Gloss and gloss variations in electrophotographic print

Glans och glansvariationer i elektrofotografiskt tryck

Mikael Hansson

2007

EXAMENSARBETE

Grafisk Teknologi
Nr: E 3533 GT

HÖGSKOLAN
Dalarna

EXAMENSARBETE, C-nivå
Grafisk Teknologi

Program Grafisk Teknologi, 120p	Reg nr E 3533GT	Omfattning 10 poäng
Namn Mikael Hansson	Månad/År 8-07	
	Examinator Veronica Näslund	
Företag M-real	Handledare vid företaget/institutionen Elisabeth Alfthan	
Titel Glans och glansvariationer i elektrofotografiskt tryck		
Nyckelord Glans, elektrofotografi, glansvariation, kemisk toner, mald toner, digitaltryck, fixering, silikonolja		

Sammanfattning

Examensarbetet utfördes på M-real Technology Centre i Örnsköldsvik. Syftet var att undersöka olikheter i glans och glansvariationer mellan kemisk och mald toner på olika papperskvaliteter i elektrofotografiskt tryck. Glans är en egenskap som ger intrycket av hög kvalitet hos en produkt. Därför är det viktigt att erhålla hög glans i kommersiellt tryck.

En testkarta trycktes på tre olika obestrukna papperskvaliteter i tre olika skrivare. Därefter mättes glans, glansvariationer, tryckytans ytstruktur, mottling och densitet. Även en visuell bedömning utfördes. Utifrån erhållen data från de olika mätningarna gjordes en multivariatanalys för att finna samband mellan de olika variationerna.

Resultaten visade att papperskvaliteter med hög ytråhet gav större variationer i yttopografin och större glansvariationer (både uppmätt och visuellt) i tryck. Ett ytråare papper gav också mer mottling i tryck. Mald toner gav mer mottling och variationer i yttopografin. Detta ökade med mängden silikon som användes.

HÖGSKOLAN
Dalarna

DEGREE PROJECT
Graphic Arts Technology

Programme Graphic Art Technology, 120p	Reg number E 3533GT	Exents 15 ECTS
Names Mikael Hansson	Year-Month-Day 2007-08-16	
	Examiner Veronica Näslund	
Company/Department M-real	Supervisor at the Company/Department Elisabeth Alfthan	
Title Gloss and gloss variations in electrophotographic print		
Keywords Gloss, electrophotigraphy, gloss variation, chemical toner, ground toner, digital print, fuser, silicone oil		

Summary

This degree project was performed at M-real Technology Centre in Örnsköldsvik. The perpose was to investigate the differences in gloss and gloss variations between chemical and ground toner and different paper grades in electrophotographic prints. Gloss is a property that gives the impression of a higher quality of a product. Therefore it is of great importance to accomplish high gloss in advertising print.

A test chart was printed on three different uncoated paper grades on three different printers. Thereafter, gloss, gloss variation, surface topography, print mottle and density were measured. A visual evalution was also performed. A multivariate analysis was acheived of the data in order to find correlations between the measured variations.

The results showed that paper grades with large surface roughness gave more variations in surface topography and gloss variations (both visual and measured) in print. A rough surface also gave more print mottle. Ground toner gave more surface topography variations and mottle which increased with the amount of silicone used.

Högskolan Dalarna
781 88 Borlänge
Röda vägen 3
Telefon: 023-77 80 00

Telefax: 023-77 80 50
URL: http://www.du.se/

Table of contents

Appendix

Appeldix A-all data from measured gloss variation in cross machine direction with GIA
Appendix B-gathered data of Perceived gloss variations
Appendix C- all data of surface topography measurements
Appendix D- Mottle measurements

1. Introduction

Gloss is a property that gives the impression of a higher quality of a product. Therefore it is of great importance to accomplish high gloss in advertising print. Gloss also gives higher colour saturation and lustre in print. However, gloss can be a disturbance when a picture or text is viewed in the specular angle of the incident light.

The purpose of this investigation was to evaluate gloss and gloss variations in electrophotographic print, i.e.

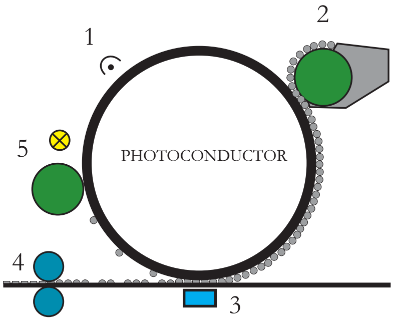
- to investigate correlation between measured and perceived gloss variations
- to investigate effect of toner type and addition of silicone in fusing on gloss and gloss variation
- to investigate effect of paper roughness on gloss and gloss variation

2. Theory

2.1. Electrophotography

The electrophotographic printing method is based on five steps:

1. Imaging
2. Inking
3. Toner transfer
4. Toner fixing
5. Cleaning



Figur 1. The image shows an overwiew of the electrophotographic process.

1. Imaging
The image carrier often consists of an aluminium drum or a flexible belt with a photoconductive coating. In the first step the photoconductive drum is homogenously charged with a corona. Then laser light or a LED array discharges the photoconductive drum either on the printing or the nonprinting areas. [1]

2. Inking
The latent image is then exposed to toner. The toner is attracted to the areas where the charge is lowest and is transferred from the toner cassette to the photoconductor. The toner is fixed to the surface by electrical force. [1]

3. Toner transfer
The toner is transferred to the paper by electrical force. The paper is charged with a corona with less negative charge. The toner is attracted to the more positive voltage and is transferred to the paper. The toner is not yet fixed to the surface and can easily be removed. [1]

4. Toner fixing
The toner is fixed to the surface in the fuser with pressure and heat (about 130°C) or with infrared light. The carrier melts when exposed to heat and is partly absorbed by the paper surface. The pressure causes the toner to attach to the surface. [1]

5. Cleaning
When the toner is transferred to the paper some of the toner particles can still remain on the surface as well as the corona charge from the previous image. Therefore the photoconductor has to be cleaned before the next printing cycle. The toner particles are removed with a brush. Then a corona charges the surface of the photoconductor homogeneously again for next printing cycle. [1]

The electrophotographic process is a non impact process (NIP). The image has to be reproduced before each print and therefore it has a greater possibility for uneven process stability. [1]

2.1.1. Fusing unit

When toner particles are transferred to the paper they have to be fixed to the paper surface through fusing and/or pressure. Otherwise they could easily be rubbed off. The fusing process is either performed without contact through radiated heat or by contact to the surface. The heat can cause problems like unintentional changes in the surface structure of the colour image. Fusers that use rollers can cause deformation of the paper sheet. This can lead to transportation problems in the finishing process. The quality of the image surface can be improved and the gloss level controlled by controlling pressure, temperature and how long the toner remains in the fuser nip. [1,2]

When the rollers come into contact with the toner image ink re-splitting occurs. Toner can accidentally be taken up by the rollers, which can cause quality loss in following prints. To prevent toner acceptance the rollers can be treated with silicone oil. This can cause unwanted gloss in printed areas. [1]

2.1.2. Toner

The main constituent for conventional toner (90%) is binder resin (consists of a natural or synthetic polymer material). Its main task is to disperse a colouring agent such as carbon black. The binder resin melts at a temperature of approximately 130°C [2]. Both dry and liquid toners are used. Dry toner particles have a diameter of around 3 to 20 µm. Liquid toners consists of a carrier liquid containing toner particles with a diameter of 1 to 3 µm (gives higher resolution in print and higher area covering). The charged toner particles are extracted from the carrier liquid during the developing process. Fixing units with radiated heat requires that an infrared absorbing agent be added in the toner causing the toner to melt during the exposure. [1,3]

There are two different types of dry toner: single- and two-component toner. Single-component toners can be subdivided into magnetic and non-magnetic toners. Magnetic toners consist of an iron oxide core surrounded by colouring constituents (pigment, binder and additives). The advantage of this type of toner is that there is no need for a blending and circulating system for carrier particles via the magnetic roller (as described below) as such needed for two component-toners. The disadvantage is that the use of an iron oxide core (if a high content of iron oxide is needed) makes printed colours dull. [1]

Two component-toners consist of a carrier particle (for example iron oxide with a diameter of 80 µm) and the toner particle (5 to 20 µm diameter). The toner particle is attached to the carrier by electrical force (see fig 2). In the development unit, the carrier and the toner are blended together and fed through a paddle wheel to the developer rollers (magnetic brushes). The toner particles are attracted to the photoconductor drum due to their electrical charge. The carrier particles are returned to the process. [1]

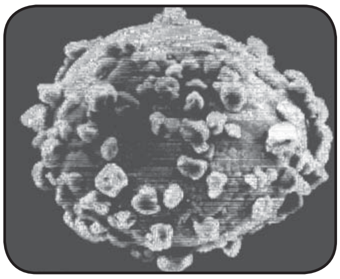


Fig 2. Shows a xerox two component-toner particle with a iron oxide carier.

Ground toner

In the production of conventional toner (ground toner), resin to be the largest component of the toner, is manufactured from monomer material. Together with pigment and an electrostatic charge control agent the resin is melted and mixed until the constituents are evenly dispersed. The resin is then cooled down to become a solid cake. The cake is blown with a high-speed air current into a jet mill. Thereafter unwanted particles are sorted out. The particles are then coated with aerosil (plastic like film for reduction of surface tension) which work as a fluidization agent and the resin is finally processed to be toner. Ground toner particles are larger than chemical toner particles and the form is irregular (see fig 3). [4,5]

A problem is the sorting process. The milling process creates grain of various sizes. Large quantities of particles are either too rough or too fine. In the sorting process 10-30% of the particles manufactured are eliminated. [4,6]

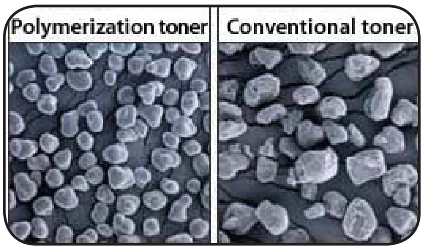


Fig 3. Shows a magnification of chemical and ground toner.

Chemical toner

In the manufacturing of polymerization toner (chemical toner) the resin (monomer oil), pigment and a charge control agent are dispersed into a dispersion medium (water). The constituents are coupled by a chemical reaction and to produce toner particles. The chemical toner particles are uniform and smaller than ground toner particles. Another advantage for this method is the reduction of energy used. Using a chemical toner in print gives enhanced contours and clearer print. [4,6]

As printers become smaller and the printing speed increases, a toner that can be fixed at low energy and endure high temperature is required. To implement this, a resin with an easily fused core needs to be coated with a resin that melts at a higher temperature (encapsulated toner). This is impossible to manufacture with the milling method. [4]

To cope with the development of smaller and faster printers encapsulated toners are required (as described above). Unlike the manufacturing process of conventional toner, such toners can be manufactured with the polymerization process. [4,6]

When a resin with a low softening temperature is exposed to a relatively high temperature, the toner particles coagulate causing reduction of the fluidity in the developing unit. This makes toner transfer to the developing roller difficult, or at worst impossible. A capsule with a high softening temperature is created to prevent coagulating. Encapsulated toner particles can be fixed at a low temperature and are resistant against high temperatures. [4,6]

2.2. Print quality

There are several print features that affect print quality, e.g. gloss and gloss variations, density and mottle. To achieve high quality prints these need to be controlled. All these features are related to toner amount and toner distribution, which depend on toner transfer and fusing. Use of silicon oil in fuser is also influencing the print result. [7,8,9]

2.2.1 Print gloss and gloss variations

Gloss is defined as the specular reflection of a surface, i.e. the ratio of incident light (Ii) and reflected light (Ir) given in percentage.

2.2.2. Print density

Density (D) is defined as the ratio of reflectance from unprinted paper (R_{paper}) and reflectance from printed paper R_{print}. Density is calculated according to following equation:

$$D = \log \frac{R_{paper}}{R_{print}}$$

Density is a dimensionless value, more correctly called optical density or print density (D). [10,16]

2.2.3. Print mottle

Print mottle is one of the most disturbing factors that influence the overall print quality. It is defined as perceived irregularities in the print density due to unintentional reflectance variation that leads to deterioration in quality. These changes in reflection can vary across a wide range of spatial frequencies. [9,11]

2.2.4. Surface roughness

Surface roughness is a measure of a surface unevenness. Surface roughness is divided into micro- and macro surface roughness. The macro roughness can be described as a surface built up by tilted facets. The micro-surface roughness is referred to the small-scale roughness of each one of the facets. They are as small as or smaller than the wavelength of light. [12]

2.3. Theory about gloss

There are different types of electromagnetic radiation, e.g. light, both visual and invisible (IR, UV), radiactive waves and radiowaves with different wavelength interval. [16]

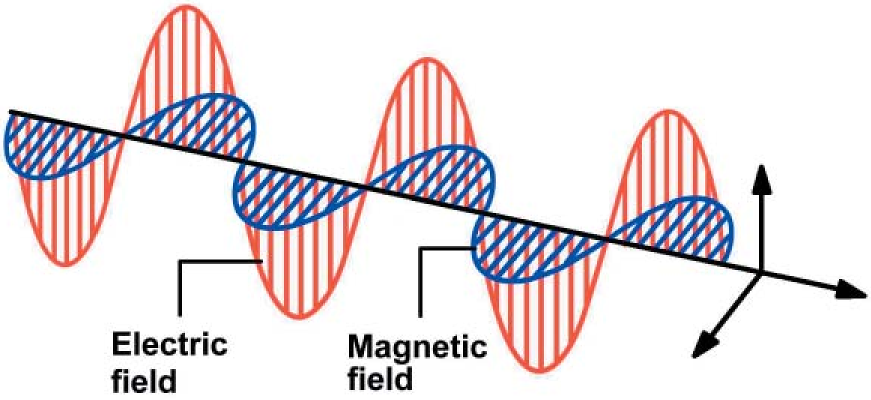


Fig 4. A illustration of light as an electromagnetic wave. The electric and magnetic filed oscillate perpenicular to each other.

