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Contents

In 2005, iarigai, the International Association of Research Organisations for the Information, Media and Graphic Arts Industries, celebrated its 40th anniversary. The organization was founded in Finland and, very appropriately, the 32nd International Research Conference of iarigai was held at Haikko Manor in Porvoo, Finland, on September 4-7, 2005.

The anniversary of the very active and still growing 40-years-old was celebrated in a very fitting way: through the presentation and discussion of research findings from the member organizations and from other organizations in the field. The discussions and the networking taking place at the conference cannot be easily documented, but this volume contains the scientific and technical papers presented. The contributions accepted for presentation were selected by the iarigai Program Committee after a double-blind review procedure, where the submitted extended abstracts were independently and anonymously reviewed by two prominent experts. The papers included here have been subjected only to slight technical editing and the responsibility for the content lies with the authors.

The conference theme was "Digitalisation and print media" and the papers covered a wide spectrum of related topics, from gravure printing of electronics to corrosion in print production, from e-books to colour rendering. In these proceedings, the papers are grouped under eight different headings to make it easy for the reader to find the papers related to a special interest area. The volume as a whole, however, gives a very good overview of the current status and focus areas of research in our field.

The success of the conference was due to many contributors. I would like to thank the authors, the reviewers, the program committee and, especially so, the organizers of the conference: VTT and its dedicated staff. The scientific content, the conference attendance, and the lively discussions all prove that iarigai continues to fulfill its mission and will celebrate a number of future anniversaries.

Nils Enlund
Chairman of the Program Committee

1

Future trends

The media industry as a catalyst for economic growth

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1. Introduction

The rapid development in Information and Communication Technology (ICT) has enabled new media service forms, such as digital television, digital printing and cross media. On the other hand, it has also changed the value chain of the media industry and made the end product more modular. This, in turn, has enabled a decentralisation and outsourcing of the media processes.

However, different companies may choose different competition strategies even in the same market situation. While some media companies concentrate on their core business and outsource as much as possible of their media production, others see managing the whole value chain as an important part of their strategy.

The scope of this study was to analyse the structural changes in the media industry and allied branches, and to find the technology trends and business logics behind these changes. We also wanted to know whether the media sector could become an economic motor for other branches, e.g. by creating new Knowledge Intensive Business Services (KIBS).

The project was carried out in close co-operation with eight Finnish companies representing both the media industry (printed and electronic media) and related branches, such as the forest industry, teleoperators and system suppliers. Although the approach angle was national, the value chain and the structural changes in the media business are today similar in most countries. The media branch is rapidly globalised. Therefore, most trends analysed here should be of interest also to an international audience of media experts.

2. Research methods

In the first step theories about the dynamics of branch structures were studied. Rather much literature were found. Executives from the eight companies were interviewed to find out the value chain of the media industry in respect to customers, products and services, types of contents, formats, markets, competition and strategies. The need for outsourcing of media processes and the corresponding needs for new business services were estimated.

During the project the Steering Committee visited research organisations and companies at the east cost of the USA. American experts shared their viewes about the future of the media sector. Together with the experts of the participating industrial partners the future of the media industry was analysed towards the year 2015. A Delphoi study was performed with the aim to estimate the expected time frames for the technical development and the volumes of different media. The megatrends in the media field were defined, and weak signals indicating hypes and break-throughs were searched for.

Finally, the media future was also studied in four different scenarios: 1) A future without surprises with the discovered trends continuing, 2) A future with strongly and rapidly expanding digital media, 3) A careful and cautious development in the media sector like in the Polonaise dance: two steps front and one step back, and 4) A horror scenario, where the Tsunami waves of the ICT society destroy the media future. The scenarios are described in the Appendix.

3. Results and discussion

The organisation structure of companies in different branches may vary cyclically between vertical and horisontal, as the products vary from modular to integrated (Fine, 2001). The dynamics is often described by a Double Helix model, or by the Lamniscate of Bernoulli - see figure 1. The driving force for the restructuring is the need to concentrate on core business by outsourcing, and the need to strategig strength via integration, respectively.

This phenomenon applies also to the media industry. However, different media companies may be in totally different parts of the organisation cycle dependent on the paradigm chosen and their degree of development. Each company must define its optimum position in this respect, and no general figures for the whole branch can be given (Lindqvist et al., 2005). Figure 2 shows the defined value chain and the core business for a company producing education materials. In Europe electronic media companies are usually horisontal in structure, whereas American are vertical (Soramäki, 2004).

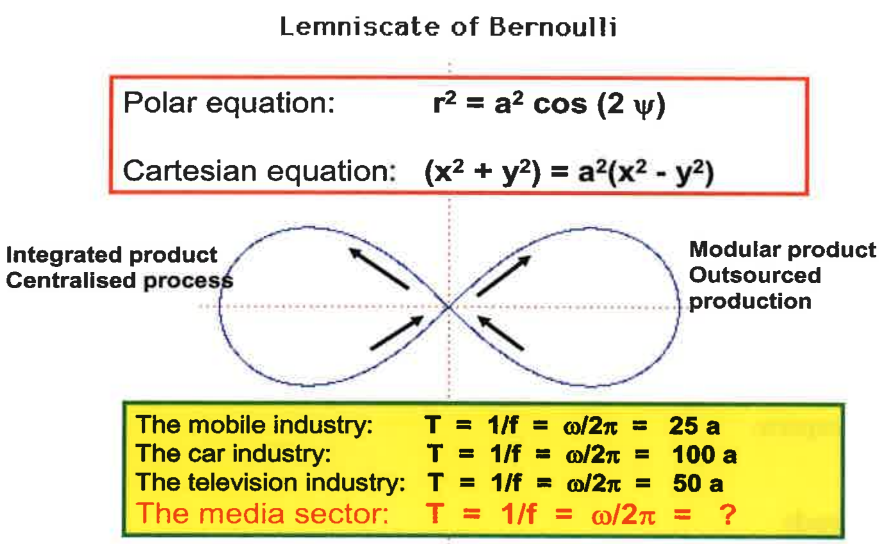

Figure 1: The Double Helix model describes the cyclic changes between vertical and horizontal company structures and modular and integrated products

Internationalisation has started in the Finnish media industry, but much slower than in other branches, like the forest industry, electronics and telecommunications. Big media companies are still mostly in national possession, and the share of export and activities abroad are mostly below one third of the turnover, though increasing (Jeskanen-Sundström et al, 2004). About 15 per cent of the media sector is in international possession and the share is expected to double in ten years.

The time spent on media has increased only marginally during the last years, and is now 9 h 20 min per day - see Figure 3 (Raulos, 2004).

Overlapping use of media has increased and user frequency varies strongly with the time of the day, from working day to weekend, and from season to season (Sabelström-Möller, 2004). Figure 4 shows the overlapping media use in Finland in 2004 (Heinonen, 2004).

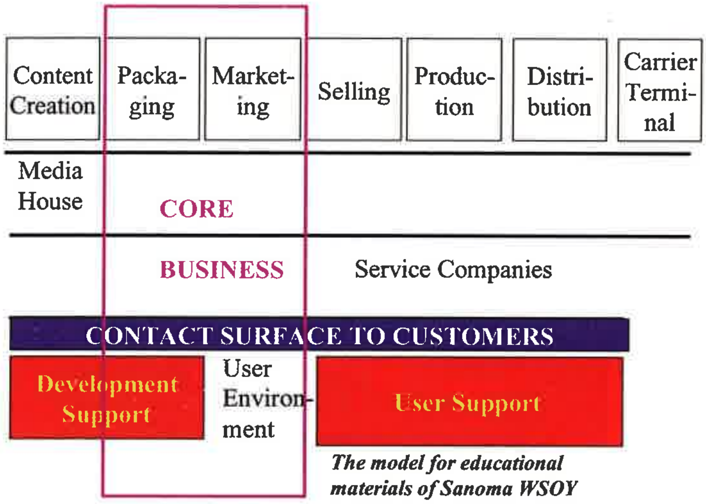

Figure 2: The value chain of Sanoma WSOY for producing educational materials

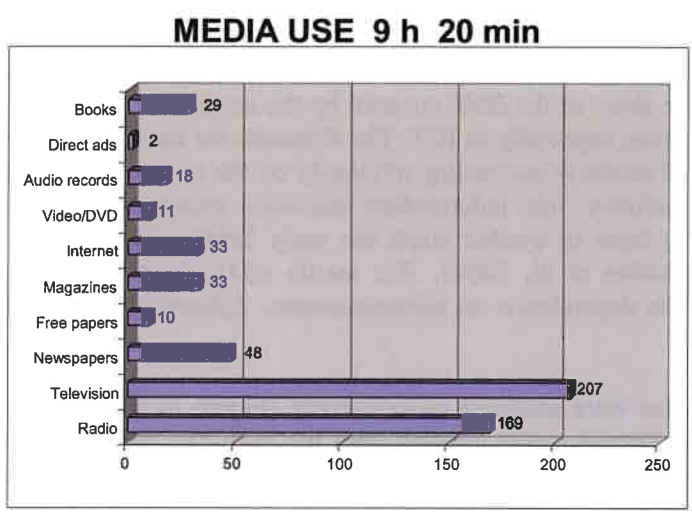

Figure 3: The media use per day and person in Finland 2004

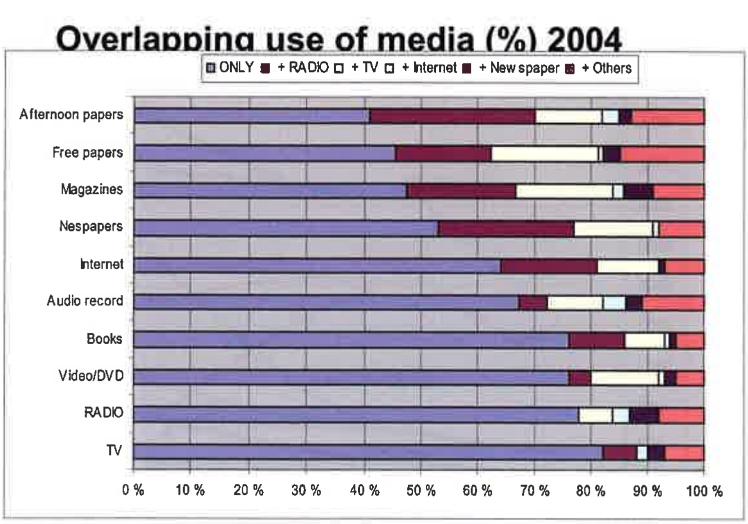

Figure 4: The overlapping use of media in Finland 2004

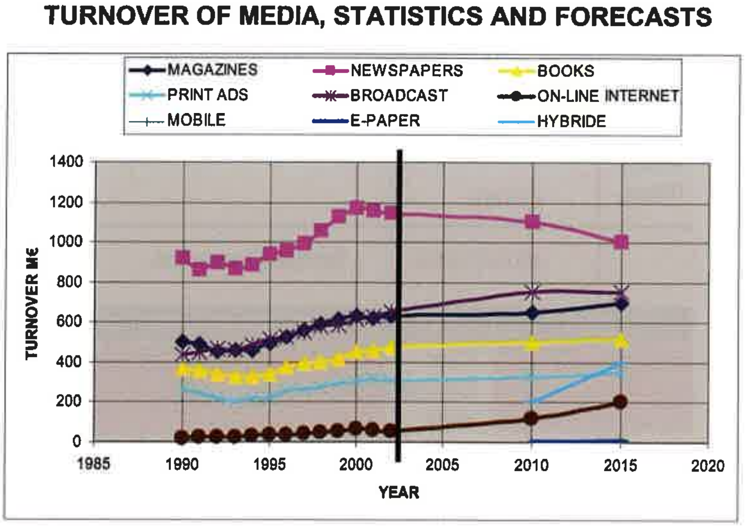

Figure 5: The development and forecasted turnover of the Finnish media industry

Although an increase occurs in the turnover of most media after the depression in the early Nineteenth (see figure 5), the relative share of the BNP covered by the media has been declining. This is due to a rapid growth in other sectors, especially in ICT. The forecasts for the future development are based on a Delphoi study. Targeted media is increasing, obviously on the costs of traditional mass media. Many suppliers to the media industry, like independent television programme producers and commercial television channels, have been in trouble since the early 2000, and the printers suffer from over-capacity (Jeskanen-Sundström et al, 2004). The media sector is also very sensitive to economic fluctuations because of its dependence on advertisements. Advertising is known to react extremely strongly on fluctuations.

Three of the four scenarios were analysed quantitatively (Figure 6) In all the scenarios the expected growth in turnover of the Finnish media industry until the year 2015 remains modest, from 3, 7 to 4 or 4,5 B€. However, the positions of the different media strongly vary between the scenarios. In the future without surprises the turnover of electronic media rises to 30 per cent of the total media turnover, whereas in the rapid growth scenario it reaches 3 B€ and overhauls by far the volume printed media.

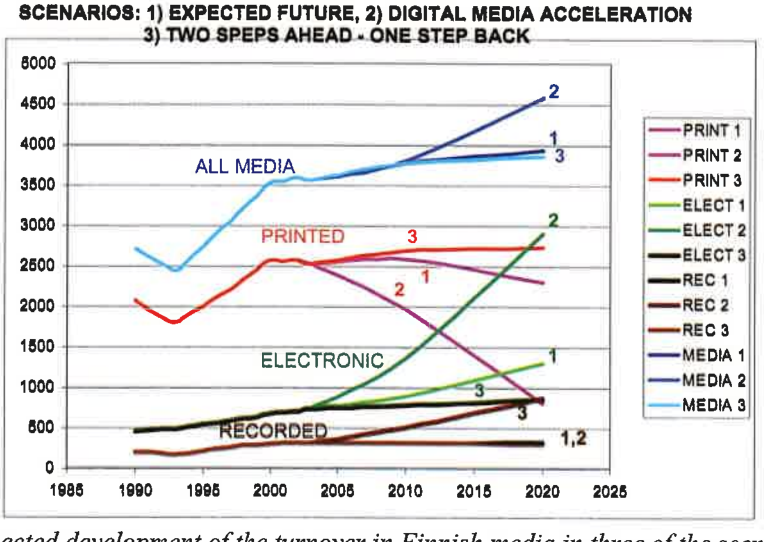

Figure 6: The expected development of the turnover in Finnish media in three of the scenarios

The study offers some general strategic hints to the media sector. First of all, each company should choose its paradigm for process modularity and company structure, depending on to what an extent the company wants to keep the whole value chain "inside" or just concentrate on its core business. This is not a "once and for ever" decision, since markets and environment change continuously. Most changes are cyclic, but the amplitude and frequency of the cycles vary.

The company also needs to decide about its globalisation strategy. The media content is almost always national, or even local, even if the format may be global. Even national contents from small countries may succeed on global market, e.g. in the movie, music and game business.

The media industry also has the ability to create and utilise knowledge based service companies in their production and product development. Such services may be customer service management, treatment of ads, tailored newspapers, distribution and new hybrid media services. In new innovative media services the interaction between content and technology must be fully understood so, that the media company can offer the optimum combination of content and information carrier to the needs of the customer.

4. Conclusions

The media sector can hardly develop to become a new motor for the Finnish economy, if we consider a "motor" to be an economic miracle comparable to Nokia in the Nineteenth. On the other hand, the branch can act as a strong catalyst for many others supporting their technical and economic growth. Such branches are the new "hybrid media", e-Business, advertising, entertainment and games, forest, manufacturing, equipment, telecommunication, electronics and the software sectors. This catalytic effect is decades above the turnover of the media branch itself.

Hybrid media is an attempt to integrate ambient environments into printed products. Using printing technology it is possible to create electronic components, intelligent media and packages. Also e-Business is an increasing area, where the role of the media industry could be of utmost importance. The media sector forms a natural link between the producers of goods and services, and the end consumers.

Another important branch, where the media industry can have a strong catalytic effect is advertisement - see Figure 7. The appearance of new channels and media on the market may at a first glance disrupt media ads and lower their efficiency. On the other hand, they offer opportunities to target the ads to clearly specified groups. The suction of the media can be utilised also to build a cultural industrial ground, where culture can be exploited commercially. The amusement industry, sport entertainment and the increasing game industry are examples of this application.

THE RELATIVE SHARES OF THE MARKETING CHANNELS

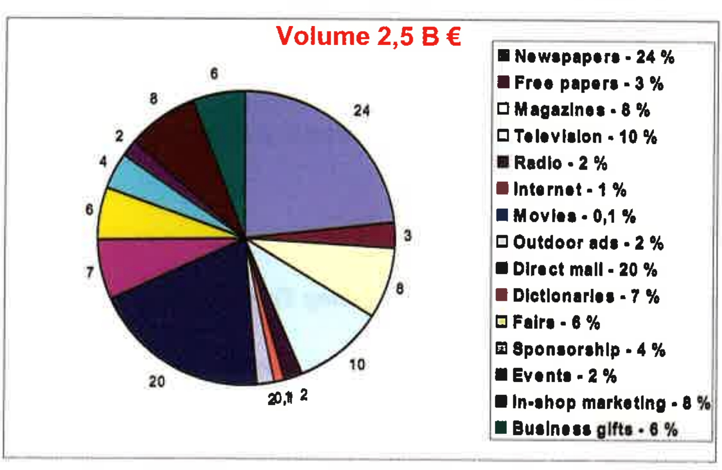

Figure 7: The relative shares of different marketing channels of the advertisement cake in Finland 2003

Nevertheless, the most important catalytic role of the media sector will remain towards the electric and electronic industries, software and telecommunication industries and, last not least, the traditional forest industry in connection with machinery and equipment manufacturers.

The catalytic effect of the media industry has been roughly estimated quantitatively. The total turnover of Finnish companies in the above mentioned branches close to the media sector is today almost 80 B€, and their potential growth until 2015 is even 100 per cent. Even if the share catalysed by the media industry on the growth in these branches on national and international markets is difficult to estimate exactly, it is clear that the economic impact is by no means marginal.

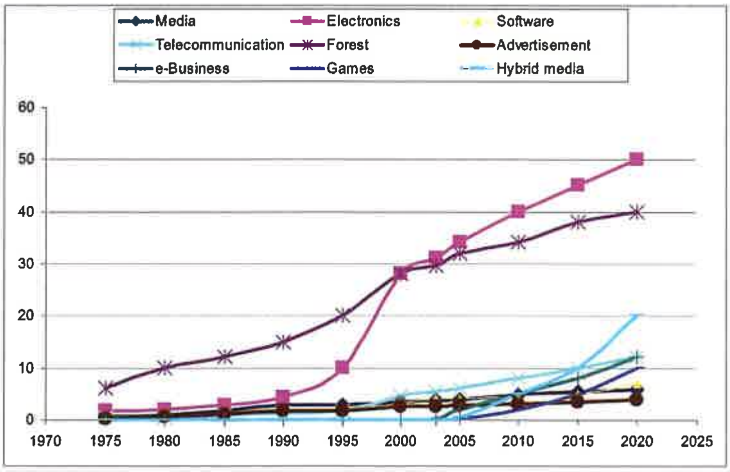

Figure 8: The development in turnover of the most important branches catalysed by the media industry in a historic perspective and their expected future

The research work reported here still leaves new challenges for further research. Such challenges are to build development models for the media sector, to establish a hybrid media network in the boarder area between the forest industry and the ICT cluster and to develop new media services especially for aging population.

Acknowledgements

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Appendix

The alternative four scenarios are:

A future without surprises with the discovered trends continuing

- A slow increase in GDP with economic fluctuations
- Enterpreneurship is strongly supported by national governments
- The further development of the Information Society is enhanced and supported
- New economic motors for the economy are searched for; no real break-through
- The "China Phenomenon" transfers the production and employments to the Far East
- Also South-America is an area for investments, but on a smaller scale
- The Baltic countries and Russia become a reserve for (cheap) labour
- Competition is increased by anti-trust legislation, deregulation and breaking monopols. (The discussion on breaking national monopols for alcohol, broadcasting etc. will continue.)
- The wellfare society remains, but most services are outsourced. Services are effectivated, prioratised and the individual risks are increased
- Immigrants from East and South solve the labour shortage especially in the wellfare sector
- EU develops toward a federal state, the member states become more dependent on EU but EU also on the rest of the world
- Mobile devices in every pocket and broadband to every little cottage
- A symbiosis between big media companies and small production plats
- The content industry remains national although multinational companies eat the mass markets.

A future with strongly and rapidly expanding digital media

- The growth in GDP is modest but contains strong and rapid cycles
- The technology bubble bursted, but the hype returned in damped form
- "The new economy" requires fast grow and market shares; leads to concentration and profitable units
- International ownership - So what? Everything is for sale
- The adventurists are heros and the real motors of the economy
- Those who succeed are rewarded generously but those who fail are not banned
- The head office of Nokia went to US, but some R&D still remained in Finland
- The final countdown started for print media, passive euthanasia started
- A market driven content industry leads to a quantitative overflow
- Common people are offered cheap entertainment, quality jornalism is for the elite
- The youngsters keep all channels on all the time

A careful and cautious development in the media sector like in the Polonaise dance: two steps front and one step back

- The economy is almost in stagnation, wellfare services must be cut
- The return of search for security
- The Nordic "People's Home" requires high taxes, but there are less active tax payers
- Solutions to problems are still searched for in ICT, but only partly found
- Nationality and independent states are important values in EU
- Environmental aspects and honesty become important values
- Immigration is restricted
- Foreign investments are considered odd
- The descent of print media stopped
- Hybrid media is the new hype
- Small states face problems in adapting themselves to the changes in the world economy
- The "Chine Fenomenon" really beats

A horror scenario, where the Tsunami waves of the ICT society destroy the media future

- EU breakes down or some member states leave the Union
- The democratic development in Russia stops
- The cheap labour countries and their tax policy finally break the western wellfare states
- Nokia was taken over by Microsoft
- The increased economic inequality leads to social conflicts and criminality
- The Orwell Society: increased control and limited freedom for citizens
- The media power is monopolised or the governments interfere with press freedom via sensorship
- Multimodal communication systems for the elite, Imposing mass entertainment for the majority, Loosers are left off-side
- Open conflicts between the western world and the islamic world
- Energy crises, prices reach heaven
- Standard of living drops dramatically in the western world
- Mass unemployment, social conflicts, strikes and lock-outs
- Threads for terrorism everywhere; citizens' rights are limite

Detection of printed codes with a camera phone

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1. Introduction

The scope of a research project at VTT Information Technology was to investigate new printed coding methods and their applications in packages. New coding methods such as two-dimensional bar codes, invisible codes, micro text and digital watermarks enable storing large amounts of information in small areas. Invisible codes are any texts, markings or codes that are printed with an ink that can be read only under UV or IR illumination or when exposed to heat. Micro text is very small text, even 1 pt, that can't be read without a magnifying device. Digital watermark is information hidden in digital content such as images, videos or audiotapes.

One advantage of new coding methods is that they can be easily decoded into human readable form with a suitable reading device. New coding methods are printable thus making them easy to be added on printed products such as packages or publications. When using codes for identification and logistics purposes every consecutively printed code has to be different. Digital printing methods enable printing variable data and inkjet printheads can be integrated to presses or production lines online for printing the codes with variable information.

Two-dimensional bar codes consist of lines of bars or cells i.e. usually small polygons and the lines are organized in a square or a rectangle i.e. a matrix. The organization of the elements depends on the bar code type and the information encoded into the symbol. Examples of two-dimensional bar codes are presented in Figure 1.

Figure 1: Linear bar code (far left) and two-dimensional bar codes (others)

Two-dimensional bar codes have many benefits compared to traditional linear bar codes. Two-dimensional bar codes have large information capacity and the information is durable because there are error correction algorithms stored in the symbol. This means that even 50% of the symbol can be destroyed, but the code can still be decoded correctly. Linear bar codes serve as a link to a database, but two-dimensional bar codes serve as an independent database. This enables that the information can be read anywhere if a suitable decoding device is available. Also the physical size of two-dimensional bar codes is scalable without affecting the amount of information.

Two-dimensional bar codes can be decoded by a reading device that has a two-dimensional CCD cell such as CCD scanners or cameras. The reading device interprets the coded information into characters i.e. human readable text. Mobile phone with an integrated digital camera i.e. camera phone can be used as a reading device for two-dimensional bar codes. The basic idea is to take a picture of the two-dimensional bar code. The decoding software installed into the camera phone decodes the information in the bar code and returns to the user the stored information. Two-dimensional bar codes can also be printed with an invisible ink. These invisible codes can be decoded with the mobile phone when using IR or UV light source for making the code visible during imaging like in Figure 2. The advantage of invisible two-dimensional bar codes is that they can be printed on some graphics depending on the ink used since the bar codes only become visible when needed.

Figure 2:
Picture of an invisible two-dimensional bar code taken with a camera phone under illumination from UV lamp

When decoding the information of a two-dimensional bar code, the colour of the symbol can also be detected. One application for colour detection is printed food quality indicators thus enabling combination of freshness information and other useful information in one symbol. Detection of colour change of food quality indicator is based on detecting the colour coordinates i.e. RGB values of a printed area that changes its colour based on a state of a packed product. The colour detection device can tell if the product is fresh based on information given by the two-dimensional bar code. The bar code can, for example, contain the reference values for the RGB values and the detection software compares these values to the detected ones. If the reference values have a too big difference from the detected values the software tells the user not to use the product.

2. Methods

In this study the ability of a camera phone to detect two-dimensional bar codes and colour coordinates were investigated. The camera phone used for imaging was a Nokia 3650 camera phone with an add-on macro lens that improved detection of small details in short distances. There are two lenses in the add-on lens i.e. 50 mm and 100 mm lenses. So a total of three lenses including the original camera lens were used. The camera phone and add-on lens are pictured in Figure 3.

Figure 3:
The camera phone and add-on lens used in the investigation

The imaging distance was chosen depending on the code size and it was typically 40-100 mm. The bigger imaging distances were needed for physically larger codes to be able to fit the code into the focus area. The smaller distances were needed for codes with smaller cells for making the code accurate enough for decoding. Two-dimensional bar codes were decoded with software made by

Intelcom installed into the camera phone. This software interprets the symbol into text, numbers and special characters. Colour coordinates of codes were detected with software developed by VTT Information Technology. This software interprets the RGB values of the coloured area.

Two-dimensional bar codes and colour codes were inkjet printed with Epson Stylus Photo 890 printer. The bar codes were printed with black ink on photographic paper (Epson Premium Glossy Photo Paper, 255 g/m^2). The colour codes were printed with CMYK inks on office paper (Future lasertech from UPM Kymmene Fine Paper, 80 g/m^2).

Two-dimensional bar code type called Data Matrix was used in the study. Data Matrix is presented in Figure 1 at the far right. The physical size and information capacity of the Data Matrix code varied. The physical size varied with the varying cell size. The cell sizes were from 0.15 mm to 0.50 mm at intervals of 0.05 mm. The information capacity varied with the amount of cells in one symbol. The amounts of cells were 10×10, 16×16, 24×24, 48×48 and 64×64. The information capacity of these is presented in Table I.

Table I: The information capacity of Data Matrix codes used in the study (ISO/IEC 16022, 2000)

Number of cells	Numeric characters	Alphanumeric characters	8-bit ASCII characters
10×10	6	3	1
16×16	24	16	10
24×24	72	52	34
48×48	348	259	172
64×64	560	418	278

The printed structure of the colour codes was a square of 2 cm times 2 cm with small squares at the four corners like in Figure 4. Detection software finds the large square to be analysed with the help of four small squares that serve as a locator pattern.

Figure 4:
The structure of the colour codes used

Three test sets of colour codes were used. In the first set the R values of the test fields varied from 0 to 250 at intervals of 25 whereas G and B values remained at 0. In the second set G values varied from 0 to 250 at intervals of 25 whereas R and B values remained at 0. In the third set B values varied from 0 to 250 at intervals of 25 whereas R and G values remained at 0.

3. Results

The results from imaging the two-dimensional bar codes with different lenses are presented in Figure 5. It was found that with camera phones it is possible to detect codes whose smallest detail i.e. cell width is as small as 0.2 mm. This equals a symbol height and width of 12.8 mm if there are 64×64 cells in a symbol thus enabling storing of almost 600 numbers or 300 ASCII characters in this symbol. When using more cells the edges of the symbol became slightly curved and detection couldn't be done. Some distortion is already seen with 64×64 codes as pictured in Figure 6.

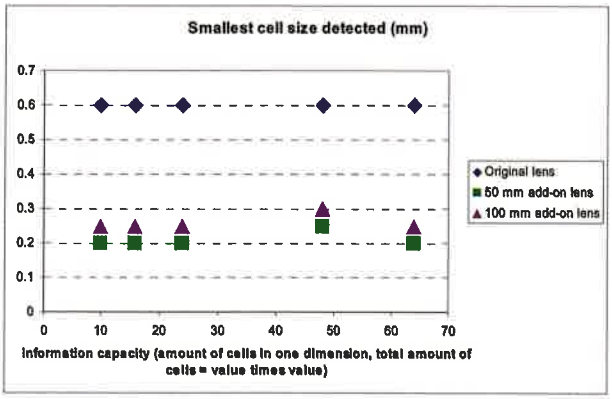

Figure 5: The smallest cell size detected with different information capacities and camera lenses

Figure 6:
Data Matrix code with 64×64 cells with the imaging distance of 50 mm. The cell size is 0.25 mm

The results from imaging colour codes are presented in Figure 7. Due to properties of the red filter in the camera' CCD cell the measured values were multiplied by 2. This was done to correct defects in the camera that affected measured values. It was found that the colour coordinates, when detected with the camera phone, were higher with small RGB values and lower with large RGB values compared to the original values.

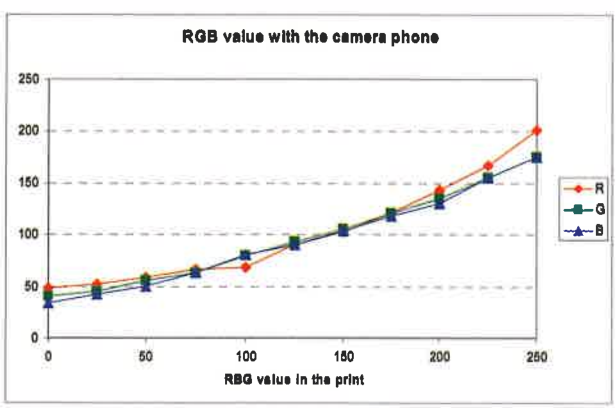

Figure 7: RGB values of the colour codes imaged with the camera phone compared to the values of the print

It might be that the CCD cells of the camera phones aren't yet stabilized enough for reliable colour detection. However, camera phones improve constantly so in a few years time colour detection by camera phone will likely become reliable. After all, the three RGB values behaved all in the same manner so some kind of a calibration could be useful in the mean time the cameras improve. VTT Information Technology is currently working to develop a reliable calibration method.

4. Discussion

Based on the results several applications for the printed codes on the packages integrated with camera phone detection were identified (Hakola, 2004). These applications for two-dimensional bar codes include identification, logistics, additional information, fitting information in small areas and integration of printed and electronic media.

In identification and logistics two-dimensional bar code can individualize the product or transport package, because with digital printing methods every printed code can be different. At any one time during the logistics cycle the code can be decoded with a regular camera phone and the individualizing information in the code read. The information in the code can be product or batch numbers, manufacturing and shipping dates, country of origin etc. With two-dimensional bar codes even consumers can get information on the precise product.

In addition to legal markings additional information on packages is useful, because nowadays there are a lot of people with allergies or special diets. These people could check from the information in the two-dimensional bar code if the packed product is suitable for them. Product information can also be encoded into the symbol and saved into the phone or, for example, elderly people can magnify the text into the mobile phone screen.

When coding the information less space is needed than when writing actual letters and numbers. Because the codes don't need as much space as written text, many special groups can be served in a small area. This idea also serves package designers that have to take into account all the markings required by legislation. The product manufacturers want to have additional information in the packages and two-dimensional bar codes are a one way to fit much information into the packages thus leaving more space for marketing texts and impressive designs that promote sells.

Figure 8:
Example of reading a two-dimensional bar code from a package with a camera phone

The additional information doesn't necessarily have to be in the bar code. The code can also serve as a link to a database where more information can be found. The code can contain an internet address and user can log into this website with the network connection in the mobile phone. Internet addresses can be very long and spelling mistakes can be eliminated by reading the address directly from the bar code.

Applications for the colour codes read by a camera phone include reliable detection of colour changes on quality indicators as well as making sure not eating, selling or purchasing spoiled groceries (Linna, 2004). Because the human eye isn't always reliable small colour changes on quality indicators can go unnoticed. If the consumer hasn't noticed that the grocery is spoiled, he can get sick. Retail stores also need quality control for making sure that they don't sell spoiled products that could harm the consumer. With camera phones the product freshness can be easily checked even when the products are already on shelves or at the cash desk..

Figure 9:
Example of a poultry package with a quality indicator

There are yet no legislations that determine what colours to use in food quality indicators so there can be a variety of colour combinations with the same colour indicating fresh or spoiled product depending on product and manufacturer. This is why the two-dimensional bar code that tells the reference RGB values is needed. This way the consumer can be absolutely sure that he has interpreted the colour codes correctly. VTT Information Technology is currently developing software for this.

5. Conclusions

In this study it was found that the camera phones are suitable for detecting even very small printed two-dimensional bar codes, but add-on lenses are needed. It is, however, expected that camera phones will have higher resolution and better lenses in a few years time which will result in detecting smaller cells and more characters in one symbol. Printing methods, both conventional and digital, are capable of printing smaller cells than can be detected with a camera phone (Print Access, Final Report 2005). As a result there is potential for using smaller cells and larger information capacities when camera phones get better. Camera phones can also be used for detecting colours for purposes such as food quality indication, but for reliable detection better CCD cells or colour calibration is needed.

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Reading with eBooks

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1. Introduction

The eBook can be defined as "a book composed in or converted to digital format for display on a computer screen or handheld device" (Merriam-Webster). EBooks have been predicted as the big challenger or even a threat to print books for a long time. Despite predictions about paperless offices the real threats to the print and paper industries haven't materialised yet.

In Finland, it is perhaps too early to predict the downfall of the traditional print books, since 2004 proved to be a hugely successful year for the book publishing industry. This proves an important point: people are still reading books even when there are so many other mediums competing for their attention. The question we are asking now is whether they are willing to change the way they read their books and start reading electronic books, or whether books printed on paper are just the thing users want in this rapidly electrifying world?

