Model for Print Quality Evaluation of Hybrid Printed Matter

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Abstract

Pressure on reducing prices and a market demand for customisation and shorter production runs give cause for investigating alternatives to conventional printing. Traditional technologies, such as flexography and offset, are all using static printing forms, while a digital printing unit prints information directly from the data file. Hence, the latter alternative makes it possible to produce short runs, even providing every printed copy with a specific design. However, one disadvantage, when high volumes are produced, is the higher cost per copy for digital printing.

Another approach is to use hybrid printing, where digital printing is used to add information onto substrates, pre-printed using conventional printing technology. Conventional technology can then be used to gain large-scale advantages, while digital printing makes it is possible to customise certain parts of the original design for any printed copy, if desired. Hence, information can be tailored to fit different segments or specific customer needs

It is always important to achieve a high and constant print quality. When a digital print is added onto a pre-printed substrate, it is essential that the final result from this combination is of high print quality too. Hence, it is important to know how the different technologies interact and how this can be measured.

The aim of this investigation was to identify factors that influence the print quality of hybrid printed matter and that are important to consider in the design and evaluation of a hybrid printing production. The focus in this study was on hybrid printed matter, where the added print was supposed to blend in with the pre-printed background.

Samples had been made by carrying out flexography and inkjet printing trials, together with a hybrid printing trial. In the latter trial, printed objects were added by a high-speed inkjet press to a pre-printed flexography substrate. The objects added consisted of elements for technical measurements and pictorial elements, aimed at fitting into a flexography pre-printed image background, for visual evaluations.

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The hybrid printed pictorial samples had different characteristics. The added print and the background had a similar or different colour content. The added print was put onto a pre-printed or an unprinted area and it was applied so that it bordered directly on or indirectly on the pre-printed elements in the background. All the trials were done on uncoated paper. Furthermore, the parameters of the added print, e.g. print speed and colour intensity, were varied.

Technical measurements, assumed to be significant for print quality, such as colour density, print gloss, print mottle and sharpness, were obtained from both printing techniques, separately and from combinations of them, with areas where inkjet had been printed on top of the pre-printed flexography backgrounds. Moreover, visual assessments were done by a panel to determine the visual impression of hybrid printed samples.

The study resulted in a quality model, identifying important factors to consider when preparing for a hybrid printing production and when evaluating print quality. The model clearly demonstrates the strong influence of the characteristics of hybrid print. These characteristics will affect the way a hybrid printing production should be planned and carried out.

Introduction

As distinct from conventional printing technologies, such as flexography and offset, where static printing forms are used, digital printing implies that information is printed directly from a data file. Hence, the use of digital printing means that it is possible to produce short runs and provide every printed copy with a specific design. When large volumes are produced however, one disadvantage is the higher cost per copy with digital printing.

Another approach is to use a hybrid printing system. The idea of hybrid printing is to have access to interesting production opportunities, resulting in value adding features and financial savings. By combining different conventional printing technologies, different non-impact printing technologies or by using a combination of conventional and non-impact technologies, it is possible to set up a hybrid printing system. For example, the combination of offset and flexography is a well-known set up for a hybrid printing system, where the flexography unit is used for coating or applying spot colours. Another instance is to combine multi-colour offset with inkjet or electrophotography for variable data printing in one colour. The combination of technologies can be set up to work inline or offline. In the case of inline, print speed is a critical aspect, since conventional technologies reach much higher speeds than non-impact technologies (Kipphan, 2001).

Downward trends in market prices and a customer demand for customisation and shorter production runs give cause for considering alternatives to conventional printing technologies. Using a hybrid printing system, conventional technology could be used to achieve large-scale advantages, while digital printing makes it possible to customise certain parts of the original design to fit different segments of customers, if that is what is wanted for each printed copy.

In order to perform this customisation task, there are two main digital printing technologies, viz. inkjet and electrophotography. One main advantage of inkjet is that the imprinting unit is kept from having contact with the substrate. Due to this non-impact process, inkjet printing can manage any thickness in the substrate (Moncarey, 2003), which means that it is possible to print on packaging material, even after it is folded into three-dimensional packages. Inkjet can attain a much higher print speed and can more easily be integrated into existing printer systems or packaging lines, when compared to electrophotography. Inkjet was therefore chosen as the digital printing technology for this particular project. Flexography was chosen as the conventional printing technology, mainly because it is used widely in the packaging industry.

The importance of different technical print quality factors for inkjet has been analysed in previous research. These studies indicate that the most significant technical print quality factors are colour gamut (or colour density) and sharpness (McFadden and Donigian, 1999; Gidlund et.al, 2004). The print quality of hybrid printed matter is an area that has not yet been investigated extensively.

It is always crucial to attain a high and constant print quality. When different printing technologies are combined, it is essential that the results from this combination also reach a high print quality. Hence, it is important to investigate how the different technologies interact and how this can be measured. In a hybrid printing context, the way that the print quality is apprehended will be affected by the differences and/or similarities among the different printing technologies.

The aim of this study was to identify factors that influence print quality and are important to consider when it comes to the design of a hybrid printing production. Moreover, the aim was to investigate whether specific measures would be relevant in the evaluation of hybrid printed matter.