The visible light of the spectrum is within the interval of 400 to 700 nm. Light that consists of all wavelengths with the same intensity in the visible spectra is perceived by the human eye as white. [13]

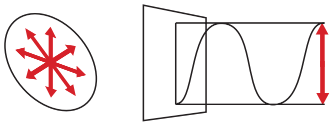


Fig 5. Illustrates upnolarized and polarized light.

Light from the sun and illuminants are unpolarized by means that the waves oscillate randomly in all directions. If all waves in a light beam oscillate in same direction the light is polarized (see fig 5). The two types of polarization that exist are s-polarization and p-polarization. S-polarization is parallel to the surface and p-polarization perpendicular to the surface. Conventional gloss measure instruments use unpolarized light, while new instruments mostly use s-polarized light from laser. [13]

2.3.1. Refractive index

The refractive index n is defined as the relationship between the velocity of light in a material v and the velocity of light in vacuum c. When light penetrates a material with a higher refractive index such as water or glass the velocity decreases. [14,13]

$$n = \frac{c}{v}$$

This leads to a change in direction of the light. The refractive index determines how the light is reflected and refracted [13]. The light penetrates the material according to Snells law:

$$\sin i = n \sin b$$

b is the penetrating angle for the light through the material, *i* is the angle of the incident light and n is the refraction index. [17]

2.3.2. Different light phenomena

There are mainly four different light phenomena that occur when light strikes the paper surface: reflection, refraction diffraction, absorption and transmission.

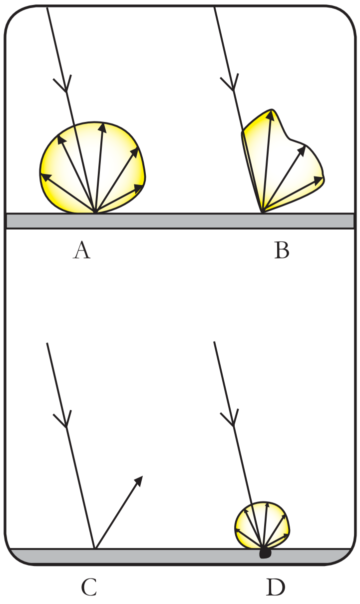
Paper consists of fibres, filler pigment particles and air. When light strikes the surface it is reflected at fibre and pigment surfaces. A part of the light penetrates into the fibres and changes direction, refracts. Some is absorbed by the fibers, while the rest is reflected and refracted again by new fibres. Some light reaches the surface again and is reflected at all different angles as diffuse surface reflection. The viewer perceives such a surface reflection as matt white. A part the incident light is transmitted through the paper and exit on the back side. [13]

Diffraction is a phenomenon that occurs when light meets particles with the same size or smaller than the wavelength of the light. These small particles oscillate with the light oscillation and act as new light sources. A particle with a size smaller than half the wavelength of the light does not affect the light. [13]

A special light scattering called Rayleigh light scattering occur when the paper contains ultra-fine filler particles or small fibril fragments. An example of this is the sky where short-wave blue light is scattered by gas molecules and particles in the atmosphere. In paper this scattering is very weak in relation to the light reflection. [13]

2.3.3. Gloss

Gloss is a property that increase the impression of paper quality. The gloss level of a paper is determined by its ability to reflect incident light. A rough surface reflects the incident light in many directions. This leads to low gloss. To achieve high gloss a smooth surface is needed. It is important to achieve a high gloss level when for example producing an advertising print. In printed areas the gloss gives shine and high colour saturation. That is because high gloss areas give a very low light scattering. Instead the light penetrates the paper surface down to the molecules which give colour. If the surface reflects the light in different directions the specular (mirror like) reflection decreases. A visually evaluated print will appear dull because of the disturbance of the non-coloured surface reflection. [16,13,17,18]



Figur 6. The image shows diffuse, mixed, specular and bulk reflection.

The reflected light consists of:

A. Diffuse reflection
B. Mixed reflection
C. Specular reflection
D. Bulk scattering.

Specular, diffuse and mixed reflection is surface phenomena, while the bulk scattering occurs inside the paper (see fig 6). When gloss is measured only the specular reflection is considered. [13,17,18]

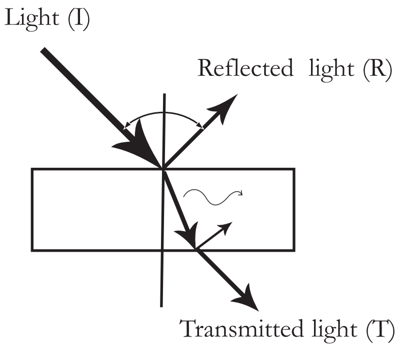
A irregular material has a further type of reflection called light scattering. This occurs due to different effects in the bulk. [16]

Gloss measurements give information about surface roughness [19]. A rough surface scatters the light more than a smooth surface. When the surface roughness increases the specular reflection decreases, while the diffuse reflection increases. [12,13]

When a lightbeam strikes the paper surface, the light is partly reflected (R) at the same angle as the incident light (I). The rest of the light is transmitted (T) into the material and is either refracted and absorbed by the paper or transmitted through the paper (see fig 7). [12,13]

If the light falls perpendicular to the surface the refractive index determines the specular reflection according to Fresnel's equation 1:

$$R = \left(\frac{n - n_0}{n + n_0} \right)^2$$



Figur 7. illustrates how a light beam behaves when hitting a surface.

n is the refractive index for the material (cellulose has a refractive index of 1,5) and n_0 is the refractive index of air (close to 1). In this case the specular reflection is 4%. The remaining light penetrates into the paper. When the angle of the incident light increases the specular reflection increases. [14] R and T are defined by the Fresnel equations:

1. $$R_s = \frac{\cos\theta - \sqrt{n^2 - \sin^2\theta}}{\cos\theta - \sqrt{n^2 - \sin^2\theta}}$$

2. $$R_p = \frac{n^2\cos\theta - \sqrt{n^2 - \sin^2\theta}}{n^2\cos\theta + \sqrt{n^2 - \sin^2\theta}}$$

3. $$T_s = \frac{2\cos\theta}{\cos\theta + \sqrt{n^2 - \sin^2\theta}}$$

4. $$T_p = \frac{2n\cos\theta}{n^2\cos\theta + \sqrt{n^2 - \sin^2\theta}}$$

where θ is the incident angle and n is the refractive index. Equations 1 and 2 are used to describe the s- or p-polarized reflection, while 3 and 4 describe the s- or p-polarized transmission. These equations describe the ratio in amplitude between reflection and transmission. To express the ratio of reflected and transmitted light in percent it has to be transformed to energy (energy is proportional to the square of the amplitude) according to the following formulas:

$$r = R^2 * 100 \qquad \text{(r = reflection in percent)}$$

$$t = 100 - r \qquad \text{(t = transmission in percent)}$$

The Fresnel equations can only be used for perfectly smooth surfaces. [13] Gloss of rough surfaces can be calculated if incident light angle, surface roughness and refractive index are known.

$$\text{Gloss} = 384{,}4 \cdot s(\theta, n) \cdot e^{\left[-\left(\frac{4 \cdot \pi \cdot \text{RMS}\ 2}{\lambda}\right)^2\right]}$$

θ= wavelength of light (0,55 μm is a mean value of white light)
s(θ,n) = Fresnel factor (expresses the reflection of light in well oriented micro-facets) [21]
RMS = stands for Root Mean Square and is calculated according to the formula:

$$\text{RMS} = \sqrt{\sum_{i=1}^{n} \frac{\left(\bar{x} - x_i\right)^2}{n}} \qquad 18$$

2.3.4. Properties that affect gloss

The surface roughness is a major factor in determining the gloss of a material and recent work indicates that even reflections from subsurface interfaces can contribute to gloss [22]. A rough paper surface gives less gloss reflection. It can be visualized as a surface that consists of many small facets that have different inclinations. When measuring this surface the gloss meter gives a low peak. If the surface is smooth the facet surfaces lie more evenly and reflect more light in the same direction which gives a higher peak when measured with a gloss meter. [14]

The reflection of light from a facet with micro roughness will not be concentrated to the specular direction, but appear as dampening of the reflection intensity. The reflection scatters over a larger area and appears as a dampening of the intensity in the specular direction. [12]

Printed paper has different bulk scattering and surface reflection. When light strikes the toner on paper the light that penetrates the surface is filtered and creates the bulk scattering we perceive as colour. Magenta toner absorbs short wavelengths and the long wavelengths emerge from the surface. Cyan toner absorbs long wavelengths and only short wavelengths emerge from the surface. Black toner absorbs all wavelengths and the bulk scattering is low. [12]

2.3.5. Properties that affect gloss variations

Surface roughness is a major factor to determine gloss variations. When the amount of tilted neighbouring facets increases, or if the facet surface gets rougher, gloss variations increases. Gloss variations are dependent of the difference between neighbouring facets. When neighbouring regions appear to have different brightness level we perceive gloss variations. If the neighbouring facets are tilted they appear darker. 12

Print mottle is the result of uneven toner transfer or absorption of the binder into the paper. This can cause gloss variations in printed areas. 22

2.4. Gloss measurement

A gloss meter measures a sample in one or more angles. The light source and the detector are fixed. Two different standard methods for gloss measurements are used: Tappi and DIN. The Tappi method uses converging beam geometry and the DIN method uses collimated beam. According to these methods the measuring angle should be 75°. [23]. The Lehmann gloss meter measures according to the Tappi method in the ISO 8254-1 standard 24. Two different measuring angles can be measured at the same time (45° and 75°). The number of measurements per sample is fed into the device. After measurement the gloss meter calculates mean value, standard deviation, min- and max value. The measure unit is percent (%) reflected gloss, where 100% is total reflection. Other measuring angles are 20°, 60°and 85° according to the BS EN ISO 2813 standard. 20° measuring angle is used for very glossy surfaces. A less glossy surface requires larger measuring angle. 26,27

2.5. Gloss variation measurement

Gloss variation measurement is dependent on aperture angle, light source and optical geometry of the instrument (such as the size of measuring area and illumination area) 13. There is no standard for gloss variation measurements. 28

2.5.1. Goniophotometer

A goniophotometer used for measurement of gloss and micro scale gloss variations. A Xenon lamp illuminates the sample and a line scan camera records the specularly reflected light. The goniophotometer is characterized by the illumination angle and the reflection angle which both are variable. 29,13

The goniophotometer gives a reasonable accuracy for measurements of micro scale gloss and micro scale gloss variations. 29

2.5.2. GIA (Gloss Image Analyzer)

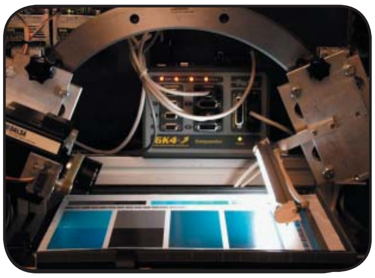


Fig 8. The image shows the GIA measuring device.

A device for measure of gloss variations called GIA (Gloss Image Analyzer) has been developed at M-real and MoRe Research (see fig 8). This is a simplification of the goniophotometer, described above, to the extent that the sample holder is fixed to one angle. The device illuminates the samples with a semi-diffuse light (a screened light source, preventing direct light from reaching the camera) from one of the two fluorescent lamps. They are placed at two different angles: one fluorescent tube at an angle of approximately 65° from the surface normal and the other at an angle of approximately 25° from the surface normal. The 65° illuminant is placed close to the sample, while the other is placed with a greater distance from the sample. The long distance gives uneven illumination and dark edges in the image. 29

The detector is a CCD line-scan camera (made by DALSA) placed in the specular direction from the illuminants. The camera gives pictures of 1x1024 pixels, with 12-bits resolution (i.e. every pixel can take on a value from zero to 4095). To get an image of 1024x1024 pixels the plate is mounted on a step table that moves under the lamp and the camera. The camera continuously takes pictures of the sample surface. The resolution can be changed by changing the distance between the camera and the sample. [29]

Before selecting measurement area it is possible to make a preview of the image. A lamp with more diffuse illumination is used in order to make the localization of the area easier. [29] The aperture setting for the camera has to be selected before the measure. The aperture is driven by a motor and a drive-belt. A value between zero and 250 can be selected (zero is a closed aperture and 250 is fully open). [29] The device has to warm up for 90 minutes to get a stable gloss level. [29]

2.6. Pair comparison evaluation

Pair comparison tests are widely used. A number of samples are judged by a panel consisting of at least 10 to 15 observers. The evaluation shall be performed in a room with neutral surrounding and standardized illumination (D50). The samples should be assembled with a grey frame. Each observer evaluates the samples for maximum one hour. After that the eyes get too exhausted. [30]

The first sample is compared with all the other samples, one by one. If the first sample is better than the other, the sample is given the value 2. If the sample is worse then the other the sample is given the value 0. If the samples compared are alike the sample is given the value 1. The first sample was then compared with the third and so on until all combinations are compared. The values for each sample is summerized. Every sample can get a value between 0 and 200. [30]

2.7. Density measurement

Density is usually measured with a densitometer. The densitometer can not calculate colours. It only measures the darkness of the colour. To measure density in different colours filters are used. Cyan, magenta and yellow are measured with red, green and blue filters. Density value is calculated from the amount of light that is transmitted through the filter. [10]

Density in print can also be calculated using a flat bed scanner. The scanner is calibrated so that measured light is proportional to the reflectance. As neither illumination nor geometry is the same as in a spectrophotometer the calibration is rather complicated [35]. A 16-bits scanner gives a 16-bits TIFF-image. Every pixel can adopt a value of 0-255. The image is converted in Matlab from image-data with using Fourier analysis (Fast Fourier Transform) to a matrix of reflection values. [32]

2.8. Print mottle measurement

Print mottle can be calculated using a flat bed scanner. The data used is the same as the ones used in density measurement before recalculation to density values. The collected data is converted using Fast Fourier Transform; the standard deviation for reflection is calculated and devided by the square root of the mean value of the reflectance to calculate a figure that defines mottle. The variation of reflection is analyzed with spectral analysis. The wavelengths are devided into intervals between 0,25-16 mm. [31]

2.9. Surface roughness and topography measurement

Two techniques used for surface roughness are Bendtsen and PPS (Parker-Print-Surf). These are not suited for the same paper grades. Measurements of surface topography can be performed with a Sture device (see 2.9.2).