Mobility is a key issue when designing eBook readers. A traditional book is mobile; it fits into a small bag, can be read almost anywhere and its batteries won't run out. Portability is essentially what people want from an eBook reader as well: lightness, thinness and paper-like qualities (Onabe, 2001). With today's display technology, producing a device like this hasn't been an easy task. LCD displays traditionally require a backlight, which in turn consumes a lot of battery power. Short battery life remains an issue that will hinder extended usage. (Harrison, 2000)

The content is eventually the most important thing: if it's interesting, people will read it, no matter what technological limitations there are. EBooks have the advantage of being quick to update and launch. Rapidly changing areas of business, research and science suffer from the long deployment time of print books, because the content becomes obsolete very quickly. Also, if there is only a niche market for a book, it might not get printed. In the mass market, it is hard to service the needs of individual consumers. EBooks offer also a market for writers who would otherwise find it difficult to get published. The material available through eBook resellers can be a lot more varied than the books offered through traditional print publishers. (Anderson, 2004)

The displays used with basic home computers are not optimal for long reading sessions. Many people still have old CRT monitors that are quite tiring for the eyes. After a long day in the office spent staring at a computer screen, many people really want something else at home. It's often much easier and more comfortable to use paper. The thickness of the book, the turning of pages and riffling through them gives the reader a lot of navigational information and an overall sense of the book. With scrollable pages and reflowing text the sense of the book is often lost and the user has a difficult time deciphering the amount of text that remains to be read. These are important factors that must be considered when designing an eBook reader. (Schilit at al., 1999)

Using today's displays, reading from screen is approximately as fast as reading on paper, but it is still sometimes experienced as uncomfortable or slow. This is partly due to the contrast and resolution of screens when compared with paper. Other aspects that affect the screen reading experience are for instance line lengths, line spacing, reflections from the display, text scrolling and navigational clues. (Hänninen, 2004)

The purpose of this study was to find out how willing people are to accept a new way of reading books. The main focus was on the subjective satisfaction of the users after their eBook reading experience. Based on the replies and reactions of the test users we wished to gain insight on the pleasurableness and potential future success of eBooks and eBook devices. The usability of eBook devices was estimated for instance in comparison to reading on a traditional computer screen. Another goal wais to find out how paper compares to these reading devices: whether the devices are good enough to substitute print for some people; what the users see as the strengths of paper and of electronic devices and how paper could be developed to rise to the challenge of new technology.

2. Methods

The test part of the study was conducted in three successive two-week periods. The users filled out a questionnaire before and after their test use period, and the questionnaires were followed up with group discussions.

After the group discussion, the test period started. Prior to receiving the device some material requested by the users was loaded onto the devices. The users received an eBook device, either an iPAQ or a Tablet PC, for two weeks. The users had a possibility to request a certain device. Of course, it would have been possible to randomly distribute the devices, but then the users' initial dislikes for certain devices might have affected the outcome. Additional tests were also carried out with a Nokia 7710 smart phone and a Rocket eBook device. More information on the devices may be found elsewhere (Pietilä, 2005).

After the two-week test period, every user filled out a satisfaction questionnaire asking basic satisfaction questions about the device, the software and the content, using for instance the SUS usability scale. The SUS (Standard Usability Scale) is a freely available, standardised scale, developed in 1986. (Brooke) One user was asked to test and use all devices. He then evaluated all the devices on the SU scale. Thus we were able to get a SUS ranking of all the devices available.

An important goal was to find out how paper compares to these reading devices: whether the devices are good enough already for some people to give up using paper; what they see as the strengths of paper and of electronic devices and how paper could be developed to rise to the challenge of new technology. The users were asked to fill out a satisfaction questionnaire about printed material in addition to the questionnaire about electronic material.

The test users were employees of Oy Keskuslaboratorio - Centrallaboratorium Ab and their families. The fact that all of the primary test subjects worked for the paper industry might have affected their initial attitude somewhat, because eBooks are an alternative to paper. The test subjects were between the ages of 5 and 56, the average age being 32 and the total amount of test users 16. Of the seven families in the study, three had children, and four children under 18 also participated in the study. Of the 16 test users, nine had a university degree. Half of the test users were female.

3. Results and discussion

After the initial group discussion, it was apparent that the users seemed quite worried about the readability of the screen. There was also a slight problem with the material: there were very few Finnish eBooks available, and Finnish material for children was even scarcer. For some languages, there was no material available in other formats besides PDF, and encrypted PDF files couldn't be viewed on the Pocket PC device.

Readers also expressed some concern over the technical aspects of the devices. For instance, if the battery on the device should run out during a trip, reading would be abruptly interrupted. It was also seen as possible that the fear of breaking the device would prevent people from taking their eBook readers along when they leave home. Small size and other useful functions besides the eBook reader were also seen as contributing factors to the users' willingness to carry the device along. Users were somewhat doubtful about the literary quality of self-published works, easily associated with the variety of material available on personal web sites.

3.1 Reading habits and computer use

Only one family out of the seven participating in this study didn't have any kind of device that could be used to read eBooks at home. The users were quite experienced at using computers and quite avid readers as well. Only two users had read nothing on screen. The participants hadn't had much experience with entire eBooks, but newspapers, magazines and long word processor documents were familiar to a majority of them. 10 participants said they read newspaper and magazine websites at least a couple of times every week.

On average, people were willing to pay more for hardcover and paperback books than for eBooks. People were ready to pay on average 23 euros for a hardcover, 14 euros for a paperback and 9 euros for an eBook. This seems to imply that the users really expect to benefit from the lower production costs of eBooks and get them at a lower price.

3.2 Satisfaction questionnaires and group discussion

The users were given satisfaction questionnaires to fill out the moment they returned the devices. This was to ensure that the users would be able to answer the questions while they still had vivid memories of their own use period. Some of the questions from the preliminary questionnaire were repeated in the satisfaction questionnaire in order to determine how attitudes and feelings had changed after the test use period.

3.2.1 Test period experiences and discussion

The users were asked to give their opinion on the device they used on five different aspects. The results are presented in Figure 1.

The Tablet PC got a lower score for every characteristic. The difference is significantly large for the aspects of lightness, where the iPAQ got an average result of 4.1 and the Tablet PC scored an average of 1.9, and for the ease of handling with iPAQ scoring 4.3 and the Tablet 2.8. The devices are nearly equal when it comes to the quality of the display, the battery life and the robustness.

The size of the Tablet affects its score for the ease of handling. Unlike the iPAQ, it can't be held with one hand - and not even with two hands for a long time, if there's no other support. Heavy things are harder to handle than small, light devices, and with heavy equipment the fear of dropping the device is often bigger. It's surprising that the iPAQ got slightly a better score (3.9 vs. 3.6 for Tablet) for robustness as well, although smaller and lighter devices could be seen as flimsy. Despite its compact size, the device felt robust and the users weren't afraid that it was going to break in their hands.

Although screen quality was one of the main concerns before the user experiment, both devices got very high scores for their screens. Users may have compared the LCD screens on the devices to their desktop CRT screens and found them more comfortable to use.

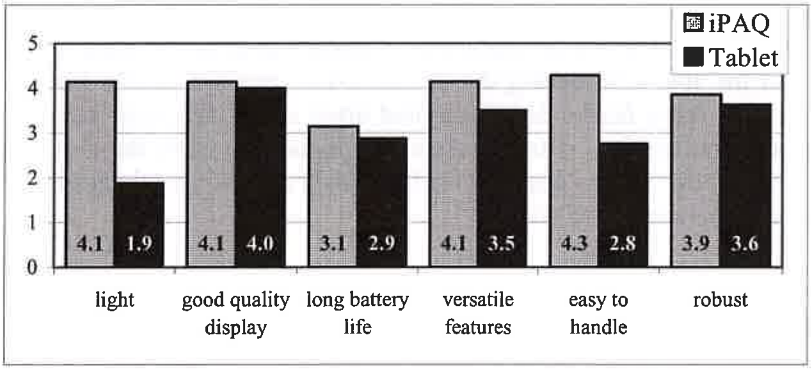

Figure 1: Characteristics of the device used

The participants were given a list of device and material features, and they were told to choose the three properties they felt were the most important to them. 15 users responded, and the results were quite clear. The results can be seen in Table I. The cells marked in bold typeface and an asterisk (*) are eBook content properties. Affordability is appreciated as a property of both content and device.

Table I: Most important device and content features

Feature	Users
lightness, portability, small size	12
extensive selection (*)	11
readability, quality of display	11
affordability (*)	7
ease of reading (*)	7
long battery life, wirelessness	6
affordability	4

Readability is fundamentally important. Although backlight and battery life came up very often in the open questions, they're not among the top three features chosen here. Instead, people are still emphasising the importance of a good quality display and its readability. The lightness, small size and portability of the device are also important, and especially so for the Tablet users, who have experienced using a heavy device.

The answers here revolve around a couple of significant themes, and it seems that most users agree on the most important things but have probably chosen a different option to express their opinion. All the people who didn't pick screen qualities among their three most desirable elements of an eBook device emphasised mobility: their choices were portability, wirelessness, lightness of the device, small size and long battery life, for instance.

A similar comparison was done with material, or actual eBook, properties. 11 users out of 16 picked "extensive selection" as one of their three most important features. This further emphasises the statement that "content is king".

Affordability is another important issue. Many users don't want to pay the same amount of money for something non-physical than they would pay for a printed book. Users were also willing to keep an eternal right to use the material and be sure that their material is preserved so that it can be read even several years later. This is a valid concern, because so far we have seen technological advances make old files and software obsolete.

The users were also asked what they thought of the display quality with regard to reading eBooks. Perhaps a bit surprisingly nobody thought the display quality to be bad. Out of the 15 users - one of whom had used both devices - who responded this question, three thought the display was very good (two iPAQ users and one Tablet user) and thirteen thought the display was quite good (6 iPAQ users and 7 Tablet users). The user who had used both devices had rated the iPAQ display as very good and the Tablet display as quite good. It seems that the screens were better than what people had anticipated. This result seems to imply that display technologies are nearly good enough in terms of quality.

Only one iPAQ user had managed to read several books. Five users, three of them iPAQ users, had read one book. Five people, all of them Tablet users, said they'd read parts of several books, and six people, three iPAQ and three Tablet users, had read part of one book. Again, iPAQ users had been reading somewhat more, but all in all, the scores are quite equal. The reasons for not finishing a book were multiple. Six people answered that they hadn't had enough time. Two users answered that the material was too difficult to read, for example because of the language. Two Tablet users thought that reading was too uncomfortable and that's why they didn't finish a book. One user also answered that the material wasn't interesting.

Many people were concerned about the readability of the screen, and many fears focus on the symptoms that reading on a display can cause. For the questionnaire, most commonly reported screen reading symptoms were listed and the users were asked to report all the problems they experienced. The results can be seen in Figure 2.

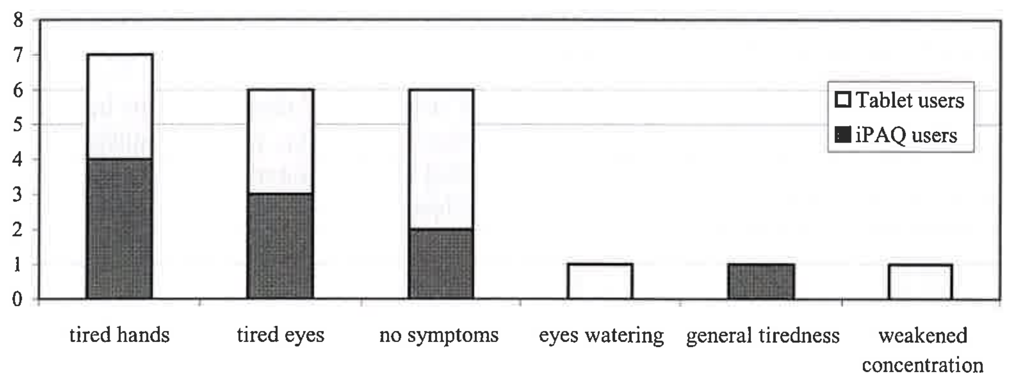

Figure 2: Symptoms experienced with eBooks in comparison with reading paper documents

Six users experienced no symptoms that would differ from ones experienced after reading paper documents. 15 users answered this question, and five of the nine users who did experience something said they had multiple symptoms. The most common symptom was tired hands, experienced by four iPAQ users and three Tablet users. There was a much bigger share of Tablet users who didn't suffer from any symptoms. This is surprising because many Tablet users seemed less impressed with their device's readability and comfort of use than their iPAQ using counterparts. Tablet users generally had used the device somewhat less than iPAQ user, so maybe there was less long term reading on the screen and thus less symptoms.

EBook use substituted mainly print reading. However, whatever the activity substituted by eBook use was, none of the users said it replaced the first activity altogether. 13 out of 15 users responded that the replacement wasn't complete, two couldn't say. Also, when asked whether this - even partial - substitution could be permanent, if the users had eBook devices after the experiment, only one iPAQ user (whose eBook use had substituted electronic media use) thought the change might have been permanent. The majority of the participants, nine users, answered that they didn't believe that eBook use would have permanently substituted any of their aforementioned activities.

Only two people doubted their future interest in eBooks. Twelve users were carefully positive, answering either that they are interested in eBooks if they are cheaper than printed ones or that they are already somewhat interested. In the future, some of the participants may consider eBooks as an option, especially if they have a good reading device available. Nobody had purchased eBooks yet, but at least one user had downloaded some more Project Gutenberg titles on his computer.

Finally, before the SUS evaluations and the open questions, the users were asked to compare eBooks as a reading platform with printed material and regular computers. The participants of this study preferred their eBook devices to regular computer screens used for reading. According to four users, regular computer screens and eBook devices were about equally pleasant as reading platforms. Six users thought the eBook device was somewhat more pleasant for reading than a regular computer screen, and four users thought their eBook device was significantly more pleasant than a computer screen when reading. Again, iPAQ users were generally more satisfied with their device.

One iPAQ user thought that reading on the eBook device was somewhat more pleasant than reading on paper, and two iPAQ users thought that reading on the device was about equally pleasant as reading on paper. Other users still preferred paper, with nine users (4 iPAQ, 5 Tablet) saying reading on the device was somewhat less pleasant and two Tablet users saying reading on the device was significantly less pleasant than reading on paper.

In Figure 3 on page 22 the results of the comparison between eBook devices and printed documents are presented. For comparison purposes, the results for Tablet and iPAQ are separated, and the results of the preliminary questionnaire are also shown. These results are from 7 iPAQ users and 8 Tablet users.

The biggest differences between the average results of iPAQ and Tablet users are in the ease of use and the affordability of eBooks. The differences between the quality, ease of reading and reliability characteristics is also significant. It seems that the iPAQ has surpassed expectations, but the Tablet hasn't done quite as well. Both devices have scored lower on the versatility scale than what was expected in the preliminary questionnaire.

In many of these cases, it's easy to see that the device has affected the ratings given to eBooks, although eBooks are just the content and the device is only a medium to display them. Tablet users haven't been very impressed with the device, and it has especially low scores for the ease of use. The general bigger satisfaction of iPAQ users in comparison to Tablet users is apparent through most of the results. Of course, the initial attitudes scores are an average over all the users, and the figures don't tell whether the change was especially big for the users of a certain device.

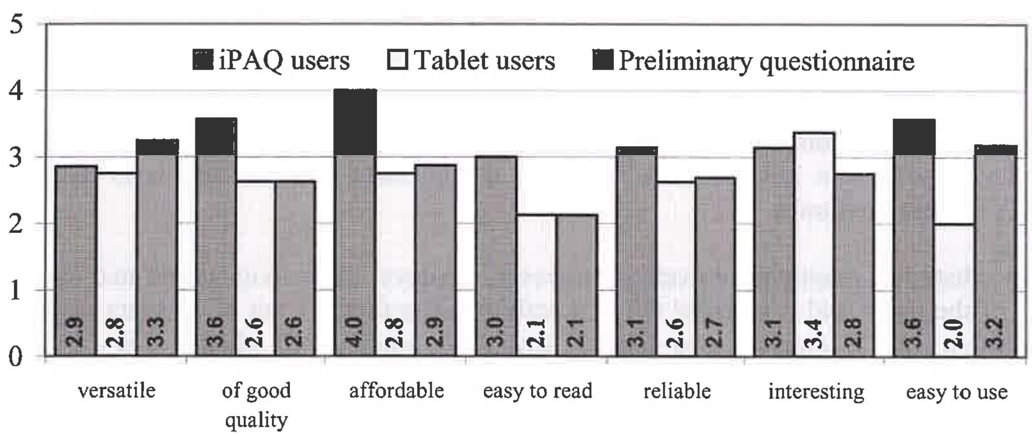

Figure 3: Comparison of print and eBook characteristics

3.2.2 SU scores

The respondents were asked to fill out any forms that were relevant to the devices they had used. In total, 6 people completed the Table PC questionnaire and 7 people completed the iPAQ questionnaire. Regular computers were rated by 12 users, the Nokia 7710 smart phone by one user, Rocket eBook by 5 users and printed material by 15 respondents.

It's quite obvious that the questionnaire was not designed to be used with printed material, and it's thus not very surprising that the scores received by printed material were significantly higher than the scores of other eBook platforms. However, only two people of the total 15 users who rated printed documents gave printed material the full score of 100 points.

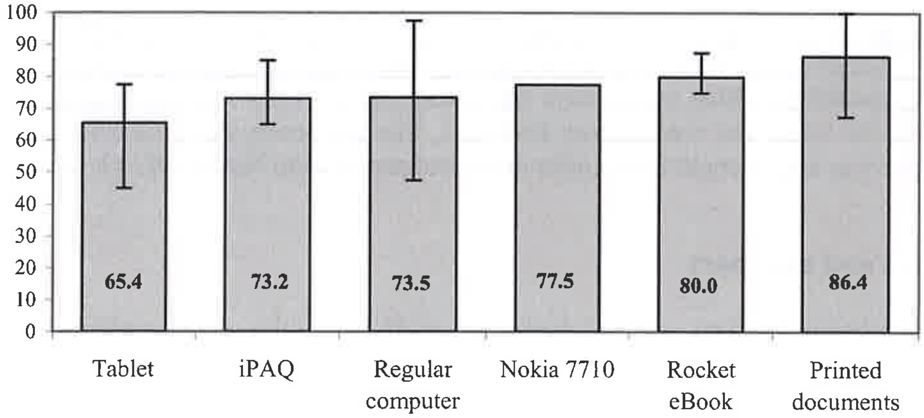

Figure 4: Device and platform SU scores

Printed material performed best in the reading platform comparison, receiving an overall average SU score of 86.4 out of 100 with the highest individual score at 100 and the lowest at 67.5. Of the actual eBook reading devices, the highest overall score of 80.0 was obtained by the Rocket eBook. The lowest individual score of all was 45, given to the Tablet, followed closely by the regular computer at 47.5. Incidentally, with the exception of paper, the regular computer also scored highest at 97.5, probably because of its familiarity to users. The overall scores can be seen in Figure 4. The Tablet, although a standard computer and therefore probably initially more familiar to users than the iPAQ, received a significantly lower overall score. All in all, Tablet users were not as satisfied with their device as were the iPAQ users.

The Nokia 7710 scored quite well, but since only one user was able to use the smart phone, the result isn't definitive. It is interesting to see that users were very happy with the Rocket eBook device, since there isn't much variance in the ratings.

3.2.3 Problems and strengths of eBooks in use

The users were asked to report what were the problems and weaknesses they encountered during their use. Many problems were related to device size and ergonomics. This seemed to be a problem especially for Tablet PC users. Battery life wasn't satisfactory, and some users thought the screen wasn't good enough. Many users expressed their difficulties in discerning the book and keeping track of where they were. There were also content problems, especially due to the limited availability of material on languages besides English.

There were some positive points to using eBooks as well. Many users commented on the saved storage space, because it's possible to fit all your eBooks on a single hard drive. There were also some practicality issues that emerged. Some users commented how it was easy to read on the screen, and many thought the backlight was a good extra benefit. The ability to get books quickly on the Internet was also a significant advantage.

3.2.4 The advantages of paper over eBook devices

As the experiment was supposed to be a comparison of electric and printed material, the users were asked to make this comparison and report their thoughts on the advantages of paper as well as the advantages of eBooks.

Paper was complimented for its reliability and readability. Users also thought that one of the appeals of paper it that people have grown accustomed to using it. It's a habit, and a pleasurable one at that. The short deployment time of paper was also a bonus, because you can just open and close a book and start reading immediately. Other issues were the readability of paper in direct sunlight, the fact that paper books can be taken and read almost anywhere, like the beach and a summer cottage with no electricity. Paper was also thought to be easier to control and discern because it's physical.

4. Conclusions and summary

Many users were hesitant at first, and had doubts especially about the screen quality of the devices. In the end, many users were surprised by the screen quality. Generally, Tablet users were more dissatisfied with their experience, because the device took too long to start up and was big, heavy and clumsy. This was reflected in their overall responses and satisfaction, which was on average significantly lower than the satisfaction experienced by iPAQ users. These differences can also be seen in the SUS scores.

Despite an overall careful response, the users found some benefits in eBooks, namely their backlight and the possibility to save space. Many new promising and energy-efficient technologies, such as electronic paper, are based on principles that don't naturally provide backlight. Since short battery life - mostly caused by the display and its backlight - was one of the biggest problems of eBook devices according to users, it is hard to find a balance between the benefits of backlight and its tendency to shorten battery life.

One problem faced with the experiment was the very limited availability of Finnish material for the devices. If there is no appropriate reading material available, advances in eBook device technology will have only a marginal effect on the popularity of eBooks. If there are no readers, there is no incentive to produce eBooks. Many publishers and users alike are treading carefully, since eBooks have been hyped before and they have failed to meet the expectations. Despite this, eBooks still have a very solid and loyal reader base and specialised publishers worldwide, but these literary works and their producers are still relatively unknown to the large public. There has to be current Finnish material available, if eBooks are to gain a substantial share of the Finnish book market.

The users who participated in this study were in the end somewhat interested in eBooks, but still a bit cautious. The success of eBooks in Finland will depend on several factors, including the economics of eBooks.

Print is often seen as a luxury product when compared to its electronic counterpart. If eBooks are priced like printed books, there will be a tough competition. In many cases, people seem to pick an option based on the "least effort" principle: whichever option is the easiest, most satisfactory and most comfortable. If eBooks are readily available, affordable and comfortable to read and the selection is large and varied enough, they have a good chance of gaining at least a small share of the market. The sales of eBooks have steadily grown worldwide, and they show a lot of potential.

It's hard to predict eBooks as the first choice for most users yet, since the general opinion seems to be that they are uncomfortable to read. The issues regarding preservation, credibility, copying, lending and reselling may further hinder the potential readers' enthusiasm.

Many users are also reluctant to invest in a separate device, especially if they feel they don't get value for their money. Since eBooks are now only slightly cheaper than printed paperback books, one would have to read perhaps dozens or even hundreds of books to break even financially after the purchase of a device. Some users don't wish to carry along extra weight in the form of a specialised device, because they have so many things to carry already. The device needs to be small and light. There's a big possibility with large-screen mobile phones and PDAs that are often carried along anyway, and eBook reading software would be just another application for which people could use their mobile devices. The relatively small screen size didn't seem to bother users much, once they got immersed in the book they were reading. If eBooks come to cell phones, it's natural that reading devices become personal, and eBooks tied to their devices will not be given even to family members, unless they can be copied onto another device.

Based on the experiments and conclusions of this thesis, it's time to answer the questions posed in the beginning. EBooks can become serious contenders, but they aren't ready for mainstream use yet. There's little or no belief in eBooks after the first wave of failures, and many publishers and device manufacturers appear to lack courage to try again. Devices will still have to come a long way to be accepted by the majority of users, although they are already good enough for some. The issues of good screen quality and readability versus backlight and long battery life have to be resolved. There needs to be more content in eBook format so that everybody will find what he or she wants.

Further research into the use of eBooks in mobile phones with large screens would be interesting, since they are a good candidate platform for electronic reading. Still, eBooks are not likely to replace printed books in the near future, but they might be an addition to traditional publishing, making available material that otherwise would be unobtainable.

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Media use of young university students in Helsinki area

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1. Introduction

Our media environment has changed over the past 15 years because of the rise of the new electronic media. The children of the 1990's have never known a world without interactive video games, personal computers, the World Wide Web and instant messaging (Roberts & Foehr 2004). Even their older siblings (born in the 1980's) have become acquainted with the new media not later than at school. The change has affected our ways of communication and information retrieval and also our ways of spending free time in all age groups. Therefore, from the point of view of paper consumption and the use of print media in the future the Finnish forest industry is interested in the habits related to the media use and the reasons behind these habits (Seisto 2003).

One particularly interesting group is young university students (aged 20-24) as media users. They lived their early childhood without the Internet or mobile phones, but as teenagers they were already familiar with these new technologies. Now as university students they are able to and also often forced to use different media because of their studies and way of life. The statistics also show that this age group (20-24) is the most active in using electronic media in Finland (Intermediatutkimus 2002). Therefore the central question that can be stated is: what role does print media play in the lives of these students?

The objective of this study was to investigate and understand the media use of young university students living in Helsinki area. The focus was especially in the use of print media. The idea was first to find out, which media are often used and especially which media are considered as the most important in their lives. The media environment in the study included basically all media from traditional media of mass communication (books, newspapers, radio, television etc.) to the electronic and communication media such as the Internet and mobile phones. Face-to-face meetings were also included in the form of communication media. So the term 'media' was seen in its broad sense as in the research of e.g. Roberts & Foehr 2004, Suoninen 2003 and Thompson 1995.

However, the idea was not just to list these important media but also to look at the lifestyle related to the media use of the students and to find out the reasons behind their behaviour. That led to the idea of searching for different *media user groups* from the point of view of print media. This analysis also included a biographical approach, i.e. what kind of media related experiences the target group had in their childhood.

2. Methods

Data collection

The target group included 13 students (aged 20-24; 5 male and 8 female) from University of Helsinki (9), Helsinki University of Technology (3) and Helsinki Polytechnic Stadia (1). Most of the students represented social, political and behavioural sciences. The students chosen for the research can be seen as an 'optional sample' (Eskola & Suoranta 1998.) The number of the people can be quite low in the sample and the idea is to examine very carefully this group, which is typical for qualitative research such as this study. As important is also careful selection of the people. The students for this research had to be full-time students (occasional working was allowed), aged 20-24 and living in Helsinki area. The amount of both male and female students had to be adequate. Also personal motivation related to media use habits and research was highly hoped for. The idea was not to look for media professionals or new media 'freaks', but students who are interested in using different kind of media and have enough media use experience for this kind of research.

The data collection methods were media diaries and interviews. The data collection process was implemented so that first every student had to fill in the media diary during a period of four days (incl. 2 weekdays and 2 weekend days). In the media diary there were four items to fill in related to every single media use occasion: Time of use, the medium which was used, the purpose of the use and how suitable the medium was for that specific purpose. The students were given a list of the media they should observe, but if necessary it was also allowed to mark down media outside the list.

After returning the diary each student was interviewed. The interviews included certain themes concerning present media use, childhood and future. Under the theme of present media use there were four sub-themes: The media environment (i.e. which media are used), media-related routines in everyday life, media contents and contexts related to media use (such as studying, working and free time). The themes in relation to childhood and future were more free in nature, the students were asked to tell quite freely about their experiences, memories and assumptions related to childhood and future media use.

This method combined aspects from media-ethnographical and biographical approaches. The ethnographical approach often requires the researcher's participation in the life of the subjects (Heyl 2001), but in this case it would have been impossible or at least very difficult to live four days separately with thirteen students. Therefore the media diaries were the appropriate tools for gaining information about the subjects' everyday life. Also in the interviews questions about everyday life and daily routines were included, so the method followed the tradition of ethnographic interviewing. The biographical approach added the aspect of life history, which fits well within the ethnographic tradition (Heyl 2001; Plummer 2001). This approach is quite fresh in the field of media use research (see e.g. Kärki 2004). The understanding of subjects' life experiences gives a better possibility to achieve deeper understanding about their media-related choices and actions.

Analysis

In the analysis the interviews were the primary data. The transcriptions of the interviews were analysed by using Atlas.ti -program for qualitative data. By coding and grouping the textual data the important meanings and explanations concerning the media use were found, and from that basis the media user groups were formed. The most often used media were picked up from the media diaries and this data was compared to the data from the interviews. The focus in the analysis was in the use of print media, which defined the aspect and exclusion.

3. Results

The most important media environment for the young students includes the following media (not in any particular order): *chat, face-to-face meetings, mobile phones, e-mail, text messages, CD's (+mp3's etc.), Internet (excluding communication), books, newspapers and television.* These media are most often used according to the media diaries and interviews, and also mentioned specifically as being the most important in general and by content in the lives of the students. Every student of the target group however did not use chat and newspapers, and those media became important when the media user groups were defined.

In addition to the list above, radio is often used but only as a background and routine medium, i.e. it was not mentioned as being important. Watching films was mentioned to be an important action, but television is the most common medium for that.

Some of the students said that they also read magazines, but the magazines were not considered to be important. The reading is often occasional, even though some minor routines related to it do exist (e.g. during the coffee or lunch break). One student slightly emphasised the significance of magazines related to his hobby (music). Thus in general the reading of magazines among students seems not to be an important action. Money and lack of time are some obvious reasons for this behaviour. Also the attitudes towards magazines seemed to reflect that magazines are fun to read sometimes, but the importance of them is minor compared to other print media or communication media.

After defining the most important media environment the idea was to take a look at the data more specific from the point of view of print media. It was interesting to notice, that the actions and attitudes towards print media were quite clearly distinctive factors among students.

From the point of view of print media there were three types of user groups among the target group: *1) The Users, 2) The Refusers* and *3) The Likers.*

The Users subscribe newspapers and read them regularly. Their appreciation towards print media is high. Media use in this group in general is versatile and well controlled. The screen media (television, movies) is popular among them. Electronic media is also used a lot, with the exception of chatting, which is not a popular action. The use of electronic media is controlled with some strong principles, e.g. chatting and console games are not used. The appreciation of print media was high in their childhood homes.

"Books are like, very positive things, because they have always been very important to me... there are warm memories related to them." (Woman, 24 years)

The Refusers do not read and do not particularly like newspapers or other paper-based media. The reasons behind this are the lack of encouraging tradition concerning books and newspapers in their childhood homes and also lack of time because of other activities often filled with electronic media. Communication is very important to this group, especially mediated interaction with new communication technology (e.g. chatting). The social relationships are partly based on electronic communication. Students in this group are however also critical towards electronic media. The freedom of choice concerning media use is important.

"I have never read any newspapers, I have never learned to begin my morning with the newspaper... I don't know if it is my fault or newspapers' that I'm not interested in reading them." (Woman, 22 years)

The Likers includes students who value print media but do not use it as much as they wanted or as much as they think they should. The most common reasons for this is lack of time or sometimes laziness, and they feel guilty about it. These students try to read newspapers (often free newspapers) when it is possible, but they are not subscribers. Books are mentioned to be important, but during the terms they do not have the time to read. In their childhood homes print media was often highly valued. Some of the students in this group do not particularly like electronic media (or electronic devices in general) because of the lack of know-how. Face-to-face meetings are very important to some of these students and their lifestyle is quite active including hobbies often related to music. Sometimes quiet time and time without any media is also considered as good and valuable time.

"It's again embarrassing to say, but as a child I used to read more good books than now... so I just don't do it anymore. It is a good habit that should not be eliminated." (Man, 23 years)

4. Discussion

It must be recognized, that grouping people is always difficult and it often gives a too simple picture of the complex human behaviour. Especially in this research one cannot simply put people into very unambiguous categories, because there are always some personal variations. The illogical nature of human discourse is also problematic: Sometimes during the interview the subject may first say an opinion and then later disprove it. The media diaries were one way to ease this problem. If the subject gave an unclear picture about his or her attitude or behaviour related to newspapers, it was easy to look at the diary and then continue the discussion from that basis.

In general it can be stated, that the media use of the students in this research is quite homogeneous: It is versatile and communication plays an important role in it. This also supports the previous studies (e.g. Intermediatutkimus 2002). The media use is quite clearly related to the phase of life and its possibilities and limitations (such as social relationships and money). The differences come from the minor factors. However, the attitudes and actions towards print media (especially newspapers) were clearly distinctive factors in the data. From the basis of that finding it is reasonable to suggest that the three user groups give a truthful picture of the subjects' media use from the point of view chosen for this study.

Communication is nowadays an action, which is enabled and also encouraged by many electronic devices and service producers. It has been said that communication has became an absolute value. Communication and interaction are also important actions in the life the students. Thompson has categorized the media from the point of view of interaction: 1) Face-to-face interaction 2) Mediated interaction (such as telephone and e-mail) and 3) Mediated quasi-interaction (such as print media and television). The first two types of interaction are dialogical in character and the third is monological (Thompson 1995). It is noteworthy, that e.g. reading books is also interaction.

When looking at the most important media environment for the students, half of the media enable dialogical interaction and half is mainly for monological interaction. The situation is still fifty-fifty despite the popularity of dialogical interaction. However, the line between the media for dialogical and monological interaction is becoming more and more blurred. The chat on the Finnish television into which one sends messages with a mobile phone and the concept of digital television are some proofs of that development. The popularity of the dialogical interaction challenges the (traditional) media for monological interaction and for print media this challenge is important.

If we take a look at the user groups among students, it can be said that the *Users* slightly favour mediated quasi-interaction by considering print and screen media important. On the other hand chatting (mediated interaction) is not a popular action among them. Of course it must be noticed, that communication with people is also important to them. For the *Refusers* mediated interaction is very important, even though it is often used to arrange face-to-face meetings. Some of the *Likers* emphasised face-to-face meetings, which is also noteworthy. In general the dialogical interaction is important to all students, but the importance of it was slightly more emphasised among the *Likers* and *Refusers*.

5. Conclusions

From the point of view of print media it can be stated that print media (i.e. books and newspapers) is still among the most important media in the life of students. Positive attitudes towards print media and routines especially related to newspapers have been learned in the childhood, i.e. the positive tradition exists. Print media is also still necessary for the studies. Print media is not (too) addictive in students' opinion; the use of print media does not need to be controlled (in comparison to some electronic media, e.g. games and chatting). Some positive expressions the students stated related to print media are e.g. reliable, credible, valuable, stable, luxurious and better.

However, the newspaper is not regarded as a necessary medium, unlike e.g. the Internet or mobile phones. The newspaper is also quite expensive to subscribe for the students, so the routine learned in the childhood may disappear. The new addictive and necessary electronic media may change and replace these old routines. Also the increased communication and the heavy use of communication media is time-consuming, and therefore the time required for using print media seems to be low among students. The appreciation of books is still quite high among university students in their studies, and the information received from the Internet is seen unreliable and less valuable. However, this attitude might change because of the heavy use of the Internet. Many of the schoolchildren of today will probably be adjusted to the Internet as a primary source of information.

From the user groups *the Users* will most probably continue valuing and using print media in their future phases of life. On the other hand, most of *the Refusers* will probably not start using print media. The most interesting people therefore are in the group of *Likers.* They do value print media but are still not active users. How can we make sure that this group will be activated into Users?

The key factors could be those elements related to print media that the target group defined as being positive. The nature of print media as being reliable, valuable, stable, luxurious and non-addictive media should be emphasised. In today's media environment filled with addictive electronic devices the valuation of relaxing and peaceful time might become even more important. The print media could very well find its place when personal time is needed.

In the life of students money is a noteworthy issue, and on the other hand freedom of choice concerning media use is valued. Therefore affordable and personified products (e.g. newspapers and magazines) could fit in well the phase of life of the students. And when speaking in a more general way, we should concentrate on searching for the strengths of both print and electronic media and try to combine those qualities in a way that answers to the needs of the people. Different kind of hybrid media products and services could be the desired solutions in the future.