Hypothesis

In order to gain knowledge about hybrid printing and print quality matters, a number of printing trails were carried out. Flexography and inkjet printing trials, together with a printing trial where inkjet was printed on top of a background printed in flexography were carried out and data was collected using technical measurements and visual assessments. From experiences gained with these printing trials, a model has been suggested that gives a description of print quality and aspects of evaluation that depend on the design of the hybrid printing production (see figures 1 and 2). In order to substantiate the relevance of this model, the results from the technical measurements and visual assessments were evaluated and analysed.

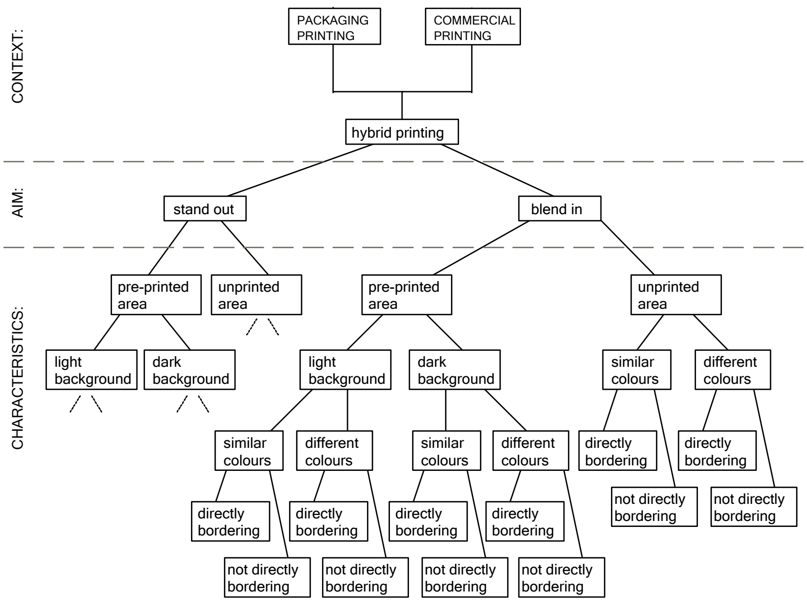

Figure 1. Choices available in a hybrid printing production.

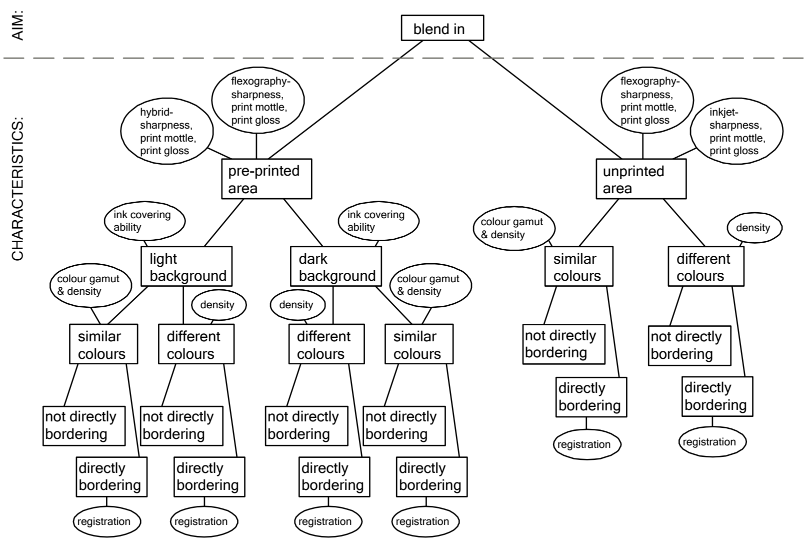

Figure 2. Suggested model for designing and evaluating hybrid printed matter.

Hybrid printing can be done in different contexts, e.g. in commercial printing, where variable financial data is printed onto pre-printed leaflets or in packaging printing, where batch number, date or more sophisticated graphical elements are printed onto pre-printed packaging material. In the latter case, the added print could either be done at the packaging supplier's/printer's, or at the filler's or even further down the line at the wholesaler/retailer.

When a digital print is added onto a package in an industrial environment, e.g. on a packaging line, it is crucial that the added print will withstand the post-handling, the packing and wrapping of the packages and the transportation. These actions can occur directly after the printing has been done, which implies there is a risk of problems with smearing. This depends, however, on such factors as drying time etc. It is therefore important to be able to measure smearing and adhesiveness, in order to ensure that the end user will receive a package having high print quality. These aspects are not covered in this study however.

The aims for using hybrid printing can be varied. The added print can be made to blend in with the background, or to stand out so that it is attention-grabbing. The focus of this investigation was to analyse added print that is meant to blend in with the background.

Hybrid print can possess different characteristics. The added print can be put onto a pre-printed area or an unprinted area. This makes a difference for to how to take technical measurements of the print quality. Printing onto a pre-printed background implies that technical measurements of the results of the combination of print technologies (i.e. inkjet printed on a flexography pre-printed area in this case) should be needed. This is the reason why measures of hybrid sharpness, hybrid print mottle and hybrid print gloss were introduced into the model. Another aspect that should be relevant when an added print has to blend in is whether the added print contains colours that are similar to or different from the background colour. Differences in colour reproduction would probably be easier to discern if similar colours were used in both techniques.