2.9.1. Bendtsen and PPS

Bendtsen and PPS are standard methods using air to measure a surface roughness. A measuring head is placed on the paper surface. Air is pressed out between the measuring head and the paper surface. The surface roughness is defined as volume of air leaking out per time unit at a certain air pressure (ml/min). Bendtsen uses a hard measuring head suited for measurements of macro surface roughness. The PPS uses a soft measuring head that adapts to the rough surface and therefore is sensitive to micro surface roughness. PPS is suited for smoother surfaces, mainly coated papers. [32] A problem with these techniques is that air also leaks through the paper. Papers with high porosity will therefore get a higher value. [32]

2.9.2. Sture

The Sture measuring device measures surface topography and consists of an optical distance sensor (based on triangulation technique), a movable table and a computer for control and handling of data. A laser beam scans the sample, is reflected and hits a PSD (Position Sensitive Detector). Where the laser beam hits the PSD is dependent on the on the altitude of the measured spot. To prevent the sample from moving, it is attached with iron bars to the movable table. [32]

The received structure data is recalculated with FFT (Fast Fourier Transform) and expressed as waves with different wavelengths from 0 to 10 mm. (the bandwidth is 0,5 mm). The size of the structure in a certain bandwidth area is given as a variance (mm^2). 32

2.10. Multivariate data analysis

Multivariate data analysis is used when several different variables should be investigated. Structure in datasets with many different variables can be related to similarities or differences between objects (samples, observations experiments etc) and also to quantitative relationships between two blocks of variables, usually called X and Y, for a group of objects. [33,34]

Two techniques that are usually used are Principal Component Analysis (PCA) and Projection to Latent Structures by means of partial Least Squares (PLS). When the PCA and PLS models are calculated the original data is combined into new components. These consist of new variables calculated as weighted sums of the original variables. Components are calculated so that the first component explains as much of the variation as possible. The second component explains as much of the remaining variation as possible. The components are orthogonal to each other meaning that information in one component is unrelated to information in another component. The variable weights are called loadings. PLS uses a special set of loading called weighted loading which takes the correlation of the variability in the X and Y blocks into consideration. Loading can be from -1 to +1 and the value reflects how important the variable is for the separations of objects that can be seen in a corresponding score plot (scores are weighted sums, weighted by the loading values, of the original variables) [33,34]

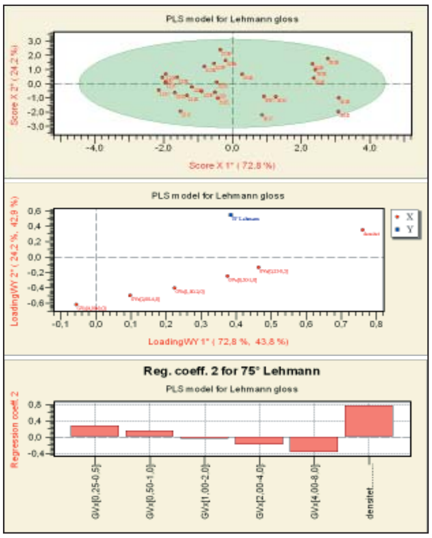


Fig 9. The image shows a score, loading and regression coeffecient plot of a PLS model.

The results are shown in score and loading plots. These are interpreted in pairs. The score diagram shows the measured objects with their new coordinates. The loading diagram shows where each variable is placed in the system for principal coordinates. The variables important for the position of an object in the score plot can be found at the corresponding position in the loading plot. Such variables will have high values for these objects. Variables found in the “opposite” position will have low values for that particular object or group of objects. Variables that are grouped in the loading plot will be positively correlated while variables opposite to each other along a line through the origin will be negatively correlated. For PLS models variables in the X block close to a variable in the Y block signifies a strong (positive) correlation between those x variables and the y variable. [33,34]

The percentages given in the legends along the x and y axes in the diagram denote the variation explained by the component along that axis. For PLS models the first percentage value in the legend in the weighted loading plot (LoadingWY) denotes the variation in the X block explaining the variation in the Y block, the second percentage value. Legends in red denotes significant components. [34]

For PLS models the regression coefficients give information about the contribution of each variable in the calculation of the predicted value. To weight the variables in the X block for their importance for the variation against the Y block often only the first component is useful if there is more than one significant component. For predictions all significant components can however be used. [34]

2.10.1. PCA and PLS Models

The PCA is used to find similarities or differences between objects and to reduce the dimensionality of the data set. The aim is to find new variables from the original variables, which are found in the directions that have the largest amount of variation. These new variables are called principal components. The purpose of the PLS is to find the variation in the X block with data that explains as much as possible of the variation in the Y block with data. [33,34]

3. Material and method

The study focused on uncoated paper grades with varying surface roughness. A test chart was printed on three different paper grades in three different printers. These were measured and analyzed at M-real Technology Centre (TC) in Örnsköldsvik. Different measuring devices were used to measure gloss, gloss variations, density, print mottle, and surface topography. Multivariate analysis of the data received was performed at TC.

3.1. Paper grades

The paper grades used for the study were uncoated fine paper in A4-format (210x297 mm) produced at M-real paper mill in Husum. The composition of fibres was 70% birch and 30% pine and spruce. The paper consisted of approximately 21% PCC (Precipitated Calcium Carbonate) filler and approximately 3 g/m^2 corn starch on the surface. [36] The paper properties were:

Property		Paper		
		A	B	C
Grammage (g/m^2)		80,3	80,2	80,2
Thickness (µm)		104	108	95,8
Bulk (cm^3/g)		1,29	1,35	1,20
Roughness Bendtsen ts (ml/min)		208	125	76
W CIE		146	160	161
Paper gloss CD (Zehntner)	20°	1,40	1,42	1,42
	60°	4,11	4,26	4,50
	75°	5,05	5,87	7,50

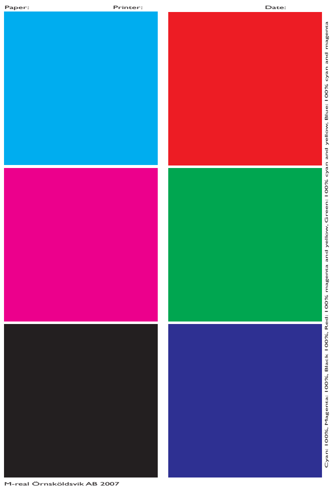


Fig 10. Shows the printed test chart.

3.2. Test chart

A test chart was made in Adobe Indesign CS2 without colour management; no ICC-profile was needed when full tone CMYK data was used. Document format was set to 210x297 mm and the resolution was set to 300 ppi.

Six full tone patches (cyan, magenta, black, red, green and blue) were placed on the test chart (see fig 10). Only cyan, black and blue patch was, however, measured. Two patches (cyan and black) with 100% toner was choosen to see if there were any differences between different colors. One patch (blue) with 200% toner was choosen to see if a higher amount toner gave different results. The size of the patches was 90x90 mm. The GIA measures an area of maximum 72x72 mm^2. The patches were made slightly larger to have margins. Yellow was not used because of measuring difficulties.

The patches were placed with 12 mm distance to the left and right margin. The distance between the patches in the middle was 6 mm, since the test chart had to be cut in two to fit the GIA measuring device. In the margins information about printer, sample and date were placed to recognize the sample after print. The test chart was saved as a PDF with all colour management turned off.

3.3. Test print

The test chart was printed in three different electrophotographic printers; Xerox DocuColor 12, Xerox 3535 and Canon CLC 1150. Xerox 3535 used a chemical manufactured toner with a wax-based binder. The other two printers used ground toner and fixing rollers coated with silicon. The printers used were:

- Xerox DocuColor 12 at M-real TC (Technology Centre at M-real in Örnsköldsvik).
  Room temperature: 21°C
  Humidity: 37% RH.
  Print date: 2007-04-16

- Xerox 3535 at DPC (Digital Printing Centre at Mid Sweden University in Örnsköldsvik).
  Room temperature: 22,6°C
  Humidity: 21,4 % RH.
  Print date: 2007-04-18

- Canon CLC 1150 at Högskolan Dalarna in Borlänge.
  Room temperature: 25,7°C
  Humidity 18,9 % RH.
  Print date: 2007-05-08

Before the test chart was printed, 50 pages with different patches and pictured were printed to warm up the printer. The prints had to be different each time during the warm up. Otherwise build-ups could occur on the photoconductor resulting in ghosting effects in print. [36,37]

For process stability measurements the printer was calibrated with a reference paper. Ten copies of the test chart were printed on this paper. The printer was then calibrated for each paper grade before printing. Ten prints were made of each of the three different paper grades. The prints were packed in black plastic bags to protect them from humidity changes and light.

3.4. Gloss measurements

Gloss and gloss variation measurements were performed at M-real paper mill in Husum and TC in Örnsköldsvik. A Lehmann gloss meter and GIA were used.

3.4.1. Gloss variation measurements with GIA

Before measuring the GIA was warmed up for 60 minutes. Thereafter the reference paper printed on the Xerox DC12 was measured. These measurements were later used to ensure that the GIA was stable. Gloss variations were measured on five papers in cyan, black and blue patches. The aperture was set to 155.

The measurement data received were the variation coefficient of gloss variation in the wavelength frequencies 0.5 to 16 mm. The data was saved as text files and collected in Microsoft Excel. Mean value and standard deviation were calculated.

3.4.2. Gloss measurements with Lehmann

Before measuring the stability was tested by measuring the same area several times. The Lehmann gloss measuring instrument was recently calibrated before the measurement and no recalibration was necessary

Five prints were measured from each paper grade and printer. Five prints of the reference paper were also measured. Two different angles for the incident light was used: 45° and 75°. For uncoated papers with low gloss 75° gives a better correlation to perceived gloss and is therefore used in the data analysis [35]. According to ISO-standard

8254-1 and 2813, 10 measuring values were used; two different measuring directions on five papers.

3.5. Other measurements

To understand which parameters are influencing the gloss and gloss variations in printed areas it was also necessary to measure properties as surface topography, density and print mottle. A perceptual evaluation was also performed in order to investigate if measured gloss variations correlated with visual impression of gloss variation.

3.5.1. Density and print mottle

A flat bed Epson scanner was used for density and mottle measurements. The results were collected and converted in Matlab using Fast Fourier Transform analysis (FFT). The results were achieved within the wavelength interval of 0,2-2 mm and 2-8 mm.

3.5.2. Surface Topography

Print surface topography was measured with a Sture measuring device (see fig 11). Before measuring, the printed papers were conditioned for 24 hours to 50% RH and 37°C. The received structure data were shown as variance within the wavelength interval 0,25-8 mm. Larger wavelengths do not give reliable information about the variance, due to possible waviness of samples. Therefore the data received within the wavelength 8-16 mm were not used. The papers were measured in cross- and machine-direction.

Fig 11. The image shows the Sture measuring device.

3.5.3. Subjective evaluation by pair comparison

The pair comparison was performed in a room with a 5000 K (D50) light temperature. The printed patches were cut and fitted into a neutral grey frame. The samples were coded to avoid recognition of different samples. The patches were studied from normal reading distance in the machine direction. The samples were tilted in different angles to establish high gloss.

Twelve samples were used in the comparison. Two samples from paper sample 1 for every colour were used to check the variation in the judgements (i.e. guarantee that the observers were not giving one sample different values).

Ten observers (people working at TC and MoRe) participated in the comparison and each observer was given approximately one our for visual evaluation of the samples.

4. Results and discussion

The results of the measurements showed that the difference achieved between the three different paper grades printed in all printers was significant. Paper A gave the lowest measured gloss and highest measured and perceived gloss variations. It also gave the largest print surface topography and mottle. The difference between the three printers was also significant. The biggest difference between the printers was the use of ground and chemical toner. The multivariate analysis showed that variation in perceived gloss variation correlated well with the measured gloss variations. The measured print surface topography did not correlate well with the perceived gloss variation. The results are presented below.

4.1. Gloss

The difference in measured gloss was observed both between the three paper grades and the different printers. The difference was larger between the three different paper grades. The highest measured gloss was achieved for paper C in the blue patches printed in all possible printers. Canon CLC 1150 with ground toner gave the highest measured gloss. Possible causes could be the use of ground toner and silicon oil. The results are presented in table 1. The paper grades are marked A, B and C.

Table 1. Gloss of cyan, black and blue patches for different papers and printers measured in machine direction. Mean value and standard deviation

	A Xerox 3535	**B** Xerox 3535	**C** Xerox 3535	**A** Xerox DC12	**B** Xerox DC12	**C** Xerox DC12	**A** Canon 1150	**B** Canon 1150	**C** Canon 1150
Cyan	24±3	29±2	33±3	20±1	24±2	27±1	27±2	34±2	41±2
Black	29±3	34±2	39±3	25±3	31±2	34±1	33±1	34±3	48±2
Blue	36±3	41±1	46±2	29±4	33±3	37±1	37±2	44±2	50±2

4.2. Gloss variations

According to figure 12 the difference in measured gloss variations in cross machine direction was both between the different paper grades and different printers. The highest gloss variations were measured for paper A in all printers (i.e. printed with both cemical and ground toner). In general, the highest achieved measured gloss variations were mainly large scale (wavelengths interval 4-8 mm). The results are shown in table 2. A diagram presenting the results from all measured wavelength intervals can be found in appendix A.

Table 2. Gloss variations of cyan, black and blue patches in the wavelength interval 4-8 mm for different papers and printers. Mean value and standard deviation.

