Test Print 1 and Test Print 2 and the ICC profile ISOnewspaper26v4 onto the a*b*-plane according to the level of lightness L*=50.

The three-dimensional CIELAB plot in Figure 10 reveal the colour gamut properties of the "ISOnewspaper" profile and the colour gamut of the Test Print 2 which contains the average measurement values of all eight coldset web offset printing presses. The plot shows obvious limitations of the Test Print 2 profile in high-saturated colours such as blue and green.

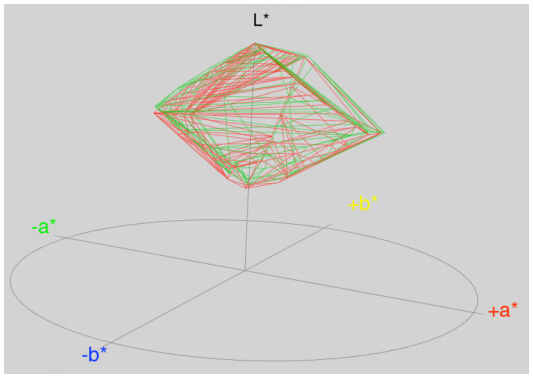


Figure 10. 3-D comparison of the "ISOnewspaper26v4" colour gamut (wireframe red) and the colour gamut of the Test Print 2 (wireframe green).

Another way of looking at the size of colour gamuts is by considering the gamut volume. The size of colour gamuts, quantified as the volume of the convex hull (Morovic, 2003) of the gamut in CIELAB colour space

was derived from the test prints of both test print runs of the eight newspaper printing plants and the ICC profile ISOnewspaper26v4.

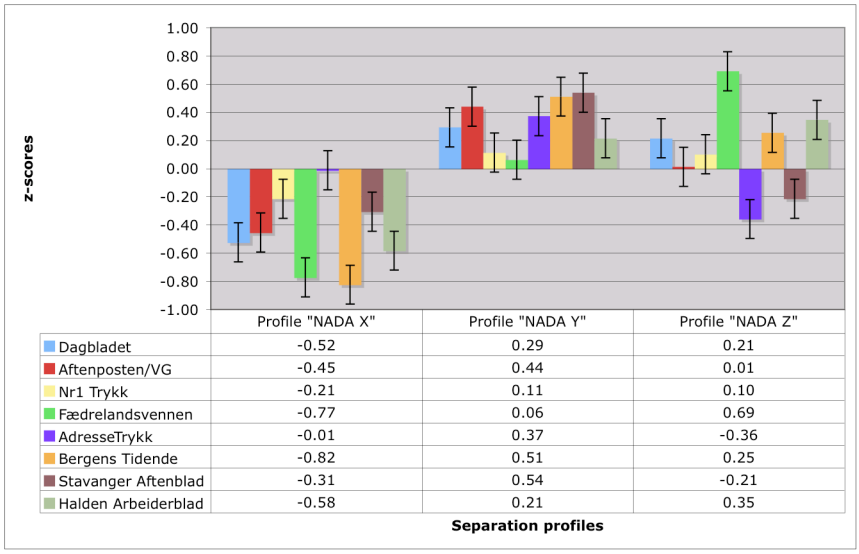
Participants:	Test Print 1		Test Print 2	
	CIELAB volume	Relative volume	CIELAB volume	Relative volume
ISOnewspaper26v4	141'403 unit	100%	141'403 unit	102%
Dagblad	167'467 unit	118%	157'895 unit	112%
Aftenposten/VG	164'914 unit	116%	128'060 unit	90%
Nr1 Trykk Kjeller	162'448 unit	115%	145'710 unit	103%
Fædrelandsvennen	156'325 unit	110%	167'996 unit	119%
Adresse Trykk	141'130 unit	100%	125'310 unit	89%
Bergens Tidende	168'351 unit	119%	169'105 unit	120%
Stavanger Aftenblad	133'830 unit	94%	143'840 unit	102%
Halden Arbeiderblad	146'215 unit	103%	148'138 unit	105%
NADA average 2007	151'091 unit	107%	139'780 unit	98%

Table 6: Comparison of the approximate relative gamut volumes of eight newspaper printing plants and the ICC profile "ISOnewspaper26v4".