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2

Offset printing

Relationships between blanket surface, ink transfer, and print quality

C. Mercier, E. Rousset, J. Kuczynski, J.-F. Bloch

1. Introduction

A general introduction to offset printing may be found in Webopedia [1]. “Offset printing is a technique whereby ink is spread on a metal plate with etched images, then transferred to an intermediary surface such as a rubber blanket, and finally applied to paper by pressing the paper against the intermediary surface”. However, what is hidden behind this intermediary surface? How is the blanket built? Does-it present a unique surface chemistry or topography? Such questions are currently addressed nowadays in industry. Todays, three types of surface finishing of blankets exist. **A cast Surface** is produced by using a special type of paper inter-leafed against the rubber's face during the curing process. It's a common blankets surface finish characterised by a smooth, shiny appearance. **A ground surface** is obtained by a mechanical grinding process after the blanket has been cured. It requires an additional manufacturing step but allows the manufacturer to achieve the close thickness (gauge) tolerances and offers various degrees of roughness profiles on the blanket surface for different printing applications. **A textured surface** is produced through a chemical process which produces a cast surface blanket without talc. Il allows various degrees of roughness. This surface texture, in combination with the face rubber, is widely accepted as having the best release characteristics of all blankets.

The objective for the manufacturers is to characterise printing blanket in considering the relationship between both tension surface and topography and print quality [2], [3]. Three stages are necessary in such global approach. First, we analyse the topography [4] and the surface tension of printing blankets. Classically, the parameters (Sa and Sz) are used by manufacturers to characterise the topography. However, are these two parameters enough to differentiate printing blankets? Then, ink transfer is performed with a IGT laboratory press. Ink's transfer is classically analysed by Walter and Fetsko equations to compute transfer coefficient and ink immobilization. Finally, texture of printed paper is characterised. The main objective is to determined critical parameters that control the print uniformity [5]. To perform measurements, two innovative methods were used. First, heavy drop method [6] was used instead of classical drop's method. Secondly, an optical profilometer is used. By the past, mechanical profilometers, atomic force microscopy (AFM) [7] or scanning electron microscopy (SEM) were used to assess blanket topography. However, the later does not give altitude. Nevertheless, SEM is used when high spatial resolution is needed.

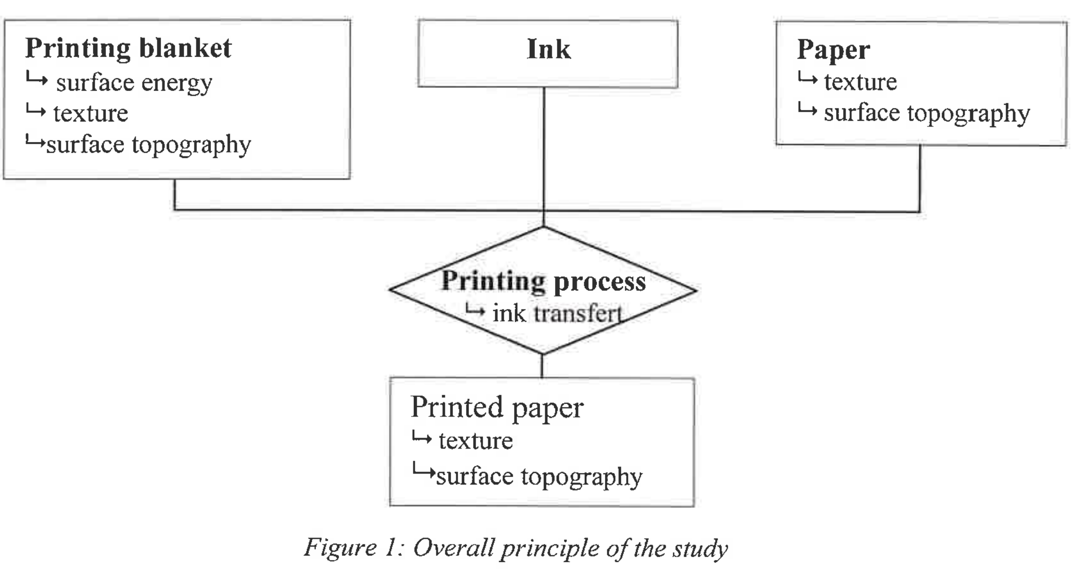

Figure 1: Overall principle of the study

Figure 1 gives an overview of adopted methodology. Texture and surface topography are main interest.

2. Analysis

2.1 Wettability

In order to characterise surface's wettability, the approach of Owens-Wendt [8] is used. Surface energy is the sum of two contributions due to dispersive (abbrev d) and dipole-hydrogen bonding forces (abbrev p). Knowing, γ^d and γ^p of a liquid and the equation 1, γ_s^d and γ_s^p are two unknown parameters. With two liquids, leading to two equations, γ_s^d and γ_s^p may be determined.

$$\gamma_l(1 + \cos\theta) = 2(\gamma_l^d \gamma_s^d)^{\frac{1}{2}} + 2(\gamma_l^p \gamma_s^p)^{\frac{1}{2}} \qquad (1)$$

The heavy drop method [9] is used instead classical drop method to provide the contact angle.

2.2 Introduction of surface parameters

In 1990's, a list of fourteen parameter [10], so-called Birmimgham 14, has been elaborated. They are classified as below. The mathematical definitions are presented in Annexe 1. The purpose of the four parameters (Sq, Ssk, Sku, Sz) is to characterise the amplitude distribution. They describe the dispersion, asymmetry, peakedness and extreme height distribution of the amplitude distribution, respectively. The spatial properties are difficult to describe parameters due to multi-scale properties of paper surfaces. The spatial parameters (Sds, Str Std, Sal) describe the density of summits of the surface, the uniformity of texture aspect, the most pronounced direction of the surface texture. The hybrid parameter (Sdq, Ssc and Sdr) is a combinaison of amplitude and spacing aspects. The three parameters (Sdq, Ssc and Sdr) depict the slope, the summit curvature and the developped surface, respectively. Finally, the functional parameters (Sbi, Svi, Sci) were introduced. A larger surface bearing index indicates a good bearing property. A larger Svi indicates a good fluid retention in the valley zone.

2.3 Ink transfer

In the field of ink transfer process, in 1955, Walter et Fetsko [11], proposed two equations: one for small and another for large amounts. Definitions are given in annexe 1. The model relates the mean quantity of ink transferred to paper, y, to the mean quantity of ink available on blanket, x. Three parameters are used: k, b, f respectively a smoothness parameter, an immobilisation parameter and an ink film splitting coefficient.

2.4 Print quality

Visual print quality has an psychological aspect. Haralick [12] lists seven such features to describe texture: energy, entropy, maximum probability, contrast, inverse different moment, correlation and run length.

3. Experiments

3.1 Heavy drop method

Two laser sensors are layed out in opposite. In the middle, the material to be studied is placed. As the drop is soft landed, it cuts the light beam. The experimental method provide height of liquide film (h).

The contact angle (Θ) using Padday's method is then given by equation.

$$\sin(\frac{\theta}{2})=\frac{h}{2K^{-1}} \qquad \text{avec} \qquad K=\sqrt{\frac{\rho g}{\gamma_l}} \qquad (2)$$

3.2 Topography

The data acquisition, technique is described in brief. A non-contact high resolution measurement is used. The workstation, Altimet's Altisurf/PaperMap, is composed of an optical sensor, a motion controller, translation stages and a software for data analysis. The samples moves in front of the optical sensor, describing either a E or S shape. Moreover, four parameters are essential during the acquisition step: the acquisition length both in cross and machine direction, spacing between two adjacent measured points in both cross and machine direction. The optical sensor has a spot of 1 µm, and a measured range of 300 µm.

4. Results and discussion

The presented results are focused on blankets, unprinted papers and finally by printed paper.

4.1 Blanket

The following nomenclature is used: (10, 15, 16), (2, 7, 8) and (9, 3) concern ground, cast and textured blankets respectively. Surface acquisition is 3*3mm, with a spacing of 2µm.

4.1.1 Qualitative analysis of surface

Three different ground blankets are presented figures 2, 3 and 4.

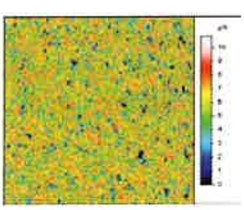

Figure 2: Blanket 10

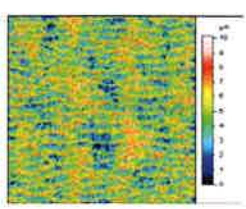

Figure 3: Blanket 15

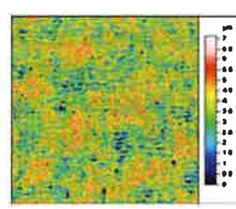

Figure 4: Blanket 16

For blankets 15 and 16, some horizontal shapes appear, due to grinding and buffing process. Distances between waves are about 150 µm for blanket 15 and 70 µm for blanket 16.

Figures 5, 6 and 7 represent different cast surfaces.

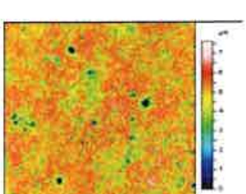

Figure 5: Blanket 2

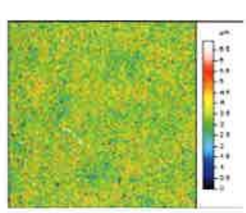

Figure 6: Blanket 7

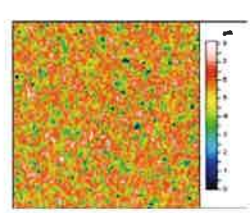

Figure 7: Blanket 8

Blanket 2 and 7 are composed of plateaus with holes or valleys. For blanket 2 mean diameter of the three visible holes is 160 µm, as for blanket 7 diameter of holes is 100 µm.

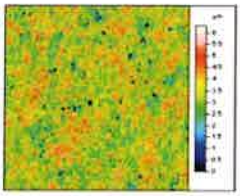

Figure 8: Blanket 3

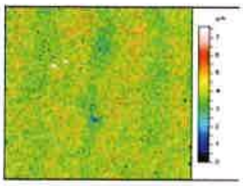

Figure 9: Blanket 9

Figures 8 and 9 represent textured surfaces of blankets of figures 4 and 6. Blankets 8 et 9 appear similar. Blankets 2 et 3 seem a little bit more different.

4.1.2 Quantitative analysis of surface

Table I: 3D parameters and energy of surfaces

		Ref	Sa (µm)	Sq (µm)	Ssk	Sku	Sz (µm)
Blanket	Ground	10	1.65	2.06	-0.321	2.94	10.8
		15	1.61	1.99	0.09	2.64	10.1
		16	1.1	1.36	-0.1	2.741	7.11
	Cast	2	0.79	1.08	-1.3	6.44	7.61
		8	0.92	1.18	-0.26	3.3	6.9
		7	1.06	1.38	-1	4.5	8.14
	Textured	3	0.83	1.05	-0.44	3.46	6.32
		9	1	1.28	-0.29	3.42	7.62

Amplitude parameters are summarised in table I. The parameter Sa is similar for blankets 10 and 15. For blankets 15 and 16, although Sa is different, Ssk and Sku are similar: they present same kind of roughness, but different maximum amplitude. Blankets 2 and 8 show a ambiguous case where Sa and Sz have opposite variations. All blankets surface have a skewness inferior to zero. Most of the surface's points are above mean line. Only, kurtosis of ground surfaces are inferior to 3. For most surfaces, amplitude distribution is sharp.

4.2 Paper

Two papers, one matt, one glossy, were candidate.

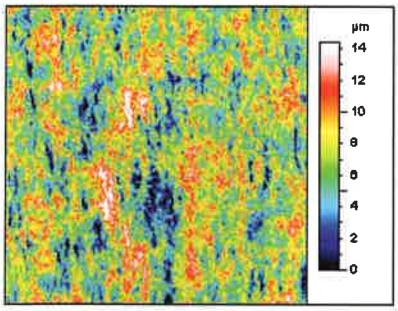

*Figure 10: Matt paper10: 5 µm, 10*10mm*

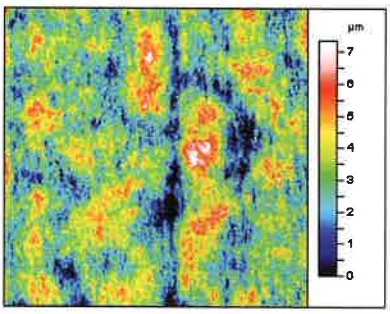

*Figure 11: Gloosy paper 5 µm, 10*10mm*

Some verticals streaks are visible on figure 10. Paper surface parameters are reported in table II.

Table II: Surface topography parameters

	Amplitude parameters					Spatial parameters				Hybrid parameters		
	Sa µm	Sq µm	Ssk	Sku	Sz µm	Sds pks/mm²	Str	Sal mm	Std deg	SΔq µm/µm	Ssc 1/µm	Sdr %
Matt paper	2.15	2.7	0.1	2.9	14.4	1572	0.32	0.3	-18.5	0.1	0.028	0.54
Glossy paper	1	1.28	0.15	3	7.31	2381	0.44	0.48	-26.5	0.068	0.02	0.23

Matt paper exhibits a surface amplitude two time higher than glossy paper. But both have skewness and kurtosis similar. Glossy paper appears more isotropic than matt paper. Only matt paper is studied in following section.

4.3 Printed paper

For printed paper and blankets, surface texture ratio (Str) and the surface auto-correlation length (Sal) are compared and reported in table III.

Table III: Surface topography parameters

		Smooth blankets				Rough blankets		
		C22	C24	C26	C27	105701	105702	105325
Blanket	Str	0.632	0.685	NC	0.742	0.707	0.618	0.791
	Sal (µm)	46.8	63.3	NC	42.4	15.7	17.9	17.6
Printed paper	Str	0.439	0.485	0.316	0.566	0.447	0.555	0.392
	Sal (µm)	21.8	19.5	9.77	39.1	13.8	27.6	19.5

Two aspects could be extract, first on modification on texture, second on visual ranking. Str of printed paper is always inferior to these of blankets. As paper seems oriented, it influences printing. Sal of paper is between Sal of smooth and rough blankets. For smooth blankets, Sal decreases, and for rough blankets, it seems to increase. Visual ranking is done on height samples, printed with two families of blankets. Same amount of ink was printed on samples. Emulsion is not considered. Three groups appear (C26, 105701) - (C22, C24, 105325) - (C27, 105702).

5. Conclusion

Some conclusions may be drawn from the presented results, concerning only solid printing, with ink without emulsion. Different surfaces may have comparable amplitude parameters but presented different visual aspects. Amplitude parameters are therefore not sufficient to discriminate blanket surfaces. From trials on matt coated paper, for range superior to 4 $g.m^2$, ink film splitting coefficient does not discriminate between blankets. The first stage of the study of relationship between both texture of blanket and printed paper was reported. Influence of paper texture was highlighted. For future, two orientations could be proposed. First, a wider range of blanket textures will be studied. Next, halftone printing and dot gain will be considered.

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Annexe 1

Ink transfer

Walter et Fetsko

small quantity $y=A^*[bB+f(x-bB)]$ $A=(1-e^{-kx})$ $B=(1-e^{-\frac{x}{b}})$

larger amount $y=b+f(x-b)=b(1-f)+fx$

Surface parameters

Amplitude parameters

Sa $$S_a=\frac{1}{MN}\sum_{j=1}^{N}\sum_{i=1}^{M}\left|\eta(x_i,y_j)\right|$$

Sq $$S_q=\sqrt{\frac{1}{MN}\sum_{j=1}^{N}\sum_{i=1}^{M}\eta^2(x_i,y_j)}$$

Ssk $$S_{sk}=\frac{1}{MNS_q^3}\sum_{j=1}^{N}\sum_{i=1}^{M}\eta^3(x_i,y_j)$$

Sku $$Sku=\frac{1}{MNS_q^4}\sum_{j=1}^{N}\sum_{i=1}^{M}\eta^4(x_i,y_j)$$

Sp $$S_p=Max(\eta_p)$$

Sv $$S_v=MIN(\eta_v)$$

Sz $$S_z=(|S_p|+|S_v|)$$

S5z $$S_{5z}=\frac{\sum_{i=1}^{5}|\eta_{pi}|+\sum_{i=1}^{5}|\eta_{vi}|}{5}$$

Spatial parameter

Sds $$S_{ds}=\frac{\text{Number of summits}}{(M-1)(N-1).\Delta x.\Delta y}$$

Str $$Str=\left.\frac{MIN(\sqrt{\tau_x^2+\tau_Y^2})}{MAX(\sqrt{\tau_x^2+\tau_y^2})}\right|_{R(\tau_x,\tau_y)\leq 0.2}$$

$$R(\tau_s,\tau_y)=\frac{1}{(M-1)(N-1)}\sum\sum\eta(x_i,y_j)\,\eta(x_{i+k},y_{j+k})$$

Sal $$Sal=MIN(\sqrt{\sigma_x^2+\sigma_y^2}) \qquad R(\tau_x,\tau_y)\leq 2$$

Std $$Std=\begin{cases} -\beta & \beta\leq\frac{\pi}{2} \\ \pi-\beta & \frac{\pi}{2}\leq\beta\leq\pi \end{cases}$$

Hybrid parameter

Sdq
$$\rho_{ij}=\left[(\frac{\partial\eta(x,y)}{\partial x})^2+(\frac{\partial\eta(x,y)}{\partial y})^2\right]^{1/2}\Bigg|_{x=x_i,y=y_i}$$
$$\approx\left[(\frac{\eta(x_i,y_j)-\eta(x_{i-1},y_j)}{\Delta x})^2+(\frac{\eta(x_i,y_j)\eta(x_i,y_{j-1})}{\Delta y})^2\right]^{1/2}$$

$$S_{\Delta q}=\sqrt{\frac{1}{(M-1)(N-1)}\sum_{i=2}^{N}\sum_{j=2}^{M}\rho_{ij}^2}$$

Ssc
$$S_{sc}=-\frac{1}{2}\frac{1}{n}\sum_{k=1}^{n}\left(\frac{\partial\eta^2(x,y)}{\partial x^2}+\frac{\partial\eta^2(x,y)}{\partial y^2}\right)\Bigg|_{\text{pour chaque sommet}}$$
$$\approx-\frac{1}{2}\frac{1}{n}\sum_{k=1}^{n}\left(\frac{\eta(x_{p+1},y_q)+\eta(x_{p-1},y_q)-2\eta(x_p,y_q)}{\Delta x^2}+\frac{\eta(x_p,y_{q+1})+\eta(x_p,y_{q-1})-2\eta(x_p,y_q)}{\Delta y^2}\right)$$

Sdr
$$A_{ij}=\frac{1}{2}\left[\left(\frac{1}{2}\left|\vec{BA}*\vec{BC}\right|+\frac{1}{2}\left|\vec{DA}*\vec{DC}\right|\right)+\left(\frac{1}{2}\left|\left(\vec{AB}*\vec{AD}\right)\right|+\frac{1}{2}\left|\left(\vec{CB}*\vec{CD}\right)\right|\right)\right]$$
$$=\frac{1}{4}\left(\left|\vec{AB}\right|+\left|\vec{CD}\right|\right)\left(\left|\vec{AD}\right|+\left|\vec{BC}\right|\right)$$
$$=\frac{1}{4}\left\{\left(\left[\Delta y+(\eta(x_i,y_j)-\eta(x_i,y_{j+1}))^2\right]^{1/2}+\left[\Delta y+(\eta(x_i,y_j)-\eta(x_i,y_{j+1}))^2\right]^{1/2}\right)\right.$$
$$\left.\left(\left[\Delta y+(\eta(x_i,y_j)-\eta(x_i,y_{j+1}))^2\right]^{1/2}+\left[\Delta y+(\eta(x_i,y_j)-\eta(x_i,y_{j+1}))^2\right]^{1/2}\right)\right\}$$

$$A=\sum_{j=1}^{N-1}\sum_{i=1}^{M-1}A_{ij}$$

$$S_{dr}=\frac{\sum_{j=1}^{N-1}\sum_{i=1}^{M-1}A_{ij}-(M-1)(N-1)\Delta x\Delta y}{(M-1)(N-1)\Delta x\Delta y}*100\%$$

The print attribute analyses of waterless offset CD printing systems

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1. Introduction

Compact disc (CD) printing has become an area of extreme interest for printers in Taiwan due to the increasing need of the digital industry over the past three years. Generally speaking, compact disc printing is done by three printing process: transfer printing, screen printing, waterless offset lithography. One of the most exciting developments in CD printing industry has been the use of waterless offset lithography printing. In the past decade, most of the compact disc printers were heavily rely on imported waterless offset CD presses, such as Kammann made in German and DIC made in Japan, to complete their printing jobs. Not until the most recent five years, there are only a few local manufacturers producing similar types of fully-automatic waterless offset presses in Taiwan. After tremendous research and development on the techniques and efforts on expanding world-wide market, the mechanical structures, quality, and stability of those made-in-Taiwan printing machines are almost as good as those made in Germany and Japan. In addition, Taiwanese printing machines have great advantages on the prices and after-sale services. The only one problem is that there has been no examination on the performances of those locally-made printing systems yet. Are there any differences, in terms of print quality and attribute, between imported machines and those made locally? Therefore, there is a great need to conduct a study to investigate the print attributes for the made-in-Taiwan CD printing systems.

This research was funded by the National Science Council (NSC) of Taiwan (NSC 2002-2212-E-144-001). Its main purpose was to construct important print attributes for the four commonly used waterless offset CD printing systems in the world, HA-OC-6 (made in Taiwan), GFS-1001 (made in Taiwan), K15-40 (made in German), and H-7 (made in Japan), respectively. Furthermore, this study was designed to compare the differences in tone value increase, print contrast, ink trapping, and colour difference among the four systems.

The results of the study do not only provide CD press manufacturers with the performances of their printing systems, but also compare the print attributes of the four printing systems, especially between those made-in-Taiwan and those imported from German and Japan. It is hoped that the results of the study could be used as a reference of investment, equipment and machine importing, and product promotion for the waterless offset CD printing industry.

2. Methods

This study was an experimental research in nature, and it intended to compare the differences in tone value increase, print contrast, ink trapping, and colour difference among the four commonly used waterless offset CD printing systems.

To study important print attributes and compare their differences for the four printing systems, a digital four colour test form was designed for this study (see Figure 1). It consists of a photographic image located in the center of the disc, YMCK tone scales (highlights, 10% to 90% tint patches in a 10% interval, shadows) around the photographic image, and CMYRGB solid patches. The photograph on the test form is a GATF test image, which emphasizes complex colour reproduction challenges.

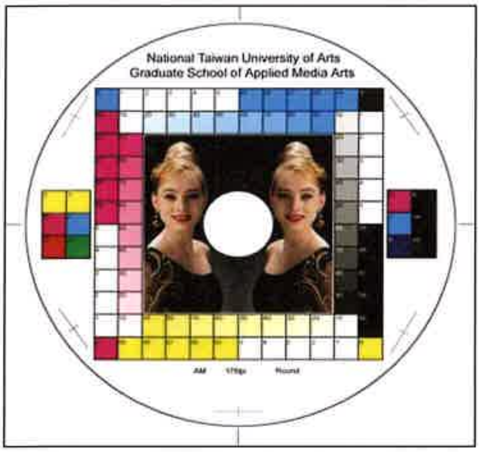


Figure 1:
The test form for the experiment

The screen technology used to output the film was AM with round dots at 175 lpi. The imagesetter utilized for this study was calibrated and linearized before the experiment. The plates used in this study were Toray waterless offset plate (negative-working) for all the four systems. Extreme care was taken to standardize the exposure time and development time to achieve the same percentage of tone value increase for all of the printing plates used to run the experiment. The UGRA Plate Control Wedge was used to standardize the amount of exposure for the plates.

Before applying the process colour ink, a white ink film was printed by a screen printing unit built into the press. During each press run, the ink density was balanced out across the discs to 1.0 for the yellow, 1.4 for the magenta, 1.3 for the cyan, and 1.5 for the black (based on GRACoL recommendation). For each of the four printing systems, 100 discs were printed after the desired materials and conditions of the press were made ready, and 50 of them were randomly sampled for data analyses. The sampling detail is displayed in Table I. A GretagMacbeth SpectroEye (a spectrodensitometer) was employed to obtain the 1%, 2%, 3%, 4%, 5%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 95%, 96%, 97%, 98%, 99% dot areas, solid ink density, 80% print contrast, ink trapping, and CIEL*a*b* values for determining colour gamut and computing colour difference.

Table I: The number of printed discs for the experiment

The type of the waterless printing systems	Printed Quantity	No. of Discs Sampled
Hanky's HA-OC-6 (made in Taiwan)	100	50
Guann Yinn's GFS-1001 (made in Taiwan)	100	50
Kammann's K15-40 (made in German)	100	50
DIC's H-7 (made in Japan)	100	50

Note: The ink density was balanced out across the discs to 1.0 for the yellow, 1.4 for the magenta, 1.3 for the cyan, and 1.5 for the black (based on GRACoL recommendation).

3. Results and discussions

This section reports the results and findings obtained through analyses of the experimental data. The software packages employed to analyze the data were SPSS 11.5 and Minitab 13. In the tables and figures presented in this paper, "TVI" represents the "Tone Value Increase", "PC" represents the "Print Contrast", and "Trap" represents the "Ink Trapping".

3.1 Descriptive statistics

The overall results of print attributes for waterless Offset CD printing are displayed from Table II to Table VI. The highlights dot reproduction, shadows dot reproduction, 10-90% tone value increase, print contrast, and ink trapping are listed and categorized according to the four waterless offset CD printing systems.

Highlight dot reproduction

Highlight and shadow dot reproductions provide very useful information by indicating the last reproducible dots in highlight and shadow tones, and identifying possible platemaking and press errors. As shown in Table II, the highlight dots reproduction of Hanky HA-OC-6 waterless printing system was far greater than that of the other three systems. In contrast, the highlight dots reproduction of Kammann K15-40 waterless printing system was smaller. Among the four systems, DIC H-7 provides the better reproduction (spectrodensitometric readings of halftone dots were closer to original tone value) in highlight area, especially between 1-3% tints. It is important to note that the S.D. (Standard Deviation) values of the dot area reading for the Guann Yinn GFS-1001 were greater than those of the other systems at all five tone values in all four ink colour, which means that Guann Yinn waterless printing system had a greater dot reproduction variability than did the other three systems.

Table II: Descriptive statistics of highlights dot reproduction for the four waterless CD printing systems

Highlight Tone Value		Hanky		Guann Yinn		Kammann		Dic	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1% Dot Area	K	3.12	0.43519	***1.20***	0.75593	0.08	0.27405	0.08	0.27405
	C	3.82	0.52255	***1.28***	1.03095	0.18	0.38809	0.24	0.43142
	M	3.64	0.52528	1.96	1.27711	0.02	0.14142	***0.66***	0.51942
	Y	3.30	0.73540	1.82	1.08214	0.00	0.00000	***0.56***	0.50143
2% Dot Area	K	5.20	0.69985	3.38	1.29189	0.04	0.19795	***1.64***	0.52528
	C	5.52	0.57994	2.86	1.67831	0.92	0.39590	***1.92***	0.39590
	M	5.44	0.54060	4.10	1.87628	0.08	0.27405	***2.76***	0.74396
	Y	5.48	0.70682	3.86	1.49843	0.26	0.44309	***1.54***	0.57888
3% Dot Area	K	7.56	0.73290	6.64	1.71143	0.08	0.27405	***4.32***	0.79385
	C	7.36	0.72168	4.80	2.16654	1.68	0.65278	***4.18***	0.52255
	M	7.48	0.50467	6.90	2.01271	0.44	0.50143	6.88	1.42342
	Y	8.54	0.70595	5.92	1.66403	0.06	0.23990	***3.66***	0.59281
4% Dot Area	K	8.96	0.72731	8.44	1.59284	0.04	0.19795	***6.38***	1.00793
	C	8.66	0.68839	***5.90***	2.18763	1.36	0.56279	7.18	0.80026
	M	8.94	0.51150	8.52	2.05277	0.54	0.57888	8.52	1.41767
	Y	9.76	0.77090	7.20	1.59079	0.00	0.00000	***4.16***	0.58414
5% Dot Area	K	10.90	1.44632	10.86	1.60369	0.08	0.27405	10.36	1.39620
	C	10.36	0.72168	***7.70***	2.41804	1.78	0.61578	9.42	0.94954
	M	10.82	0.52255	10.48	1.94033	0.98	0.55291	12.22	1.79898
	Y	11.78	0.24807	8.92	1.56283	0.00	0.00000	***6.36***	1.57480

Note: the italic bold values indicate that they are the closest values to original tone values.

Shadow dot reproduction

The purpose of evaluating shadow dot reproduction is to examine what the maximum dots that a printing process can print. In Table III the overall dot area percentages of Kammann K15-40 waterless CD printing system were much greater than those of the other three. It is interesting to note that Kammann K15-40 had dot loss phenomenon in magenta. Among the four waterless CD printing systems, DIC H-7 provides better dot reproduction in shadows (spectrodensitometric readings of halftone dots were much closer to original tone value), and there is a dot loss phenomenon in the 99% tint. To sum up, all of them did not have good dot reproduction in shadows. On the other hand, DIC H-7 waterless printing system had greater dot reproduction variability than did the other systems. The S.D. (Standard Deviation) values of the dot area of DIC H-7 were greater than those of the other three systems.

Table III: Descriptive statistics of shadows dot reproduction for the four waterless CD printing system

Shadows Tone Value		Hanky		Guann Yinn		Kammann		Dic	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
95% Dot Area	K	98.84	0.37033	99.04	0.19795	99.56	0.50143	96.84	1.48956
	C	98.36	0.52528	96.50	0.61445	99.58	0.49857	97.02	0.71400
	M	100.00	0.00000	98.82	0.56025	96.14	0.60643	99.74	0.52722
	Y	97.04	0.75485	99.68	0.51270	100.00	0.00000	96.26	1.02639
96% Dot Area	K	98.96	0.19795	99.80	0.40406	100.00	0.00000	96.98	1.33233
	C	98.70	0.46291	96.84	0.50950	99.66	0.47852	97.10	0.97416
	M	100.00	0.00000	99.02	0.47337	94.60	0.75593	99.98	0.14142
	Y	96.94	0.71171	99.90	0.30305	100.00	0.00000	97.12	0.96129
97% Dot Area	K	98.90	0.30305	99.96	0.19795	100.00	0.00000	97.36	1.24146
	C	99.06	0.23990	97.32	0.51270	99.90	0.30305	97.32	0.86756
	M	100.00	0.00000	99.78	0.41845	95.32	0.71257	100.00	0.00000
	Y	96.66	0.79821	99.98	0.14142	100.00	0.00000	97.40	1.10657
98% Dot Area	K	99.12	0.38545	99.94	0.23990	100.00	0.00000	98.38	1.08590
	C	99.50	0.50508	98.02	0.37742	100.00	0.00000	98.08	0.82906
	M	100.00	0.00000	100.00	0.00000	96.02	0.68482	100.00	0.00000
	Y	96.80	0.78246	100.00	0.00000	100.00	0.00000	97.84	1.20136
99% Dot Area	K	99.08	0.34047	100.00	0.00000	100.00	0.00000	98.38	1.06694
	C	100.00	0.00000	99.00	0.40406	100.00	0.00000	98.24	0.87037
	M	100.00	0.00000	100.00	0.00000	97.50	0.64681	100.00	0.00000
	Y	96.86	0.80837	100.00	0.00000	100.00	0.00000	97.86	1.21235

Regular dot reproduction

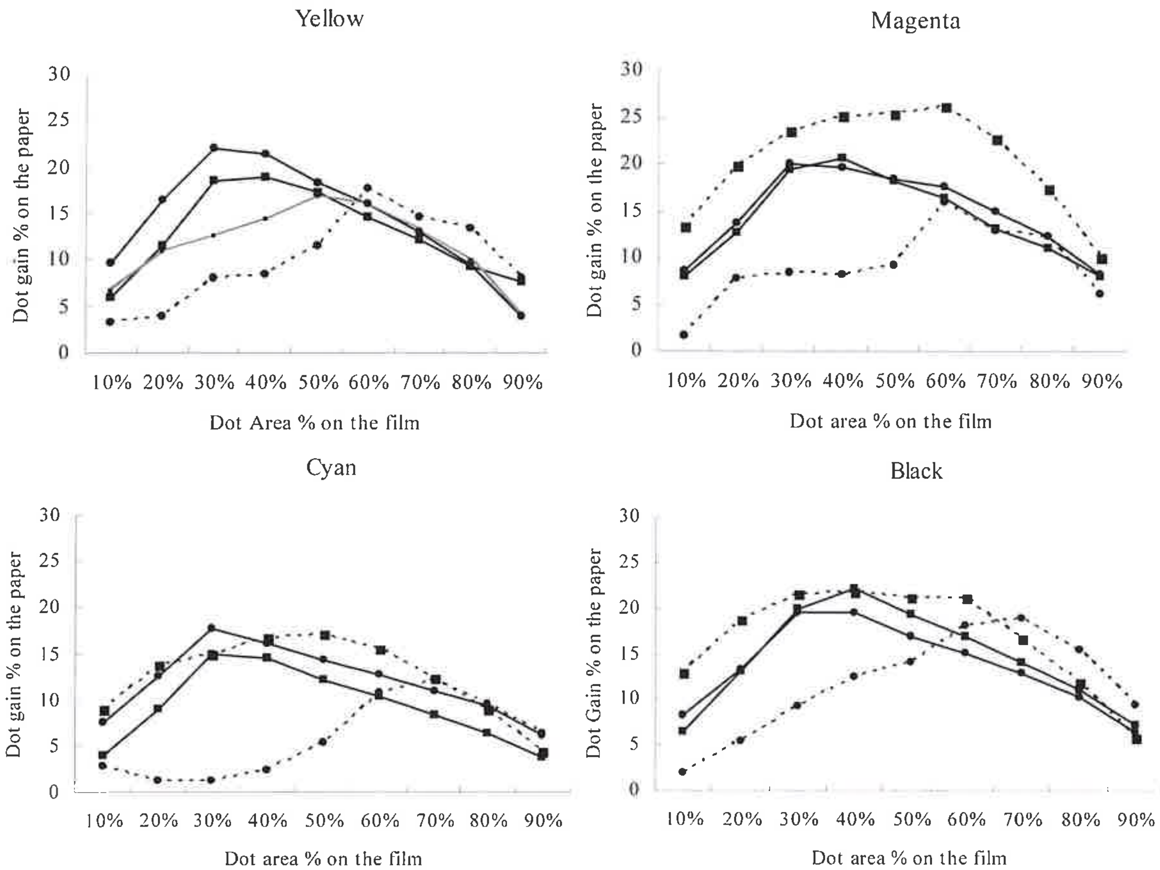
Table IV depicts the 10-90% tone value increase (TVI) statistics for the four waterless CD printing systems. As showed in Table IV, Kammann K15-40 printed the least TVI with the smallest standard deviation value at 10-50% percent tone levels for all four process colour. For the 60-80% percent tints, the least TVI occurred when Hanky HA-OC-6 was employed in black colour and Guann Yinn GFS-1001 was employed in cyan and yellow. On the other hand, the overall results indicated that DIC H-7 printed a greater TVI at 10-60% tints than did the other three systems (in cyan, magenta, and black colour). In the three-quarter tone and shadow, Kammann K15-40 system printed a greater TVI than did the other systems, especially in black, cyan, and yellow colour. As for the dot reproduction stability, as shown in the S.D. (Standard Deviation) columns of Table IV, Kammann K15-40 printed less dot reproduction variability than did the other systems for all four colour. DIC H-7, in contrast, printed greater dot reproduction variability than did the other three systems for all four colour.