	A Xerox 3535	**B** Xerox 3535	**C** Xerox 3535	**A** Xerox DC12	**B** Xerox DC12	**C** Xerox DC12	**A** Canon 1150	**B** Canon 1150	**C** Canon 1150
Cyan	0,76 ± 0,14	0,53 ± 0,10	0,40 ± 0,04	0,52 ± 0,02	0,48 ± 0,01	0,41 ± 0,04	0,90 ± 0,10	0,78 ± 0,08	0,82 ± 0,03
Black	0,77 ± 0,08	0,59 ± 0,11	0,44 ± 0,04	0,61 ± 0,02	0,54 ± 0,02	0,45 ± 0,04	1,09 ± 0,11	0,76 ± 0,16	0,70 ± 0,07
Blue	0,55 ± 0,06	0,42 ± 0,07	0,33 ± 0,04	0,65 ± 0,02	0,59 ± 0,02	0,46 ± 0,04	0,85 ± 0,07	0,59 ± 0,11	0,59 ± 0,03

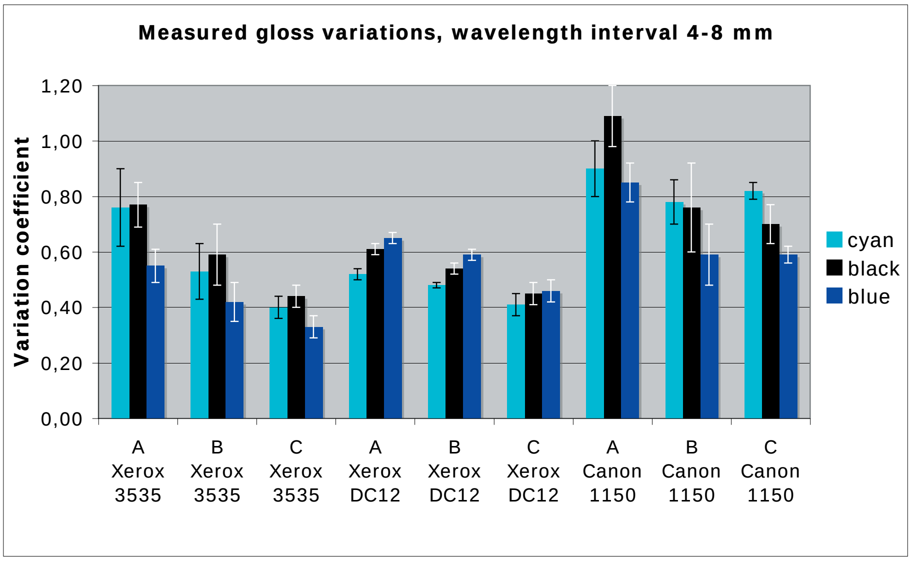


Fig 12. Measured gloss variations of cyan, black and blue patches for different papers and printers.

4.3. Subjective gloss variation

The perceived difference in gloss variations was both achieved between the three different paper grades and also between the three different printers (see fig. 13). The largest perceived gloss variations were generally achieved for paper A, printed in all printers (i.e. printed with both chemical and ground toner). The results can be seen in table 3.

Table 3. Variation coefficients for perceived gloss variations. Mean value and standard deviation.

	A Xerox 3535	**B** Xerox 3535	**C** Xerox 3535	**A** Xerox DC12	**B** Xerox DC12	**C** Xerox DC12	**A** Canon 1150	**B** Canon 1150	**C** Canon 1150
Cyan	162 ± 28	113 ± 36	50 ± 40	66 ± 38	35 ± 31	49 ± 24	132 ± 47	92 ± 44	142 ± 52
Black	147 ± 37	104 ± 39	51 ± 46	67 ± 30	42 ± 31	39 ± 22	147 ± 47	100 ± 35	142 ± 58
Blue	71 ± 43	55 ± 44	27 ± 51	101 ± 33	83 ± 28	80 ± 37	161 ± 45	141 ± 39	149 ± 48

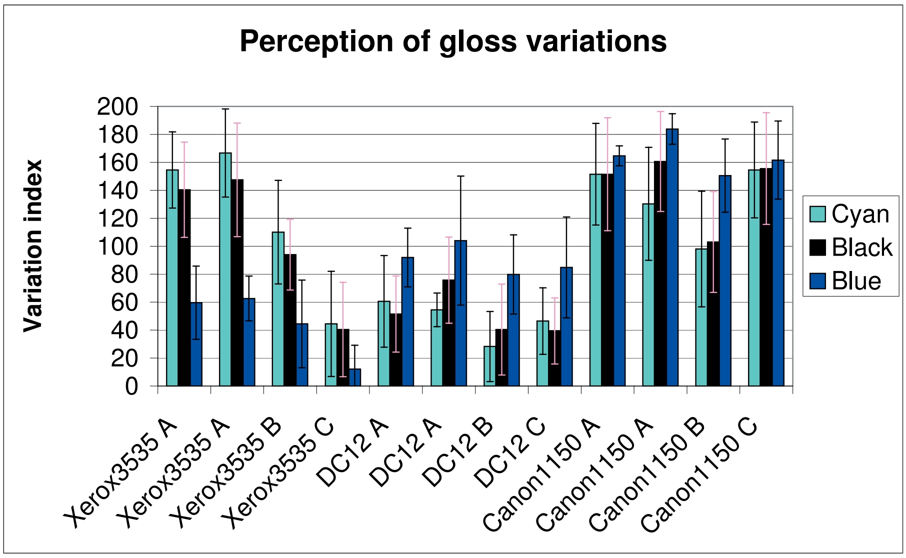


Fig 13. Perceived gloss variations of cyan, black and blue patches for different papers and printers. Both results of sample A is presented in this diagram.

4.4. Print surface topography

The difference in surface topography in print was mainly achieved between the three different paper grades. The use of chemical or ground toner gave almost the same measured surface topography except the black patch for Canon CLC 1150 with ground toner and a high amount of silicone oil, which gave a very large measured surface topography on paper A. A dammage in form of a scratch in the measured area in the black patch can explain this. The measured large-scale surface topography was greater in cross machine direction than machine direction (see appendix C). Paper A, printed in all three printers gave highest measured surface topography. The results can be seen in table 4.

Table 4. Variation coefficients for measured print surface topography in wavelengt interval 4-6 mm in machine direction. Mean value and standard deviation.

	A Xerox 3535	**B** Xerox 3535	**C** Xerox 3535	**A** Xerox DC12	**B** Xerox DC12	**C** Xerox DC12	**A** Canon 1150	**B** Canon 1150	**C** Canon 1150
Cyan	3,2 ± 0,6	2,4 ± 0,3	2,3 ± 0,4	3,4 ± 0,4	2,9 ± 0,4	1,9 ± 0,3	4,4 ± 0,5	2,5 ± 0,5	2,3 ± 0,3
Black	3,9 ± 0,7	3,2 ± 0,5	2,8 ± 0,3	3,1 ± 0,5	2,3 ± 0,4	2,0 ± 0,3	6,8 ± 1,4	2,6 ± 0,3	2,0 ± 0,2
Blue	2,8 ± 0,3	2,6 ± 0,5	1,9 ± 0,3	3,1 ± 0,8	2,5 ± 0,5	2,0 ± 0,2	4,3 ± 0,9	2,7 ± 0,1	2,4 ± 0,3

4.5. Mottle

The difference in measured print mottle between the three different paper grades was clear, except for paper grades printed on Xerox 3535 with chemical toner, where there was no difference in mottle (see fig 14). There was almost no difference between the other two printers with ground toner. Paper A gave the highest measured print mottle in all printers. The results are shown in table 5 and 6. See also appendix D.

Table 5. Variation coefficients for measured print mottle, wavelength interval 0,5-2 mm. Mean value and standard deviation.

	A Xerox 3535	**B** Xerox 3535	**C** Xerox 3535	**A** Xerox DC12	**B** Xerox DC12	**C** Xerox DC12	**A** Canon 1150	**B** Canon 1150	**C** Canon 1150
Cyan	0,13 ± 0,01	0,12 ± 0,01	0,11 ± 0,01	0,35 ± 0,01	0,29 ± 0,01	0,26 ± 0,01	0,44 ± 0,03	0,34 ± 0,01	0,28 ± 0,02
Black	0,68 ± 0,16	0,71 ± 0,05	0,63 ± 0,06	2,28 ± 0,1	1,95 ± 0,05	1,56 ± 0,1	2,48 ± 0,08	1,8 ± 0,14	1,26 ± 0,11
Blue	0,64 ± 0,08	0,54 ± 0,11	0,45 ± 0,06	1,07 ± 0,05	0,81 ± 0,08	0,56 ± 0,02	1,68 ± 0,11	1,03 ± 0,12	0,66 ± 0,36

Table 6. Variation coefficients for measured print mottle, wavelength interval 2-8 mm. Mean value and standard deviation.

	A Xerox 3535	**B** Xerox 3535	**C** Xerox 3535	**A** Xerox DC12	**B** Xerox DC12	**C** Xerox DC12	**A** Canon 1150	**B** Canon 1150	**C** Canon 1150
Cyan	0,07 ± 0,01	0,07 ± 0,01	0,06 ± 0	0,22 ± 0	0,18 ± 0,01	0,15 ± 0,01	0,25 ± 0,01	0,19 ± 0,01	0,15 ± 0,01
Black	0,44 ± 0,12	0,42 ± 0,04	0,33 ± 0,03	1,36 ± 0,08	1,1 ± 0	0,88 ± 0,06	1,5 ± 0,1	1,05 ± 0,04	0,67 ± 0,04
Blue	0,38 ± 0,08	0,31 ± 0,11	0,23 ± 0,06	0,65 ± 0,04	0,46 ± 0,05	0,31 ± 0,01	0,94 ± 0,06	0,59 ± 0,08	0,38 ± 0,21

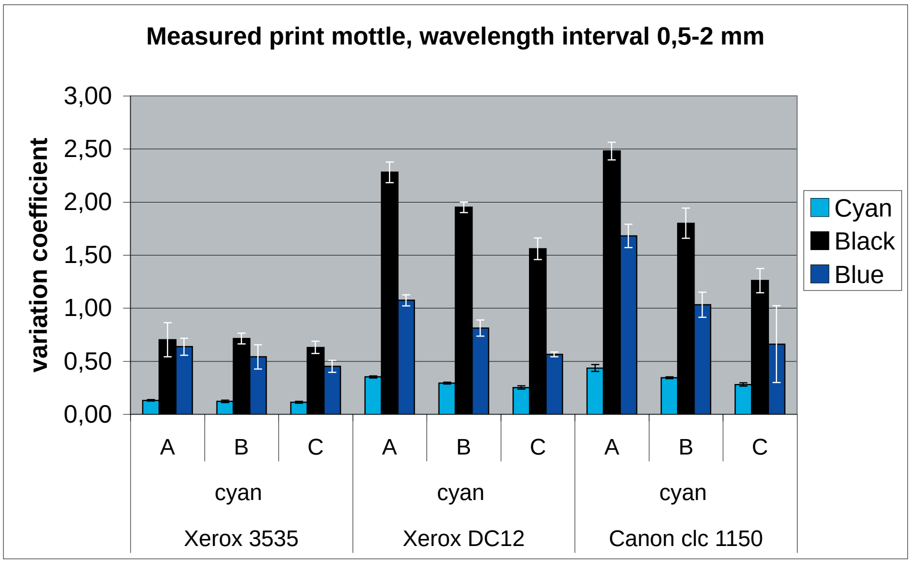


Fig 14. Measured print mottle in cyan, black and blue patches for different papers and printers.

4.6. Density

According to table 7 the three different paper grades printed in the same printer had almost the same density. There was little difference between the three printers. The difference was mainly achieved between the different color patches. Noteworthy was that the black and blue almost had the same density even though blue is printed with 200% toner.

Table 7. Measured print density.

	A Xerox 3535	**B** Xerox 3535	**C** Xerox 3535	**A** Xerox DC12	**B** Xerox DC12	**C** Xerox DC12	**A** Canon 1150	**B** Canon 1150	**C** Canon 1150
Cyan	0,69 ± 0,005	0,70 ± 0,005	0,71 ± 0,004	0,69 ± 0,005	0,71 ± 0,008	0,72 ± 0,000	0,74 ± 0,005	0,78 ± 0,008	0,79 ± 0,023
Black	0,78 ± 0,004	0,79 ± 0,010	0,80 ± 0,014	0,74 ± 0,007	0,72 ± 0,005	0,78 ± 0,003	0,80 ± 0,006	0,84 ± 0,010	0,86 ± 0,009
Blue	0,76 ± 0,015	0,77 ± 0,007	0,77 ± 0,015	0,71 ± 0,004	0,72 ± 0,008	0,72 ± 0,005	0,83 ± 0,005	0,85 ± 0,005	0,85 ± 0,012

5. Multivariate data analysis

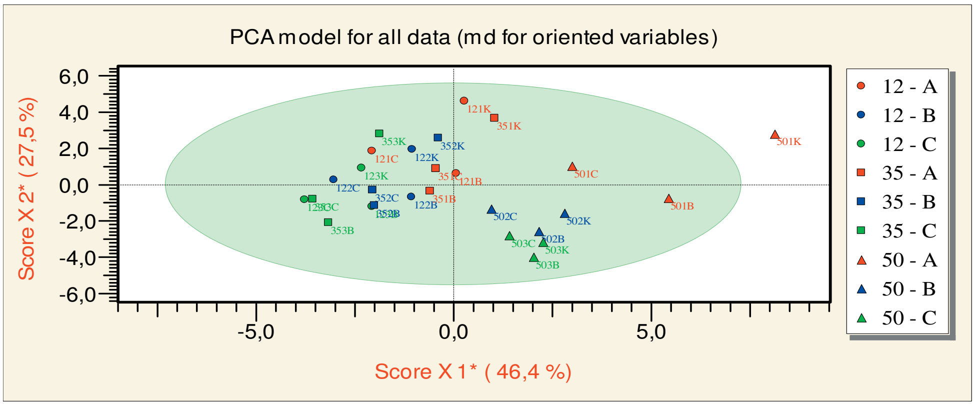
Multivariate analysis was used to study correlation between different measurements and between measurements and visual evaluation of gloss variations.