Moreover, there should be an observable difference if the added print is placed on a light or a dark background. If printing was done on dark backgrounds, the covering ability of the ink would be more crucial than if light backgrounds were used. Hence, it would be important to have a measure of the ink covering ability and the colour reproduction of the added print.

To provide matching colours from both technologies, it may not be satisfactory to obtain measurements of the colour gamut of the different technologies separately when applied on a blank substrate. An ICC profile, based on a standard colour chart printed onto a pre-printed background, might be useful for producing correct colours when printing is made onto such backgrounds. However, if an added print is to fit into a pre-printed background, it is probably important that the added print has the same shading effects (depending on lighting, shadows etc.) and this could present a challenge.

When added print is placed onto unprinted areas, it should make a difference as to whether the added print has been placed either directly bordering or not directly bordering the background print. Misfit concerns would be crucial (and instantly noticeable) if an added element is to fit into a cut-out area in the background as compared to if the added element is to be printed in the middle of a white, unprinted panel. Speed is probably a vital factor, when it comes to misfit and registration.

When the aim is to have the added print standing out, it is possible to take advantage of the differences in print quality between the two techniques. It might be practical to adjust parameters, such as print gloss, density and sharpness. In this particular case, issues of colour matching should not be as crucial as with the case where blend in is aimed at. This area, however, is not meant to be covered by the research carried out in this project. A few concluding remarks on this matter appear in the chapter on discussion.

Limitations

In this investigation only one substrate, one inkjet press and one flexography press were used. Only two types of motifs were used for the visual evaluation. Therefore, no conclusions regarding the general outcome of the print quality obtained with a hybrid print can be made. The investigation, however, has given a good overview of the relevant issues that will be of interest for further research. To be able to draw more general conclusions, more substrates, inks and presses, together with more combinations of pre-printed backgrounds and added print need to be evaluated.

Material and methods

Substrate and printing presses

Water-based flexography was the chosen conventional technology and water-based inkjet was the chosen digital printing technology. Since both inks are water-based, it is likely that the added inkjet print would perform better on the pre-printed substrate than if the inks were based on different solvents. No detailed investigation of the chemistry was made however. The flexography press used was a Comexi FJ 2108. The high-speed inkjet four colour (CMYK) press used was based on the Scitex Versamark 9" continuous binary inkjet printer heads. The printer heads had a resolution of 300 dpi and a minimum droplet size of 44 pl.

It is a challenge to find suitable substrates for a hybrid printing trial, since their characteristics need to fit with both of the printing technologies included in this project. Flexography printing is known to give good printing results on a wide variety of substrates, while inkjet technology can be more sensitive to the characteristics of the substrates. For example, plastic substrates, which work well in flexography printing, can be difficult to print with water-based inkjet and can result in smearing effects. On the other hand, inkjet will give a better ink coverage on rough or non-planar surfaces such as corrugated board. For this project, however, a substrate that has proved to give good printing results with inkjet was chosen. Thereafter, it was tested in the flexography press. The chosen substrate, Jet Set Color, is an uncoated paper, suitable for high speed inkjet printing and it was the substrate that was preferred by the inkjet printing house. The paper characteristics are presented in table 1.

Table 1. Paper characteristics.

	Grammage [g/m²]	**Surface roughness Bendtsen [ml/min]**	**ISO Brightness [%]**	**CIE Whiteness**	**Gloss 75º CD/MD [%]**
Jet Set Color	90	129	99,5	156	4,6/4,8

Test forms

Three test forms were created, viz. one flexography test form, one inkjet test form and one hybrid test form. All test forms consisted of images for visual evaluation and test charts for technical measurements.

The flexography test form included colour patches for print gloss, print mottle, sharpness (black line on a printed yellow area), grey balance, density and colour gamut measurements. The test form also comprised two images, viz. a photographic image of a *lorry* with a light grey toned loading body and a graphical image of a *food packaging* with an unprinted white panel area and a small cut-out area.

The inkjet test form contained the same elements as the flexography test form. To measure sharpness, an additional line was added (black line on a white paper background). The test form also consisted of a lorry image and packaging image, together with an altered version of the lorry image. In this altered lorry image, the blue sky was transformed to only include cyan.

The test chart on the hybrid test form included colour patches for obtaining technical measurements of hybrid prints (inkjet on a pre-printed flexography background), viz. hybrid print gloss, hybrid print mottle and hybrid sharpness. The test chart also contained colour patches, which could be used to measure the covering ability of inkjet inks. Furthermore, the test form contained graphical elements, which were mounted at coordinates corresponding to the white panel on the packaging image and even at other positions on the image. In the same way, different logotypes were mounted onto the loading body of the lorry image. Some of the logotypes were used twice but, in the pre-press, they were given different colour intensities (referred to as full and slightly reduced colour intensities), which led to different densities on the printed samples.

Each of the test documents was created in Adobe InDesign CS. ICC profiles were added to the image objects using Adobe Photoshop CS. Consequently, ICC profiles were applied on the images and not on the InDesign document as a whole. PDF-files with high resolutions, based on the InDesign documents, were created.