The TVI curves of 10-90% tints are exhibited in Figure 2. It shows the greatest TVI occurred at 30-40% dots for the made-in-Taiwan CD printing systems. Among the four systems, magenta ink colour had the greatest TVI amount and cyan had the least amount. Figure 2 also shows that the DIC H-7 (dashed line with square spot) printed a greater TVI and Kammann K15-40 (dashed line with round spot) yielded the least TVI. It is also important to note that the TVI values between 10-60% tints for Kammann K15-40 were smaller than the other three systems for all four colour.

Table IV: Descriptive statistics of regular dot reproduction for the four waterless CD printing systems

Regular Dot Reproduction		Hanky Mean	Hanky S.D.	Guann Yinn Mean	Guann Yinn S.D.	Kammann Mean	Kammann S.D.	Dic Mean	Dic S.D.
10% TVI	K	8.22	2.54181	6.54	1.71678	***2.02***	0.62237	12.82	2.31843
	C	7.58	0.85928	4.06	2.20769	***2.88***	0.59385	8.96	2.98951
	M	8.48	0.70682	7.88	1.82544	***1.68***	0.51270	13.24	3.08757
	Y	9.60	0.63888	5.96	1.38446	***3.36***	0.63116	6.64	2.11660
20% TVI	K	13.22	3.16415	13.14	1.91674	***5.44***	0.70450	18.70	3.39417
	C	12.60	1.34012	8.92	2.17443	***1.16***	0.54810	13.66	2.38713
	M	13.58	0.94954	12.60	2.02031	***7.70***	0.83910	19.74	4.06611
	Y	16.50	0.88641	11.50	1.29756	***4.00***	0.63888	10.80	1.60357
30% TVI	K	19.62	2.63330	20.00	2.00000	***9.26***	0.89921	21.64	3.76753
	C	17.66	1.64887	14.82	1.99683	***1.28***	0.64015	14.94	2.47774
	M	20.08	1.17526	19.36	1.97701	***8.36***	0.87505	23.38	5.00567
	Y	22.04	1.00934	18.46	1.01439	***7.96***	0.72731	12.56	1.99141
40% TVI	K	19.50	2.54951	22.06	1.84513	***12.54***	0.73429	21.82	3.45638
	C	16.16	1.56961	14.50	2.10199	***2.46***	0.67643	16.68	2.42807
	M	19.50	1.28174	20.54	2.32300	***8.22***	0.91003	25.04	4.79353
	Y	21.38	0.98747	18.98	1.02000	***8.38***	0.83029	14.32	2.08434
50% TVI	K	16.82	2.37065	19.24	1.72094	***14.10***	0.95298	21.16	3.27863
	C	14.28	1.51240	12.14	1.96925	***5.42***	0.81039	17.00	2.57935
	M	18.38	1.24360	18.10	1.96136	***9.10***	0.88641	25.38	3.54499
	Y	18.22	0.99571	17.20	1.10657	***11.52***	0.90891	16.94	1.98371
60% TVI	K	***15.06***	2.15151	17.00	1.53862	18.12	0.91785	21.08	3.21882
	C	12.68	1.28476	***10.24***	1.81333	10.68	0.79385	15.50	2.32335
	M	17.46	1.09190	16.28	1.67868	***15.88***	0.89534	26.12	2.80408
	Y	16.06	1.13227	***14.66***	1.08063	17.76	0.98063	16.00	1.65369
70% TVI	K	***12.86***	1.86274	14.14	1.16075	18.90	0.93540	16.72	2.65760
	C	10.92	1.24278	***8.26***	1.44010	12.18	0.80026	12.32	1.91066
	M	14.86	1.06924	13.10	1.43214	***12.94***	1.01840	22.70	2.11168
	Y	13.02	1.03982	***12.06***	0.95640	14.62	0.77959	13.22	1.77615
80% TVI	K	***10.22***	1.29819	11.14	0.83324	15.58	0.49857	11.88	2.09606
	C	9.42	0.88271	***6.34***	1.18855	9.56	0.73290	8.94	2.06437
	M	12.18	0.84973	***11.04***	1.10583	12.34	0.82338	17.32	1.46301
	Y	9.42	1.01197	***9.18***	4.43405	13.34	0.65807	9.80	1.44279
90% TVI	K	6.52	0.61412	7.32	0.47121	9.56	0.50143	***5.74***	1.49571
	C	6.16	0.61809	***3.80***	0.75593	6.44	0.57711	4.34	1.30321
	M	8.26	0.52722	7.88	0.62727	***6.18***	0.71969	9.94	0.86685
	Y	***4.00***	0.88063	7.60	0.72843	8.08	0.34047	4.06	1.54405

Note: the italic bold values indicate that they have least tone value increase values.



Note: —•— represents Hanky HA-OC-6 waterless CD printing system
—▪— represents Guann Yinn GFS-1001 waterless CD printing system
---•--- represents Kammann K15-40 waterless CD printing system
---▪--- represents DIC H-7 waterless CD printing system

Figure 2: 10~90% TVI curve

Print contrast

Print contrast (PC) is a print index that is calculated from the solid ink patches and 75% tint patches. The value is a measure of shadow contrast and is the degree to which viewers can distinguish printed tones in the shadow area of a reproduction. In general, the higher the print contrast the better the shadow detail rendition. Table V shows the average print contrasts for the four waterless CD printing systems.

Table V: Descriptive statistics of print contrast for the four waterless CD printing systems

Print Contrast	Hanky		Guann Yinn		Kammann		Dic	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
K	40.81	1.77719	***42.24***	2.95006	30.13	1.52443	32.73	3.17599
C	35.53	1.83266	***44.62***	1.83035	36.88	1.40657	38.33	2.65204
M	27.44	1.92969	***33.09***	2.85123	27.76	2.48524	12.06	5.87014
Y	26.85	1.79640	***41.05***	1.96506	23.76	1.46569	25.64	1.94832

The results indicate that Guann Yinn GFS-1001 had the greatest print contrast percentage values for all CMYK colour among the four systems. It is interesting to note that the maximum print contrast value was found in cyan colour for the four systems (except for Hanky HA-OC-6). As for the print contrast stability, the standard deviation values of the DIC H-7 were greater than those of the other three systems. Kammann K15-40, conversely, had smaller standard deviation values than did the other systems (except for magenta colour).

Ink trapping

Ink trapping values are measures of the transfer of an ink onto a previously printed surface compared to ink transfer on blank paper. Accepted trapping is generally somewhere between 75% and 95%; the higher the percentage is, the better the ink trapping. Table VI shows that the Guann Yinn GFS-1001 had a higher ink trapping than did the other three systems. Among the four systems, the cyan-yellow overprint (green trap) had the largest trap value, followed by cyan-magenta overprint (blue trap) and magenta-yellow overprint (red trap). As for the ink trapping stability, Kammann K15-40 had smaller ink trapping variability than did the other three systems in red (magenta-yellow overprint) and green (cyan-yellow overprint) colour. In Contrast, DIC H-7 had greater ink trapping variability than did the other systems for the all three overprint colour.

Table VI: Descriptive statistics of ink trapping for the four waterless CD printing systems

Ink Trapping	Hanky		Guann Yinn		Kammann		Dic	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Red-MY	73.14	1.65381	73.92	2.24826	***77.18***	1.20695	53.28	3.27663
Green-CY	85.86	1.17820	***99.24***	1.07968	90.04	0.87970	95.28	2.59544
Blue-CM	67.56	1.10951	***92.92***	1.78245	88.90	1.89790	83.04	3.14260

Note: Printing colour sequence: K-C-M-Y

3.2 Differences in the print attributes between waterless offset CD printing systems

In this section, One-way ANOVA and Paired-t Test statistical procedures were employed to examine whether the differences in dot reproduction readings of the four systems were significant. The hypothesis being tested was whether the reading differences between systems were equal to zero. The significant level (α) was set at .05 for all tests. The results are exhibited in Table VII. As shows in Table VII, the differences in print attributes between Hanky HA-OC-6 and Guann Yinn GFS-1001 systems at all nine tone levels, print contrast, and ink trapping were significant, with the exception in black TVI between 20-30% tints, 50% TVI of magenta colour, 80% TVI of yellow colour, and red colour trapping (magenta-yellow overprint). As for Hanky HA-OC-6 versus Kammann K15-40, the differences in all print attributes were significant, with the exception in 80% TVI of cyan and magenta colour and print contrast of magenta colour.

As for Hanky HA-OC-6 versus DIC H-7, the differences in print attributes at all print attributes were significant, except for cyan TVI in 40% and 80% tints, and yellow TVI between 60-90% tints. As for Guann Yinn GFS-1001 versus Kammann K15-40, the differences in all print attributes were significant, excluding 60% TVI of cyan colour and 60-70% TVI of magenta colour. As for Guann Yinn GFS-1001 versus DIC H-7, the differences in all print attributes were significant, with the exception in 10%, 50% and 80% TVI of yellow colour, 30% TVI of cyan, and 40% TVI of black. As for Kammann K15-40 versus DIC H-7, the differences in all print attributes were also significant, except for 70% TVI of cyan colour.

Table VII: Hypothesis testing on the print attributes between waterless offset CD printing systems

Print Attributes		Hanky v.s. Guann Yinn		Hanky v.s. Kammann		Hanky v.s. Dic		Guann Yinn v.s. Kammann		Guann Yinn v.s. Dic		Kammann v.s. Dic	
		Ha: $\mu_H \neq \mu_G$		Ha: $\mu_H \neq \mu_K$		Ha: $\mu_H \neq \mu_D$		Ha: $\mu_G \neq \mu_K$		Ha: $\mu_G \neq \mu_D$		Ha: $\mu_K \neq \mu_D$	
		p-value	Sig.	p-value	Sig.	p-value	Sig.	p-value	Sig.	p-value	Sig.	p-value	Sig.
10% Tint TVI	K	.000	yes	.000	yes	.000	yes	.000	yes	.000	yes	.000	yes
	C	.000	yes	.000	yes	.002	yes	.000	yes	.000	yes	.000	yes
	M	.033	yes	.000	yes	.000	yes	.000	yes	.000	yes	.000	yes
	Y	.000	yes	.000	yes	.000	yes	.000	yes	**.060**	**no**	.000	yes
20% Tint TVI	K	**.879**	**no**	.000	yes	.000	yes	.000	yes	.000	yes	.000	yes
	C	.000	yes	.000	yes	.007	yes	.000	yes	.000	yes	.000	yes
	M	.002	yes	.000	yes	.000	yes	.000	yes	.000	yes	.000	yes
	Y	.000	yes	.000	yes	.000	yes	.000	yes	.018	yes	.000	yes
30% Tint TVI	K	**.418**	**no**	.000	yes	.002	yes	.000	yes	.008	yes	.000	yes
	C	.000	yes	.000	yes	.000	yes	.000	yes	**.790**	**no**	.000	yes
	M	.029	yes	.000	yes	.000	yes	.000	yes	.000	yes	.000	yes
	Y	.000	yes	.000	yes	.000	yes	.000	yes	.000	yes	.000	yes
40% Tint TVI	K	.000	yes	.000	yes	.000	yes	.000	yes	**.666**	**no**	.000	yes
	C	.000	yes	.000	yes	**.206**	**no**	.000	yes	.000	yes	.000	yes
	M	.007	yes	.000	yes	.000	yes	.000	yes	.000	yes	.000	yes
	Y	.000	yes	.000	yes	.000	yes	.000	yes	.000	yes	.000	yes
50% Tint TVI	K	.000	yes	.000	yes	.000	yes	.000	yes	.000	yes	.000	yes
	C	.000	yes	.000	yes	.000	yes	.000	yes	.000	yes	.000	yes
	M	**.396**	**no**	.000	yes	.000	yes	.000	yes	.000	yes	.000	yes
	Y	.000	yes	.000	yes	.000	yes	.000	yes	**.420**	**no**	.000	yes
60% Tint TVI	K	.000	yes	.000	yes	.000	yes	.000	yes	.000	yes	.000	yes
	C	.000	yes	.000	yes	.000	yes	**.119**	**no**	.000	yes	.000	yes
	M	.000	yes	.000	yes	.000	yes	**.140**	**no**	.000	yes	.000	yes
	Y	.000	yes	.000	yes	**.833**	**no**	.000	yes	.000	yes	.000	yes
70% Tint TVI	K	.000	yes	.000	yes	.000	yes	.000	yes	.000	yes	.000	yes
	C	.000	yes	.000	yes	.000	yes	.000	yes	.000	yes	**.634**	**no**
	M	.000	yes	.000	yes	.000	yes	**.521**	**no**	.000	yes	.000	yes
	Y	.000	yes	.000	yes	**.494**	**no**	.000	yes	.000	yes	.000	yes
80% Tint TVI	K	.000	yes	.000	yes	.000	yes	.000	yes	.022	yes	.000	yes
	C	.000	yes	**.390**	**no**	**.134**	**no**	.000	yes	.000	yes	.048	yes
	M	.000	yes	**.341**	**no**	.000	yes	.000	yes	.000	yes	.000	yes
	Y	**.710**	**no**	.000	yes	**.131**	**no**	.000	yes	**.349**	**no**	.000	yes
90% Tint TVI	K	.000	yes	.000	yes	.001	yes	.000	yes	.000	yes	.000	yes
	C	.000	yes	.021	yes	.000	yes	.000	yes	.013	yes	.000	yes
	M	.001	yes	.000	yes	.000	yes	.000	yes	.000	yes	.000	yes
	Y	.000	yes	.000	yes	**.812**	**no**	.000	yes	.000	yes	.000	yes
PC	K	.004	yes	.000	yes	.000	yes	.000	yes	.000	yes	.000	yes
	C	.000	yes	.000	yes	.000	yes	.000	yes	.000	yes	.000	yes
	M	.000	yes	**.462**	**no**	.000	yes	.000	yes	.000	yes	.000	yes
	Y	.000	yes	.000	yes	.002	yes	.000	yes	.000	yes	.000	yes
Trap	R	**.051**	**no**	.000	yes	.000	yes	.000	yes	.000	yes	.000	yes
	G	.000	yes	.000	yes	.000	yes	.000	yes	.000	yes	.000	yes
	B	.000	yes	.000	yes	.000	yes	.000	yes	.000	yes	.000	yes

Note: significant level (α) = .05; μ denotes the mean of print attributes

3.3 Discussion in colour characterization

Colour can be defined in numerical way, thus it is logical extension to use CIELAB values to numerically specify the difference between two colours. The numerical measure between two colour is calculated using a metric called Delta E (ΔE). A large ΔE value between two samples means that theses samples as distinctly different colour, and a small ΔE value suggests that the colour look very similar (Sharma, 2004). The equation of ΔE is:

$$\Delta E = \left[(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2\right]^{1/2}$$

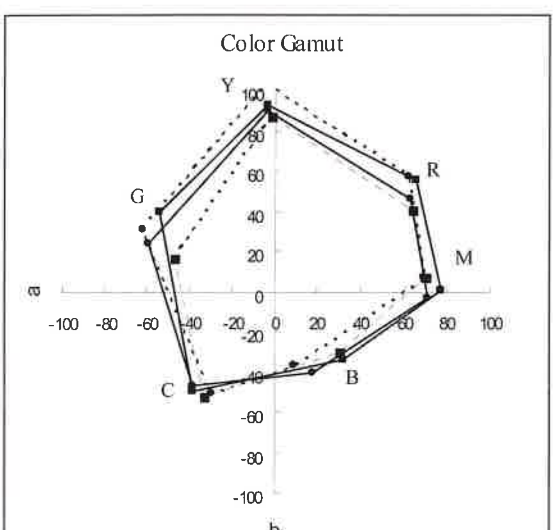
The colour difference for cyan, magenta, yellow, red, green, and blue colour at solid patches among the four systems was discussed in this section. The "one sample t-test" statistical procedure was applied to test the colour difference and the test value is 8. The results were displayed in Table VIII. According to Table VIII, Hanky HA-OC-6 and Guann Yinn GFS-1001 systems have significant colour difference in red, green, and blue colour. As for Hanky HA-OC-6 versus Kammann K15-40, Table VIII shows that the colour differences between the two systems are all significant at .05 level in all Cyan, Magenta, Yellow, Red, Green, Blue colour. Table VIII also shows that the colour differences between Hanky and DIC systems are significant at .05 level in cyan, magenta, green, and blue colour. As for Guann Yinn GFS-1001 versus Kammann K15-40 systems, Table VIII shows that the colour differences between the two systems are significant at .05 level in all colour excluding red colour. As for Guann Yinn GFS-1001 versus DIC H-7 systems, Table VIII shows that the colour differences between the two systems are significant at .05 level in all colour except for yellow colour. As shown in Table VIII, the colour differences between Kammann K15-40 and DIC H-7 systems are significant at .05 level in yellow, red, green, and blue colour.

Table VIII: Hypothesis testing on the colour difference between waterless offset CD printing systems

Colour	Hanky v.s. Guann Yinn		Hanky v.s. Kammann		Hanky v.s. Dic		Guann Yinn v.s. Kammann		Guann Yinn v.s. Dic		Kammann v.s. Dic	
	Ho : $\mu\Delta E_{@H\,vs\,G} = 8$		Ho : $\mu\Delta E_{@H\,vs\,K} = 8$		Ho : $\mu\Delta E_{@H\,vs\,D} = 8$		Ho : $\mu\Delta E_{@G\,vs\,K} = 8$		Ho : $\mu\Delta E_{@G\,vs\,D} = 8$		Ho : $\mu\Delta E_{@K\,vs\,D} = 8$	
	p-value	Result	p-value	Result	p-value	Result	p-value	Result	p-value	Result	p-value	Result
C	.000	ΔE=3.43 < 8	.000	ΔE=11.8 > 8	.000	ΔE=8.87 > 8	.000	ΔE=12.2 > 8	.025	ΔE=8.38 > 8	.000	ΔE=5.54 < 8
M	.001	ΔE=7.34 < 8	.000	ΔE=11.1 > 8	.000	ΔE=11.8 > 8	.000	ΔE=10.6 > 8	.000	ΔE=11.2 > 8	.000	ΔE=4.31 < 8
Y	.000	ΔE=2.90 < 8	.000	ΔE=12.9 > 8	.000	ΔE=4.45 < 8	.000	ΔE=10.9 > 8	.000	ΔE=5.78 < 8	.000	ΔE=15.9 > 8
R	.000	ΔE=9.52 > 8	.000	ΔE=11.2 > 8	.011	ΔE=7.13 < 8	.000	ΔE=4.57 < 8	.000	ΔE=15.1 > 8	.000	ΔE=17.1 > 8
G	.000	ΔE=17.1 > 8	.000	ΔE=9.61 > 8	.000	ΔE=15.6 > 8	.000	ΔE=14.2 > 8	.000	ΔE=25.8 > 8	.000	ΔE=22.1 > 8
B	.000	ΔE=15.6 > 8	.000	ΔE=10.2 > 8	.000	ΔE=16.3 > 8	.000	ΔE=23.1 > 8	.001	ΔE=6.64 < 8	.000	ΔE=22.3 > 8

Note: The t-test value = 8, $\alpha = 0.05$

Figure 3 illustrates the colour gamut for the four waterless offset CD printing systems. As shown in Figure 3, both Hanky HA-OC-6 and Guann Yinn GFS-1001 systems printed wider colour gamut than the others did, and the DIC H-7 system had the smallest colour gamut among the four.



Note:
—•— represents Hanky HA-OC-6 waterless CD printing system
—▪— represents Guann Yinn GFS-1001 waterless CD printing system
---•--- represents Kammann K15-40 waterless CD printing system
---▪--- represents DIC H-7 waterless CD printing system

Figure 3: The colour gamut for the four waterless offset CD printing systems

3.4 Other findings - Process capability analyses for waterless CD printing systems

In the printing industry, monitoring solid ink density (SID) during a press run is essential when comparing any printed material. Many research reports have indicated that SID has a greater influence on tone value increase than any other factors. The higher the SID printed for a given condition, the more the midtone gained in density. As the midtone gets darker, shadow contrast decreases and the shadows get denser. Therefore, there is a great need to examine the process consistency and capability of the solid ink density for the four systems.

The statistical procedure used to analyze the consistency for each variable are Individual Control Chart (I Chart), Moving Range Charts (MR Chart), and Capability Analysis. Process capability ratio (PCR or Cp index) is a measure of how capable a process is of meeting specifications. A Cp index of 1 means that a process is exactly capable of meeting specifications, while less than 1 means that it is outside specification limits. In this study, the target values of CMYK solid ink density were determined based on GRACoL (General Requirements for Applications in Commercial Offset Lithography) specifications. Ideally, one would like to see a Cp much larger than 1, because the larger the index, the more capable the process. Some practitioners consider *1.33* to be a minimum acceptable value for this statistic, and few believe that a value less than 1 is acceptable.

Due to the lack of historical parameters of lower specification limit (LSL) and upper specification limit (USL) for the observed solid ink density, a method of determining the proper LSL and USL is necessary. In this study, the LSL and USL for SID were determined based on the following procedures (Montgomery, 1997):

1. Construct the trial I and MR control chart of each solid ink density for the four systems.
2. Examine every control chart; if it is in control, then use the lower control limit (LCL) and upper control limit (UCL) as the LSL and USL. If it is in out-of-control condition (for most cases), reconstruct the control chart after eliminating all out-of-control points in the initial charts to obtain the revised values for the mean, LCL, and UCL.
3. To obtain the average variation of the four systems, the difference between revised LCL and UCL of each system obtained in the previous step is computed and named $6\sigma_{revised}$, i.e., $UCL_{revised} - LCL_{revised} = 6\sigma_{revised}$. Then $3\sigma_{revised}$ of each system is computed for the purpose of obtaining the "average $3\sigma_{revised}$" of the four systems, $3\hat{S}_{revised}$ namely, i.e.,

$$3\hat{S}_{revised} = (3\sigma_{revised\_Hanky} + 3\sigma_{revised\_Gaann\ Yinn} + 3\sigma_{revised\_Kammann} + 3\sigma_{revised\_DIC}) / 4 \quad (1)$$

4. For each systems, the final LSL and USL are obtained by subtracting from and adding $3\hat{S}_{revised}$, to revised mean of each system, i.e.,

$$LSL_{final} = Mean_{revised} - 3\hat{S}_{revised} \quad (2)$$

$$USL_{final} = Mean_{revised} + 3\hat{S}_{revised} \quad (3)$$

5. The LSL_{final} and USL_{final} were used to assess the relative Process Capability Ration (PCR) for the *revised* individual measurement control chart (I-Chart) of each solid ink density value for the systems. The LSL_{final} and USL_{final} for each solid ink density of the four systems value are exhibited in Table IX.

Table IX: The LSL_{final} and USL_{final} of each ink colour for the systems

Solid Ink Density	Hanky HA-OC-6		Guann Yinn GFS-1001		Kammann K15-40		DIC H-7	
	LSL	USL	LSL	USL	LSL	USL	LSL	USL
Black	1.40073	1.62347	1.49693	1.72433	1.62982	1.85256	1.25213	1.47487
Cyan	1.12293	1.38728	1.16573	1.43008	1.18303	1.44738	1.17183	1.43658
Magenta	1.01598	1.35923	1.13668	1.47993	1.04088	1.38413	1.04838	1.39163
Yellow	0.83521	0.98610	1.06396	1.21485	1.08476	1.23565	0.81056	0.96145

Capability analysis for black colour. The capability analyses of black solid ink density for the systems are exhibited in Figure 4, Figure 5, Figure 6, and Figure 7. As shown in those figures, the Kammann K15-40 system has the largest relative PCR (Cp = 2.43), followed by Guann Yinn GFS-1001 system (Cp = 1.43), Hanky HA-OC-6 system (Cp = 1.35), and DIC H-7 system (Cp = .33).

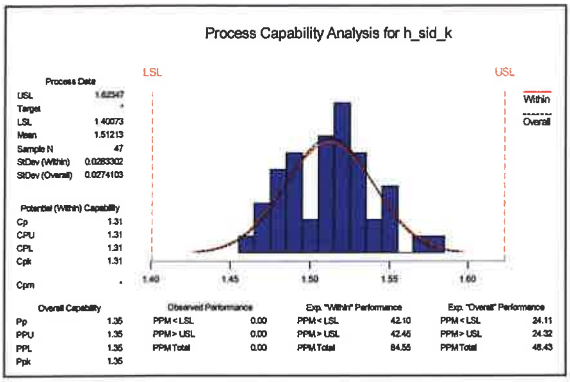


Figure 4: Process capability analysis of black SID for Hanky HA-OC-6 system

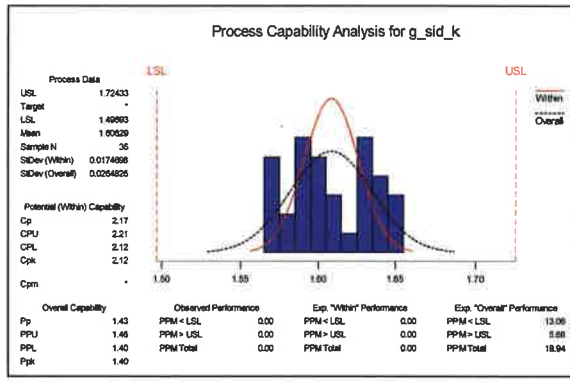


Figure 5: Process capability analysis of black SID for Guann Yinn GFS-1001 system

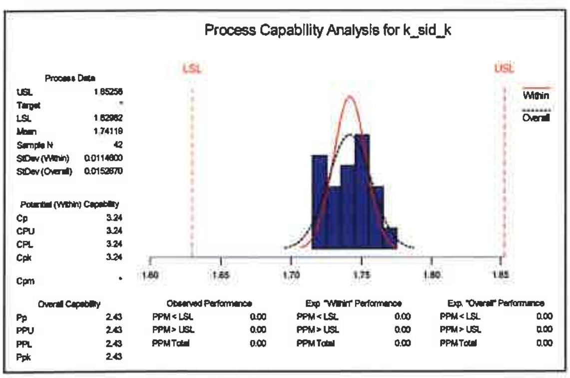


Figure 6: Process capability analysis of black SID for Kammann K15-40 system

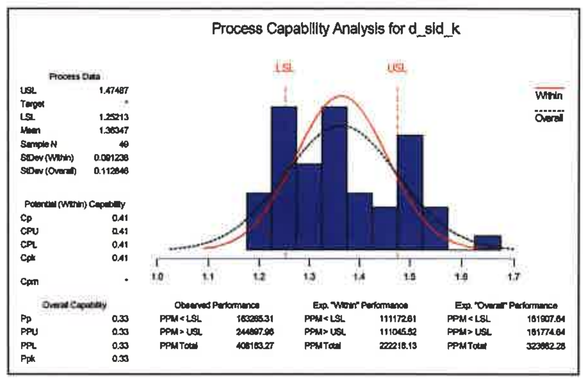


Figure 7: Process capability analysis of black SID for DIC H-7 system

Capability analysis for cyan colour. The capability analyses of cyan solid ink density for the systems are exhibited in Figure 8, Figure 9, Figure 10, and Figure 11. As shown in those figures, the Guann Yinn GFS-1001 system has the largest relative PCR (Cp = 2.10), followed by Hanky HA-OC-6 system (Cp = 1.83), Kammann K15-40 system (Cp = 1.40), and DIC H-7 system (Cp = .33).

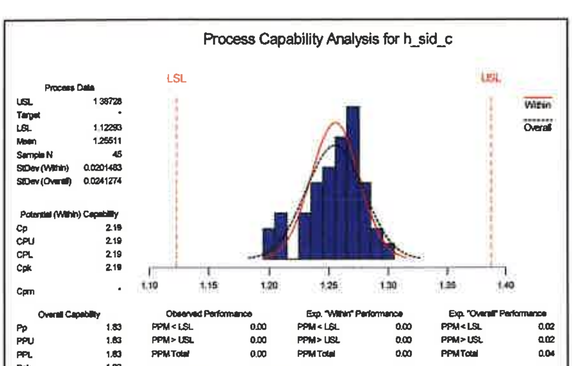


Figure 8: Process capability analysis of cyan SID for Hanky HA-OC-6 system

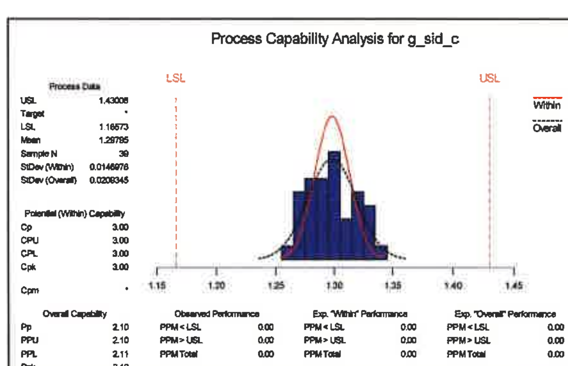


Figure 9: Process capability analysis of cyan SID for Guann Yinn GFS-1001 system

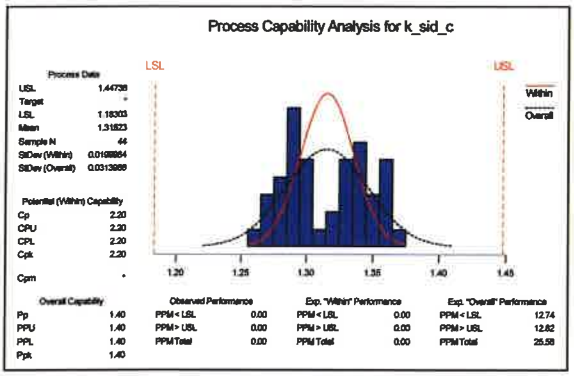


Figure 10: Process capability analysis of cyan SID for Kammann K15-40 system

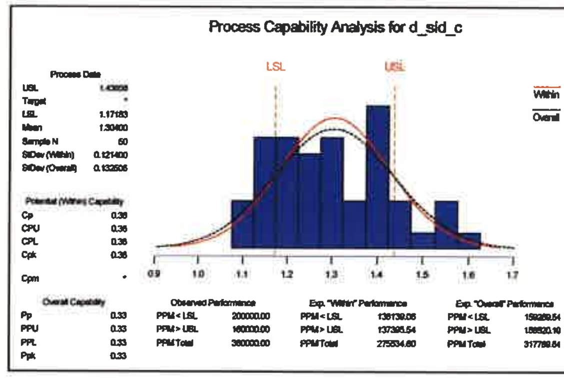


Figure 11: Process capability analysis of cyan SID for DIC H-7 system

Capability analysis for magenta colour. The capability analyses of magenta solid ink density for the systems are exhibited in Figure 12, Figure 13, Figure 14, and Figure 15. As shown in those figures, the Kammann K15-40 system (Cp = 2.33) has the largest relative PCR (Cp = 1.85), followed by Guann Yinn GFS-1001 system (Cp = 1.72), Hanky HA-OC-6 system (Cp = 1.52), and DIC H-7 system (Cp = .39).

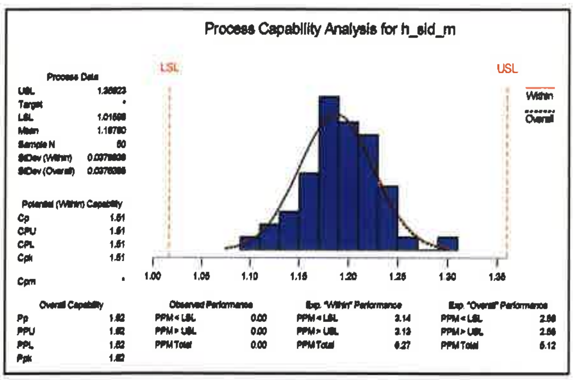


Figure 12: Process capability analysis of magenta SID for Hanky HA-OC-6 system

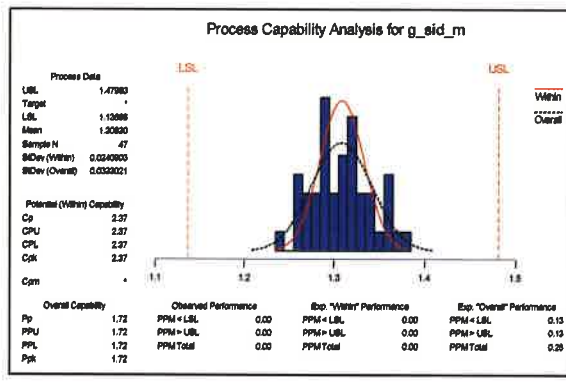


Figure 13: Process capability analysis of magenta SID for Guann Yinn GFS-1001 system

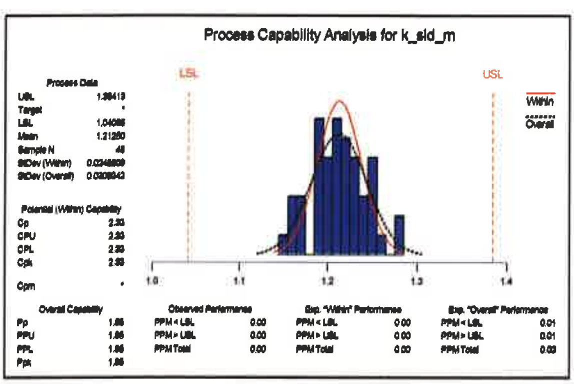


Figure 14: Process capability analysis of magenta SID for Kammann K15-40 system

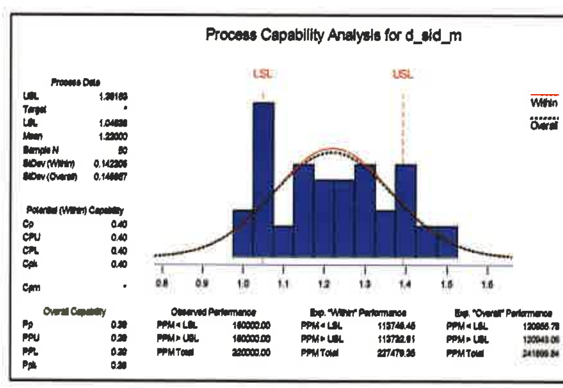


Figure 15: Process capability analysis of magenta SID for DIC H-7 system

Capability analysis for yellow colour. The capability analyses of yellow solid ink density for the systems are exhibited in Figure 16, Figure 17, Figure 18, and Figure 19. As shown in those figures, the Kammann K15-40 system has the largest relative PCR (Cp = 2.78), followed by the Hanky HA-OC-6 system (Cp = 1.91), Guann Yinn GFS-1001 system (Cp = .63), and DIC H-7 system (Cp = .54).