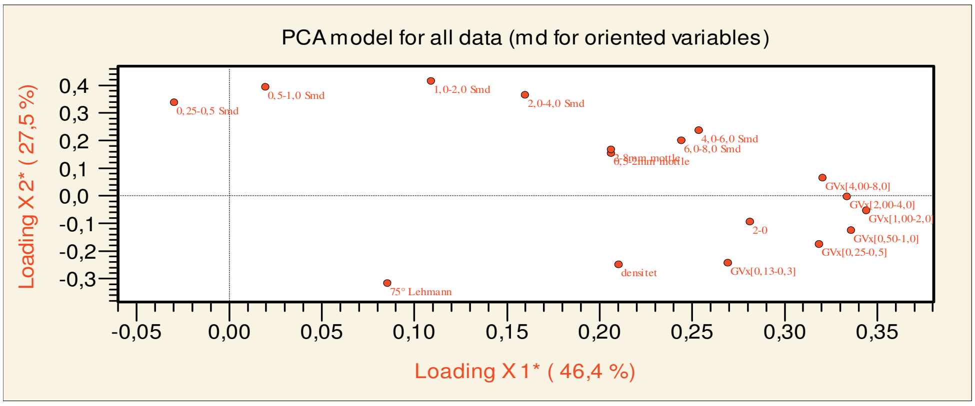
5.1. PCA model for all data in machine direction

The PCA model gave a god correlation between all measured data with five significant components explaining 95,8% of the variations (see fig 15-17). Most of the variations could be explained by the X-axis. Most important in the first component are gloss variation results, followed by topography variations in long wavelengths The main difference was between different printers, but there was also a notable difference between different paper grades. Paper A has the highest surface roughness.

- 2-0 = pair comparison
- *GVx* = Gloss variations cross machine direction
- *GVy* = Gloss variations machine direction
- *Scd* = Surface topography cross machine direction
- *Smd* = Surface topography machine direction
- *Lehmann* = gloss measurement

In the diagram the circle represents the Xerox DC12, the square Xerox 3535 and the triangle Canon 1150.





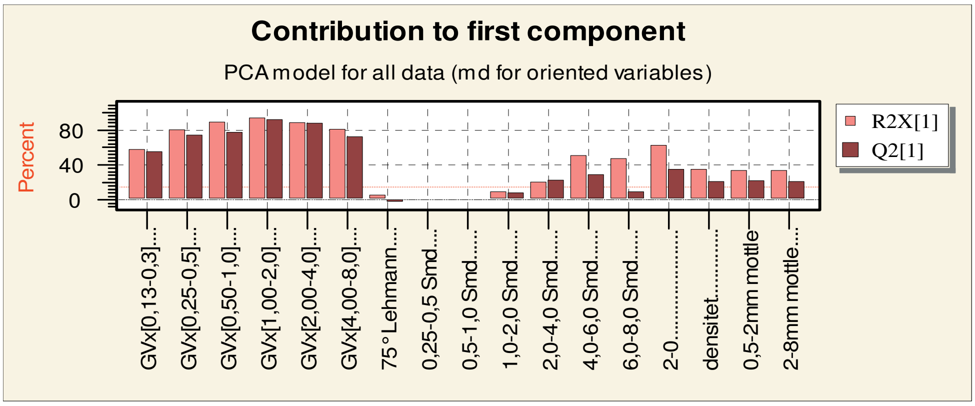


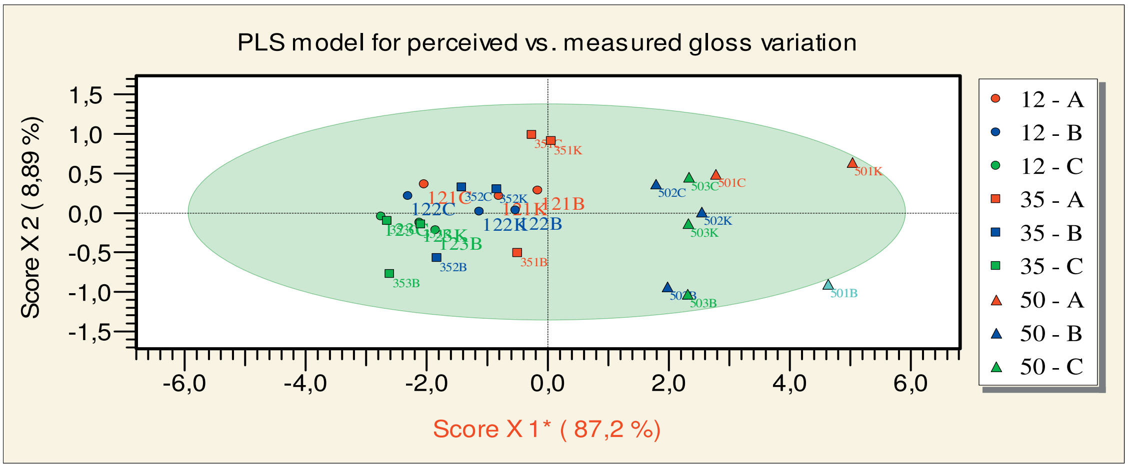
Fig 15-17. Shows diagram of the PCA model of all data in machine direction.

5.2. PLS models

Correlation between perceived and measured gloss variations

The perceived gloss variations correlated best with the measurements made in the machine direction. The model had one significant component where 87,2% explained 70,4% of the variations. Gloss variations in cross machine direction did not affect perceived gloss variations. This should be expected as the observers looked at the samples in machine direction. Large-scale gloss variations gave more perceived gloss variations. Small-scale gloss variations gave the opposite effect. Most of the variations could be explained by the first component, but the second component is also significant.

There was a clear difference between the three different paper grades, especially for papers printed in Canon CLC 1150. The other two printers showed similar gloss variations. The highest perceived gloss variations were found in the cyan patches from the Canon CLC 1150 (see fig. 18). Adding mottling, gloss and density to the multivariate analyze did not increase the degree of explanation for the model. The result of the multivariate analysis is shown in diagram 18-20. The different paper are marked A,B and C.



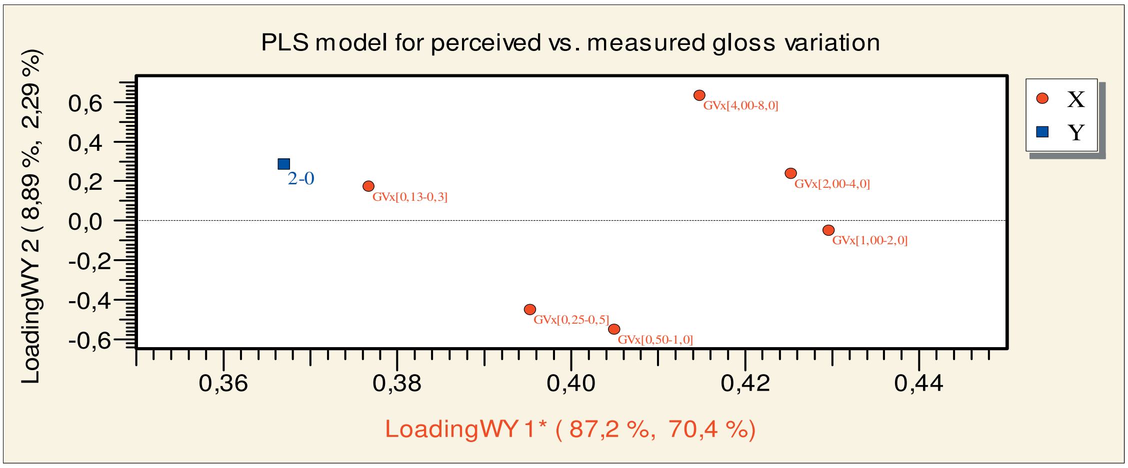


Fig 18-19. Diagram of the PLS-model for perceived gloss variations and measured.

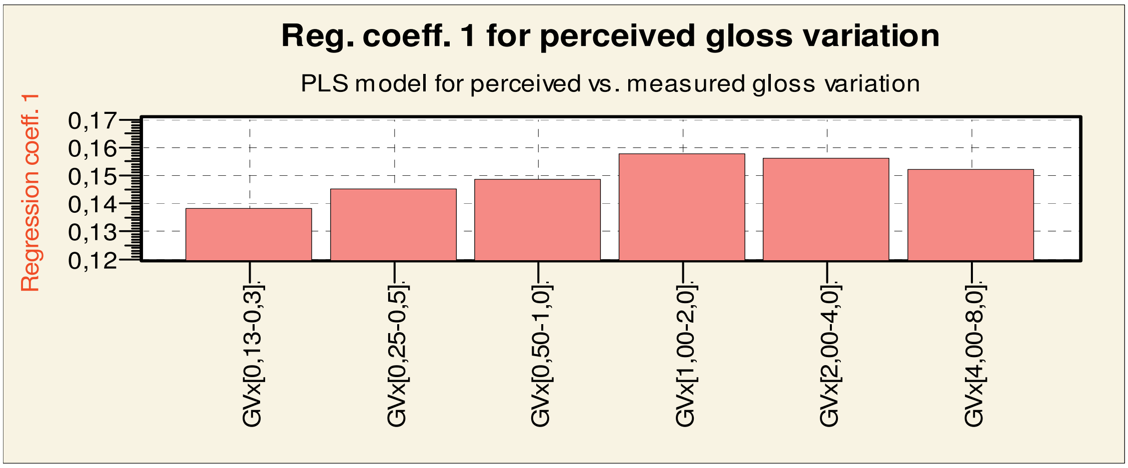


Fig 20. Diagram of the regression coefficient for perceived gloss variations and measured.

Correlation between gloss and measured gloss variations and density

The PLS multivariate model gave a large degree of explanation with three significant components (95,5% explained 84,8% of the variations). Most of the variations could be explained by the X-axis. Gloss is mainly explained by two components, and according to the model density is the most important factor (see fig 22 and 23). Thus there is a strong correlation between density and gloss. The differences between the paper grades were noticeable but the main difference was between the different printers.

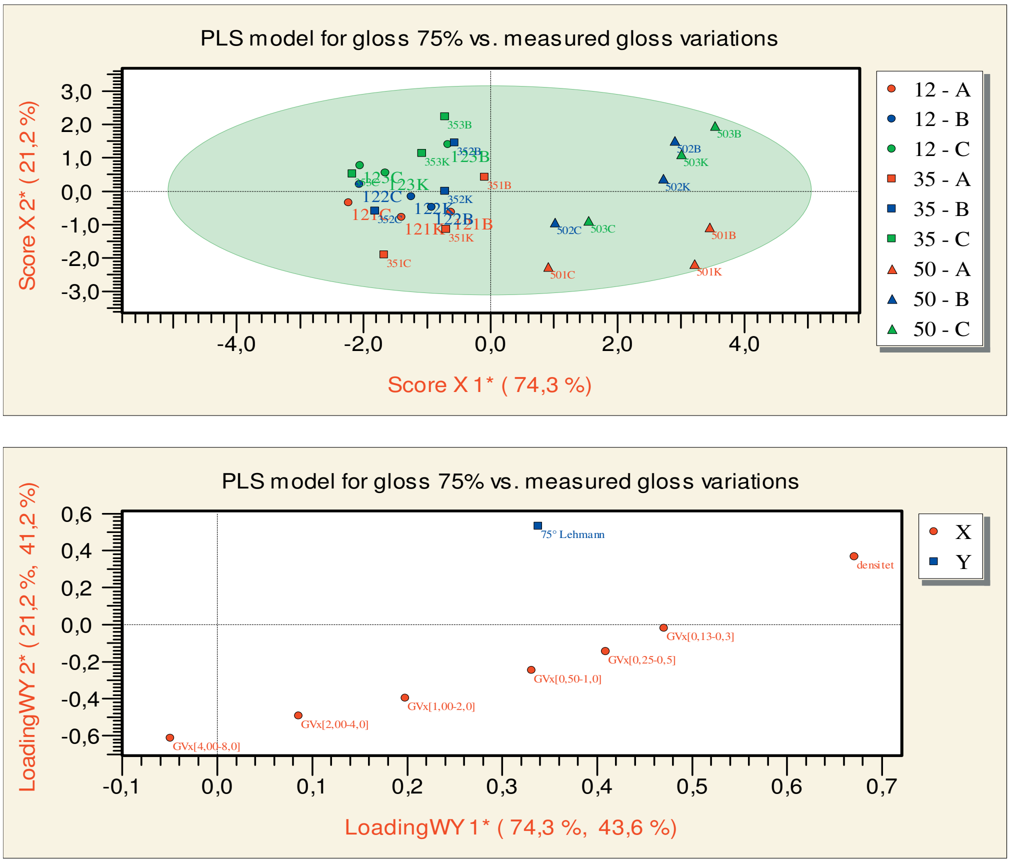


Fig 21-22. Diagram of the PLS-model for perceived gloss variations and measured.

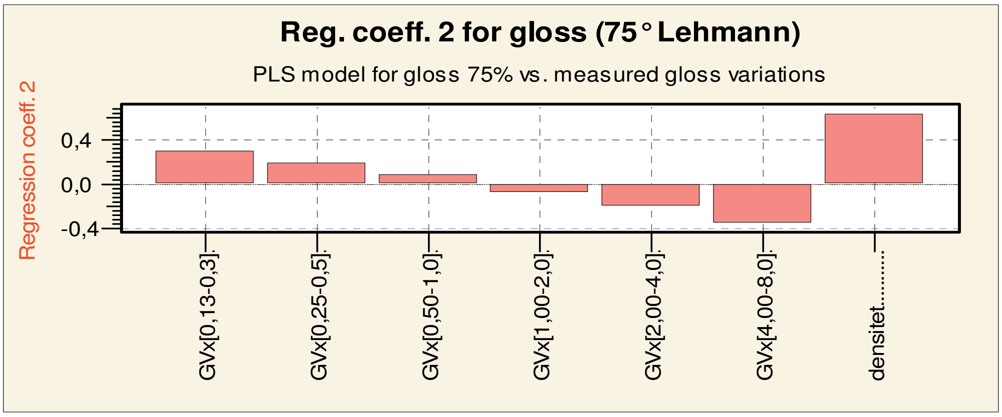


Fig 23. Diagram of the regression coefficient for gloss versus measured gloss variations and density.

6. Conclusion

Based on the results presented the following conclusion was made:

- Perceived gloss variations correlate well with measurements of gloss variations in long wavelengths (2-4 mm). Large-scale gloss variations increases the perception of gloss variations. The perceived gloss variations were not notably affected by different gloss level or density. The perception of gloss variations corresponded well with measured gloss variations. The multivariate analysis also showed that a rougher surface in print had some affect the perception of gloss variations.