It is obvious that the density changes affect the gamut volumes as well. However, it can be seen in Table 6 that "Fædrelandsvennen" and "Bergens Tidende" provides the largest gamut volume (even 20% larger than the "ISOnewspaper26v4") in Test Print 2, whereas the volume given by participant "Adresse Trykk" is 89% of that given by "ISOnewspaper26v4". Although participant "Stavanger Aftenblad" has shown the second largest mean colour difference comparing to "ISOnewspaper26v4" as seen in Table 3, the relative gamut volume is virtually equal to that of the "ISOwebcoated". This reinforces the fact that colour differences say something more specific about individual colours whereas relative gamut volumes refer to their ranges.

The following are the results in terms of z-scores, which have been obtained in the psychophysical experiment. For each image and newspaper printing plant the 3 x 1 matrices of ranking order results for each observer were arranged over the 25 observers and the raw data from the experiments were treated statistically to obtain z-scores. The precisions of the experimental results are described in terms of 95% confidence interval (CI), which is calculated using equation (1) using the mean (R), standard deviation (σ) and the number of observations (N). Using case V of the method proposed by Thurstone, the standard deviation of the z-scores is assumed to be $\sigma = 1/\sqrt{2}$.

$$95\%\ \text{confidence interval} = R \pm 1.96\frac{\sigma}{\sqrt{N}} \qquad (1)$$



	Profile "NADA X"	Profile "NADA Y"	Profile "NADA Z"
Dagbladet	-0.52	0.29	0.21
Aftenposten/VG	-0.45	0.44	0.01
Nr1 Trykk	-0.21	0.11	0.10
Fædrelandsvennen	-0.77	0.06	0.69
AdresseTrykk	-0.01	0.37	-0.36
Bergens Tidende	-0.82	0.51	0.25
Stavanger Aftenblad	-0.31	0.54	-0.21
Halden Arbeiderblad	-0.58	0.21	0.35

Figure 11. Rank order z-scores for each heat-set web press and separation (The error bars represent 95% of population distribution).

Figure 11 presents the results in terms of z-scores for each newspaper printing plant. For the number of images and observations, CI was calculated to be ±0.13. Overall it can be noticed that "NADA X" performs worst for all participants, except for "Adresse Trykk". "NADA Z" performs significant best for participant "Fædrelandsvennen". On the other hand "NADA Y" was ranked significantly best for the participants "Aftenposten/VG", "Adresse Tykk", "Bergens Tidende" and "Stavanger Aftenblad". Note that the profiles "NADA Y" and "NADA Z" do not indicate a significant difference either for "Dagbladet" nor "Halden Arbeiderblad" in terms of preferred pleasantness.

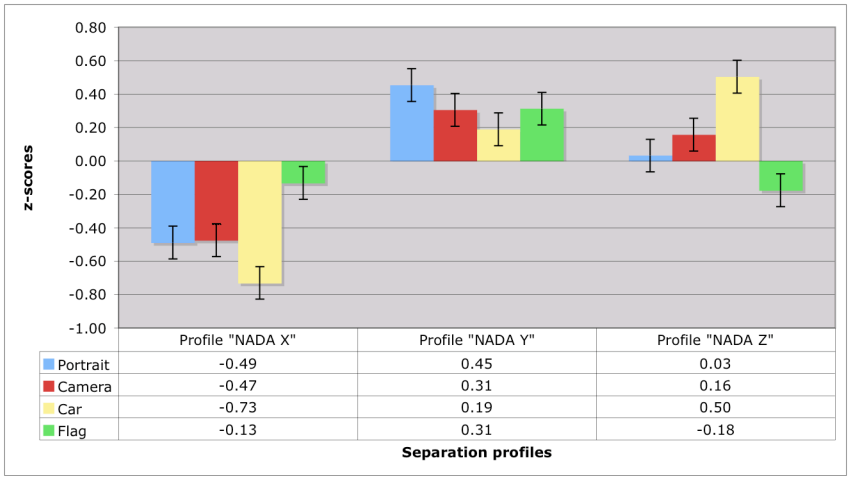


Figure 12. Ranking order z-scores for each type of image and separation (The error bars represent 95% of population distribution).

Considering Figure 12 the experimental results identify the profile "NADA Y" as the candidate, which scored best for the images "Portrait", Camera" and "Flag". "NADA Z" performs significant best for the image "Car". However, "NADA X" was ranked significantly worst in terms of preferred pleasantness.

Image	Profile "NADA X"	Profile "NADA Y"	Profile "NADA Z"
Portrait	3	1	2
Camera	3	1	2
Car	3	2	1
Flag	2	1	3
Overall	**3**	**1**	**2**

Table 6. Ranking of separation profiles for each image (1=best, 3=worst).

Table 6 gives the ranking of the performance of the three separation profiles for the four images. As it can be seen the profile "NADA Y" was significant best except for the image "Car" and the profile "NADA Z" was second. Figure 13 presents the results in terms of z-scores for all four images and all eight newspaper participants.