During the period between a first preparatory flexography printing trial (done to obtain data for creating an ICC-profile) and the actual flexography printing trial, there were some changes made to the ink pigments. These changes of pigment led to a better ink coverage. This kind of adjustment leads to uncertainties of whether colours would be entirely correctly reproduced, but in this case the colour gamut volume was found to be similar and based on visual inspections, the colour reproduction was considered to be good.

Printing trials

To evaluate the pure flexography print quality factors, as well as to create the pre-printed background for the hybrid printing trial, a flexography printing trial was carried out. The flexography test form was printed on the selected substrate, i.e. Jet Set Color, using the 34 lines/cm screen frequency and the 180 lines/cm anilox. The printing trial was executed at a speed of 150m/min.

To evaluate pure inkjet print quality factors, two printing trials were performed. Two different ink levels were tested, viz. LUT12 and LUT10. LUT 12 was the default ink level used at the printing house, while LUT 10 gives slightly less ink, i.e. fewer droplets. In these trials, the corresponding test document was printed onto the Jet Set Color substrate. For LUT 12, two different speeds were evaluated, viz. 8 m/min and 120 m/min.

The flexography printing trials were carried out at Walki Wisa Converflex AB and the inkjet printing trial and the hybrid printing trial was done at Posten ePP in Sweden. The samples were encoded according to table 2.

Table 2. Sample encoding.

Sample	Technique	Speed [m/min]	Ink level
F1	Flexography	150	
IJ1	Inkjet	120	LUT 12
IJ2	Inkjet	8	LUT12
IJ3	Inkjet	100	LUT 10
F1/IJ1	Inkjet on flexography	150/120	LUT 12
F1/IJ2	Inkjet on flexography	150/8	LUT 12

Technical evaluation

Traditional print quality factors

To obtain the colour gamut, colour patches representing the colour gamut surface were measured with a GretagMcBeth SpectroScan spectrophotometer. The measurements were done using D50, a standard illuminant, at an observer angle of 2° and using a neutral filter. The CIELAB values obtained were processed in a Microsoft Excel® routine, which calculated and visualised the colour gamut area and volume.

The spectral values of the full-tone cyan, full-tone magenta, full-tone yellow and the CMY black patch were obtained using a SpectroScan. The measurements were taken using D50, a standard illuminant, at an observer angle of 2° and using a neutral filter. The density value was obtained, according to ISO 5-3:1995 and ISO 5-4:1995. The density was specified for the whole spectral range and for the maximal density.

Sharpness and print mottle were measured using a Matlab® image analysis routine. The test areas were scanned using an Epson Expression 10 000XL, a desktop scanner. Sharpness was measured on two areas, one vertically printed and one horizontally printed black line (0.8 mm wide) on a yellow background. For each test area, two metrics were calculated, viz. raggedness and blurriness. Hence, four sharpness metrics were produced, referred to as vertical raggedness, vertical blurriness, horizontal raggedness and horizontal blurriness. Raggedness was defined according to ISO 13660 (2001), i.e. as the standard deviation of the distance from a calculated ideal smooth edge. Blurriness was calculated as the mean width of the edge zone. The edge zone is the part of the image with reflectance in the range of ⅓ to ⅔ of the total reflectance range from print to background. For the inkjet samples, two additional areas were measured. They were one vertically printed and one horizontally printed black line (0.8 mm wide) on an unprinted background. From these two areas, the metrics of raggedness and blurriness were obtained. Print mottle was measured from three areas, viz. full-tone black, full-tone cyan and full-tone green. Mottle values were obtained using a multi scale analysis of the lightness in the measurement area. The digital image obtained was scaled two dimensionally and mottle analysis was performed on each scaled image. Scaling works as a low pass filter, giving the mottle value for different frequencies by analysing the difference between the differently scaled images.

Print gloss measurements were performed using a Zehntner glossmeter ZLR 1050M. Measurements were done on a full-tone black area and on a full-tone green area at an angle of 75º, according to TAPPI T 480.

The CIELAB values for 25 CMY grey patches, ranging from black to white, were measured using a GretagMcBeth SpectroScan spectrophotometer. The measurements were taken using D50, a standard illuminant, at an observer angle of 2° and using a neutral filter. The grey balance was visualized by plotting a* versus L* and b*versus L* for these patches. Hence, the difference from relative neutral grey (a*=b*=0) was illustrated.

Hybrid print quality factors

Sharpness of the hybrid printed sample was measured in an area with an inkjet printed black line (0.8 mm wide) on a flexography printed yellow background. The measurement was performed in the same way as for the traditional sharpness measurements of raggedness and blurriness. Print mottle was measured using four hybrid printed areas, viz. full-tone inkjet key black printed on a flexography printed full-tone key black and a full-tone green area, as well as full-tone inkjet green printed on a flexography printed full-tone key black and a full-tone green area. The measurements were carried out in the same way as for the traditional print mottle and print gloss measurements, respectively.