- Gloss variation varies significantly between different printers with the highest level for the printer using ground toner and a high amount of silicon oil, while the Xerox printers with ground toner and chemical toner give similar gloss variations. The gloss level in print, when printing with ground toner, was dependent of the amount of silicon oil. A greater amount of silicone oil gave a higher gloss level in print and quite contradictory larger surface topography in print.

- Gloss variation is higher for rough paper in all printers used. Papers with large surface roughness gave less gloss than papers with a smoother surface. The paper surface spread the incident light in many different directions and just a small part of the light was reflected in the specular angle giving low measured gloss. High paper surface roughness generated large surface topography variations in printed areas, which gave higher gloss variations (both measured and visual). The results also showed that a rougher paper surface gave more mottle in print.

A paper with a smooth surface is the obvious choise to acheive high gloss and prevent gloss variations in print. This paper should be printed with chemical toner which gives a relativly high gloss level, but much less mottle in print and less gloss variations (both measured and visual) than ground toner.

7. Final words

This study has been a great experience and I would like to thank all the people at TC and MoRe for supporting me with material, knowledge and time. Especially I would like to thank my supervisor Elisabeth Alfthan who has been a great support.

8. References

1. Kipphan Helmut (2001). *Handbook of Print Media.* Springer-Verlag, s.689-700. ISBN: 3-540-67326
2. Ientilucci Emmet (1994-02-22). *Fundamentals of Xerography.* [Internet] Available: www.cis.rit.edu/~ejipci/Reports/Xerography.pdf
3. Freepatentsonline (2007-08-12). *Toner binder, toner, electrophotographic method and apparatus therefore.* [Internet] Available: www.freepatentsonline.com/5618648.html
4. OKI (1998-08). *Encapsulated Toner Fixed by Low Temperature.* [internet] Available: http://www.oki.com/en/otr/html/nf/otr-161-15-2.html
5. Fluharty Allan (2005-04-08). *A Comparison of Conventional Toner to Chemically Produced Toner using Life Cycle Assessment.* [Internet] Available: http://vienna.bioengr.uic.edu/RET/Reports/Final%20Reports/FluhartyTechPaper.pdf
6. Konica Minolta (2007-08-08). *Polymerization toner.* [Internet] Available: www.konicaminolta.com/about/research/core_technology/material/toner.html
7. Fahlcrantz Carl-Magnus et al. (2007-08-11). *Print Mottle Evaluation of Flexographic Prints- Using a Scanner-based Measurement System.* [Internet] Available: www.t2f.nu/s2p2/S2P2_IPQ_21.pdf
8. Laboratory of Media Technology (2007-08-11). *Flexographic Printing and Varnishing of Coated Papers.* [Internet] Available: www.media.hut.fi/julkaisut/diplomityot/462.html?language=en
9. Fahlcrantz Carl-Magnus (2005-12). *On the evaluation of print mottle.* [Internet] Available: www.csc.kth.se/utbildning/forskar/avhandlingar/doktor/2005_2006/FahlcrantzCarlMagnus.pdf
10. Sharma Abhay (2004). *Understanding Color Management.* Thomson s. 114-116 ISBN: 1-4018-1447-6
11. Rosenberger Roy et al. (2007-08-11) *Predicting half-tone print mottle using digital imaging & stochastic frequency distribution analysis.* [Internet] Available: http://www.verityia.com/pdf/predicting.pdf
12. Norberg Ole (1997). *Gloss and gloss variations.* [Report] Project number 4669
13. Pauler Nils, *Paper Optics. Lorentzen & Wettre.* s. 4-22 ISBN 91-971 765-6-7
14. Lecture KTH (2007-08-11). *Brytning, reflexion, polarization och spridning.* [Internet] Available: http://www.laserphysics.kth.se/courses/optkom/kapitel2.pdf
15. Johansson Per-Åke. *Glans och glansmätning.* STFI compendium
16. Pauler Nils (2007-05-15). M-real TC Örnsköldsvik. [verbal,mail]
17. Sundström Anna (2002). T*ryckglansens beroende av bestrykningsskiktets mikrostruktur.* [Internet] Available: www.t2f.nu/t2f_rapp_f_35.pdf
18. Ekström Anneli (2004). *Glans-vad är det och hur mäts det?* [Internet] Available: http://staffwww.itn.liu.se/~sasgo/TNM015/2004/Projekt_rapporter/Ekstrom.pdf
19. Bryntse Göran (2007-04-17). Högskolan Dalarna. [Verbal]
20. Computer graphics forum (1994). *A survey of Shading and Reflectance models.* [Internet] Available: http://dept-info.labri.fr/~schlick/DOC/cgf1.ps.gz, 20070811-16:48
21. Arney J.S. et al (2006). *Interpretation of gloss meter measurements.* Rochester Institute of Technology
22. SAPPI (2007-08-08). *Print Mottle.* [Internet] Available: www.sappi.com/NR/rdonlyres/451819EC-CC19-44EF-B3EC-6AA6DA283295/0/PrintMottle.pdf
23. ISO 8254-1 (1999). *Paper and board – Measurement of specular gloss.*
24. Wågberg Kristina (2007-08-08). M-real TC Örnsköldsvik. [mail]

25. Nadal É. Maria et al (2000-12). *New Primary Standard for Specular Gloss measurements.* [Internet] Available: http://slp.nist.gov/appearance/nadal_jct2.pdf
26. PRA (2007-08-11). *Gloss Measurement.* [Internet] Available: www.pra-world.com/technical/testingopticalgloss.htm
27. Béland Marie-Claude (2001). *Gloss variation of printed paper: Relationship between topography and light scattering.* Royal Institute of Technology Stockholm, Sweden. Doctoral Thesis s.14 ISBN: 91-7283-131-6
28. Oittinen P. et al (1990). *Micro scale gloss of papers and prints.* International Printing and Graphic Arts Conference compendium
29. Andreas Wallberg (2203). *Evaluation of a New Device for Measurements of Gloss Variation.* Diploma work performed at M-real
30. Johansson Per-Åke et al (1984). *Subjective evaluation by pair comparison: Pitfalls to avoid and suggestions for the presentation of results.* Pentech Press. ISSN: 0349-0211
31. Anderson Jens (2007-08-09). MoRe Research Örnsköldsvik. [Verbal]
32. Bergvall Robert (2006). *Penetration och absorption av vätska i kartong.* Luleå Tekniska universitet. ISSN 1402-1617 [Internet] Available: http://epubl.ltu.se/1402-1617/2006/186/LTU-EX-06186-SE.pdf
33. Thesis Project (2007-04-18). *Analysing techniques.* Umeå Universitet. Compendium
34. Otto Lindeberg (2007-09-18), Extract Information AB. [Mail]
35. Alfthan Elisabeth (2007-05-10). M-real TC Örnsköldsvik. [Mail,Verbal]
36. Ericsson Gunilla (2007-04-16). M-real TC Örnsköldsvik. [Verbal]
37. Andersson Mattias (2007-04-18). MoRe Research Örnsköldsvik. [Verbal]

Proofreading: Elisabeth Alfthan
Lars Hansson

Appendix A- all data from measured gloss variation in cross machine direction with GIA

Sample			**GVx[0.13-0.3]**	**GVx[0.25-0.5]**	**GVx[0.50-1.0]**	**GVx[1.00-2.0]**	**GVx[2.00-4.0]**	**GVx[4.00-8.0]**
Xerox 3535	A	cyan	0,03	0,78	1,76	1,74	1,15	0,76
	B	cyan	0,03	0,72	1,52	1,42	1,00	0,53
	C	cyan	0,03	0,61	1,26	1,08	0,75	0,40
DC12	A	cyan	0,03	0,63	1,34	1,20	0,85	0,52
	B	cyan	0,03	0,61	1,28	1,15	0,81	0,48
	C	cyan	0,03	0,58	1,22	1,05	0,71	0,41
Canon 1150	A	cyan	0,07	1,51	2,94	2,35	1,47	0,90
	B	cyan	0,08	1,36	2,60	2,11	1,34	0,78
	C	cyan	0,10	1,49	2,72	2,13	1,39	0,82
Xerox 3535	A	Black	0,03	0,86	1,91	1,80	1,17	0,77
	B	Black	0,03	0,84	1,76	1,56	1,05	0,59
	C	Black	0,03	0,72	1,48	1,24	0,82	0,44
DC12	A	Black	0,04	0,90	1,84	1,52	0,96	0,61
	B	Black	0,04	0,89	1,76	1,44	0,92	0,54
	C	Black	0,04	0,76	1,45	1,17	0,76	0,45
Canon 1150	A	Black	0,11	1,97	3,67	2,81	1,74	1,09
	B	Black	0,12	1,66	2,88	2,18	1,34	0,76
	C	Black	0,15	1,68	2,80	2,06	1,24	0,70
Xerox 3535	A	Blue	0,03	1,14	2,31	1,78	0,92	0,54
	B	Blue	0,02	0,87	1,76	1,36	0,81	0,42
	C	Blue	0,02	0,74	1,47	1,09	0,67	0,35
DC12	A	Blue	0,04	1,02	2,01	1,66	1,09	0,65
	B	Blue	0,05	1,01	1,95	1,58	1,00	0,59
	C	Blue	0,04	0,84	1,57	1,22	0,78	0,46
Canon 1150	A	Blue	0,13	2,31	4,03	2,78	1,49	0,86
	B	Blue	0,14	1,86	2,93	2,00	1,11	0,59
	C	Blue	0,16	1,98	3,05	1,99	1,10	0,59

Appendix B- gathered data of Perceived gloss variations

Cyan

Prov märkning	1,0	2,0	3,0	4,0	5,0	6,0	7,0	8,0	9,0	10,0	11,0	12,0
Klartext	DC1(9)	CC1(9)	DC3	CC3	DC2D	CC2	CC1	XC3	DC1	XC1(9)	XC2	XC1
A	109,1	190,9	100,0	109,1	72,7	72,7	172,7	9,1	54,5	145,5	54,5	109,1
B	81,8	181,8	36,4	109,1	9,1	81,8	109,1	63,6	45,5	163,6	127,3	190,9
C	100,0	181,8	36,4	127,3	0,0	18,2	100,0	54,5	72,7	163,6	145,5	200,0
D	36,4	118,2	63,6	172,7	45,5	127,3	163,6	18,2	45,5	154,5	63,6	190,9
E	45,5	118,2	45,5	154,5	0,0	90,9	118,2	45,5	54,5	190,9	145,5	190,9
F	18,2	181,8	45,5	154,5	45,5	154,5	200,0	0,0	72,7	90,9	109,1	127,3
G	36,4	90,9	27,3	200,0	9,1	90,9	72,7	127,3	54,5	172,7	145,5	172,7
H	81,8	136,4	18,2	163,6	36,4	145,5	127,3	45,5	54,5	154,5	72,7	163,6
I	109,1	36,4	72,7	27,3	90,9	36,4	63,6	100,0	181,8	181,8	136,4	163,6
	36,4	163,6	45,5	200,0	36,4	100,0	109,1	36,4	36,4	154,5	127,3	154,5
Medel:	65,5	140,0	49,1	141,8	34,5	91,8	123,6	50,0	67,3	157,3	112,7	166,4
Stdav:	34,5	50,0	23,9	51,6	30,8	43,6	43,5	39,6	41,8	27,1	35,9	29,7

Blå

Prov märkning	1,0	2,0	3,0	4,0	5,0	6,0	7,0	8,0	9,0	10,0	11,0	12,0
Klartext	DB3	CB3	DB2	CB2	DB1	CB1	CB1(9)	XB2	DB1(9)	XB3X	XB1	XB1(9)
A	45,5	200,0	90,9	163,6	109,1	163,6	163,6	72,7	100,0	0,0	36,4	54,5
B	54,5	172,7	109,1	118,2	81,8	172,7	190,9	54,5	54,5	0,0	109,1	81,8
C	63,6	127,3	118,2	127,3	81,8	163,6	181,8	18,2	200,0	0,0	36,4	81,8
D	36,4	163,6	72,7	172,7	90,9	154,5	190,9	81,8	118,2	9,1	72,7	36,4
E	118,2	154,5	72,7	172,7	90,9	163,6	200,0	9,1	118,2	9,1	36,4	54,5
F	100,0	181,8	81,8	172,7	109,1	154,5	181,8	18,2	100,0	0,0	54,5	45,5
G	118,2	172,7	18,2	172,7	45,5	172,7	172,7	90,9	36,4	45,5	81,8	72,7
H	136,4	109,1	81,8	109,1	109,1	172,7	181,8	36,4	90,9	36,4	72,7	63,6
I	36,4	36,4	109,1	54,5	109,1	36,4	36,4	145,5	145,5	163,6	163,6	163,6
	90,9	172,7	72,7	145,5	109,1	163,6	190,9	18,2	118,2	9,1	36,4	72,7
Medel:	80,0	149,1	82,7	140,9	93,6	151,8	169,1	54,5	108,2	27,3	70,0	72,7
Stdav:	37,3	47,6	28,2	39,1	20,6	41,1	47,8	43,5	45,4	50,5	41,1	35,3

Appendix B- gathered data of Perceived gloss variations

Svart

Prov märkning	1,0	2,0	3,0	4,0	5,0	6,0	7,0	8,0	9,0	10,0	11,0	12,0
Klartext	DS3	CS3	DS2	CS2	DS1	CS1	CS1(9)	XS2	DS1(9)	XS3	S1x	S1(9)x
A	27,3	163,6	18,2	127,3	90,9	190,9	190,9	90,9	100,0	45,5	90,9	63,6
B	18,2	163,6	81,8	90,9	36,4	172,7	190,9	90,9	45,5	45,5	118,2	145,5
C	0,0	109,1	90,9	36,4	54,5	90,9	145,5	109,1	145,5	36,4	200,0	181,8
D	36,4	154,5	45,5	118,2	63,6	172,7	190,9	63,6	63,6	0,0	145,5	145,5
E	54,5	181,8	0,0	127,3	36,4	163,6	145,5	81,8	72,7	27,3	136,4	172,7
F	54,5	181,8	18,2	163,6	54,5	172,7	172,7	54,5	72,7	18,2	109,1	127,3
G	36,4	200,0	9,1	90,9	18,2	90,9	90,9	127,3	72,7	118,2	163,6	181,8
H	81,8	72,7	63,6	81,8	90,9	190,9	190,9	100,0	63,6	18,2	127,3	118,2
I	36,4	18,2	54,5	72,7	90,9	72,7	54,5	190,9	109,1	145,5	172,7	181,8
	45,5	172,7	36,4	90,9	18,2	118,2	127,3	127,3	45,5	54,5	172,7	190,9
Medel:	39,1	141,8	41,8	100,0	55,5	143,6	150,0	103,6	79,1	50,9	143,6	150,9
Stdav:	22,3	57,5	31,0	35,3	28,6	45,5	47,6	38,9	30,9	46,0	33,7	39,8