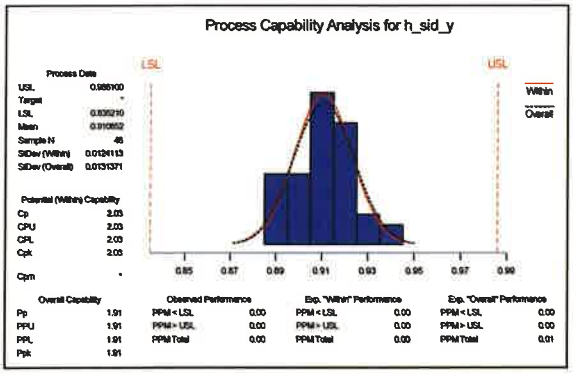


Figure 16: Process capability analysis of yellow SID for Hanky HA-OC-6 system

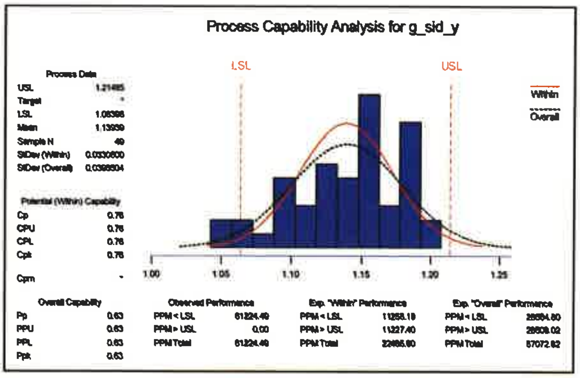


Figure 17: Process capability analysis of yellow SID for Guann Yinn GFS-1001 system

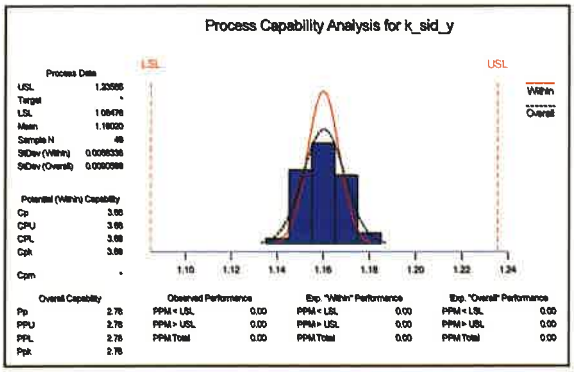


Figure 18: Process capability analysis of yellow SID for Kammann K15-40 system

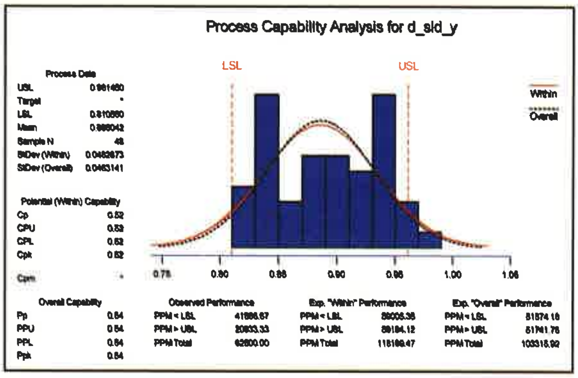


Figure 19: Process capability analysis of yellow SID for DIC H-7 system

Summary of capability analysis

Based the presentation of Figure 4 to 19, Table X summarizes the capability performance of the four systems in solid ink density, in terms of relative Cp indexes. According to Table X, this study concludes that the DIC H-7 system had the poorest performance (smallest Cp value) in solid ink density. Furthermore, its SID Cp values for all colour are all smaller than 1.00; it implies that DIC H-7 system was the least capable press of producing consistent results in solid ink density. Table X also shows that the Kammann K15-40 was the most capable system of producing consistent density among the four systems in black, yellow, and magenta colour, in terms of relative CP. Guann Yinn GFS-1001 system was the most capable system of producing consistent density in cyan colour. In addition, Hanky HA-OC-6 system generally had good performance in printing consistent density (the Cp value for the all colour are all higher than 1.3). In summary, this study concludes that the Kammann K15-40, Guann Yinn GFS-1001, and Hanky HA-OC-6 are capable systems of producing consistent solid ink density.

Table X: Relative PCR (Cp Value) of the four printing systems in SID

Cp Value	Hanky HA-OC-6	Guann Yinn GFS-1001	Kammann K15-40	DIC H-7
Black	1.35	1.43	***2.43***	0.33
Cyan	1.83	***2.10***	1.40	0.33
Magenta	1.52	1.72	***1.85***	0.39
Yellow	1.91	0.63	***2.78***	0.54

Note: **Bold** indicates the best in the group.

4. Conclusions

This experimental study constructs important printing attributes for the four commonly used waterless offset CD printing systems in the world, including HA-OC-6 (made in Taiwan), GFS-1001 (made in Taiwan), K15-40 (made in German), and H-7 (made in Japan). Furthermore, this study compared the differences in solid ink density, tone value increase, print contrast, ink trapping, colour difference among the four systems. This study also conducts capability analysis for solid ink density. The overall conclusions were listed below:

- The Japanese DIC H-7 press had the best dot reproduction in highlights among the four presses, and all of the four systems did not have good dot reproduction in shadows.
- The Germany Kammann K15-40 press printed the least tone value increase in between highlights and midtones among the four systems.
- The made-in-Taiwan Guann-Yinn GFS-1001 system printed the least tone value increase in between 60-80% tints and printed the greatest print contrast among the four systems.
- As to the ink trapping of green and blue colour, the Guann-Yinn GFS-1001 system had the best performance (greatest trapping percentage) among the four systems. As to the ink trapping of red colour, K15-40 press outperformed the other three.
- There were significant differences in tone value increase, print contrast, and ink trapping among the four printing systems in all four colour.
- Guann-Yinn GFS-1001 and Kammann K15-40 printed the greater colour gamut than did the other two, and DIC system printed the smallest colour gamut among the four. In addition, the colour gamut of Hanky tends to be more in blue than in other colour spaces; the colour gamut of Guann-Yinn tends to fall more in red and that of Kammann tends to fall more in yellow.
- When it comes to process capability, in terms of solid ink density, the Kammann K15-40, Guann Yinn GFS-1001, and Hanky HA-OC-6 were capable systems of producing consistent density based on the relative PCR or CP computation. The DIC H-7 system, conversely, had the poorest performance (smallest Cp value) in printing consistent density.

5. Recommendations

Finally, the study provides some recommendations for the industry and further research:

- Although there were significant differences in most of print attributes among the four printing systems, regardless of they were made in Taiwan or imported, this study suggests that Germany Kammann K15-40 is a relatively stable system because its print attribute variations was low, compared with the others.
- The operational conditions and procedures of the four systems are not alike. Further researches are necessary for press manufacturers to study various combinations of screen rulings, dot shapes, screen technology, print colour sequence, and inking temperatures (cooling systems) to establish a more standardized condition and procedure for each systems.
- The industry people should take into account the print attributes found in this study when choosing printing systems to complete their printing jobs for different originals.
- Since there are no industry-wide specifications for the compact disc printing, this study recommends that further researches be necessary to survey the CD printing industry for the sake of constructing the industry profile and establishing print attribute specifications for the industry.

Acknowledgements

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Studies of ink trapping II - Pinhole formations on the printed surface

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Abstract

There are many pinholes on a surface on a black printed matter using a cast-coated paper with a black offset proofing ink. A number of the pinholes (**N**) increased with increasing the lapse of the time during initial 6 hrs after the trapping. The **N** value at 24 hrs decreased with increasing amount of transfered ink (**y**). In the trapping with a synthetic paper ink, we obtained similar relations. With web offset ink, many pinholes were measured on the printed surface immediately after the trapping. The **N** value at 24 hrs was independent of the **y** value. The ink trappings were carried out using polyethylene terephthalate (PET) films. There are many pinholes on the printed surface. The pinhole formation mechanism was clarified by means of **y-N** relations, time-profiles of the **N** value, effects of drying temperature and drying atmosphere, etc. In these runs, we detected many air bubbles between the PET film and the ink layer.

1. Introduction

We detected many ink peaks on a printed surface immediately after trapping.[1] The number of the peaks decreased with increasing the amount of ink transfered (**y**). We also measured same number of the ink peaks on the ink roll to the peak number on the printed surface. Because the ink peaks must yield by cutting enlarged cavities, the ink trapping progresses through the cavitation theory. At **y** = 1.0 g m^{-2}, because the number of the ink peaks (ca. 7×10^9 m^{-2}) agreed well with the number of the pinholes on the paper surface, the cavities seem to be yielded by air supply from the paper surface. In the ink trappings using plastic films, we also detected many ink peaks on the printed surface. Since it is difficult to supply air to form the cavities from the plastic surface, we couldn't conclude the ink transfer mechanism on the plastic sheet.

After the trapping, the ink peaks became lower and hollows on the printed surface became thick according to the lapse of the time after the trapping.[2] At that time, we detect many pinholes on the printed surface. They increased with increasing the lapse. We studied the pinhole formations to obtain some aspects of the ink trapping and high quality printed matter.

2. Experimental

2.1 Sample

Cast-coated paper (Oji paper Co. Ltd.,) and two art papers (Gojyo Paper Co. Ltd. and Mitsubishi Paper Milling Co. Ltd.,) were used as the print substrates with polyethylene terephthalate film (PET film, 0.20 mm thickness). The data on the print substrates are listed in table I.[3] The average roughness (JIS B-0601-1982) of the paper was measured using a Tokyo Seimitsu Co. Ltd. Surfcom type 1400D-12 with a non-contact type laser detector E-DT-SL12A type (cut-off value: 0.4 mm). Three black inks (for offset proofing, synthetic paper and web offset) were used. Tack value and contents of ink published by the makers,[4] were listed in table II.

Table 1. Physical data of paper

paper	weight / g m^{-2}	air permeanbility / s	oil absorbency / s	Ra / µm
cast-coated paper	110.0	28,000	2135	0.2
art paper A	127.9	> 30,000	-	0.2
art paper C	127.9	11,400	3370	0.2
PET film	141.0	-	-	0.1

Table 2. Tack value and contents of ink

ink	tack value	contents / %			
	at 293 K	pigment	vihicle	plant oil	petrolium oil (Bp. range)
offset proofing ink	15.7	ca. 20	ca. 35	ca. 25	ca. 20 (549 - 619 K)
synthetic paper ink	20.4	ca. 20	ca. 35	ca. 35	ca. 10 (549 - 619 K)
web-offset ink	8.8	ca. 20	ca. 35	ca. 10	ca. 35 (508 - 539 K)

2.2 Ink trapping

Ink trapping was performed using an Akira Seisakusyo Co. Ltd. RI tester RI-4 type at ca. 293 K. The nip width between the inking and paper rolls was adjusted to 2 mm. After 10 minutes to distribute the ink, the ink trappings were carried out. The **y** value was determined gravimetrically. Immediately after the trapping, the printed matters were divided to two parts after measuring the **y** value. A part was dried under very weak nitrogen stream at 293 K in a vacuum drying oven. Another part was stored at 293 K in atmosphere. Some samples were divided to four parts. Some parts were stored in a refrigerator (ca. 278 K), a dark room (ca. 293 K) and a drying oven (ca. 303 K). The fourth part was dried by weak air current (ca. 293 K). With an UV curing ink, every printed matter was divided to two. A part of the printed matter was irradiated for 3 min using a 300 W high pressure Hg lamp without filters from 200 mm distance at 293 K. The other part was stored for 24 hrs at 293 K.

2.3 Measurements

Immediately after the ink trapping, the wet surface was observed directly with a type VP-6300 digital microscope (Cheyenne Co. Ltd., Osaka, Japan) at magnifications of 450 times with a Nikkon calibration gauge for the microscope. The microscope images were corrected using Adobe Photoshop ver. 6.0.

Shimazu Co. Ltd. SPM-9500 type atomic force microscope (AFM, Kyoto, Japan) with Si3N4 micro cantilever was used to measure the surface of the printed matter.[5)] Samples (10 mm x 10 mm) were adhered to the sample stage using double-sided tape. In each sample, at least five areas were measured. The **N** values were otained by averaging the measured numbers. Average deviations are below 15%.

3. Results and discussion

3.1 Pinhole formation

We observed many pinholes on the printed surface at 24 hrs after trapping. They were divided roughly to two groups, i.e., large ones (ϕ = 5-10 µm) and small ones (1-2 µm). Figure 1 shows a microscope image and an AFM image of the pinholes. The large ones looked like gaps of ink particles attached on the paper surface, as reported already.[5, 6)] The small ones looked like hollows on the printed surface. Although a number of the former ones was independent of the lapse of the time after the trapping, the number of the latter ones increased with increasing the lapse.

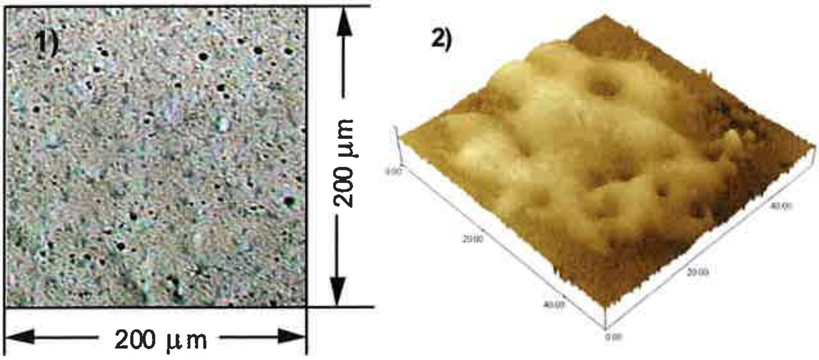

Figure 1: Digital microscope image (1) and AFM image of the printed matter

3.2 Pinhole formation on printed paper

The ink trappings were carried out using the black offset proofing ink and three papers, i.e., the cast-coated paper and two art papers. The **N** value at 24 hrs after the trapping decreased with increasing the **y** value [**N** = 5.8 x 10^9 (**y** = 1.0 g m^{-2}), 2.3 x 10^9 (*ca.* 4 g m^{-2}), as shown in Fig. 2a. The **y-N** relation of the cast-coated paper agreed completely with those of the art paper.

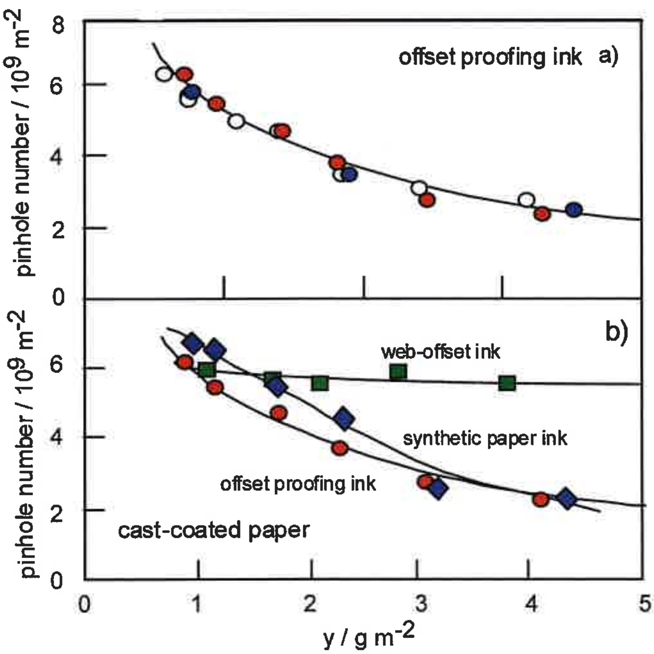

*Figure 2: Relations between the amount of ink trapped and the number of pinholes. The effect of the printing substrate on the printing with offset proofing ink [**a**, cast-coated paper (●), art paper A (○), and art paper C (●)] and that of the ink on the printing with the cast-coated paper [**b**, offset proofing ink (●), synthetic paper ink (◆), and web-offset ink (■)*

We studied the effect of ink variation on the **N** value of the printed matter using the cast-coated paper with black inks for synthetic paper and web offset. With small amount of the synthetic paper ink (**y** = 1.0 g m^{-2}), the **N** value was larger than that of the offset proofing ink [**N** = 7.0 x 10^9 m^{-2} at 24 hrs after the trapping]. The **N** value decreased with increasing the **y** value to the value with offset proofing ink (Fig. 2b). On the other hand, the **N** value of the printed matter with the web offset ink was independent of the **y** value (**N** = 5.9 x 10^9 m^{-2}, **y** = ca. 1.0 g m^{-2}). When we controlled the ink distribution (milling) time on the tester (from 3 to 15 minutes) using the offset proofing ink before trapping, the **N** value decreased slightly.

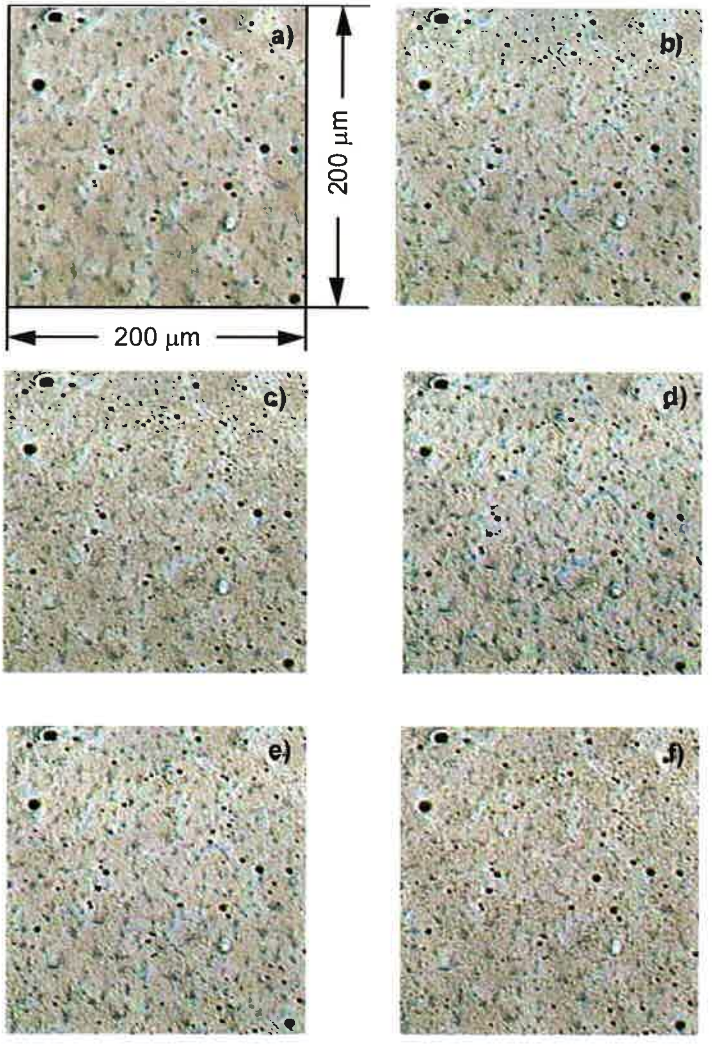

Figure 3: Digital microscope images measured at 0 (a), 1 (b), 2 (c), 4 (d), 6 (e) and 24 hrs (f) after the trapping. Substrate, cast-coated paper; offset proofing ink; y = 0.89 g m^{-2}

Figure 3 shows the microscope images monitored at the same area. Using the cast-coated paper with the offset proofing ink, the **N** value increased rapidly in the lapse of the time during initial 6 hrs after the trapping, as shown in Fig. 4. At **y** = *ca.* 1 g m^{-2}, the **N** value of the printed matter immediately after the trapping (1.7 x 10^9 m^{-2}) is about one third smaller than the value at 6 hrs (5.5 x 10^9 m^{-2}). After 6 hrs, the **N** values were independent of the lapse. In the trappings using various papers and the offset proofing ink, the same relations were obtained. Using the cast-coated paper with the web offset ink, the **N** value increased slightly in the lapse of the time from 5.0 x 10^9 m^{-2} (immediately) to 6.0 x 10^9 m^{-2} (at 24 hrs after the trapping).

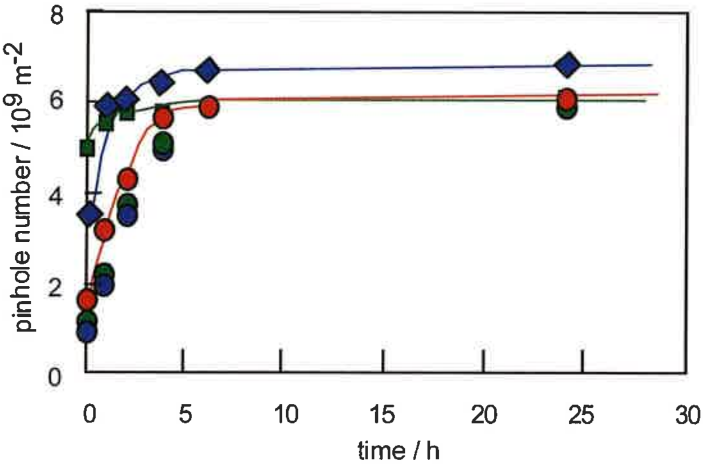

Figure 4: Time profiles of the pinhole number (y = ca. 1.0 gm^{-2}). ● with cast-coated Paper and the offse proofing ink, ● with the art paper A and the offset proofing ink, ●: with the art paper C and the offset proofin ink, ◆: with the cas coated paper And synthetic paper ink, ■: with he cast-oated paper and the web-offset ink

3.3 Pinhole formation with PET film

We measured the **N** value of the printed matter at 24 or 48 hrs (in the printing with web offset ink) using the PET films with various inks. The **N** value also decreased with increasing the **y** value as the trappings using the paper, as shown in Figure 5. With the offset proofing ink in particular, the **N** value was about one order magnitude smaller than the values using the paper.

The time profile of the **N** values was studied by monitoring the same area printed using the offset proofing ink, shown in Figure 5. Except the web offset ink, the **N** values increased in the lapse of the time during initial 6 hrs after the trapping [**N** = 7.5 x 10^8 (t = 0), 3.0 x 10^9 (t = 6 hrs, offset proofing ink); 5.5 x 10^8 (t = 0), 3.6 x 10^9 m^{-2} (t = 6 hrs, synthetic paper ink)]. After 6 hrs, the **N** values were independent of the lapse. On the other hand, the **N** value of the web offset ink printed matter increased slowly [from 7.5 x 10^8 (t = 0) to 5.8 x 10^9 m^{-2} (t = 48 hrs)].

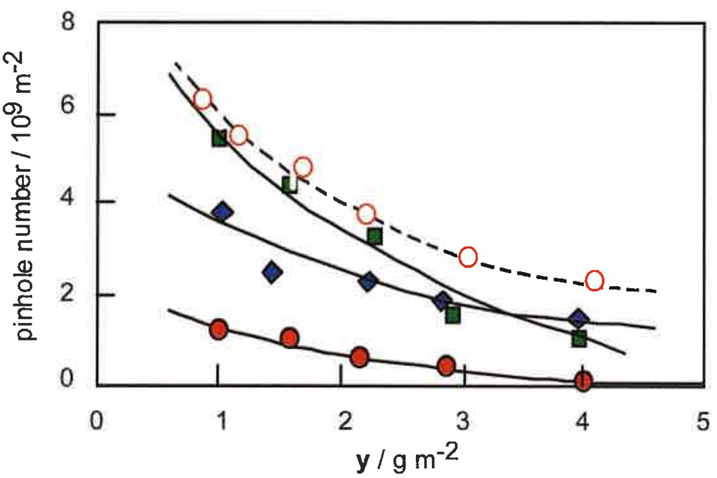

Figure 5:Relations between he amount of ink trapped and the number of the Pinholes in the printing on the PET film. Ink ●: offset proofin ink, ◆: synthetic paper ink, ■: web-offset ink. The relation using cast-coated paper and the offset proofing ink was also plotted (○)

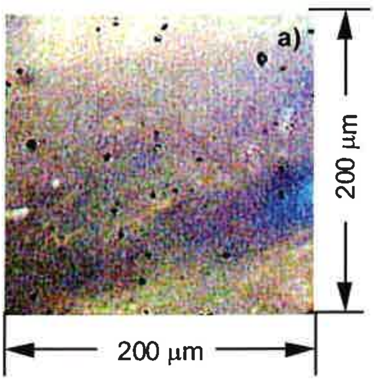

Figure 6: Microscope images of printed matters at t = 0 (a) and 24 hrs after the trapping (b) monitored form the back side through the PET film

Characteristics of the PET film are transparency and not to supply air from the surface. Immediately after the trapping, we detected many air bubbles fixed between the plastic sheet and the ink layer (small and large bubbles) by observations from back side through the film [ϕ = 1-2 (small ones), 5-15 μm (large ones), ca. 5 x 10^7 m^{-2}], as shown in Fig. 6. The small ones were also detected in the ink layer (ϕ = ca. 2 μm). Unfortunately, it was difficult to measure them for depth of the field of the microscope. We assumed that the small ones were formed by suspension of air into the ink in the milling and the large ones were done by pressing rough ink surface on the ink roll to the printing substrate at the ink trapping. By increasing the lapse of the time monitored, the number of the air bubble decreased slightly.

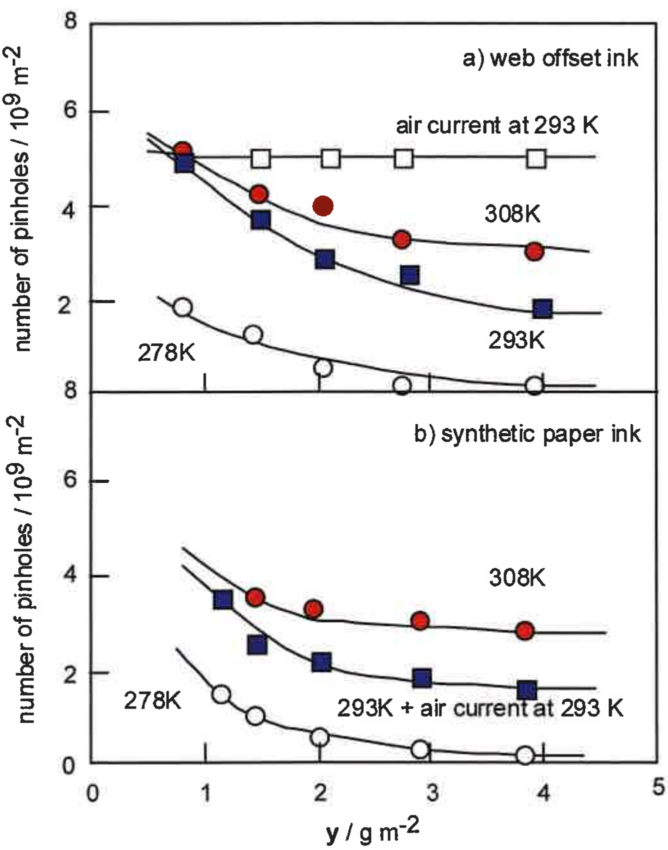

Figure 7: Effect of drying temperature on the N value in the trappings of the web-offset in (a) and the synthetic paper in (b). The N values at 24 hrs after the trapping were plotted against the ***y*** *value. Temperature: 278 (○), 293 (■) and 308 K (●). The samples were dried by air current at 293 K (□)*

3.4 Effect of oxygen on pinhole formation

Since the synthetic paper ink contains relatively large amounts of plant oil (such as soybean oil and tung oil) and small amount of the petroleum solvent with oxidizing catalyzer, the printed matters must dry by oxidations of ink vehicle and solvent. If the pinholes yield by contraction of the ink according to oxidizations, the pinholes are hardly formed on the PET film in nitrogen. Every printed matter was divided to two parts immediately after trapping. One part was stored for 24 hrs under weak nitrogen stream and the other part was done in atmosphere. Unfortunately, both the **N** values of the printed matter were agreed well with each other. We can't conclude whether the pinhole formation is caused not by the oxidations of the ink vehicle and solvent or enough oxygen has been already absorbed into the ink before the trapping.

3.5 Effect of temperature on the pinhole formation

The web offset ink constitutes relatively large amount of low boiling point petroleum solvents (bp. range: 508-539 K). If the solvent vaporization makes pinholes on the printed surface, the **N** value is affected seriously by drying temperature. On the other hand, the synthetic paper ink doesn't contain the low bp. solvent. Using the PET films with the web offset ink and the synthetic paper ink, effects of drying temperature on the **N** value of the printed matter were studied (drying temp. = 278, 293, and 308 K). The printed matters were divided to four parts for each run immediately after trapping. In each the ink, the N value increased with rising temperature, as shown in Fig. 7. The effect of air current was also studied using both samples. The air current increased the N value of the web offset ink printed matter, although the N value of printed matter with the synthetic paper ink was independent of the current.

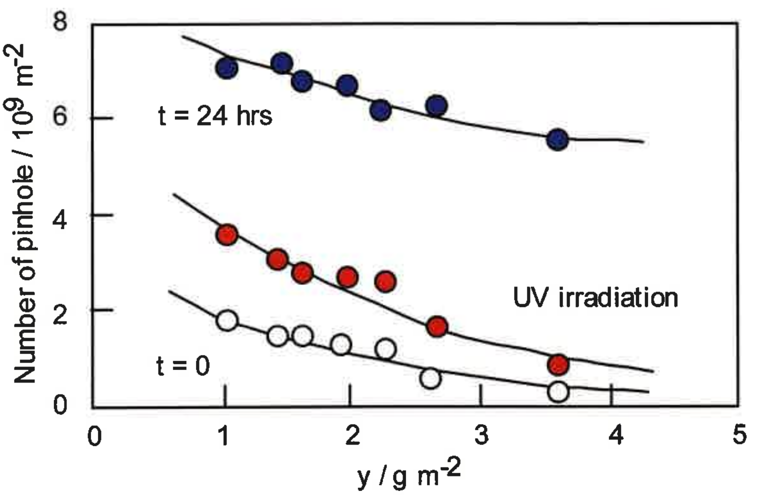

Figure 8: Plots of the N value vs. the y value in the trapping using the cast-coated paper with the UV curing ink. Immediately after the trapping, ○; after UV irradiation, ●; after 24 hrs, ●

3.6. Effect of UV irradiation on the pinhole formation

Since the printed matter with the UV curing ink dries rapidly by irradiation, many pinholes seem to yield by contraction of the printed ink. We studied the time profile of the **N** value of the printed matter using the cast-coated paper with the UV curing ink. Immediately after trapping, the printed matter was divided to two parts. One part was irradiated using the Hg lamp and the other part was stored in the dark room for 24 hrs. Because the **N** value of the former part is a half smaller than the value of the latter one (Fig. 8), the pinholes aren't yielded by the polymerizations.

3.7 Pinhole formation mechanism

We assumed two mechanisms of the pinhole formation, as followings. (1) After trapping, the ink solvents are absorbed by the paper and are vaporize. By decreasing the solvent concentration, expanded vehicle (before printing) seems to be contracted and then to form the pinholes. (2) Many small air bubbles are emulsified into the ink in the milling of the ink. Relatively large air bubbles are fixed between the PET film and the ink layer in the ink trapping. They seem to come out to the surface.

Using the papers with the various inks, the **N** values of the printed matter increased in the lapse of the time. Because the paper absorbs the ink solvents from the paper surface slowly, the pinholes seem to be yielded according to decrease the solvents. This effect on the printed surface must become weak according to the increase of the ink thickness, as seen in the **y-N** relations.

Using the PET film with the offset proofing ink and the synthetic paper ink, the **N** values of the printed matter increased rapidly during initial 6 hrs. Since the latter ink contains rather high concentration of the oxydizing catalyzer, this ink seems to contract according to oxidations of the plant oil and the vehicle. Unfortunately, the effects of drying atmosphere on the **N** value were not detectable. As the printed UV curing ink seems to contract according to dry, we expect to detect many pinholes on the surface by the irradiation. The **N** value of the irradiated sample was smaller than the value of the sample dried on standing. It is indicated clearly that the polymerizations were not caused to form the pinholes. We detected many air bubbles in the ink layer in the printings using the PET film with the offset proofing ink and the synthetic paper ink. Some of them must act as cavities in the ink trapping on the plastics films and some of them yield the pinholes.

The web offset ink contains large amount (ca. 40%) of low boiling point petroleum solvent. With air current, the **N** value of the printed matter on the PET film increased from 7.5×10^8 m^{-2} (immediately) to 6.0×10^9 m^{-2}, (at 48 hrs). Thus, the web offset ink on the PET film dried by vaporization of the petroleum solvents.

4. Conclusions

There are many pinholes on the printed surface. They increased with increasing the lapse of the time during initial 6 hrs after the trapping. We studied the pinhole formations to clarify the ink trapping mechanism and to obtain high quality printed matter. In the ink trappings on the papers, the pinholes were yielded by the osmosis of the ink solvent into the paper.

In the printings on the PET film, we detected many air bubbles fixed between the plastic and the ink layer (small and large bubbles). We assumed the smaller ones were formed in the ink milling and the larger ones were done at the ink trapping. Using the offset proofing and synthetic paper inks, there are many pinholes. They seemed to be yielded by the air bubbles. Using the web offset ink, since this ink contains a lot of low boiling point petroleum solvents, the pinholes were formed by the evaporation of the ink solvent.

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3

Gravure printing

Benchmarking gravure cylinders vs. web-offset plates

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Abstract

This paper deals with an important part of a forthcoming survey of the European Publication Printing Industry - and highlights the developments in recent years of the processing costs of producing either offset plates or gravure cylinders. In 1985-1986, one of the most comprehensive studies of the publication printing industry was carried out by the European Rotogravure Association in Munich. This study was the first of its kind and a comparable study has, to author's knowledge, never been compiled. The objective of the present paper is to determine what factors are important when the choice of a particular printing method is made, and if this process was fundamentally different in 1985 than to-day. The hypothesis is that there were some determining factors in 1985 such as the economic consequences (processing costs and market prices), the speed (lead-time) and finally the quality of the printing process to be chosen. In order to make the two studies comparable a statistical analysis of various European macro economic indices has been used, and now 20 year later the first follow-up study is now available.

With an abundant number of players marketing and selling CTP-solutions, there is a tremendous competition in the world market. Hence, most industry observers have the opinion (or belief) that producing web-offset plate's to-day is much cheaper and easier than processing gravure cylinders. The gravure cylinder processes are still considered to be very expensive, cumbersome and old fashioned to the great disadvantage of the gravure printing process. What is often forgotten is that the recent web-offset plate technology is in fact emulating the much earlier developed gravure technology, going directly from the digital file to the image carrier. The big difference is that modern PC and networking technology has made the direct digital interfaces very much cheaper for the gravure printing industry than it was 20 years ago for the first pioneers, and the reliability of the engraving process has reached a level where gravure proofs are no longer necessary.