The CIELAB values for inkjet patches of red, green, blue, cyan, magenta, yellow and black, when printed on a flexography printed full-tone cyan area, full-tone green area, full-tone black area and grey area (40%) were measured using the GretagMcBeth SpectroScan. The CIELAB values obtained were then compared to the CIELAB values for the same patches, when printed on an unprinted area, to illustrate the covering ability of inkjet ink, as well as the inkjet colour reproduction, when printed on pre-printed flexography areas. Comparisons were done by calculating the colour difference between the two sets of CIELAB values, according to;

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

Visual assessments

Three visual assessments were done to evaluate how observers perceive images produced by the use of two different printing technologies. The prints were mounted onto cardboard and cropped without any visible frames. The samples were presented to a panel of observers in a standard daylight viewing illumination of D50.

Visual assessment 1

Category scaling was the method used in the first assessment. This method is suitable when the prints are easy to mix up and when the effort from the panellist should not be too demanding (Engeldrum, 2000). In the assessments, four samples of the packaging image and seventeen samples of the lorry image were used. Each sample contained one or two elements added by inkjet.

The parameters investigated concerned the accordance between the added inkjet print and the flexography background, when it comes to *overall print quality, saturation, print mottle*, *print gloss* and *sharpness*. An additional parameter, *proportion/position***,** was included, in order to conclude whether a bad positioning or the size of the added print affected the impression of the general print quality. The observers gave each sample a score between one and seven for each parameter. A score of 7 means very good and 1 means very bad. The study was carried out by 15 observers, each one previously experienced with making visual assessments of print quality.

Visual assessment 2

In the second assessment, category scaling (Engeldrum, 2000) was also used. However, here a reference image was included, i.e. the flexography printed *lorry image*. The reference sample was compared to two inkjet printed *lorry image*s (the original and the adjusted image). The idea of this direct comparison was to make it easier to see any dissimilarities among the different printing technologies.

The parameters investigated were *overall print quality*, *saturation, hue, print mottle*, *print gloss* and *sharpness*. The assessment was done by 14 observers, each one previously experienced with making visual assessments of print quality.

Visual assessment 3

In the third assessment, 13 observers, having no previous experience with the visual evaluation of print quality, gave their opinion about whether they could see if two printing technologies were used or not. The same samples were used, as in the first visual assessment. The observers viewed each sample for 5 seconds and, thereafter, gave their answers.

Each observer was also asked to say what their judgment had been based on. Further, they were asked to give their opinion, using the terms, *very easy, easy,* *difficult* or *very difficult,* about the difficulty level in deciding whether two technologies had been used or not.

Results

Technical measurements

Inkjet had a slightly larger colour gamut volume then flexography. However, the techniques covered different parts of the CIELAB space (see figure 3). Inkjet was able to reproduce more colours in the light green area, whereas flexography reproduced more colours in the dark red-yellow area.

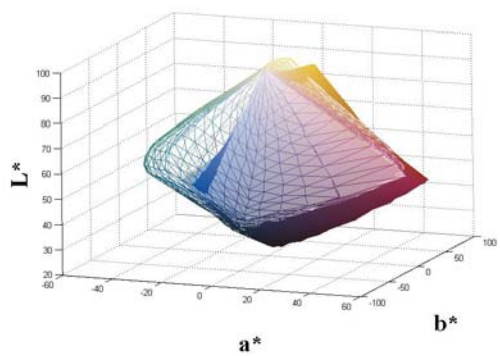

Figure 3. Colour gamut volumes for F1 (solid) and IJ1 (grid).

Similar results for inkjet and flexography were found in vertical sharpness. However, horizontally, IJ1 had a much larger raggedness and blurriness values than the other samples. The biggest difference in print mottle was seen in key black, where the flexography print had a significantly higher value. Furthermore, sample IJ3 had a noticeably higher mottle value than the other inkjet samples (IJ1 and IJ2). No significant difference was found between the samples for print gloss level or grey balance.

The results from the sharpness measurements are presented in figure 4.

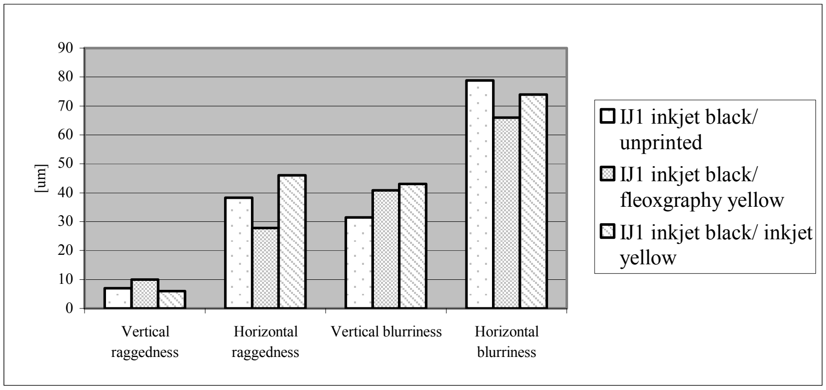

Figure 4. Results from the sharpness measurements.

The hybrid sharpness, inkjet black on flexography yellow, differed from the traditional sharpness measurements, viz. inkjet printed on an inkjet printed yellow area and inkjet printed on an unprinted area.