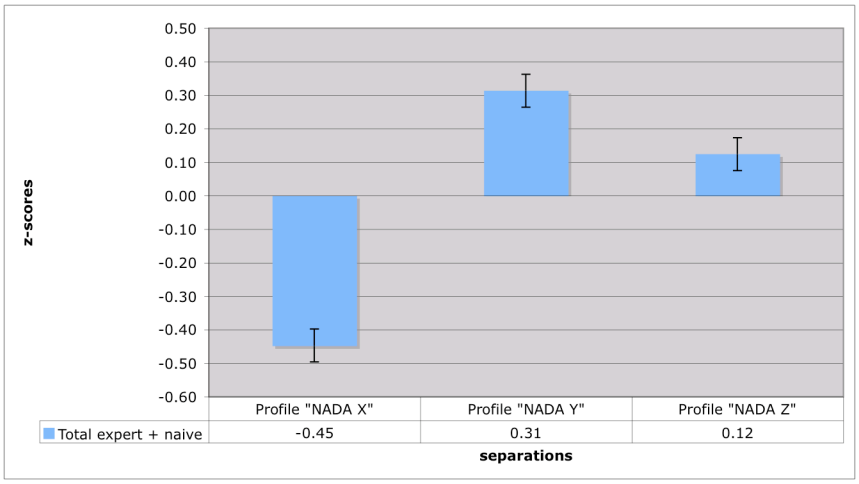


Figure 13. Overall z-scores for the three separation profiles.

For the total number of images, newspaper printing plants and observations, CI was calculated to be ±0.05. Notice, overall, the "NADA Y" profile performed significant best and the "NADA Z" profile second best.

Conclusions and perspectives

As seen previously the results considering the short-term repeatability all participants are within an acceptable tolerance. By preserving the solid CMYK density values within +/-0,1 tolerance and reducing the density variations across paper width (uniformity) the long-term repeatability performance will improve.
Considering dot gain the results have shown rather high variations due to inconsistent RIP compensation both within the colours cyan, magenta, yellow and black and within the participating printing plants and results in visually different grey balance. This might be explained due to missing "uniform" dot gain agreement within the Norwegian "newspaper standard" or might be forced by invalid measurement technology using dot meter technology on paper substrate (Wroldsen 2007). The inconsistency of the density values on the solid primary colours, especially in Test Print 2, has affected the colorimetric values (CIELAB coordinates). Hence, for most of the participants the colour difference between Test Print 2 and CIELAB coordinates in ISO 12647-3:2005 has exceeded the ISO tolerance.
Although the quantitative evaluation has demonstrated some obvious restrictions there is a large potential improving the target values of the ISO 12647-3:2005 to obtain a better coherence between the newspaper

participants. Nevertheless to preserve the daily printing conditions and to match the colorimetric requirements of the adopted standard profile it is highly recommended to perform press control according to a well defined standard such e.g. ISO 12647-3:2005.
As can be seen from the results of the psychophysical experiment the ICC profile "NADA Y" performs significantly better than the other two profiles, "NADA Z" and "NADA X" respectively. However, it has to be noticed that the measurement parameters of "NADA Z" does not match the calibration parameters of most the participants in Test Print 2. Therefore it might be not expected that "NADA Z" will perform better then "NADA Y". Moreover the colorimetric difference between the measurement data of "NADA Y" and "NADA Z" results in a colour difference ΔE^*_{ab} 2,5 which will be classified as rather small. The separation parameters are identical. On the other hand the print variations within the 8 newspaper printing plants in Test Print 2 are between ΔE^*_{ab} 2.2 and ΔE^*_{ab} 5 which means that the print variations are larger then the colorimetric difference between "NADA Y" and "NADA Z". Hence, the print variations and not the profile information only may have determined the print quality.
However, the outcomes in this study demonstrate an obvious need for standardising the behaviour of coldest-offset newspaper printing to preserve best print quality. Furthermore it shows the importance of adopting international standards than using insufficiently defined house standards to preserve equal results among newspaper printing presses.
Finally, it is of interest to consider other potential directions for further work in the field of process control and print quality assessment. Colour difference metrics for image quality assessment has been widely used for various applications. However there is not very often a strong correlation between the objective evaluation and the visual assessment. Furthermore the interpretation of the complete image quality assessment considering the colour difference calculation is dependent on the application and the acceptance. Moreover, the acceptability threshold considering print quality assessment is defined as a vague concept and one that depends strongly on application and industry.

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