1. Introduction

In 1985 the European Rotogravure Association (ERA) conducted a study on gravure and web-offset, and the study was called "Separating the facts from the myths" (Bjurstedt 1986). The investigation included in depths interviews with the leading industry managers, and the processing costs of producing various printed products for each individual company were investigated. The figures were given to the investigator under a non-disclosure agreement. Subsequently the data, containing some 500 files, was processed, and a summary of the findings was given to the members of the Association in 1985. However, it was not possible to identify any individual company, but every participating company was given their relative position in the study. Later in 1986 an official report from the Association was published to the graphic art industry. During the spring of 2005 a new study has been compiled by the author under a similar non-disclosure agreement. This time, however, in depth discussions with the leading supplier of CTP-technology and Engraving systems have been included in the study, as the technical developments, in particular in the high power laser area, are progressing very fast.

Automation and robots controlled by networking computers have been introduced in both the cylinder making department as well as in the plate making department, and modern processes need very few people.

Web-offset printers have profited greatly from the new CTP-technology (Computer to Plate) which has come to the market during the last decade. The new technology has lowered the entry level for the web-offset industry, improved the print quality and made longer runs possible. The gravure industry has been slow to respond to the challenge, but recently new efforts in developing alternative methods for the publication printing industry is slowly coming to the market. Newly developed technologies in the engraving area, both for the traditional electro-mechanical engraving heads as well as the new laser engraving units, have automated the calibration processes and significantly improved the production rates and shortened the lead-time. Many gravure printers are now able to use sophisticated process controls of the processing of cylinders, and the processing costs of cylinders have plummeted. These new developments made it clear that a new survey comparing costs, lead-time and quality was indeed needed.

2. Why benchmarking and how

During the Drupa 2004 a series of in depth interviews were conducted with many top managers in the industry, in particular in the supplying industry. Most comments about the gravure process stated that cylinder making was still a major drawback. Web-offset technology was seen almost everywhere in the exhibition and made a strong impact on most visitors. Nevertheless, some new developments were shown concerning the production of gravure cylinder that was not quite obvious to everyone. Hence, the concept of doing a benchmarking investigation of the current processing costs of gravure cylinders and web-offset plates became an obvious possibility and had to be explored.

Benchmarking is a relative new methodology but has been used in the industry for some time. Notably here is the automotive industry, where many of the most important competitors are comparing the number of hours used in the assembly line to produce a new car. Among those participating in an annual benchmarking exercise are Daimler-Mercedes, GM, Volvo Cars (now belonging to Ford Motor Co), Honda and Toyota. By analyzing the results the European car manufacturers have been able to improve their efficiency and closing the productivity gap to the Japanese industry. "Examples provide an irrefutable standard of comparison that stimulate people to perform better" as stated by Karlöf (Karlöf et al 2001). He suggests that the methodology of Benchmarking shifts the burden of proof to those who question why something should be changed.

However there are not much scientific research in the publication printing industry conducted on the subject matter, but Slimani has suggested a model of benchmarking for prepress companies (Slimani 2000). She suggests in her paper (which is a part of her dissertation) that there are certain benchmark factors which are both relevant and seen as success factors. Such success factors quoted in her study were performance, reliability, efficiency, customer expectations and customer satisfaction.

One of the important factors is the notion that the prepress technology has gone so far that technical quality seems to be approximately the same for all companies. A remark here would of course be that this statement presumes that most prepress companies are frequently investing in leading edge technology. This is not quite true in the gravure printing industry, where one often finds rather old equipment - still operating technically well but not always up to recent standards or possible performance.

As the present investigation does not only compare gravure cylinders and web-offset plates, but also compares different companies, it has a dual purpose. This duality makes this study of particular interest. Some may comment that when comparing an internal process, the customer expectations and customer satisfaction are not quite relevant. But on the other hand, when it comes to compare printing forms, these two success factors are indeed very valid. They really determine the final print quality, which in the end the customer is paying for. Most customers to the publication printing industry in Europe are delivering pages in PDF-format which are ready for engraving or plate making. Here, the active communication between the customer and printing company is one of the determining factors in achieving a quality printed product as demanded by the market. To-day, to the benefit for both customers and printers, there is an established ISO standard for gravure publications which defines the various parameters.

The previous study conducted by ERA in 1985-1986 was one of the first of its kind and very comprehensive and included a number companies from Scandinavia, the UK and Central Europe. In this new investigation 22 companies have been participating, among those four of the major suppliers. Some of the companies from 1985 are still in operation and also part of the present study. However, other companies have merged, changed ownership, structure and in some cases gone out of business. Another study from the Gravure Research Institute (G.R.I.) in the US became available in 1987. In this investigation the GRI study is only used as a relative reference (the number of companies included in the US study is not known). GRI was merged with GTA (Gravure Technical Association) in1989, and the new association is the Gravure Association of America (GAA).

3. Hypothesis

In the ERA study from 1985-1986 stated, that for processing one 4-colour page in A4 size, the relationship between the cost of gravure cylinder and web-offset plate was about 3:1. The study presumed that the preparation costs of text and images (prepress) prior to cylinder and plate processing were approximately the same for both processes. The publication printing industry used halftone separations, manual planning and montage (or in the case of many gravure printers, colour page make-up systems) and preproofing of the current standard. Most of gravure printers did all this work in-house, to the contrary to many web-offset printers who were outsourcing.

During the last decade with the advancements of prepress technology (Bjurstedt 2005) customers are now using the PDF-technology by Adobe. Almost all prepress work are now sent by wire from each customer, and pages are supplied, including colour profiles (ICC) defined by the printer, ready to be engraved or exposed. The lead-time prior to the press-room is getting very short, which is a great burden to the printer, as he has to control that all pages are correct and ready to be processed. This is, however, a major change since 1985-1986, and the printer of to-day has very little influence and control of the creative process. Hence, it is of vital interest to the publication printer to have technical communication process with his customer. Remakes are very costly, independent of the printing process chosen.

The technology shift during the last 10-15 years has had an enormous impact on the publishing industry, and the printing industry has been forced to close or move to the customer most operations producing prepress pages. The entry level of publishing a new magazine has never been lower than to-day, and new titles are being introduced very frequently in all markets in Europe.

The previous technology was quite expensive and complicated, and only trained operators were in control of the technology. These processes have now been simplified to such level that it has become everybody's standard procedure. Hence, the proliferation of the prepress technology has made it much easier for even very small printing companies to handle these processes. During the last decade the development of the CTP-technology and web-offset plate making has undergone tremendous progress. To-day there is hardly any web-offset printer who does not use CTP-technology.

Even if direct digital engraving has been the standard procedure for almost all European gravure printers since the beginning of the 1990-ies, the process of producing gravure cylinders have not progressed until the last few years. One important progress, however is, that to-day there is no need for gravure proofs for publication works. In 1985-1986 it was not uncommon that certain gravure companies were proofing their cylinders up to three or four times, in particular for the most demanding advertising pages on the back-side or inside of a cover, and between each proofing process there were also many hours of manual corrections. To-day, the majority of the European gravure industry is still using quite old cylinder processing equipment, and mechanical engraving systems can be as old as 20 years but possible to update to reasonable technical standard. Substantial investments in new gravure cylinder technology, however, have been implemented by some of the larger companies in Europe. Again, one must not forget the impact from the customers, demanding higher reliability, quality and short lead times.

Hence, the hypothesis is that the current relations are still much in favour of web-offset plate making. The previous ratio has increased further during recent years, because there has been a tremendous investment boom in the European web-offset industry with the introduction of more advanced CTP-systems. This investigation will determine whether this hypothesis is true or not.

4. Prepress technology in 1985-1986

In 1985 the production methods in the prepress area were mainly manual with the extensive use of graphic films in both printing processes. However, some of the very advanced gravure printers were using digital technology, which drove the electro-mechanical engraving units. Some year's earlier precylinder operations in the gravure industry had moved from using continuous tone films to halftone films in the so called OT-conversion process. (OT stands for Offset-Tiefdruck meaning that continuous tone films were replaced by litho film (i.e. halftone films in the German language)). Most publication gravure printers had large prepress departments, where customer's pages - text composition, images scanned and pages assembled - were processed. Halftone separations made it possible to use commercial available preproofs, such as Matchprint and Cromalin, although the colour gamut match in many instances was questionable. Halftone film (or line film) was much cheaper and easier to process than the continuous tone film, and there was no pre-proofing concept available for this kind of films.

4.1 Web-offset plate making

Web-offset plate making was still basically manual with stripping of pages in 8-page montage as planning format. There were both negative and positive films in use, which varied depending on the market. In the US most web-offset printers were using negatives, whereas in central Europe most printers used positives. Some printers (Kipphan 2001) made single pages and subsequently copied the pages by step-and-repeat units (Krause, Misomex). Planning of single pages was said to be faster and more accurate than the planning of a full montage.

After exposure the plate was fed into the developing unit, rinsed and then gummed up. For longer runs the plate could be heat-treated (baked). In the middle of 1985 a service life of the plate of more than 100 000 revolutions were rare. Several sets of plates had to be used for longer runs.

4.2 Gravure cylinder processing

In 1985 most European publication printers had abandoned the old etching technique and switched to the mechanical engraving method. The first commercial engraver - the Helioklischograph from Dr Hell - was first shown at Drupa 1965 (Picture 1), but it took about 20 years until all etching departments in the gravure industry were closed in Europe. The break-through came in the early 1980-ies, when Dr Hell developed new scanning heads for descreening halftone films. The cell structure produced by the Helioklischograph is semi autotypical (Picture 2), which means variable depth and surface whilst the cell structure on etched cylinders was classic - same surface but variable in depth.

All printers were using single page make-up. The single films were copied to bromides, a material called Opalines, which was a white opaque film. These were mounted on a scanning cylinder, page by page sideways and lengthways, one cylinder for each colour. The scanning cylinder was read and simultaneously a copper cylinder would be engraved. The process of producing bromides was rather expensive and slow (Gravure - Process and Technology 2003). Eventually, with the event of the digital prepress operations a direct digital interface was developed by the most important suppliers, Scitex, Crosfield and Dr Hell. The first major installation, using a networked Scitex Response system, of a filmless operation in gravure was already in 1982 at Gutenberghus (now known as Egmont Magazines) in Copenhagen (Bjurstedt 2005). The direct digital interfaces were much faster, obtained a better cell quality and were easier to control than the previous methods.

5. Contemporary technologies

The extreme fast progress of digital technology in the 1990's had a great impact on the printing industry, in particular in the prepress area. New and affordable software packages for editorial and image manipulation were quickly accepted by the publishing industry, and the previous analogue technology was soon abandoned. With the help of modern PC and server technology as well as new networking protocols, such as Ethernet and Internet, the digital revolution in the printing industry created a chain of reactions. Postscript 3 was indeed superior to the previous versions, but there was still a need for improving the lithographic print quality (Bjurstedt 2005). Larger size formats were not easy to do plan manually, and the first step was called CTF - or computer to film. With the digital workflow, however, there was a need for new tools, such as automatic imposition, trapping and pre-flight control (Bjurstedt 2005).

As a result, new digital workflow techniques were introduced, all based on the PDF-technology (a subset of Postscript), which improved the control and transparency in the prepress process. Larger image-setters became available to the market, and web-offset printers could start using a digital work-flow creating a plate-ready film as output. All these new techniques created a dramatic change in the way the industry had worked, because the customer suddenly gained complete control of the work flow and indeed the prepress work. Previously, the publication printing industry processed all the pages and controlled the both prepress work and the work-flow.

5.1 Prepress technology

The photographic film had some serious disadvantages, such as smaller dots could not easily be reproduced, and the film material had a very high sensitivity and affinity for dust particles (static electricity). New screening technologies which could improve the print quality of lithography were introduced, but the film material limited the possibilities of these new technologies when the plates were exposed the old fashion way. An urgent need for a new technology, exposing the offset plate directly was needed, and it was called Computer to Plate - CTP. The common opinion in the graphic art industry is that plate making for offset has made dramatic progress during the last few years, and many technical solutions were developed with the emerging Computer to Plate technology.

5.2 Web-offset plate making

In 1993-1994 the first attempts of CTP-technology were tested in the industry. Among the pioneers were DuPont, Autologic (now part of Agfa) and Creo Inc. (now part of Kodak). DuPont was using a silver based plate for shorter runs, up to 50 000 copies in the newspaper market, and the CTP-device was a reengineered Pagefax receiver unit from Crosfield Electronics (at the time partly owned by Dupont). The major limitation in this particular combination was the quality of the plate, and the resolution and format of the receiver. The latter was optimized for newsprint (newspaper production) and could not for commercial work.

In the end of the 1990-ie, more advanced screening algorithms, imposition and trapping systems became available as well as Preflight systems (Picture 3 and 4). With these technical developments the CTP technology quickly matured and became accepted by the offset printers. Another contributing factor was of course the PDF-technology which made digital prepress affordable for all customers. Then many of the prepress companies were marketing larger size CTP-devices suitable for web-offset plates in the 32 or even 64 page press formats (Picture 5). Heat-treatment (baking) has given a service life of up to a million copies (Kipphan 2000).

Recent developments, with faster laser diodes and an abundance of different plates available on the market, made CTP-technology and plate marketing extremely competitive. During the interviews with various suppliers it has been quite obvious that this particular market is the buyer's market, with hard pressure on prices and margin. There is hardly any independent CTP producer after the latest merger between KPG (Kodak) and Creo Inc. It seems, after many deliberations, that all the suppliers are really struggling to maintain a reasonable profitability.

5.3 Gravure cylinder processing

Most of the European gravure publication printers have engraved the cylinders digitally since the middle of the 1990-ies. The gravure cylinder processing market, however, is dominated by only two players - Hell Gravure Systems, Germany and Dätwyler AG, Switzerland. These two companies are both offering the full range of equipment for processing cylinders for both publication and packaging printing in gravure, and may offer their customers turn-key solutions. Hell Gravure Systems is a recent management buy-out from Heidelberg (Dr. Hell by acquired by Linotype in 1990, and in 1995 Linotype was acquired by Heidelberg).

Unfortunately, most of the technical development concerning engraving technology was on a very low level during most of the major part 1990-ies, because the owners were not very interested in the gravure market. However, after the MBO more funding for technical developments has become available, and many new products have been brought to the market. Hell Gravure Systems is affiliated with the Kaspar Walter Group in Munich, and together they can offer complete integrated lines of plating and engraving of cylinders.

The only contester is the Swiss company Dätwyler AG, which has been active in the cylinder processing (plate making units) market during more than 25 years. Since a decade the company has been developing a direct laser engraving technology using zinc rather than copper as the cylinder surface (the zinc layer is subsequently chromed to obtain the perfect printing surface). They have been very successful in the packaging market, but there is to-day only one major installation in gravure publication printing - Bauer Druck in Cologne. The Bauer installation is now considered to be very successful, but it has taken considerable time to move the first installation into success. In the autumn of 2005 another major installation will be at the Polish subsidiary of Bauer Druck, and will be operational later the same year. The cell structures can easily be modified by the laser (Picture 6), and the direct laser engraver from Dätwyler is said to improve the ink release and hence the printability on most publication printing papers.

The growing competition from Dätwyler has prompted Hell Gravure Systems to improve the mechanical engraving technology. During DRUPA 2004 the first prototype of a new laser engraving technology was shown but very little detail was published. The new laser system from Hell will engrave either on copper or chrome, but is not be marketed for publication gravure until sometimes in 2006/2007. Recent mechanical engraving heads may engrave up to 12 kHz, which is quite an achievement as the first head could only do less than 4 kHz (Picture 7). The majority of the existing heads are still in the 4 kHz which indicates a large market for upgrades and improvements.

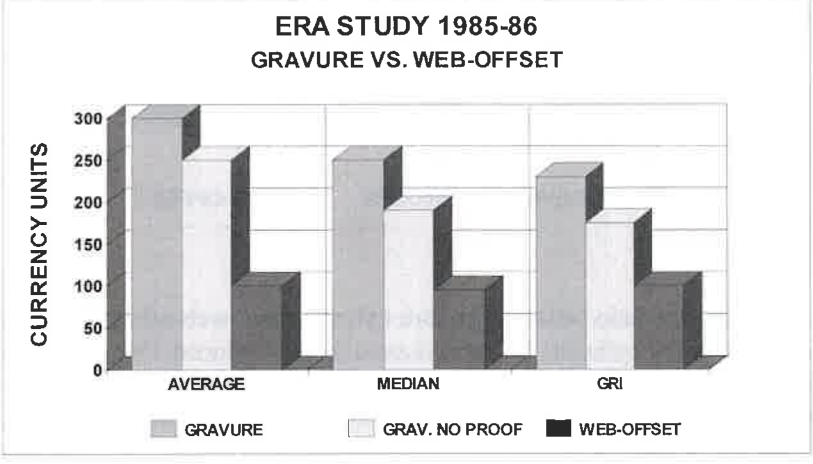
However, the direct laser engraving has an advantage of speed of more than double the engraving speed (8 channels of 7.5 kHz in comparison to 140 kHz), when smaller sizes of cylinders are compared. This advantage will of course change when using wider cylinders, as one channel is needed for each ribbon. Nevertheless, the calibration, loading and unloading of a cylinder, whether using laser or mechanical heads, still take a very large part of the process time needed for one cylinder. When compared with web-offset, the CTP-technology is much easier and faster to implement, in particular when using very fast laser diode arrays rather than a single beam. Further, the power of the lasers for CTP is only in the milli-watt range (mW), but in order to engrave in metal (like copper or zinc) the power is exceeding 300 W.

Recently, more advanced products have also been developed in the plating of copper or chrome of the cylinders. These allow the user the full automation inclusive loading/unloading and transport to a cylinder storage. The complete cylinder processing cycle is controlled by networked PC, and the processes in the individual plating or finishing unit can virtually run without any human intervention. Also the engraving units - the electromechanical or laser engravers - are to-day fully automated, and any changes of format, gradation etc. as well as calibration, is now controlled by the network Even an individual cylinder can be controlled, and some users have a chip built in each cylinder for easy identification and control.

6. Analysis of data from 1985-1986

The summary showed that generally speaking web-offset plates were cheaper and faster to process with a ratio of 1:3 to the disadvantage of gravure cylinders. However, this number was only valid when the worst scenario gravure was used - standard offset size A4, one gravure wet proof, some corrections on the cylinders etc. The project concluded, nevertheless, that the gravure printing process was stated to be very competitive from 32pp signatures (and larger), if best practice and technology were used (Bjurstedt 1986). The results of the 1985-1986 study can be found in Diagram 1.

Diagram 1



The figure to the right is showing the numbers from the US Study from Gravure Research Institute previously mentioned (the result converted in European currency as very favourable at the time, because of the recess of the dollar). However those companies using best practice and processing a reasonable numbers of cylinders would easily reach a ratio of 2.5:1 or less. One important observation at the time was that the variable cost of producing one gravure cylinder was low compared to a web-offset plate. Hence, with the right management and technical awareness, the gravure cylinder processing was indeed competitive.

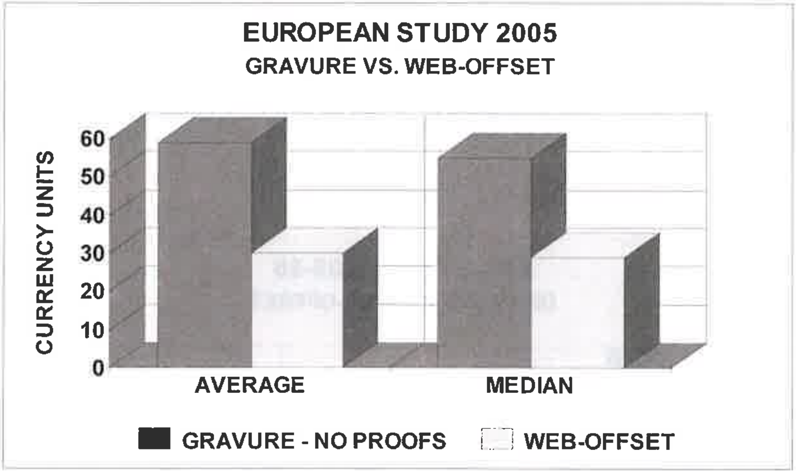
Consistent with these known facts some gravure printers pioneered the new digital technology already in 1983 and were among the first to benefit from the use of direct digital interfaces to the cylinder engravers. By doing so they omitted the use of graphic film, which greatly reduced costs, improved the quality of the final printed product and shortened the lead times.

As already has been mentioned within a decade later most gravure printers followed in their footsteps and went digital. This enabled many publication printers to go directly to the press without having to proof the cylinders. Simultaneously, some of the leading advertising agencies and admittedly some other customers embraced the new digital technology and demanded that their digital artwork - ready-to-be-printed - should be distributed by telecommunication. Only for very prestigious and expensive advertisements was proofing still needed.

7. Analysis of data from 2005

During the winter of 2005 further interviews have been conducted with a substantial number of printers - both gravure and/or web-offset printers - using the same technique as in 1985-1986. For the first time a benchmarking methodology has been used in the publication printing industry on a European basis. The validity of the statistics collected has been assured, and a sufficient number of printers answered. A similar non-disclosure agreement as in 1985 has been used (Diagram 2).

Diagram 2



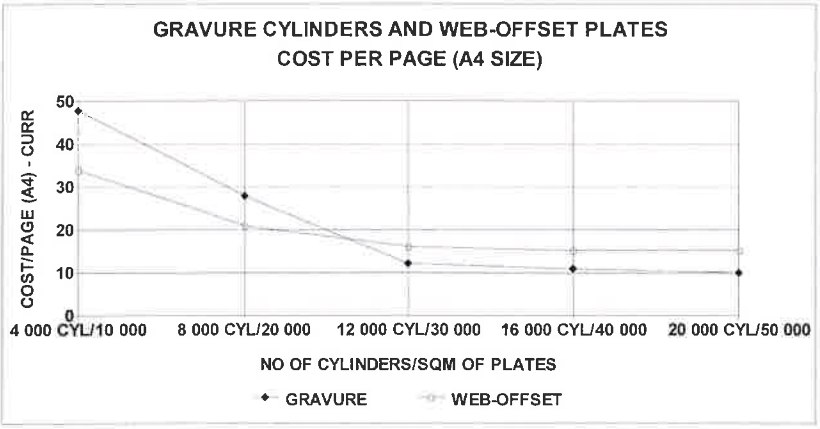
The recent results show that the ratio between gravure cylinders and web-offset plates has been reduced to about 1:2, and when using wider cylinders the ratio is even further reduced. One of the major conclusions is the great change of attitude and procedure among gravure printers. To-day with the improved computerized control of the process, there is no need to carry out corrections or proofing of the cylinders.

By abandoning the old bad practice modern gravure printers are now able to produce gravure cylinders much cheaper and with much more reduced lead-times than ever before. Another significant change is that the element of fixed costs in web-offset plate making has grown since the introduction of the CTP technology. Using the "old" manual technology, the element of fixed costs in plate making was very low.

Nevertheless, the spread among the European gravure printers is indeed very large. The statistics shows, that the cost of processing small and medium size cylinders in low numbers is very high. Consequently, printers with low volumes and small or medium size cylinders have high costs and will face strong competition from modern web-offset printers. With a limited number of pages on the cylinder, the unit cost becomes very high. On the other hand, those printers utilizing the very wide cylinders in greater volumes have very low cost per page, some even lower than the mean/average of web-offset pages (Diagram 3).

The cost per page among web-offset printers seems to converge into a European average, and the spread is significantly smaller than among the gravure printers. My assumption is, that the competition in the European market for plates and CTP-devices has been extremely tough during recent years and that the cost of equipment and materials from different suppliers have become very close to-day, almost to a point of a standard European level. Furthermore there is almost impossible for a supplier to be competitive in the web-offset market, if he can not offer both plates and CTP devices as a combined business.

Diagram 3



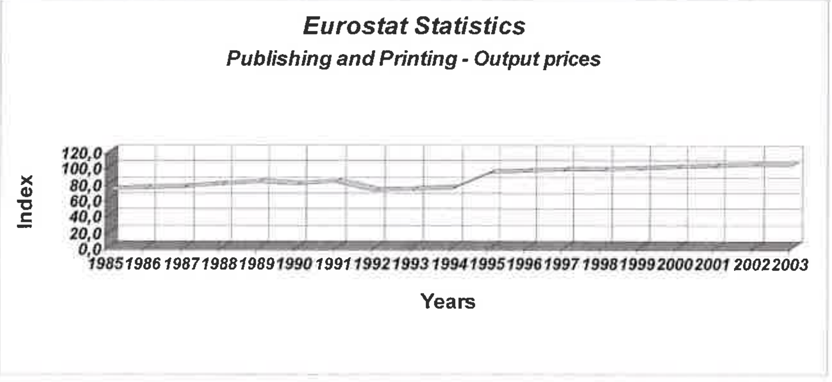
The price elasticity in cylinder processing is rather weak, which means that if a printer decides to invest in wider cylinder face width, i.e. going from 2.5m to 3.7m the increase in the investment is much less than 50% - typically about 20-30%. Web-offset plate making is much more surface dependant, even if there is, as in cylinder processing, no linear relationship for devices needed for larger plate sizes. The maximum plate size for publication printing is today about 1.3 x 2.2m (or almost $3m^2$) in comparison to the maximum size cylinder which is 1.4m x 4.3m (or $6m^2$), i.e. the double size. Web-offset plates twenty years ago were slightly larger than $1m^2$, but already then the largest gravure cylinders were almost $4m^2$.

The marginal costs, defined as the variable costs (consumables, materials, energy costs and some maintenance for one additional plate/cylinder), are very low in processing another cylinder. In this context for both gravure and web-offset, wages and social costs are considered to be fixed in a short medium term. However, the marginal cost in plate making is much higher as another plate has to be processed. Diagram 3 shows the relationship of the cost per page between gravure cylinder processing and web-offset plate, and it seems that the break-even level is about 10 000 cylinders (equal to 25 000 m^2).

8. Best practice of contemporary technologies

A statistical analysis of recent numbers from the statistical office of the European Union (Eurostat) indicates that the general production cost index in the printing and publishing business has increased by 32% in current prices during the last 20 years, Diagram 4. The annual figure shown is the average taken from the individual index figure of these countries, which has been participating in the study. During the recession about 15 years ago the cost index decreased by almost 10%, and during the last decade the index has increased with less than 10%. The cost control in the business has become tight, and many companies have been forced to cut costs by reducing the workforce and/or other actions.

Diagram 4



Hence, when taking the general development of the production cost index in perspective, the cost reductions in the plate and cylinder processing has indeed been very substantial. The introduction of new technology has given a reduction in running prices of about 80% in gravure cylinder processing (if the previous proofing costs are included). The relevant figure in web-offset plate making is about 65%. The general trend in the industry has had an increase of less than 1.2% (compounded) annually, which shows that the above mentioned reductions in prepress area are quite dramatic.

Nevertheless, it is believed that most of the economic benefit of lower costs in preparing cylinders and/or plates has not remained within the printing industry, but has been transferred to the customers. It has been a buyers' market during the last decade, but that is quite another story.

8.1 The investment model

In this investigation an investment model is introduced. This model shows the actual cost of using modern technology, whether it is CTP for web-offset or direct digital engraving for gravure cylinders. The model is simulating the cost, estimated per A4-page or m^2, using the same annual volumes in all processes. The condition of work is the same, such as personnel costs and number of working shifts. However, manning levels used in the model have been taken from the advice from each supplier and is supposed to cover file and data handling, cylinder or plate processing including plating processes in gravure. Similarly, depreciation, maintenance and service contracts and cost of consumables have been submitted by each participating supplier.

The annual production of cylinders (and plates) has been converted into surface (m^2) area for an easy comparison. The annual surface area has been chosen to either 10 000m^2 or 20 000m^2, which is equivalent to 4 000 and 8 000 cylinders respectively. However, these production levels are quite small, but interesting for a middle size gravure production in the European market. The width of the cylinder is only 2.5m holding 32 pages in A4 size - in 8 ribbons and 4 pages around in landscape mode (4U). With larger circumferences, 48 pages in 6U or even 64 pages in 8U can be engraved. Modern gravure presses and cylinder processing equipment can accommodate from 4u to 6U and 8U.

A comparison with this configuration should be advantageous to web-offset plate making.

8.2 The investment model for web-offset plates

The investment model for web-offset plate making has a few very central issues, such as the investment costs for the CTP-devices, the capacity and the procurement of plates and chemistry. The model calculates the cost per m^2 and for a 16 pages plate (size 1240 x 980 mm) as well as the marginal costs for another plate (or m^2 plate). It is quite obvious, that with the present performance of contemporary CTP-devices (from Agfa or Fuji) the capacity level is very low. Another issues is whether there are one or two CTP-units needed in the model. However, the assumption is when a four shift operation with very close deadlines is chosen, a second back-up unit would be needed for redundancy.

An example of concluding page of the model shows the capacity, lead-time and the cost per m^2 and other figures of the model can be found in Appendix 1.

8.3 The investment model for gravure cylinder processing

In the gravure model there are many more variables such as the investment in all plate processing equipment, logistics to handle the cylinders, investment of the base cylinders etc. as well as the capacity of engraving units. There are two different engraving systems on the market, hence the model has been divided between mechanical or laser engraved cylinders.

The number of engraving units differs, as the laser engraving unit has a higher frequency rate - 140 kHz - as compared to mechanical engraving heads of 7,5 kHz/ribbon and head. That means that the laser engraver is always faster than the mechanical engraver, unless more than 18 heads (channels) is used (more than 16 channels is not yet commercial available). It is expected, however, that in a rather short period of time, new mechanical heads running at 12 kHz will be available for the most modern models. The calibration and other pre-engraving operations are still quite a substantial part of the total process time for both processes. In theses procedures much more work for enhancement and shorter turn-around cycles is needed.

According to the model - and the size of cylinders chosen - there is only a marginal difference in the cost performance between mechanical or laser engraved cylinders. In both cases, a part of the maintenance cost have been applied as well as the additional costs of the plating process (Cr/Co or Cr/Zn respectively and the power needed for plating) for one cylinder. Nevertheless, there is a distinct difference in the marginal cost, which is due to the maintenance of the stylus (diamond tips) for mechanical engraving heads. However, in the case of laser engraving, this marginal cost is only the power/energy used for one additional cylinder.

Examples of concluding page of the model can be found in Appendices 2 and 3.

8.4 Comparison of the Investment Model for gravure and web-offset

A comparison of the relative costs for gravure using either mechanical engraving (EMG) or laser engraved cylinders(DLG) and web-offset plates as well as the lead time for producing plates and cylinders for a 64 page signature with 4+4 colours have been done using the input from those suppliers participating in the study. However, there has not been possible to add any overhead costs into the model, as these costs would undoubtedly vary from printer to printer depending on organization or size of the company etc. The absolute numbers are available for the author, but as these numbers have been given under condition of non-disclosure, these can not be shown. In Table I the summary can be found:

Table I: Comparison of gravure cylinders and web-offset plates - relative figures. € per page in A4 size - 64 page signature

Annual Capacity	EMG	DLG	CTP
10 000 m2/4 000 Cylinders	1.4	1.4	1.0
20 000 m2/8 000 Cylinders	0.8	0.8	0.6

Web-offset plate size = 1 240 x 980 mm. Gravure cylinder size = 875 x 2 500 mm.

The model shows, that with increasing volumes, gravure cylinders become relatively seen cheaper to process.

This is of course consistent with the numbers noticed in the present investigation. When looking at the individual answers about cylinder costs, it became very evident that with higher numbers and larger cylinders, the cost per page can become as low as 1:1 in comparison with a web-offset plate. These facts can easily be verified by changing the parameters in the model itself. Although the calculation is not shown here, using the investment model of present standard size of 3m face width, the gravure process is as cheap to produce as a web-offset plate calculated per page. (a cylinder with 3.7m face can accommodate 48 pages in 4U or 72 pages in 6U in comparison with a present maximum of 32 pages in plate processing). Even with the standard size of a gravure cylinder of 2,5m width, a relationship of 1:1,3 can be expected when comparing up to date technology in both processes.

The marginal cost of producing another 1 m^2 of plate resp. gravure cylinder surface can be found in Table II.

Table II: Comparison of gravure cylinders and web-offset plates – relative figures. The marginal cost of producing one additional plate or cylinder

Annual Capacity	EMG	DLG	CTP
10 000 m2/4 000 Cylinders	0.8	0.3	1.0
20 000 m2/8 000 Cylinders	0.7	0.3	0.9

It is obvious that the laser engraving method has a much lower marginal cost than both web-offset plates technology and mechanically engraving. When the production of cylinders or plates has to be increased, the cost advantage in the gravure process is quite obvious. However, it is quite easy to produce another plate with modern CTP-technology, and in many cases this request can be handled by the press room operator if something goes wrong in the press room. This is still an unlikely scenario in a gravure press room, but on the other hand remakes of cylinders caused by some malfunction in the press room are indeed very rare.

Another factor of great importance is time to market. In this context the lead time is defined as the time from receiving digital artwork for processing plate or cylinders until these are ready for the press room. It is assumed, however, that handling and control as well as the preparation of data are more or less the same, independent of the process chosen. This is particular true when PDF-files with the relevant colour profiles (ICC) are received from the customers.

Lead-time to press is still a major drawback for the gravure process, even if the time in absolute values has improved tremendously during the last few years. Nevertheless, the time difference is still between 3-4 hours. In the press room, however, part of this loss can be regained in modern gravure presses with automatic cylinder loading/unloading and modern presetting technique of colour register and folder. There is no significant difference between laser and mechanically engraved cylinders, although the number of engraving units in the department has a significant importance to the lead-time.

Table III: Comparison of gravure cylinders and web-offset plates - relative figures. Lead time to produce cylinders or plates for a 64p signature

Annual Capacity	EMG	DLG	CTP
10 000 m2/4 000 Cylinders	4.6	4.2	1.0
20 000 m2/8 000 Cylinders	3.1	2.1	0.5

9. Conclusions

It is clear from the results obtained that the present hypothesis is false. The results may even be regarded as a surprise, and to the contrary of the belief of many observers in the industry. The relationship has improved from 3:1 to 2:1 (or even less) during the last decade. Although no numerical data is available from 1995, it seems plausible that the relationship ten years ago probably was even worse seen from a web-offset printer's perspective. Due to the proliferation of the CTP-technology and the extreme competitive web-offset markets during the last five years, the web-offset industry has been able to restore some of the previous advantages. Much of the focus in the printing industry has been devoted to lithography and indeed the CTP-technology, which was very obvious during the recent DRUPA exhibition in 2004. The only new gravure cylinder technology shown was the Creo/Acigraf (similar to the Think Laboratories of Japan concept) Exactus concept with autotypical cells (Picture 8). This process may process cylinders at very low rate, much less than the numbers shown in the Investment Model, but yet there is no information available from the first installation at R.R.Donnelley in the US.

It seems that the gravure users has been able to claw back some of the recent advantages of web-offset plate making by the introduction of faster and more automated processes needing much less manning than before. Nevertheless, there are still some very distinct advantages with web-offset plate making. Simplicity and speed are still the two major factors, which should not be underestimated, and there are many players in this particular market. Furthermore the investments needed for a turn-key CTP-solution are much less than for a similar capacity in gravure cylinder technology. The numbers given by the individual suppliers to the investment model indicate that the investments in gravure cylinder process equipment may be more than 4 times higher. For an entry level company who needs more base cylinders than those included in the model, this figure can be even higher.