When inkjet key black was printed on flexography cyan, black and green, the print mottle increased, when compared to the print mottle obtained when inkjet key black was printed on an unprinted area. Compared to the print mottle of the pure flexography areas, the hybrid print mottle was higher for inkjet black on flexography cyan and inkjet black on flexography green, whereas it was lower for inkjet black on flexography black.

The print gloss measured on the hybrid printed areas did not differ significantly from the gloss measured on the flexography and inkjet samples.

The inkjet inks used in this investigation were intended to be used on a white background and were, therefore, of a transparent type. As a result, the covering ability of inkjet ink printed on flexography was generally poor. Most colours, except key black, gave very large ΔE values (>10), when printed on flexography cyan, black, grey and green. Hence, the colour reproduction of inkjet, when printed on pre-printed flexography areas, was poor.

Visual assessments

The results from visual assessment 1 are presented in table 3, as the mean score of the evaluated quality factors. Mean scores were calculated for:

- the two types of images; *packaging* and *lorry* images (4 packaging images , 17 lorry images)
- the two types of added print on the lorry images; *logotype* and *logotype and side of the lorry* (14 images with logotypes and three images with logotypes and side of the lorry).

- the two speeds used when printing the added inkjet print onto the lorry image; *8m/min*. and *120m/min* (4 lorry images).
- the two types of pre-press handling of the added print; *full colour* intensity and *slightly reduced colour* intensity (two lorry images).
- the two types of added print on the packaging images; added print containing *similar* or *different* colours to some of the colours in the background (4 packaging images).

Table 3. Mean scores of visual assessment 1.

	Image type		**Added print** (lorry)		**Speed** (lorry)		**Colour intensity** (lorry)		**Printed colours** (packaging)	
	Packaging	**Lorry**	**Logotype**	**Logotype & side**	**8m/min**	**120m/min**	**Full**	**Reduced**	**Different**	**Similar**
Saturation	4.33	5.30	5.60	3.91	5.77	5.57	5.20	5.83	5.47	3.20
Print gloss	5.80	5.97	6.02	5.73	6.18	5.98	5.90	6.00	6.17	5.43
Sharpness	4.55	5.06	5.23	4.24	5.38	5.08	4.87	5.63	4.90	4.20
Print mottle	4.93	5.26	5.47	4.29	5.58	5.32	5.20	5.70	5.53	4.30
Proportion/ Position	4.98	5.20	5.47	3.96	5.42	5.22	5.80	5.70	5.50	4.47
Overall	4.70	5.04	5.45	3.16	5.48	5.18	5.47	5.97	5.03	4.37

Both types of images (lorry and packaging) showed the best accordance between the added inkjet print and the flexography background in print gloss. The biggest difference between the two types of images was seen in saturation, where the lorry samples had higher scores.

Among the lorry samples, the accordance was judged as better for the samples where only the logotype was printed with inkjet. The accordance tended to be slightly better when a lower speed was used, especially in sharpness. The overall accordance for the lorry samples with reduced colour intensity was higher than for the full colour samples.

When graphical elements, containing similar colours to some of the colours in the background, were added to the packaging image, the accordance was worse than when elements with different colours were added.

The packaging image was also used for printing elements into a cut-out area. At the higher speed (120m/min), miss registration occurred, revealing the unprinted white area. The score in proportion/position decreased from 5.40 to 3.53 and the overall score decreased from 4.73 to 4.00.

The accordance scores from visual assessment 2, where two inkjet samples were compared with a reference flexography printed sample, were found to be noticeably lower than the accordance score obtained in visual assessment 1, where the observers compared the added print with the pre-printed background.

Visual assessment 3 showed (see table 4) that the added logos onto the lorry image blended in very well compared to the images, where also the loading body of the lorry were printed by inkjet. The majority of the observers thought that the lorry images with the added logotype were printed using one technique only. Very few observers thought that the samples, with the logotype and the side of the lorry added by inkjet, were printed using only one technique. About half of the observers thought that the packaging image was printed using only one technique. In table 4, the results are presented for the three categories of samples (lorry/logotype, lorry/logotype/side, and packaging), showing the percentages of the observers that believed only one technique had been used (including all the images in the category). In the second column, values are adjusted if observers made a comment that things in the image, other than the added print, were disturbing. The last two columns represent the adjusted figures, calculated when the observers answered that they thought that two technologies had been used, but that they found it either difficult or very difficult to state this.

Table 4. Mean percentages of samples considered as printed using only one technique.

Type of image	Values	Adjusted values	Excl. very difficult	Excl. very difficult + difficult
Lorry/logotype	0.60	0.66	0.72	0.82
Lorry/logotype/ side	0.15	0.15	0.21	0.31
Packaging	0.40	0.46	0.48	0.63

Moreover, the results showed that for the same added logotype, a higher speed gave such an impression to the observers that more of them thought that two techniques had been used. Changing the colour intensity of the added print had an effect on the visual appraisal. For one logotype, more observers thought that the reduced version had been printed with one technique, whereas for the other logotype, more observers thought that the full intensity version had been printed with one technique.