Appendix C- Surface topography measurements

		0,25-0,5	**0,5-1,0**	**1,0-2,0**	**2,0-4,0**	**4,0-6,0**	**6,0-8,0**
Xerox 3535	A cyan cd	0,46	2,31	3,46	4,97	5,80	9,00
	B cyan cd	0,38	1,38	2,49	3,47	4,07	5,21
	C cyan cd	0,42	1,85	2,97	4,22	2,35	1,92
Xerox DC12	A cyan cd	0,66	2,20	3,57	4,50	6,09	10,89
	B cyan cd	0,39	1,41	2,23	3,38	3,75	5,50
	C cyan cd	0,29	1,08	1,66	2,35	2,89	3,56
Canon clc1150	A cyan cd	0,63	2,39	4,07	6,78	8,57	20,10
	B cyan cd	0,39	1,39	2,43	3,69	3,33	9,33
	C cyan cd	0,33	1,10	1,74	2,67	3,10	5,30

		0,25-0,5	**0,5-1,0**	**1,0-2,0**	**2,0-4,0**	**4,0-6,0**	**6,0-8,0**
Xerox 3535	A cyan md	0,36	1,67	3,98	3,99	3,16	3,32
	B cyan md	0,30	1,17	2,62	3,81	2,40	2,19
	C cyan md	0,24	1,09	2,04	2,88	2,34	2,02
Xerox DC12	A cyan md	0,51	1,95	3,79	4,55	3,42	4,25
	B cyan md	0,32	1,27	2,51	3,49	2,91	1,97
	C cyan md	0,26	1,01	1,81	2,78	1,94	1,52
Canon clc1150	A cyan md	0,40	1,87	4,19	5,52	4,42	4,47
	B cyan md	0,28	1,29	2,70	3,64	2,51	2,49
	C cyan md	0,25	0,99	1,87	2,67	2,25	2,00

		0,25-0,5	**0,5-1,0**	**1,0-2,0**	**2,0-4,0**	**4,0-6,0**	**6,0-8,0**
Xerox 3535	A black cd	3,48	4,35	5,42	6,29	7,28	10,11
	B black cd	3,64	3,74	3,97	4,15	4,39	6,70
	C black cd	4,33	4,29	3,97	4,38	4,33	6,41
Xerox DC12	A black cd	5,59	5,06	5,45	6,54	7,15	9,24
	B black cd	4,30	3,59	3,44	3,95	4,02	4,84
	C black cd	3,25	3,14	2,84	3,18	4,13	4,93
Canon clc1150	A black cd	1,56	3,25	4,56	7,42	10,62	27,67
	B black cd	0,88	1,69	2,54	3,38	3,62	5,90
	C black cd	0,58	1,35	1,78	2,60	3,50	6,41

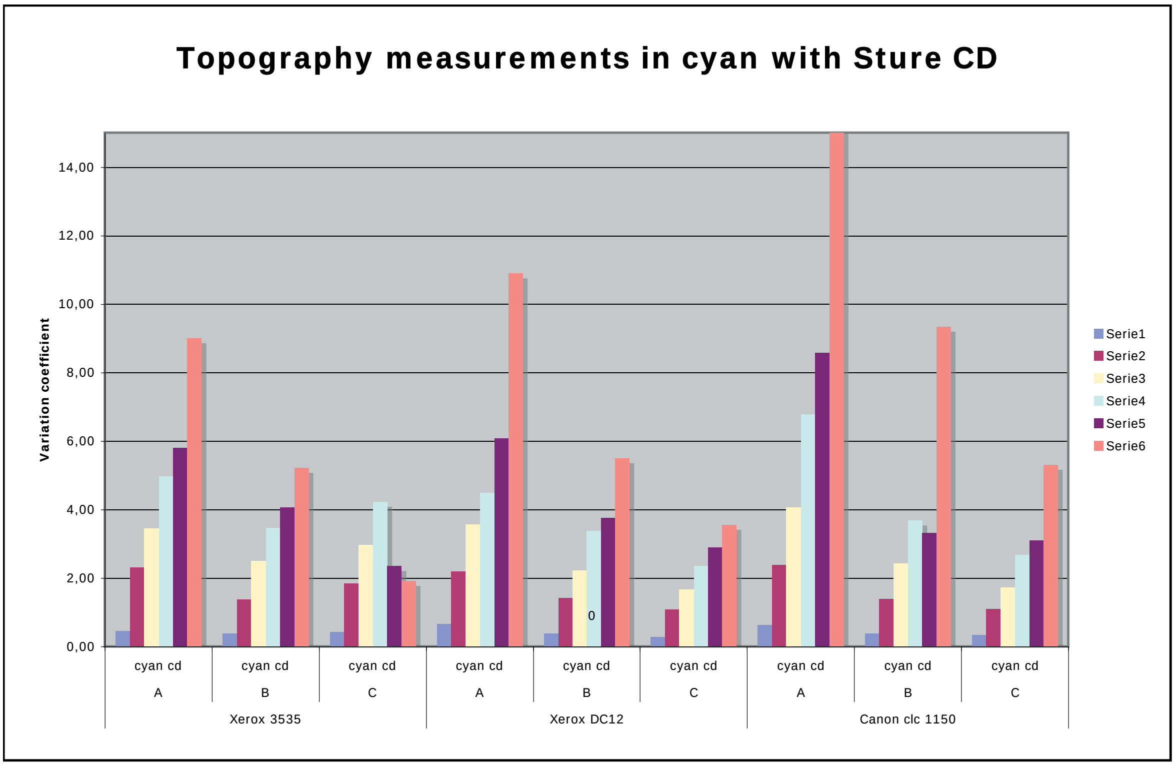
		0,25-0,5	**0,5-1,0**	**1,0-2,0**	**2,0-4,0**	**4,0-6,0**	**6,0-8,0**
Xerox 3535	A black md	3,36	4,17	5,71	5,99	3,87	3,51
	B black md	3,53	4,02	4,99	5,00	3,15	2,51
	C black md	4,85	4,70	4,78	4,81	2,79	2,29
Xerox DC12	A black md	3,69	4,46	5,59	5,41	3,12	3,23
	B black md	3,11	3,26	3,36	3,84	2,28	1,91
	C black md	2,73	2,89	2,82	2,77	1,95	1,95
Canon clc1150	A black md	0,79	2,40	4,64	6,12	6,77	11,41
	B black md	0,53	1,58	2,72	3,50	2,63	2,33
	C black md	0,51	1,30	2,03	2,80	1,97	1,85

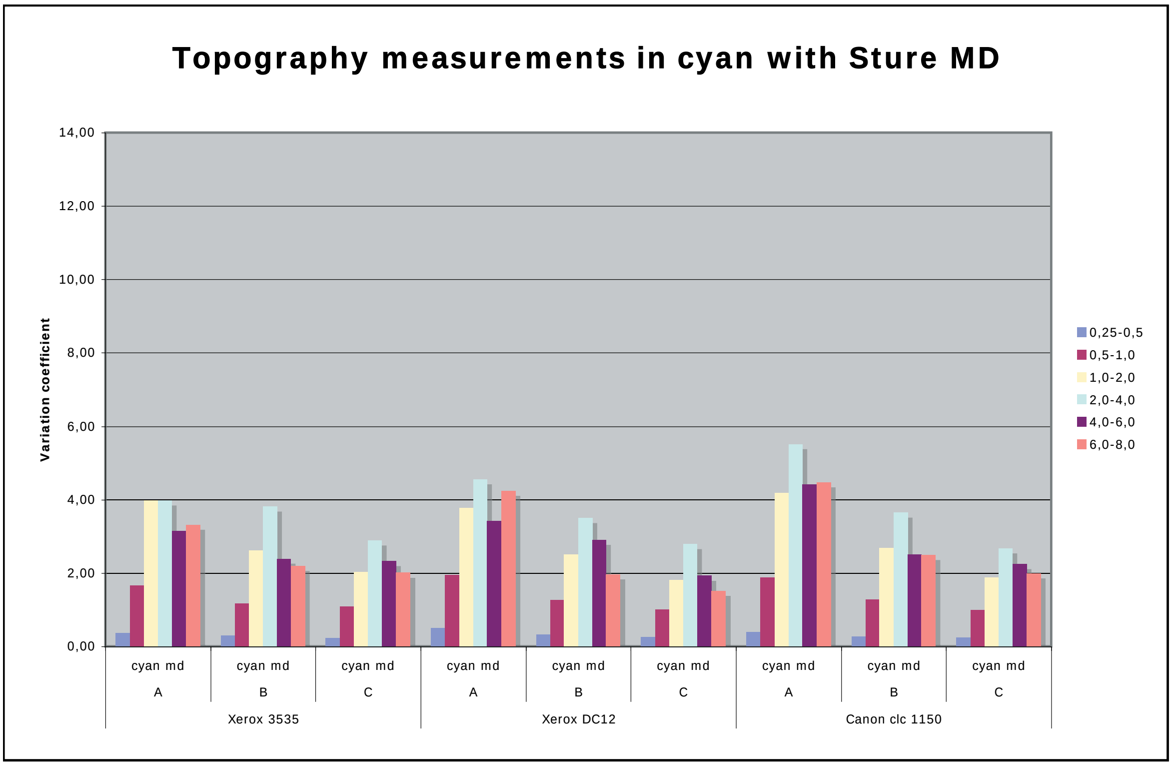
Appendix C- Surface topography measurements

			0,25-0,5	**0,5-1,0**	**1,0-2,0**	**2,0-4,0**	**4,0-6,0**
Xerox 3535	blue cd	A	0,33	1,74	3,25	5,33	7,46
	blue cd	B	0,24	1,22	2,26	3,78	5,08
	blue cd	C	0,18	0,93	1,63	2,91	3,89
Xerox DC12	blue cd	A	0,42	1,85	3,13	5,14	7,67
	blue cd	B	0,38	1,25	2,20	3,57	4,77
	blue cd	C	0,26	0,99	1,63	2,55	2,89
Canon clc 1150	blue cd	A	0,32	2,12	4,21	7,17	8,55
	blue cd	B	0,19	1,22	2,34	3,98	4,41
	blue cd	C	0,21	0,90	1,71	2,68	3,46

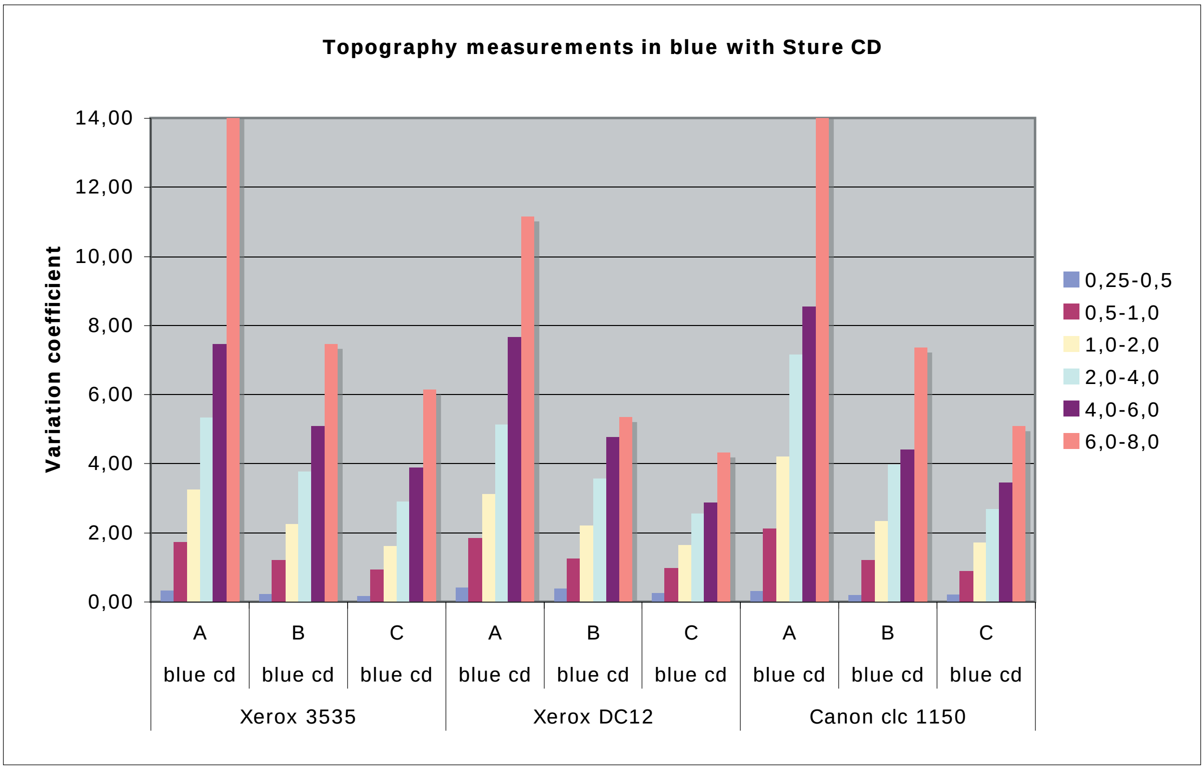
			0,25-0,5	**0,5-1,0**	**1,0-2,0**	**2,0-4,0**	**4,0-6,0**
Xerox 3535	blue md	A	0,24	1,32	3,43	3,97	2,80
	blue md	B	0,19	0,98	2,57	3,50	2,55
	blue md	C	0,19	0,78	1,67	2,76	1,91
Xerox DC12	blue md	A	0,33	1,55	3,36	4,30	3,08
	blue md	B	0,29	1,19	2,33	3,15	2,52
	blue md	C	0,20	0,91	1,75	4,30	2,00
Canon clc 1150	blue md	A	0,23	1,47	3,51	4,70	4,28
	blue md	B	0,15	0,96	2,55	3,66	2,68