Some industry observers believe that with the present huge investments in the gravure industry in the UK and Italy, the engraving technology will be further enhanced. The problem is that there is yet an entry level to be established for new players or for those rather well established gravure printers with ageing press room equipment but only with a need for a medium to low capacity (Puri 2003). The capital expenditures are in relation to web-offset equipment still substantial.

The only way the cylinder processing can be improved is by more automation and faster processes. Laser technology in cylinder engraving has been slow in gaining acceptance among gravure publication printers. This is, however, already well spread among the packaging engravers. Most certainly there is a lack of entrepreneurship among the publication printers, and new technology has some difficulties in getting the necessary attention and acceptance. With newly installed laser engravers and up-to-date mechanical engravers the cell structures in gravure can be improved substantially, and as a consequence the gravure print quality will probably leap-frog to an almost continuous tone (photographic) level, which was common with the old and classical etching methods in the 70's.

Web-offset (surface variable lithography) can never come even close to similar photographic quality, even if the CTP technology has enabled very much improved screening technologies, such as FM and hybrid screening for the web-offset market. What improvements in plate making for web-offset printers can be expected in the near future? The process-less plate is now available, but with a limited service life. It is questionable whether the total cost of ownership will improve significantly. The single most important cost item is the basic plate, and the cost is of course depending on the world market price of raw aluminium. It is not expected to see a slump of the aluminium price on the world market, rather the opposite, when demand from the construction and automotive industries are rising from new emerging markets such as China and India.

In what direction will the demand for high print quality go? The demand for print quality is the most determining factor when choosing a particular printing method. In some market good enough quality is indeed good enough!

Some final points:

- Investments in gravure cylinder processing is about 4 times higher than the current CTP-technology compared on a turn-key level and with similar capacity;
- Recent advances in the prepress technology has benefited the web-offset process more than the gravure production;
- Lead-times have substantially been reduced with modern prepress technology;
- Nevertheless, lead-times in gravure are still an issue - about 2-3 hrs longer in cylinder processing than plate making;
- The cost per page for both processes are converging;
- Cylinder processing costs have their own dynamics ....;
- Gravure is still a process for larger companies with many presses (more cylinders to process) and large cylinders (more pages on the cylinders);
- An entry level for the gravure process is still to be found.

Acknowledgements

I would like to thank all those companies who have actively been taken part in this study, and in particular extending many thanks to all the gravure and web-offset printers who have calculated their internal costs with great interest and commitment. Without their work the article would never has been possible to write.

Finally many thanks goes to Hell Gravure Systems GmbH, Max Dätwyler AG, Agfa Sweden and Fuji Film, Sweden; for most valuable input and comments as well as in depth technical discussions. Illustrations to this article have been given and authorised by the each company respectively.

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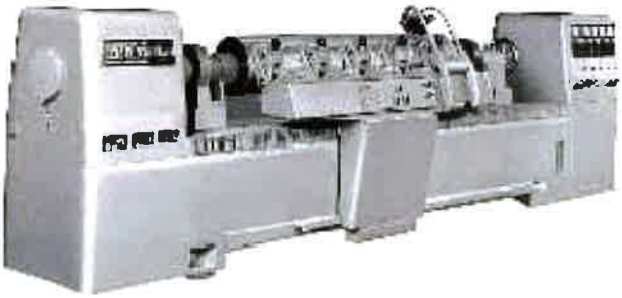

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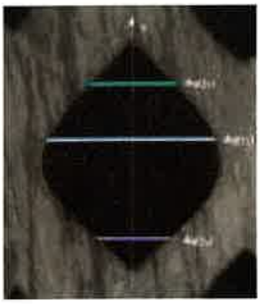

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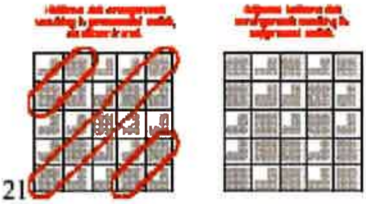

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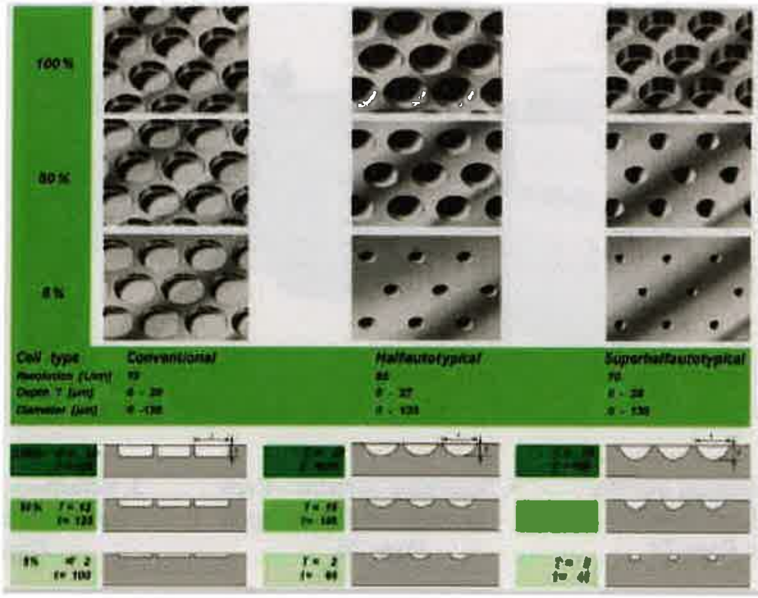

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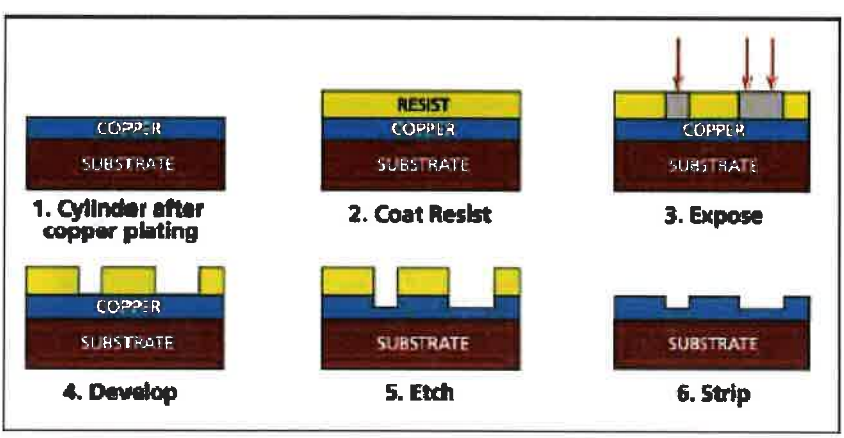

INVESTMENT MODEL - COPYRIGHT ANDERS BJURSTEDT, ROYAL INSTITUTE OF TECHNOLOGY, STOCKHOLM, SWEDEN

COMPARISON BETWEEN WEB-OFFSET PLATES AND GRAVURE CYLINDERS - REL. FIGURES

COMPARISON GRAVURE VS WEB-OFFSET - CYLINDERS AND CTP-PLATES - ANNUAL FIGURES

CAPACITY	EMG	DLG	CTP
10 000 M²/4 00 CYL	1,4	1,4	1,0
20 000 M²/8 000 CYL	0,8	0,8	0,6

NB. WEB-OFFSET PLATES = 16PP IN SIZE (1280 X 980 MM)
GRAVURE CYLINDERS = 32 PP (875 X 2500 MM)

10 000 M² CTP IS EQUAL TO		1,0	

ONE ADDITIONAL PLATE/CYLINDER TO 1 SQM - MARGINAL COST

MARGINAL COSTS	EMG	DLG	CTP
10 000 M²/4 500 CYL	1,9	0,9	1,0
20 000 M²/9 000 CYL	1,6	1,6	0,9
10 000 M² CTP IS EQUAL TO		1,0	

COMPARISON GRAVURE VS WEB-OFFSET - CYLINDERS AND CTP-PLATES - LEAD TIME TO 64PP SIGNATURE

MARGINAL COSTS	EMG	DLG	CTP
10 000 M²/4 500 CYL	4,6	4,2	1,0
20 000 M²/9 000 CYL	3,1	2,1	1,0
10 000 M² CTP IS EQUAL TO		1,0	

Royal Institute of Technology -Media Technology and Graphic Art

GENERAL INFORMATION ABOUT PLATE COSTS

ANNUAL NUMBER OF SQUARE METERS			10 000	M^2	
ANNUAL COST PER M^2			[redacted]	€/M^2	
NUMBER OF PAGES PER M^2			14		
TOTAL				€/FOUR COLOUR PAGE (SIZE - A4 OR CLOSE)	
LEADTIME FOR A SET OF EIGHT PLATES			0,9	PER SET - NET HRS WITH TWO CTP UNITS	64 PP - 1,2 HRS
LEADTIME FOR 48 PP			0,9		
THEORETICAL CAPACITY OF EXPOSURE					
PER EXPOSING UNIT	[redacted]	PER SHIFT			PER SHIFT AND WEEK
NUMBER OF UNITS	1	NUMBER OF WEEKS		52	
NUMBER OF PLATES - THEORETICAL CAPACITY				[redacted]	80% UTILIZATION
CAPACITY UTILIZATION			12%		
MARGINAL COSTS FOR ONE ADDITIONAL PLATE (16 PP) (MATERIALS + ENERGY COSTS)			[redacted]	€	
MARGINAL COSTS FOR ONE ADDITIONAL M^2 (MATERIALS + ENERGY COSTS)					

ALL OTHER COSTS ARE FIXED IN THE SHORT AND MEDIUM TERM

Royal Institute of Technology

GENERAL INFORMATION ABOUT PLATE COSTS

ANNUAL NUMBER OF CYLINDERS ENGRAVED			4 000	NET - EXCLUDING REMAKES	
ANNUAL COST PER CYLINDER			[redacted]	€	
NUMBER OF PAGES PER CYLINDER			32	A4 SIZE OR CLOSE	
TOTAL				€/FOUR COLOUR PAGE (SIZE - A4 OR CLOSE)	
COST PER M^2 CYLINDER ENGRAVED				€/M^2	
LEADTIME FOR A SET OF EIGHT CYLINDERS 7,5 KHZ HEADS				PER SET - NET HRS FOR WITH TWO ENGRAVING UNITS	64 PP
THEORETICAL CAPACITY OF ENGRAVING					
PER ENGRAVING UNIT	[redacted]	PER SHIFT		[redacted]	PER SHIFT AND WEEK
NUMBER OF UNITS	2	NUMBER OF WEEKS		52	ANNUALLY
NUMBER OF CYLINDERS - THEORETCAL CAPACITY				[redacted]	*80% UTILIZATION OF PRODUCTIVE TIME*
CAPACITY UTILIZATION			22%		
MARGINAL COSTS FOR ONE ADDITIONAL CYLINDER (MATERIALS + ENERGY COSTS)				€	
MARGINAL COST PER M^2 ENGRAVED CYLINDER				€	
MARGINAL COST PER 16 PP				€	

ALL OTHER COSTS ARE FIXED IN THE SHORT AND MEDIUM TERM

SUMMARY.xls

Gravure printing: material characterisation for all-organic capacitor

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1. Context and objectives of the study

Organic materials give rise to an increasing interest for applications in electronics since the discovery of conducting polymers. In addition, printing techniques, when adequately adapted, have been used to produce electronic devices for some years. The necessary materials for printed electronics are readily available and appropriate printing methods are being developed for their production. Although the techniques are still new, their potential was demonstrated in many applications (Schultze, 2005) (Liu, 2003). The corresponding inks are formulated with specific ingredients, the substrates may need special treatment, and the techniques must be controlled. However, none of the consumables is fundamentally different from those used in conventional printing. There is no doubt that screen and inkjet printing are among the most widely used processes in printed electronics, but some experiments are conducted with flexography, lithography or gravure printing.

The aim of this study is to determine the characteristics of the materials required to produce all-organic capacitors with a gravure printing system. The objectives are slightly different from those of conventional printing: the visual rendering is not indeed as essential as the electrical characteristics of the printed components. The latter will depend on the physical and chemical attributes of each printing process.

As a matter of fact, surface properties of substrates will determine the required ink viscosity and the surface tension will then ensure good wetting and adhesion on the surface. Finally, the process parameters (printing pressure, speed, ink quantities ...) should be optimised.

2. Research methods

2.1 Ink formulation and physico-chemical adjustments

The typical operating viscosity of gravure inks ranges from 10 to 80 mPa.s, depending on the speed and the pressure applied during printing. The inks may be solvent or water based. The current trends are water-based inks developments due to the increase of environment friendly layers.

Two kind of ink were studied according to their electrical characteristics: conductor or insulator. The former is a commercial dispersion of thiophene polymer in water, mixed with a surfactant and eventually with a low volatile co-solvent, so as to obtain good rheological and physico-chemical properties. The latter is an ethylene glycol-based ink with a dielectric polymer.

The static surface tension of the inks was determined using a Kruss tensiometer and the "Du Noüy ring" method.

Inks viscosities were measured on a rotational TA instrument rheometer with a cone plane geometry. The inks were transferred on an IGT F1 tester.

Resistance of the printed patterns is characterised with a Fluke 45 multimeter and with a two-point system (distance between points is 1 cm).

Two testing rolls were used. The first one, an IGT gravure test form whose reference is: 402 153 432 has ten engraving cells (depth 33 to 11 μm); the resolution is 70 l/cm (IGT website).

We created the second capacitor test form, as shown in figure 1, which was generated with a resolution of 200 l/cm. Three parts allow printing the different layers of a capacitor.

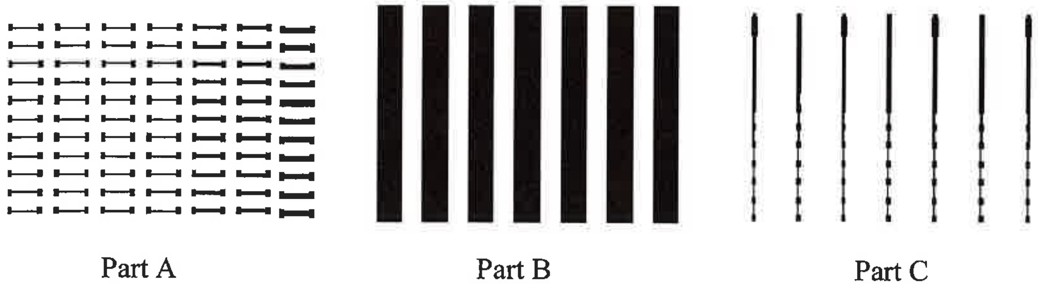


Figure 1

Part A represents the first electrode of the capacitor. The patterns are in the range of 100 μm to 400 μm in width and are 1cm in length. Of course, we used a conductive ink for this layer. Part B allows printing of insulator layers and finally part C permits to lay down the second electrode of the capacitor with a conductive ink. Figure 2 represents the pattern of the capacitor with the three different layers.

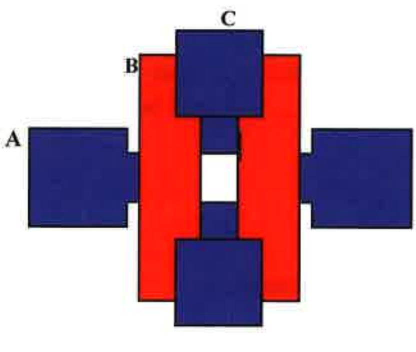


Figure 2

The white rectangle represents the capacitor; it is a superposition of three layers (conductor/ insulating/conductor).

2.1.1 Conductive ink

Poly (3,4-ethylenedioxythiophene) (PEDOT) doped with the poly(styrenesulfonate) (PSS) polyanion is commercially available in the form of an aqueous dispersion (Baytron P; Bayer AG). Baytron P is a dispersion of the oxidized (p-doped) (Austin. 2003) PEDOT containing PSS as a counterion, where the latter is in excess. The negative charge of PSS with respect to the positively charged chains of oxidized PEDOT makes the colloidal particles stable in the aqueous media.

It has many advantages over other conducting polymers, such as low band gap, excellent thermal stability and a high transparency in the visible range (transparency is a function of the thickness layer). However PEDOT:PSS has low conductivity problems: less than $1 S.cm^{-1}$, which is lower than that of some good conducting polymers by one or two orders of magnitude. Recently, it has been observed that by addition of poly-alcohols (alcohols with more than two OH groups on each molecule) to a PEDOT:PSS solution the conductivity of the formed film can be enhanced by over 100-folds (Ouyang J. 2005)

Figure 3 shows the PEDOT:PSS molecule:

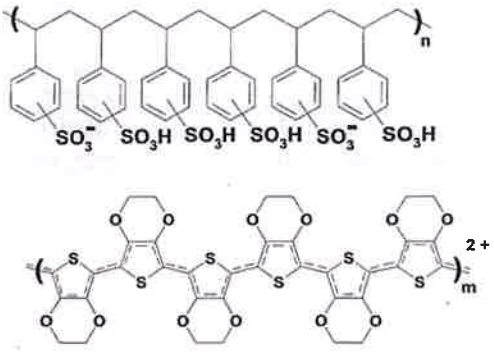


Figure 3

Surfactants are often used to reduce the surface tension of solutions. These molecules possess both a hydrophilic and a hydrophobic part which determine their solubility in water. The adsorption and chains orientation at the interface significantly decreases the water surface tension when the surfactant concentration increases. At a given concentration, the surfactant effect reaches a maximum: when no space is left on the surface, micelles are formed. This step is better known as critical micellisation concentration (CMC). Beyond this concentration, the static surface tension of the solution is less affected.

Rheological and physico-chemical properties of the commercial dispersion of polymers have to be adapted so as to obtain good transfer, good adhesion and good wetting. The first step is the increase of PEDOT particle concentration which induces viscosity rise. Agitation and slight heating of the dispersion leed to speeding up of the evaporation. Next the secondary solvent (ethylene glycol) is added and finally the surface tension is regulated with a surfactant. Different surfactants are used according to their hydrophobic hydrophilic balance (HLB, their ionic or non-ionic structure and of course solubility is another important factor which has to be taken under consideration. We present in this paper a commercial surfactant the polyoxyethylene-(20)-sorbitan monooleate (Tween 80) used to obtain the ink surface tension characteristics (Ballarin. 2004). It presents a relatively low HLB = 15 which prevents the solution to foam and it is a non ionic surfactant.

2.1.2 Insulating ink

Most of conventional inks generally have insulator properties due to their composition. Our insulating ink is a solution of polyvinyl phenol (PVP) in ethylene glycol with different mass percentage.

This polymer is one of the best insulating polymers because it exhibits a high dielectric constant: ε = 3,3. Another interest of this polymer is its high solubility properties with a lot of solvents. We have chosen ethylene glycol for its viscosity and surface tension whereas a lot of research is done with isopropanol. Isopropyl alcohol is well adapted for inkjet printing because it possesses low viscosity and low surface tension. These properties are not simply-adapted for gravure printing applications. The inks prepared are at the range of 5 to 30% wt in polymer.

2.2 Characterisation of polymer substrates

The surface energy of different polymer substrates (polyethylene terephtalate, polybutylene terephtalate and polycarbonate) was measured, in order to predict the wetting of the inks. Two different methods were employed to determine the contact angle θ between the solid surface and the liquid drop. The technique chosen will determine the starting hypothesis, i.e. whether the drop size can be neglected when compared to the capillary length

($\kappa^{-1} = \sqrt{\frac{\gamma_L}{\rho_L g}}$, where g is the gravitational acceleration and ρ_L the liquid density).

The polar and dispersive components of the surface energy of the solid were calculated using the Owens-Wendt approach (Owens-Wendt. 1969) which expands the Fowkes theory to non dispersive or polar interactions. These authors separate the work of adhesion into two elements, one dispersive and one polar.

$$W_{SL} = 2\sqrt{\gamma_L^D \cdot \gamma_S^D} + 2\sqrt{\gamma_L^P \cdot \gamma_S^P} \qquad (1)$$

Applying the Young-Dupré's equation to a series of well-known liquids leads to the surface energy and its components.

- The first method is based on a goniometer connected to a video camera and an image analysis software program. This device was developed in our laboratory (Aurenty. 1997). A 200 fr/s camera downloads the evolution of the triple points (where the liquid, solid and vapour meet) and the height of the drop. The contact angle is calculated with the tangent equation: $\tan\frac{\theta}{2} = \frac{2h}{D}$ (where θ is the contact angle, h is the drop height and D is the drop size). This formula is valid for a portion of sphere, which is the case for low drop sizes, as their weight does not affect the drop volume. In this study, because the drop volume is lower than 10 µL, this hypothesis will be met. The advantage of this method is that it allows fast dynamic phenomena to be studied.
- The second method measures the contact angle by the heavy drop method (or Padday method) (Viallet. 1999). The radius of the drop should be ten times higher than κ^{-1}. The liquid pressure is considered to be uniform on the solid. These two conditions being established, the drop height is almost equivalent to the critical thickness (for which the wetting coefficient balances the energy induced by the hydrostatic pressure). The height in the central zone of the pancake-shaped drop is determined by an optical system consisting of a white light source and a photodiode. The variations of the liquid surface position were easily detected on a 1 µm scale.

We determine the contact angle by: $\mathrm{Sin}\left(\frac{\theta}{2}\right) = \frac{h}{2\kappa^{-1}}$

Surface disparities will not affect this measurement. This is one of the main interests of this technique.

In industrial processes, a surface treatment is carried out on polymer substrates. One of these is called the "corona effect"; it improves the adhesion between the substrates and the layer, as well as the wetting of polymer films.

When a conductor reaches a high electrical potential, the nearby electrical field may become as intense as to cause ionisation of the molecules in the air. The electrostatic force affects the flow of the ions generated: the latter will move on field lines.

This treatment leads to the formation of peroxide functions (OOH) which may rapidly be decomposed and free radicals are formed.

2.3 The relation between conductivity and process characteristics

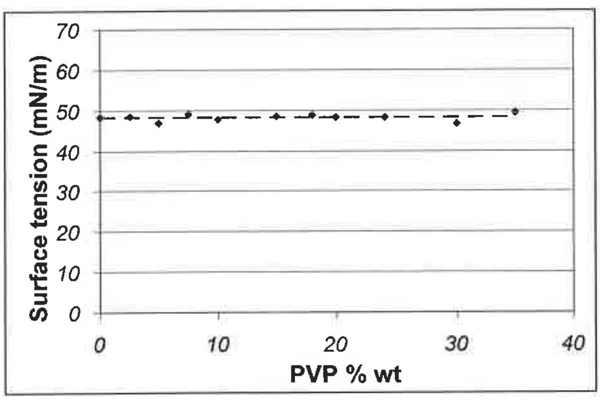
The conductivity of a printed layer of thiophene ink may be linked to the different process parameters: the pressure applied by the gravure roll onto the substrate, the transfer speed and the ink volume. Better results may be obtained at low speeds, with high ink viscosities; thus the cells can be emptied correctly. A minimal volume of ink must be used to fill the cells completely. Two relevant parameters for reproducibility (the pressure and the impression speed) control the ink volume which is transferred. Homogeneity of the layer may increase with the use of a co-solvent.

3. Experimental results

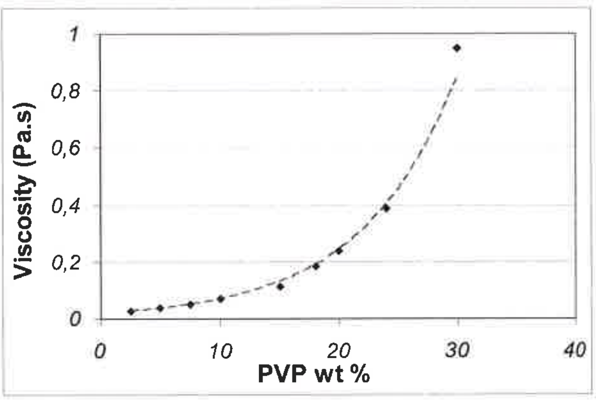
3.1 Rheological and physico-chemical properties of insulating inks

The insulating ink is ethylene glycol-based. We started by measuring the influence of the polymer mass percentage on both the viscosity and the surface tension. Ethylene glycol has an apparent viscosity of 221 mPa.s and static surface tension of 48.4 mN/m.

The graphs 1 and 2 represent respectively the evolution of the surface tension and the viscosity of the insulating inks in function of the % wt of PVP.



Graph 1



Graph 2

Experimental results are represented with points; the dotted line is the equivalent mathematic model.

In this range, the viscosity is exponentially proportional to the concentration of the dielectric polymer in the solution: η = 0,0201 exp(0,1246 C_m (η is the viscosity in Pa.s and C_m is the polymer mass concentration in % of total volume)).

For these concentrations the limit of solubility is not reached, however it should be determined in order to optimise the inks' electrical characteristics. A compromise must be found between the polymer concentration (which induces the ink viscosity) and the final insulating value of the printed layer.

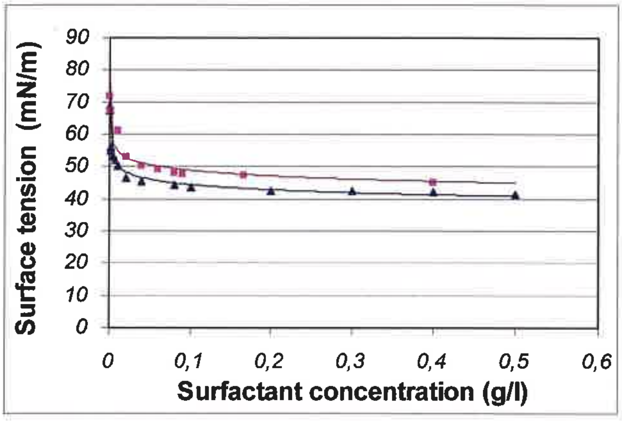
It is interesting to note that for Cm = 35 the viscosity value is 4.5 Pa.s, the limit of solubility should be around this point.

The dielectric polymer does not influence the surface tension of the ink. The value is the same for all the solutions (49.3 mN/m); the fluctuation is 2% with respect to the ethylene glycol surface tension.

3.2 Rheological and physico-chemical properties of conductive inks

The conductive ink is based on a commercial dispersion of thiophene derivative polymer in water. The surface tension of the Baytron P is 71 mN/m and its viscosity is about 0.1 Pa.s.

The determination of the critical micellisation concentration (CMC) of the Tween 80 was first determined in water and then in Baytron P. The graph 3 presents the evolution of the surface tension of water and Baytron P in function of the surfactant concentration.



Graph 3

The points represent the experimental results and the lines the mathematic model. The experiment with water is represented by triangle marks.

The CMC of the surfactant is about 10^{-2} g/l for the two experiments. We have chosen a concentration of 0.5 g/l so as to be larger above the CMC value and thus dynamic effect is reduced. Addition of surfactant does not affect the viscosity of the ink.

Typically, the proportion of co-solvent used in a dispersion of Baytron P (ethylene glycol or glycerol in our case) is in the range of 10 to 20% wt.

Table I presents the viscosity and the surface tension of different modified Baytron P solutions.

Table I

	Baytron P	Baytron P Ethylene Glycol 20% wt	Baytron P Surfactant 0.5 g/l	Final ink
Surface tension (mN/m)	71	58	45	47
Viscosity (Pa.s)	0,1	0,12	0,1	0,3

3.3 The effects of corona treatment

When the polymer sheets receive a corona treatment, the surface tension is increased by 40%. The dispersive component, which represents the adhesion power, is multiplied by 2.5.

Table II shows an example of PET plastic substrate before and after corona treatment, the contact angle was measured with the goniometric method.

Table II

Before treatment		After treatment	
γ_S^D	γ_S^P	γ_S^D	γ_S^P
25,8 mN/m	**9,6 mN/m**	**25,1 mN/m**	**24,3 mN/m**

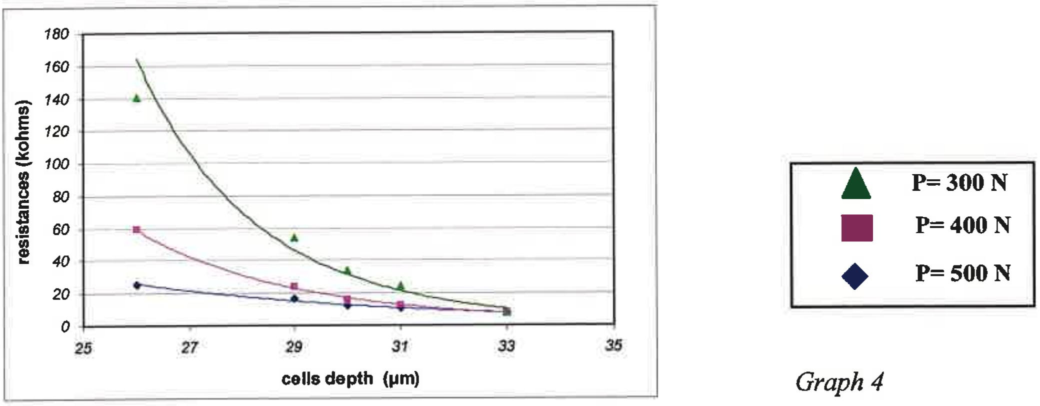
The corona treatment is an important asset for the transfer of the inks on plastic supports.

3.4 Ink transfer and printing characterisation

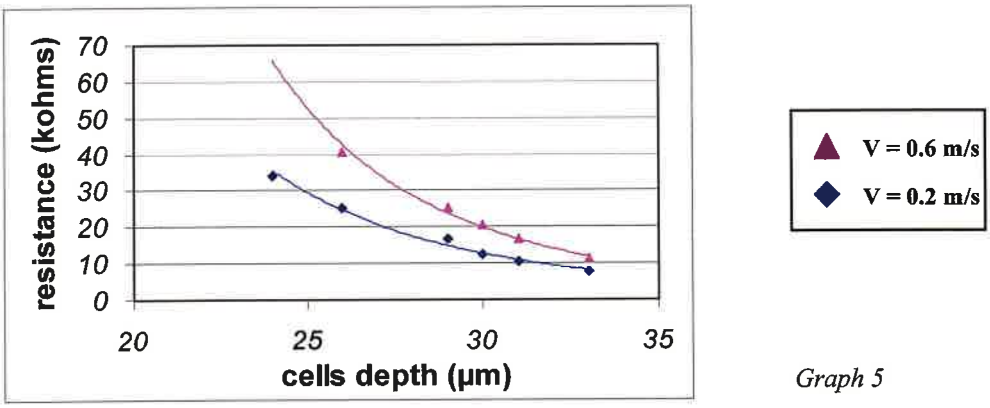
Insulating ink was well transferred on polymer substrates and on paper with the two test forms. The most important result of the experiments was achieving a good of conductive ink transfer.

The final test is the measurement of the layer resistance with a two-point system (the distance between the two points is 1 cm). We obtain good results on plastic substrates with the low resolution test form (70 l/cm) but the spreading of the ink is not of good quality when using the capacitor test form which has a resolution of 200 l/cm.

A resistance can only be measured with the conductive ink patterns printed using the low resolution test form. Graph 4 presents the resistance values according to the cells' width for different printing pressure.



Graph 4



Graph 5

We observe that printed layer resistance decrease with respect to the increase of the cells' depth. Indeed, the deeper is the cell the thicker is the layer. The pressure is an important parameter in the ink transfer; here it influences the resistance layer. For an equivalent depth, the resistance decreases with the pressure growth.

We can then observe the printing speed influence on the resistance layer. Graph 5 presents the resistance layer according to the cells' depth and two different printing speeds.

We observe that the printing speed influences the ink transfer and consequently the resistance layer. For an equivalent depth, the higher is the speed the higher is the resistance.

In the same conditions (P = 300N and V = 0.3 m/s), a layer of silver conductive ink has a resistance of 1 Ω to 10 Ω.

4. Conclusions and perspectives

The realisation of an all-polymer capacitor with a gravure printing device has not yet been published to our knowledge. The process and the requirements to get good printing are developed in this paper. Understanding, comprehension and optimisation of process parameters which can be controlled on the IGT laboratory press are, indeed, essential to achieve good quality printing. Electrical characteristics of printed layers could then be implementing.

After properties adjustments of the inks, we were able to observe the influence of two relevant parameters: the pressure and the printing speed on the resistance printed layer.

The resolution of the test form seems to be a limiting factor in our studies.

The future works will carry on the printing of multilayer patterns. We will try to optimize the inks parameters in order to increase the electric properties of our printed patterns. The electric characterisation of multilayer pattern will be the final objective.

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The effect of speed and viscosity on line quality in rotogravure printing with reference to printed electronics

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Abstract

An experimental was carried out to investigate the effect of print speed and ink viscosity on the reproduction of fine lines in the gravure printing process. Using a commercial web printing press, line reproduction using the fine black separation on a paper substrate was measured using digital image capture and analysed using custom software. The quality of the lines was defined in terms of line width, line width standard deviation and the percentage solid content of each line. The lines were prone to edge rippling and internal and external voids. The quality of the lines was found to be highly dependent on the orientation of the lines with those in the print direction being of a significantly higher quality than those in the cross print direction. The viscosity had a significant effect on the line quality with more uniform and wider lines being printed at lower viscosity. The speed had a smaller effect than the viscosity but there was a significant interaction between the viscosity and the press speed.

Keywords

Lines, rotogravure, speed, viscosity

1. Introduction

Rotogravure is the premier printing process used for high quality graphics and packaging. Its primary advantages being speed, quality and robustness of the image carrier. As such it is a potential method for the micro manufacture of electronic materials, smart packaging and RFID. It offers significant improvements in terms of speed, resolution and productivity compared to screen printing and traditional electronic manufacturing.

The viscosity of the inks for the gravure process is generally low and may contain up to 80% solvent which therefore lends itself to thin ink films and the solvent laden solutions required by many organic semiconductors, [1]. This may not be ideal for particulate laden conducting inks, which may typically be 75% particulate by mass, [2] and subsequently may be of too high a viscosity.

The robust image carrier in rotogravure is a distinct advantage over other processes as it is not subject to phenomena such plate swelling (flexography), plate wear (offset litho) or screen wear and tension loss (screen). Although the engraved cylinders can be engraved accurately, the reproduction of the features on the printed substrate is a subject to wide variety of variables including press speed, substrate characteristics, ink viscosity and doctor blade settings, [3, 4, 5].

One of the principal factors which will determine is suitability for micro manufacture is the dimensional characteristics of printed features; the simplest of these being a line. This investigation examines the potential of rotogravure for printing fine lines appropriate for the manufacture of printed electronics using a graphic ink which enabled easier evaluation yet had similar rheological and drying properties to the organic semiconductor inks.

2. Method

A full factorial experiment was carried into the effect of viscosity (at three levels of 16s, 19s and 22s as measured by a Zahn 2 efflux cup) and production speed (at three levels of 1.67, 3 and 5 m/s). The investigation was carried out on an automatic viscosity controlled commercial printing press printing nitro-cellulose resin based graphic inks to 80gsm one side coated paper. The viscosity of the ink was set by addition of thinner and the press was allowed to stabilise for 5 minutes after each change of viscosity. The speeds and viscosities chosen lie within the normal operational limit of the process.