Discussion

Different printing technologies will give different print quality even though the same substrate is used (Eidenvall et al., 2000). Differences in print quality factors will give rise to different appraisals of the prints. Depending on the techniques used, different print quality factors will be of importance, more or less. This project highlights factors that were shown to be relevant for hybrid printing and which are discussed in detail below. However, more research will be needed to investigate the correlation between the technical measurements and the visual assessments of hybrid printed matter.

Technical measurements

The two printing technologies gave different results in many print quality factors. Differences were also noted among the different inkjet samples. The differences in vertical and horizontal sharpness measurements among the inkjet samples indicated that the web was vertically stable and that the droplets were deformed when the speed was increased. Therefore, the inkjet sharpness will be affected by the choice of printing direction, which, in turn, might influence the choice of layout.

In key black, the inkjet samples had significantly less print mottle, whereas flexography samples had less print mottle in cyan and green. This indicated that it is important to measure print mottle in the colour/colours that are to be used. The grey balance was very similar for the two techniques, which implied that no colour shifts appeared revealing that two techniques were used. The print gloss was so low that it could hardly be seen. Hence, print gloss did not affect the accordance between the two techniques at all. However, for other paper/ink combinations, the print gloss might be of importance and, therefore, it can not be overlooked in all types of hybrid printing trials.

Hybrid printed samples

When inkjet was printed onto the flexography pre-printed substrate, the outcome of the technical quality measurements of sharpness and print mottle differed, not unexpectedly, from the traditional measurements of inkjet sharpness. The flexography print seemed to have an effect on the inkjet ink setting, which, in turn, influenced sharpness and print mottle**.** This indicated that these measurements were important to include in the print quality model.

In general, there was an improvement in sharpness, when inkjet was printed onto flexography, compared to measurements for the inkjet black on the inkjet yellow. Horizontally, the hybrid sharpness was better, compared to the measurement for inkjet black on an unprinted area. Since the area of measurement in this case consisted of an already dry flexography area, where a black inkjet line was printed, no feathering occurred (which might occur in the other case, when the two adjacent colours were inkjet printed at the same time). This indicated that a better sharpness of the inkjet print can be achieved with the use of hybrid printing. The poor ink covering ability of the inkjet print made the colour of the flexography print shine through.

For the setup used here, there were no noticeable differences in print gloss. When inkjet was printed on top of a flexography area, the print gloss remained at the same low values as for the flexography printed area. Although print gloss was not of any great importance in this printing trial, print gloss could very well be an important measurement if other printing techniques, substrates or inks are used.

Inkjet ink covering ability and colour reproduction

The ink covering ability of the inkjet ink used in this investigation was poor. This led to insufficient colour reproduction on dark (full tone) flexography printed backgrounds. The colour reproduction improved significantly, when inkjet was printed on top of a lighter flexography printed area (40% key black). Hence, a good ink covering ability would be preferred if the added print is to be placed on a dark background, whereas the inkjet ink covering ability will not be as critical on a light background. Furthermore, a poor ink covering ability could be an advantage when the added print is printed on top of a light background, since it allows the inkjet printed element to blend in with the pre-printed flexography image. This was clearly seen in the lorry image, where the logotypes blended in very well with the shaded side of the lorry. Due to the poor ink covering ability, the added logotypes were given a touch of these shading effects, meaning that the shading of the background (and at a closer look even the flexography raster cells) could be seen through the added print. This can explain why nothing was appraised as standing out from these images. These samples were given high scores in visual assessment 1 and the majority of the observers in visual assessment 2 could not see that two printing techniques had been used.

The samples, where both the shading and the logo were printed by inkjet onto the lorry image, got low scores. On these samples, the shading effect did not appear very well on the logotype. Hence, if a separate logotype is to be integrated into another image, it would likely be easier to get a natural look if it is added through hybrid printing.

Colour gamut and density

Although the colour gamut volumes for both techniques were similar, they did not completely overlap. Inkjet reproduced more colours in the light green area, whereas flexography reproduced more colours in the dark red-yellow area. Some of the samples used in the visual assessments included two similar red elements, i.e. one printed with inkjet and the other one with flexography. These samples were seen as having a worse accordance in print quality when compared to the samples having no similar colours and printed using the two techniques. Hence, differences in the shape and the size of the different colour gamuts might lead to lower print quality, when the same colours are to be reproduced and the aim of the added print is to blend in with the background. However, if the differences are known, the range of reproducible colour or the colours used could be adjusted in the pre-press stage. Even if the same colours were not to be reproduced, density was still thought to be important. Well-matching colour density tended to improve the correlation of perception of the overall print quality.

For the samples having logotypes that appeared as having a higher colour intensity than the background, the logotypes were more or less perceived as projecting from the images. A typical comment from several observers was that the logotypes were noticed first when their colour intensity was higher. This effect could be useful for creating attention-grabbing elements.

The accordance of saturation seemed to be higher when a logotype was printed onto the lorry image, compared to when the original and adjusted inkjet samples were compared to the reference flexography image in visual assessment 2. The accordance of sharpness and print mottle seemed to be better when the logos were printed onto the lorry. An explanation for this, which was expected beforehand, is that it would be easier to compare different print quality factors when the samples to be compared contain the same objects. It could be of interest for future research to test whether the difference in perception of hybrid printed images depends on the size of the added print. Is it easier to get inkjet printed details to fit into a pre-printed background image, compared to adding larger pictorial elements?