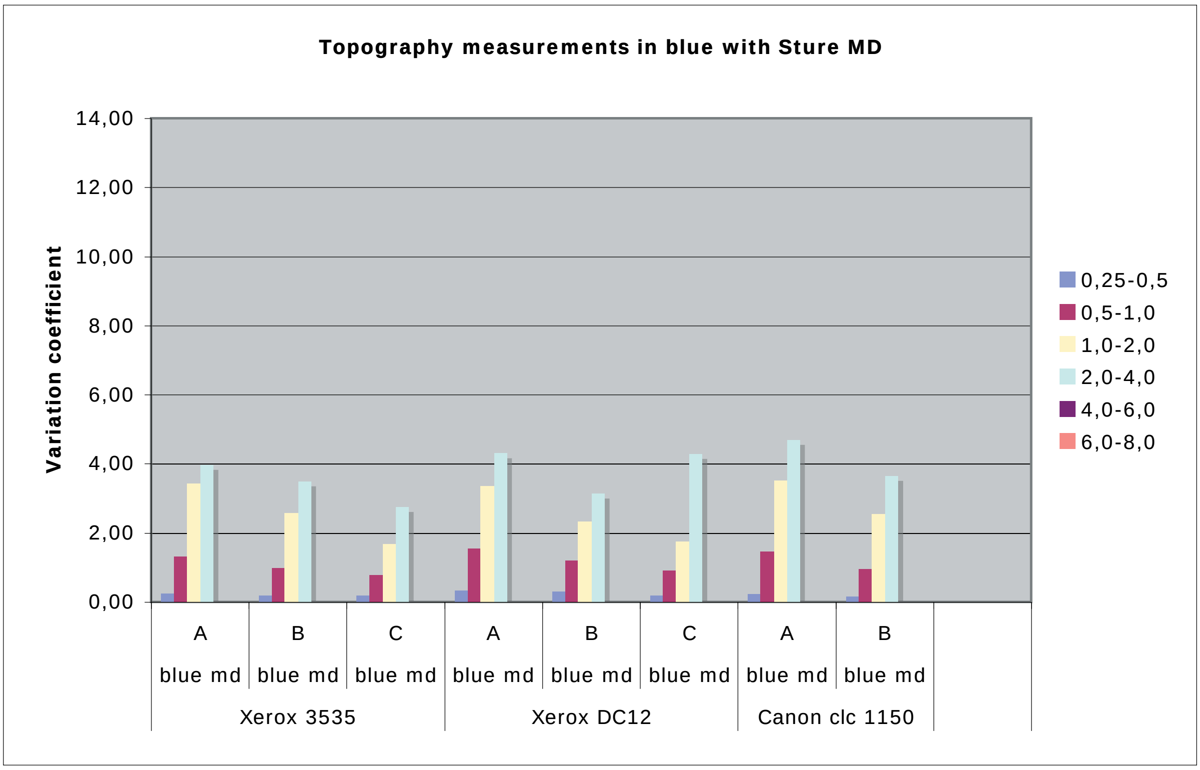
Appendix C- all data of surface



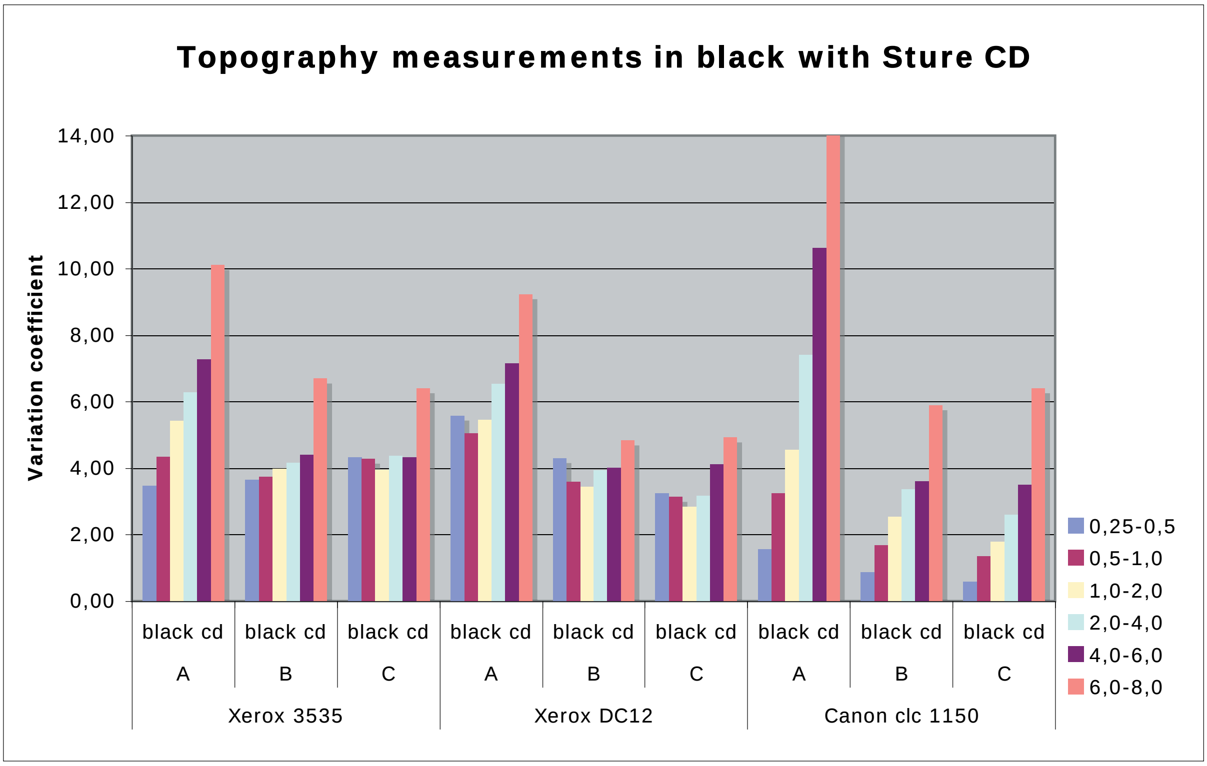


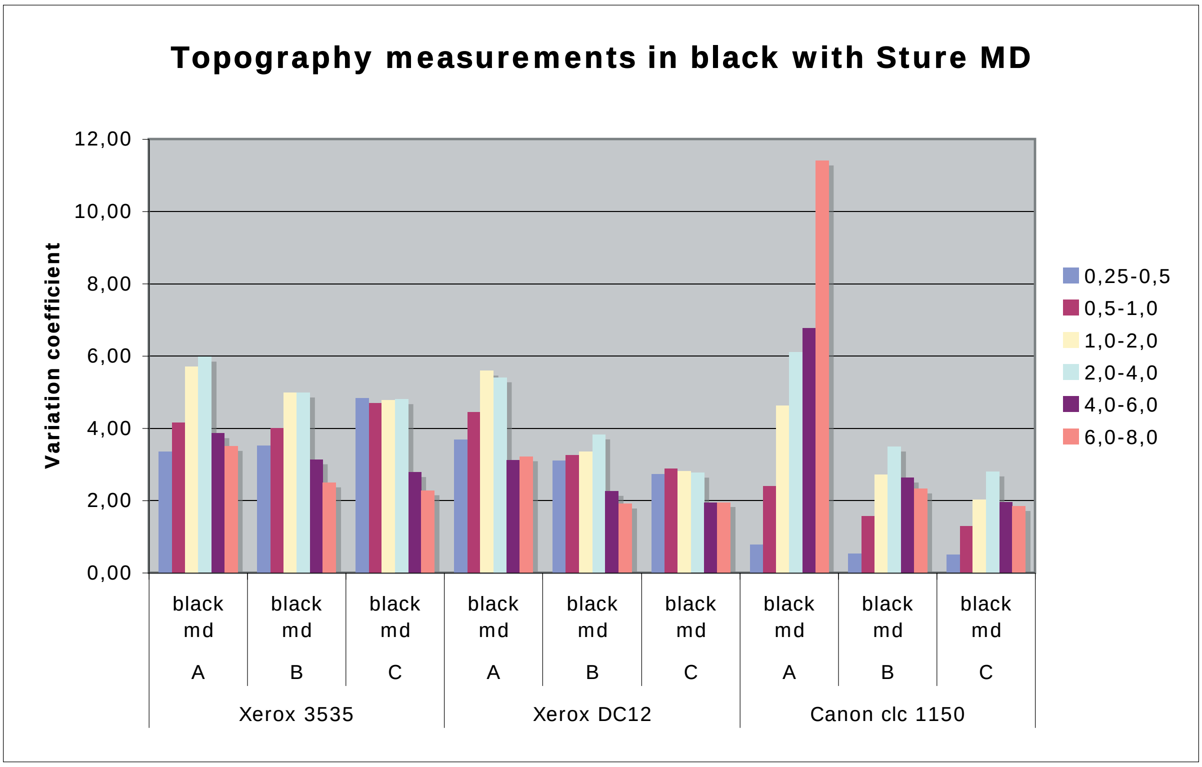
Appendix C- all data of surface topography measurements





Appendix C- all data of surface topography measurements

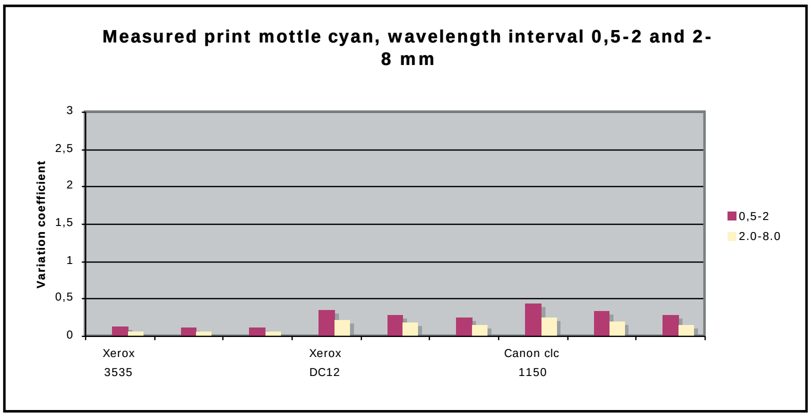




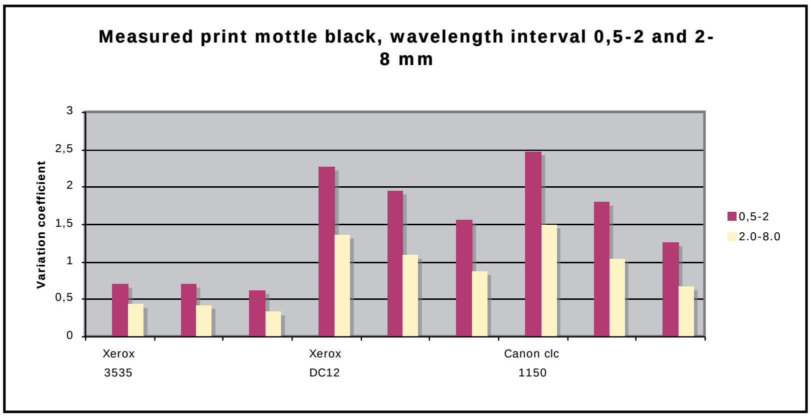
Appendix D- Mottle measurements

1DFFT horisontelt		**mottle**			
				0,5-2	**2.0-8.0**
	Xerox 3535	cyan	Prov A	0,13	0,07
			Prov B	0,12	0,07
			Prov C	0,11	0,06
	Xerox DC12	cyan	Prov A	0,35	0,22
			Prov B	0,29	0,18
			Prov C	0,25	0,15
	Canon clc1150	cyan	Prov A	0,44	0,25
			Prov B	0,34	0,19
			Prov C	0,28	0,15
	Xerox 3535	black	Prov A	0,70	0,44
			Prov B	0,71	0,42
			Prov C	0,63	0,33
	Xerox DC12	black	Prov A	2,28	1,36
			Prov B	1,95	1,10
			Prov C	1,56	0,88
	Canon clc1150	black	Prov A	2,48	1,50
			Prov B	1,80	1,05
			Prov C	1,26	0,67
	Xerox 3535	blue	Prov A	0,64	0,38
			Prov B	0,54	0,31
			Prov C	0,45	0,23
	Xerox DC12	blue	Prov A	1,07	0,65
			Prov B	0,81	0,46
			Prov C	0,56	0,31
	Canon clc1150	blue	Prov A	1,68	0,94
			Prov B	1,03	0,59
			Prov C	0,66	0,38

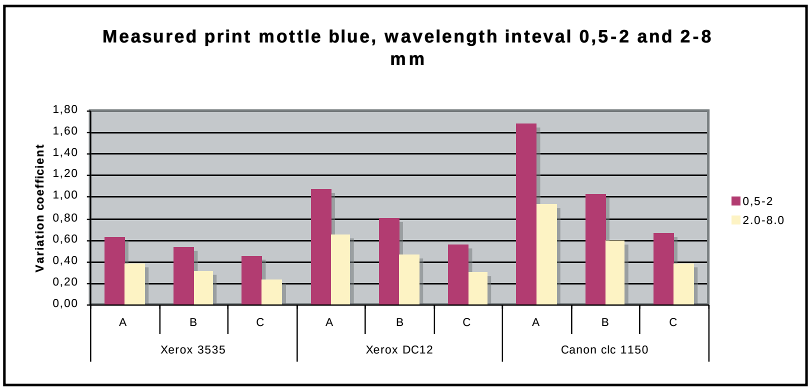
Appendix D- Mottle measurements



Measured print mottle cyan, wavelength interval 0,5-2 and 2-8 mm



Measured print mottle black, wavelength interval 0,5-2 and 2-8 mm



Measured print mottle blue, wavelength inteval 0,5-2 and 2-8 mm