Registration, pre-press and positioning

The visual assessment confirmed that a misfit occurring on a cut-out is a bad prerequisite for the added print to blend in. Hence, when the added element directly borders an element in the background, registration is critical. It seems that it is easier to make hybrid printed images look natural if elements are added onto an unprinted[1] or lightly printed panel space, given that the inkjet ink covering ability is adequate. In other words, the tolerance for having misfit would be higher in these cases. Hence, in the quality model, it is important to distinguish between pre-printed and un-printed areas and, among the unprinted areas, between having the added element bordering or not directly bordering the background elements.

According to the technical measurements, speed influenced the inkjet sharpness. A tendency to impaired sharpness with an increased speed could be seen in the visual assessments. Miss-registration also became a problem when speed was increased. This was noticed when the added print was meant to fit into a cut-out. However, for the other samples, no major differences due to an increase in speed were noticed in the visual assessments. Hence, it seems that it would be possible to print at high speeds without any major disturbances in print quality, as long as the added print does not have to fit into a cut-out.

Conclusions

It has been possible to confirm the relevance of most aspects of the suggested print quality model, meaning that factors in the model have been identified as influencing print quality. Even though the model was created for colour hybrid printing, it could also be applied when only one key colour is used for the added print. More research is needed to make an adequate validation of the model and to be able to state that the results are valid for other kinds of printing equipment and ink. In order to properly define the relation between the technical print quality measurements and the visual appraisals additional studies need to be performed. More research should also be conducted involving hybrid printing on dark backgrounds and how to make the added print stand out.

[1] Unprinted area – although the area does not contain any ink from the first printing technology, it has still gone through the press and the paper characteristics might, therefore, have been slightly altered.

This study shows that it is possible to create hybrid printed images, where the observer cannot perceive that two different printing techniques have been used. The print quality achieved differed between the two technologies and this difference must be taken into account. However, by adjusting parameters such as speed, density, colour matching etc., the print quality of a single technique can be slightly altered. Hence, the accordance in print quality between the two printing techniques could be adjusted so as to have the added print blend in or stand out better from the pre-printed background.

The sharpness and print mottle measurements of the hybrid printed samples differed from the measurements of inkjet and flexography, made individually. Hence, these specific hybrid measures are relevant to consider when the added print is to be printed on top of a pre-printed area. For the techniques and inks used in this project, there was no noticeable difference in print gloss. Using other printing techniques, print gloss could very well be a critical measurement.

When the added inkjet print is printed onto a pre-printed dark background, a high covering ability of the inkjet ink is required and a correct colour reproduction will otherwise be difficult to achieve. When the inkjet print is added onto a light background, a poorer ink covering ability might be an advantage, since tonings, shadows etc. will be visible through the print, causing the added print to blend in, to a greater extent.

When similar colours are to be printed, it is essential that the colour gamuts of the two techniques overlap, so that the same colours can be reproduced. If no similar colour is to be printed, a gamut overlap is not needed, yet colour density will be of importance.

Good registration and positioning are of great importance for the overall impression when the added print is a cut-out or when it directly borders a pre-printed background object. If the inkjet covering ability is acceptable, it might be easier to make hybrid printed images look natural if the added elements are printed to a pre-printed area or unprinted area, not directly bordering any background elements.

A higher colour density in the added inkjet print can lead to a visual impression that the added print stands out from the rest of the image. This could be used to advantage if the aim of the added print is for it to stand out.

This print quality model demonstrates challenges arising from the setup of a hybrid printing production, which are important to give consideration to in pre-press work. Depending on the layout specifications, hybrid printing is more or less challenging with regard to achieving the best possible perceived print quality. Taking a less challenging path in the quality model, it is easier to assure good print quality without making extensive technical and visual assessments.

Summary of the conclusions:

- It was quite possible to have an added print blend in into a pre-printed background.
- The choice of whether to print on unprinted or pre-printed areas affects print quality and the technical measurements that need to be done.
- Inkjet ink covering ability seems to be an important parameter to consider.
- The choice of background colour influences the print quality (light vs. dark background).
- The choice of colour tends to influence print quality (similar or different colours for the background and added print).
- Registration and positioning of the added print are critical when the added print is put into a cut-out area or directly bordering a pre-printed area (speed influences).
- Elements can be perceived as standing out, depending on the density levels used.

Future research

It would be interesting to carry out a closer investigation into how printing onto a dark background should be done to make the print blend in with the backgrounds. Another aspect is to further investigate how attention-grabbing effects can be created, i.e. how to make an observer focus on a special specific spot of the image (specific message) and yet retain a natural looking image?

Furthermore, it would be interesting to investigate how the ink covering ability of different inks could affect how an observer perceives hybrid printed matter. It could also be interesting to make visual assessments of print quality, when ICC profiles, adapted to background colours, are used.

Pre-press work is highly critical for good results. One problem is that, when an image is adapted for flexography, it is not necessarily adapted for inkjet if the colours are to be matched. There might be a need for developing pre-press software to facilitate the necessary preparations required for hybrid printing production. Finally, registration issues at high printing speeds are also an interesting area for future research.

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