The cylinder used was electromechanically engraved with diamond and engraving pattern suitable for the black separation. Although lines are being printed, which do not require screening, the limitations of the mechanical nature of the engraving process mean that some degree of screening is always required. This also reduces high localised wear of the doctor blade or cylinder. The black separation was chosen as it has the highest detail rendition and also has the 45 degree screening pattern which does not give preference to lines printed in the horizontal of vertical direction.

The measurement was carried out optically using a high resolution monochrome CCD camera, stabilised Xenon light source and bespoke image processing software. This allowed 576 sample pixel scans to be taken along the length of each line. Being black lines on a white substrate the lines were easily segmented using a mid peak greyscale histogram method and analysed in custom software, [2].

The line quality was defined in terms of width, edge roughness (by standard deviation of the width) and percentage solid. This last characteristic is considered important as it is the microstructure of the line which is important and not simply the visual macroscopic reproduction of the line. Typically line reproduction in rotogravure is subject to internal voids within line where the ink fails to transfer or fails to flow out after printing. This leads to a internal and external failures of the lines, Figure 1.

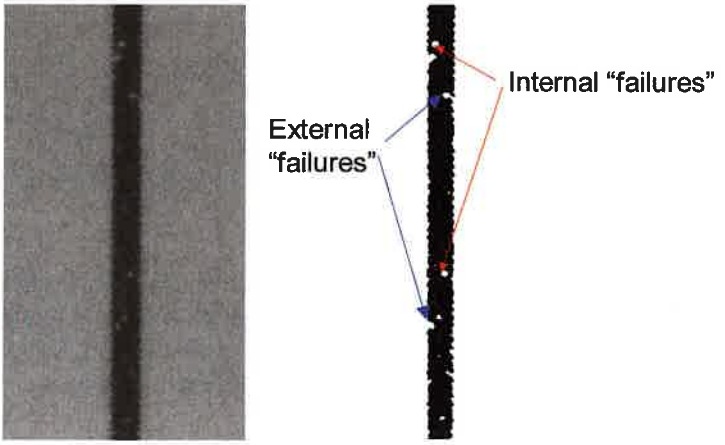

Figure 1: The lines as printed and segmented image highlighting the general failures in reproduction

In addition, towards the edges of lines it is possible that the smaller more shallow engravings form “satellite” areas of ink which are not bound physically into the line structure at all, Figure 2. In this instance the ink has transferred to the substrate but has been unable to flow to form a coherent solid ink film. From a macroscopic viewpoint, these contribute to the width of line but have no contribution to make to the microscopic properties of the line, e.g. for conduction.

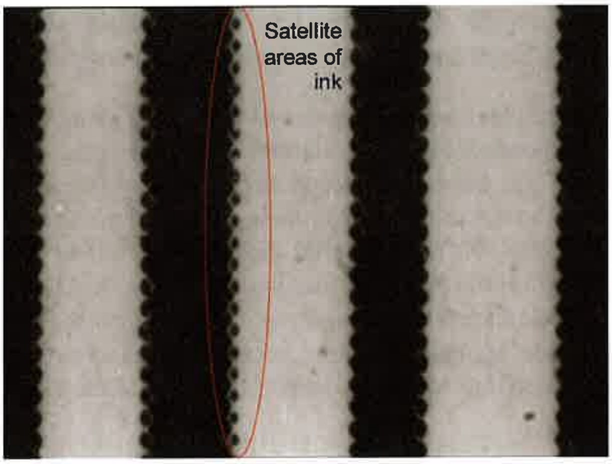

Figure 2: Satellite areas of ink outside the line boundary

The integrity of the line was calculated by examining the proportion of unprinted area within the boundary of each line over the sample length and is expressed as %solid. The % solid for each line of pixels is defined between the boundaries of the line as:

$$\%solid = \frac{\text{Black pixels}}{\text{White pixels} + \text{black pixels}} \qquad (1)$$

An overall mean is obtained by taking the average for line of pixels in the image. Thus a value where 100% indicates a line with no inner voids (or failures). Lower values of %solid indicated increasing number of internal failures within the line structure.

The line quality characteristics were measured on four 300 micron lines at angles of 0°, 45°, 90° and 105° to the print direction, Figure 3. For each angle the camera orientation to the line was altered such that the line was vertical within the frame. This ensured a consistent measurement length and that differences in the digitisation of the line played no part in differences between the print angles.

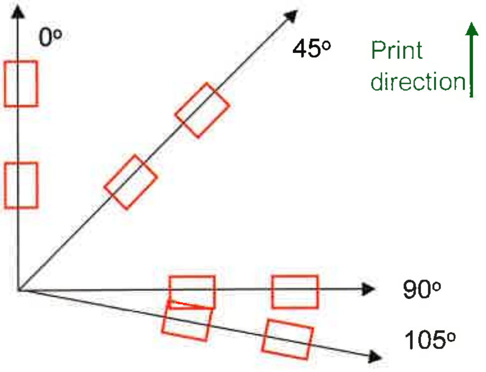

Figure 3:
The measurement angles investigated

3. Results

Statistical analysis of the lines showed that there was little difference in the line quality of successive prints over the 32 samples measured. This is in line with other studies on rotogravure, [3], which reported that the process is inherently stable over short time periods. Measurement along each of the lines also showed minimal variation along the length of the lines. Thus although there may be significant difference in line width along the line, the variation is repeatable and periodic. Measurement of 5 samples was deemed sufficient to record all important features of the printed lines.

The edges of the lines for all samples showed significant variations along the length of the lines, with a regular variation which corresponded to the individual engraved cells. The printed thickness, edge characteristics and integrity of the lines were found to highly dependent on orientation to the print direction with lines parallel (0°) to the print direction being the thickest and least sensitive to changes in viscosity and speed. Perpendicular (90°) to the print direction the effect of speed and viscosity were significant with variations of up to 40 micron in line width, Figure 4. All lines were measured thinner that specified in the digital file. Reducing the viscosity of the ink increased the printed width of the lines as a result of the low viscosity ink "spreading" during printing or due to improved release of the ink from the cells. The effect of the speed on line width was small compared to the effect of the ink viscosity.

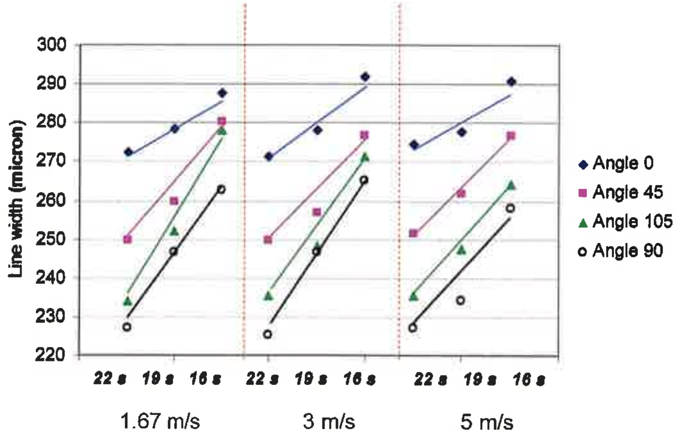

Figure 4: The effect of viscosity and speed on the measured line width at four angles of orientation relative to the print direction

Lines printed in parallel to the print direction were significantly more uniform than those printed perpendicular to the print direction, typically having only a standard deviation of 1.5 micron over the experimental range compared to 2.5 micron for lines printed at an angle to the print direction, Figure 5. Increased speed resulted in a poorer quality line, particularly perpendicular to the print direction. Reduced viscosity improved the line edge quality at all speeds. This can be attributed to the ink spreading to fill the undulations at the edge of the lines.

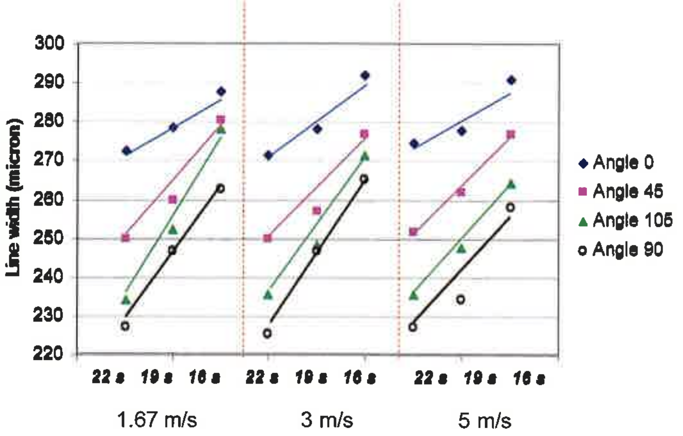

Figure 5: The effect of viscosity and speed on the measured line edge roughness at four angles of orientation relative to the print direction

The viscosity had a significant impact on the integrity of the printed lines with increasing viscosity increasing the number of voids present in the line, Figure 6. Increasing speed increased the number of voids present in the line, particularly perpendicular to the print direction. This can be attributed to the failure of individual cells to transfer resulting in visible omissions of cells within the line.

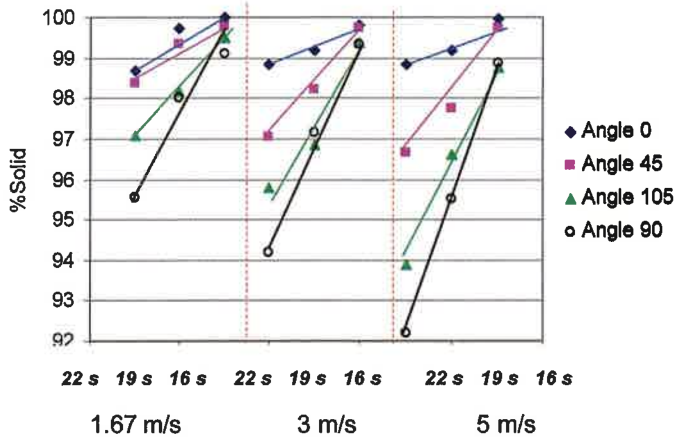

Figure 6: The effect of viscosity and speed on the measured line integrity at four angles of orientation relative to the print direction

Visual inspection of the lines printed clearly shows the characteristics displayed in previous figures. All lines showed regular patterning along their lengths due to the engraving stylus method used to manufacture the cylinders, Figure 7. Parallel to the print direction there is no discernable difference between either side of the line. Significant variations in line edge quality were observed between the leading an trailing edge of lines printed perpendicular to the print direction. At the trailing edge, the ink from individual cells can be seen on the substrate, while the voids were more or less uniformly distributed through the line, Figure 7.

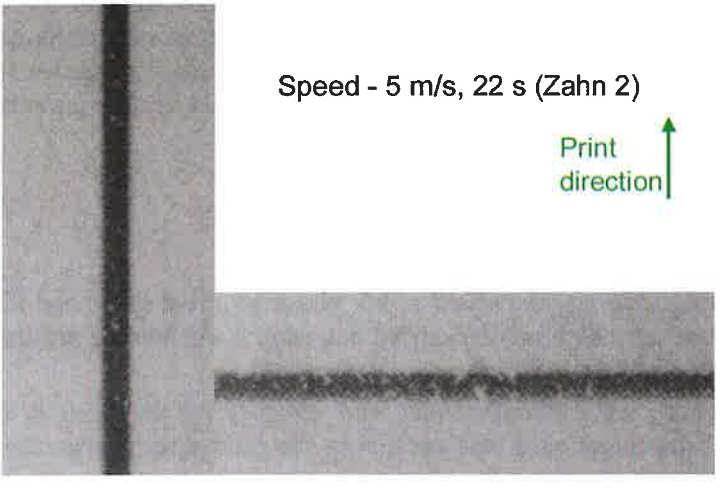

Figure 7: Microscope images of the printed lines showing the difference between lines printed in the orthogonal directions

An interaction existed between the press speed and viscosity. The width of the lines with the lower viscosity inks were the most sensitive to changes in press speed. The press speed affected the edge roughness of the lines to an equal degree for all ink viscosities. The number of voids present in the lines increased significantly as the press speed increased for the highest viscosity ink but remained constant for the low viscosity inks.

The most likely explanation for the improved quality in the print direction and the difference between the leading an trailing edge of the line is associated the wiping action of the doctor blade. The wiping action of the blade on the cylinder produces hydrodynamic pressure in the ink which facilitates ink to cell transfer. In the print direction the ink is subject to significant amount of time under the doctor blade when it can be transferred into the gravure cell as the line remains under the doctor blade continuously. In the cross machine direction the ink only has a small amount of time when the hydrodynamic force is acting to push the ink into the cell. The line features found highlight the need for a means of identifying the different characteristics of lines, beyond a width and standard deviation of width.

The findings have implications for micro manufacture by gravure printing but are also applicable for graphic applications where fine lines must be printed, e.g. in the printing of bar coded labels. Although some of the intra line voids may be associated with the paper substrate used in the study, the smooth coated nature of the substrate would suggest that the voids produced are a function of the gravure ink transfer mechanism when higher viscosities inks are removed from the cylinder at high speed. The true reproduction of the cylinder engraving pattern seen at the edge of the lines on the print shows the high intrinsic reproduction quality of gravure but highlights that when true straight lines are required in micro fabrication by print there may need to be alter the engraving method, e.g. laser engraving. Reducing the viscosity of the ink improves the edge quality of the line at the expense of line spreading. This may not be viable when lines are to be printed close together.

In any electronic production system there is a need to reduce the line thickness and proximity of the lines (termed “track and gap” in the electronics industry) in order to reduce device size, improve performance and to place additional functionality in the device. A further area of study is required on the realistic track and gap obtainable with high speed rotogravure printing and the influence of printing parameters on this behaviour.

The investigation has used two dimension image capture techniques to investigate the lines. As the viscosity is controlled by the quantity of thinner (and hence percentage of solid content) an assessment of the lines should be carried out using a three dimensional measurement technique such as white light interferrometry in order to yield a true measure of the material transferred. This would be best measured on an impermeable substrate such as a polymer film as a reference substrate layer would be easier to establish, [5].

4. Conclusions

An experimental investigation into the effect of ink viscosity, press speed and line orientation on line resolution in rotogravure printing has been carried out using a commercial printing press. Using image analysis, the main findings of the work are:

- The printed thickness, edge characteristics and integrity of the lines is highly dependent on orientation to the print direction. Lines parallel to the print direction are the thinnest and largely unaffected by speed and viscosity.
- The viscosity and speed has a significant effect on lines perpendicular to the print direction. Lines printed at high viscosity are most prone to voids within the boundary of the line.
- Of the two parameters, the viscosity has the most significant impact on the width and integrity of the printed lines.
- There is an interaction between the press speed and viscosity with the higher viscosity inks being the most sensitive to changes in press speed.

Further work should examine:

- The use of alternative engraving techniques which do not involve screening
- The use of polymer film substrates and the electrically active inks
- Minimum track and gap potential of the gravure process.

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4

Digital printing

The limiting characteristics of electrophotographic systems and direct observation of maximal resolving power

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In the recent years, there has been strong and stable interest to manufacturing new electrophotographic devices with improved operating characteristics (Gaynor, 2002, Yamana, 2004). Here emerges the question as to limiting characteristics that may be achieved at development of new electrophotographic devices. With the knowledge of the charge carrier mobility value and the mobility dependence on the temperature and electric field *F*, it is possible to estimate a limiting resolving power and other parameters of photoreceptors that are the heart of all electrophotographic devices. In the consideration that follows, the properties of the most-used organic two-layer photoreceptors are analyzed.

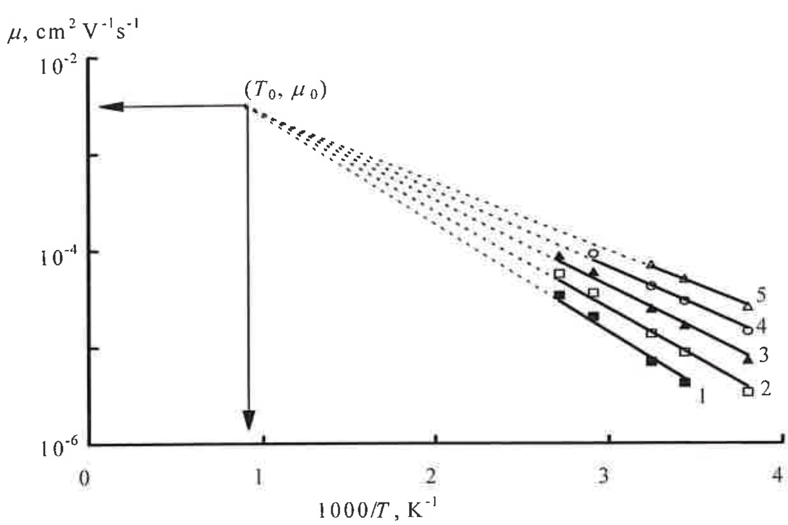

Figure 1: Temperature dependence of the hole drift mobility in API at different electric fields F (×10⁵ V/cm): 2.1 (curve 1), 2.8 (curve 2), 3.57 (curve 3), 4.28 (curve 4), and 5.0 (curve 5)

After exposure of a dot (*H* in diameter) with sharp edges the charge carrier packet is generated and moves through the exposed part with mobility $\mu(F)$. Figures 1 and 2 demonstrate the hole mobility dependence on the temperature and electric field, accordingly, for the transport layer consisting of aromatic polyimid (API) the structure of which is shown in Figure 3 (Vannikov, 2001).

As seen in Figures 1 and 2, the temperature and electric field dependence of mobility is governed by Gill's equation (Borsenberger, 1998):

$$\mu(F) = \mu_0 \exp\left\{\left(-E_m/k\right)\left(\frac{1}{T} - \frac{1}{T_0}\right)\right\}\exp(-2R/r_0),\quad E_m = \Delta_m - \gamma F^{0.5} \qquad (1)$$

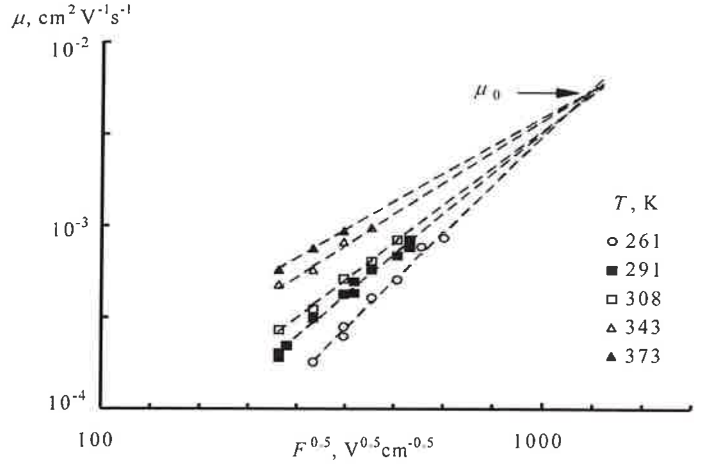

Figure 2:
Field dependence of the hole mobility in API at different temperature

Δ_m is the activation energy of mobility in the zero electric field, T - absolute temperature, T_0 - glass transition temperature of the polymer matrix forming the photoreceptor transport layer, γ - Pool-Frenkel's constant, R - an average distance between the neighboring transport sites, r_0 - the wave function decay constant of the transport site and for organic molecules it equals 1,5 Å (Borsenberger, 1998). So, we shall use the equation (1) further.

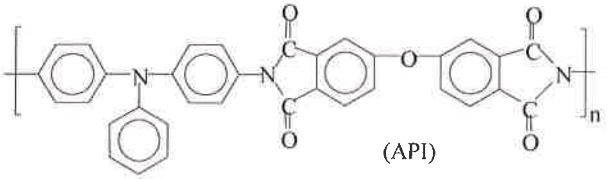

Figure 3:
Chemical structure of API

The packets of charge carriers are generated in the generation layer (GL) of photoreceptor by laser pulses and drift through the transport layer (TL) to the photoreceptor surface to form the electrostatic image, as shown in the Figure 4. The transit time of charge carriers through TL determined by the formula:

$$t_{tr} = L/[\mu(F)\times F] \qquad (2)$$

here L, F are the transport layer thickness and electric field, accordingly, $F = V/L$, where V is a surface potential of the layer. For the transit time t_{tr} the packet boundary is expanded for a distance of d along the layer surface due to both the charge carrier electrostatic repulsion ($F(r)$) and diffusion (D), as shown in Figure 4.

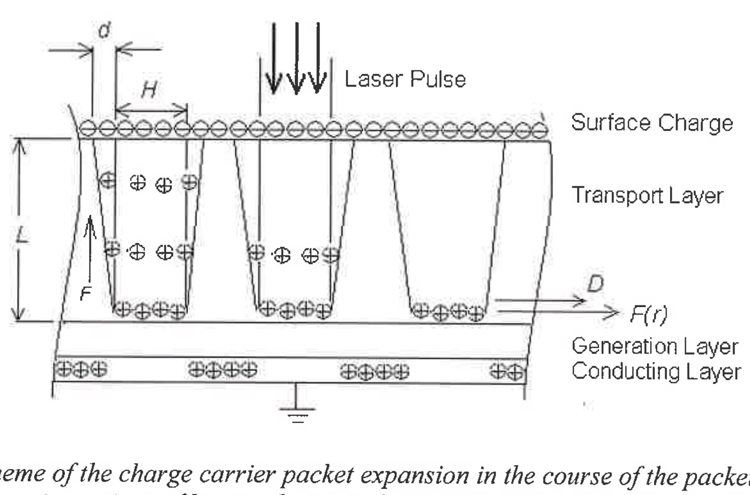

Figure 4: The scheme of the charge carrier packet expansion in the course of the packet drift through the transport layer. Successive actions of laser pulses are shown from left to right. The details are given in the text

We can't use the modulation transfer function (MTF) method to determine the resolving power, as for the electrophotographic photoreceptor the line spread function depends on the line weight or in other words the charge number in a pixel. Because of this, below is given a simple first hand consideration of the electrostatic image formation. The estimation of diffusion component and electrostatic repulsion one is carried out as follows. The charge number in a single packet was believed to be approximately equal to the charge number on the discharged area. The expansion d is determined as a distance traversed by an extreme charge carrier of the packet in lengthwise direction for a time t_{tr}:

$$d = (2Dt_{tr})^{0.5} \tag{3}$$

here D (cm^2/s) is a diffusion coefficient and it is connected with mobility in the zero field $\mu(0)$ by Einstein law:

$$\mu(0) = De/kT = \mu(F) = \mu_0 \exp\{(-\Delta_m/k)(\frac{1}{T} - \frac{1}{T_0})\}\exp(-2R/r_0) \tag{4}$$

k - Boltzmann's constant, e - an electron charge. From (1) - (4) the following formula is obtained for expansion d:

$$d = (2Dt_{tr})^{0,5} = [2L\mu(0)kT/\mu(F)eF]^{0.5} = [(eF/2LkT)exp(\gamma F^{0.5}/\kappa)(\frac{1}{T} - \frac{1}{T_0})]^{-0.5} \tag{5}$$

A numerical value of d can be found by substituting into (5) typical characteristics of organic photoreceptor at room temperature: $L = 20$ µ, dielectric constant $\varepsilon = 3{,}5$, $V = 300$ V, $T_0 = 373$ K and $\gamma = (e^3/\pi\varepsilon\varepsilon_0)^{0.5}$. Using these values, we have $d = 0.13$ µ.

Taking the packet (and the line) broadening d to be not more than 0.1 H to produce the image of high quality, it is possible to obtain an expression for the limiting resolving power of the photoreceptor electrostatic image:

$$R_{lim} = (2H)^{-1} = 0{,}05d^{-1} = 0{,}05[(eF/2LkT)exp(\gamma F^{0.5}/\kappa)(\frac{1}{T} - \frac{1}{T_0})]^{0.5} \tag{6}$$

It follows from Equation (6) that for diffusion mechanism $R_{lim} \cong 4\times10^2$ mm^{-1} or ~ 19000 dpi. Clearly d does not depend on the dot thickness and the line weight as shown in Figure 5, curve 1. In Figure 5, curve 2 represents a relationship between d and H in the case of the charge carrier electrostatic repulsion in the packet. The relationship was calculated by summing over interactions of an extreme charge carrier with each of the charge carriers random distributed in the packet. In this case, the packet expansion d increases with increasing H as the charge carriers in the packet grows in number. The curve growth retardation is connected with increasing the mean distance between charge carriers in the packet and an extreme charge carrier as the dot diameter increases.

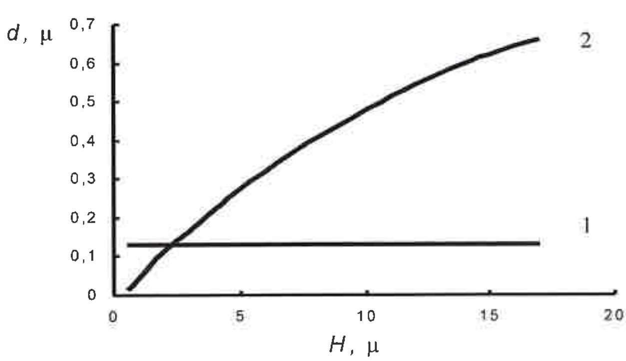

Figure 5: The interrelation between the dot thickness H and the packet expansion d.
1. Diffusion component. 2. Electrostatic repulsion component

It should be noted that in the case of the common transport layer, as seen in Figure 5, the electrostatic repulsion mechanism determines the packet boarding for the dot thickness more than 2 μ, but d < 0.1 *H* in this range and does not limit the resolving power. At H < 2 μ diffusion predominate in the packet expansion process. Thus above $R_{lim} \cong 4\times10^2\,mm^{-1}$ or ~ 19000 dpi is limiting values for the photoreceptor resolution. The resolving power R of the majority of the current electrophotographic units is only about 2400 dpi and determined by the size of the toner particles. At present a maximal resolving power achieved for the printing electrophotographic machine FC-22 "Toshiba" is 9600 dpi. The obtained result testifies that the possibility exists to increase further the photoreceptor resolution at least twofold.

The goal of this work is also to explore experimentally the maximal resolving power of electrostatic charge pattern. Aromatic polyimide doped with J-aggregates of cyanine dyes was used as a photoreceptor layer. This transparent layer has the same transport characteristics as original API presented in Figures 1 and 2. Besides J aggregates will do the high photosensitivity of the layer. Figure 6 shows the structure of cyanine dye used and J-aggregate.

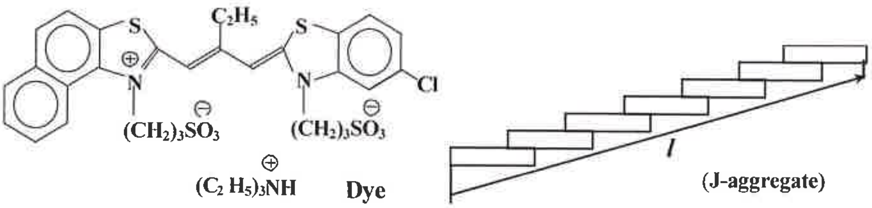

Figure 6: Structure of API, cyanine dye, and also packing of the dye molecules in J-aggregate (brickwork structure)

J-Aggregates of cyanine dyes may be considered to be nanocrystalline compounds intermediate in molecular scale between structurally ordered crystals and single organic molecules. Under photo-irradiation J-aggregates generate charge carriers. Besides, importantly, J-aggregates have the highest optical third-order susceptibility $\chi^{(3)}$. The third order susceptibility of the J-aggregates increases in proportion to $l^{2.4\pm0.1}$, where l is the conjugation length of the J-aggregate (Figure 6), and achieves the extremely high value of $\chi^{(3)} \cong 4\times10^{-6}$ esu. The resolving power of the electrostatic charge pattern on this layer was examined using photorefractive (PR) effect (Vannikov, 2002). PR effect is induced by two interfering laser beams and consists in reversible creation of charge grating, which is shifted in space relative to the bright fringes of interference zone. The charge grating forms as a result of photoinduced charge generation in bright interference fringes and charge separation by electron trapping near these regions and by the shift of mobile holes to dark regions in the applied field F. In turn, the charge grating induces the periodic space-charge field F_{sc} and the phase grating due to the refraction index modulation Δn in the result of electrooptical effect on the base of third-order susceptibility $\chi^{(3)}$. The interaction of interfering laser beams with phase grating is accompanied by energy transfer from one beam to the other with the resulting attenuation of the first beam and the amplification of the second. Of two beams that beam gains which has the lager angle of incidence. So, the energy transfer evidences uniquely that the charge grating is formed.

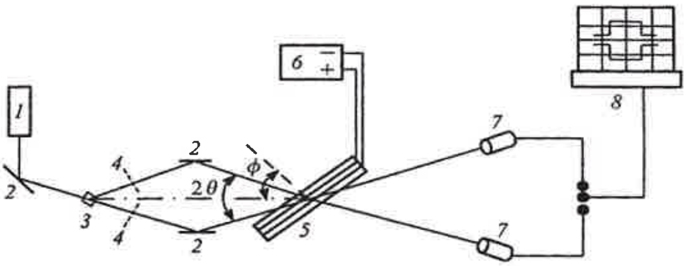

Figure 7: Setup for measuring the charge grating formation in polymer layer. 1 - Ar-Kr laser; 2 - mirrors; 3 - light splitter; 4 - shutters; 5 - sample; 6 - dc voltage source; 7 - photodiodes; 8 - PC; 2θ - the angle between two beams; ϕ - tilt angle

Measuring the characteristics of the phase grating that is a counterpart of the charge grating, it is possible to determine the parameters of the last. The two-beam coupling technique shown in Figure 7 was used to characterize PR effect.

The measurements were realized using Ar-Kr laser with a wavelength 647 nm. A linearly polarized laser beam was divided with a splitter into two beams (beam 1 and beam 2) of equal intensity. These writing beams were overlapped in the layer to create a fringe pattern (Figure 8).

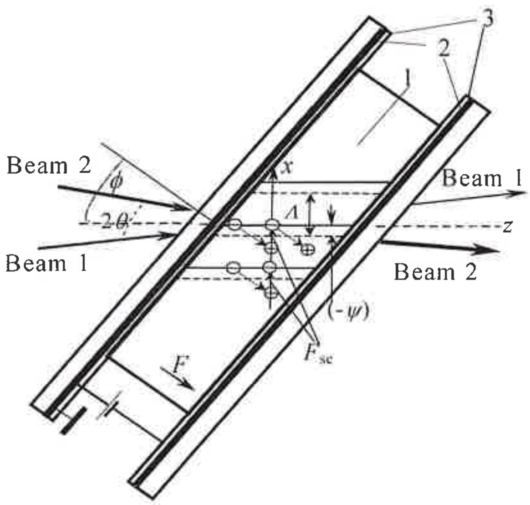

Figure 8:
A schematic representation of the interaction geometry of the writing beams 1 and 2 with polymer layer consisting of API containing cyanine dye: nanocomposite layer (1), ITO-electrodes (2), Al_2O_3 - insulating barrier layer (3). F is the applied dc electric field. Solid and dashed lines inside the nanocomposite layer denote the interference and phase grating, accordingly. Electrons are trapped near bright bands, holes drift to dark regions. The periodic field E_{sc} is directed along x-axis, Λ is the grating period, $\psi = 2\pi\Delta x/\Lambda$ and Δx are the phase and spatial shifts between gratings, respectively

The intensity of each writing beam was about 30 mW/cm^2. The tilt angle was $\phi = 45°$ and the angle between two beams was $2\theta = 15°$. The external electric field F was applied using both the corona discharging technique and sandwich-like samples with two transparent ITO (In_2O_3, SnO_2) electrodes. The sample based on J-aggregates of carbocyanine dye with a thickness L about 3 μ was used. The grating spacing $\Lambda = \lambda/[2n\sin(2\theta/2)] = 1900$ nm at $\lambda = 647$ nm (index of refraction $n \approx 1.3$). It is evident that $\Lambda = H$. Figure 9 shows the temporal dependence of the intensity of beam 2 measured at room temperature after the electric field $F = 50$ V/μ turning on at a moment $t = 0$. When the both beams were switched on, the intensity of beam 2 increased and beam 1 decreased by approximately equal quantity indicating the formation of charge grating shifted relative to the light intensity grating (Figure 8).

It follows that the experimentally obtained values of resolving power represent $H = 1/\Lambda = 5.2\times10^2$ mm^{-1} at $\lambda = 647$ nm. This figure is close to the foregoing limiting value $R_{\lim} \cong 4\times10^2$ mm^{-1} or ~ 19000 dpi.

At last, three beams were used to determine the lifetime of the charge grating. Besides two beams of 647 nm forming the charge grating, the measuring beam 3 from He-Ne laser (λ = 533 nm) was directed along bisector between two writing beams. The beam intensity measured after passing beam 3 through the layer did not change when two beams of 647 nm were switched on. The beam 3 intensity also did not change when only dc electric field F was applied in the absence of beams 1 and 2. When beams 1 and 2 and electric field were switched on the beam 3 intensity decreased due to diffraction on the forming charge grating. The shutdown one of three components (beams 1 and 2, electric field F) led to the charge grating destruction and restoration of the beam 3 intensity. The recovery time of the beam 3 intensity characterizes the charge grating lifetime that appeared equal to about 10 s. Certainly the estimation of lifetime τ of the charge grating formed on the polymer layer surface using results photorefractive experiment is no more than rather rough approximation as in the first case the grating consists of like charges and unlike charges form the grating in the second case. However it is believed that the grating of like charges has lifetime τ more than the grating of unlike ones.

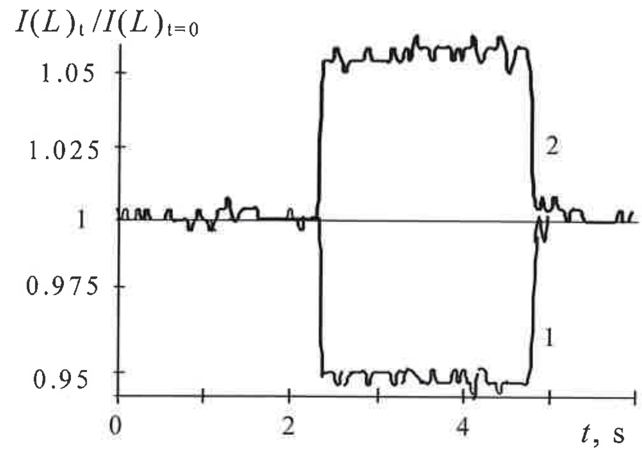

Figure 9: Kinetics of two-beam coupling measured at F = 50 V/μ. Beam 1 (1), beam 2 (2)

The electric characteristics of the transport layer allow us also to estimate the maximal printing speed by electrophotographic units. When rotating the electrophotographic cylinder, the time of transit by charge carriers through the transport layer must be less than the time of the cylinder rotation from an exposing unit to a developing unit $t_{ex\to dev}$, $t_{tr} < t_{ex\to dev}$, otherwise electrostatic image has no time to be formed. On the other hand, the time of the surface potential dark decay τ must be much more than the time of the cylinder rotation from a charging unit to the developing one, otherwise the electrostatic image contrast is entirely lost. The last condition can be expressed thus: $\tau \gg 2t_{ex\to dev}$. So, a condition of the high quality image production is written by the formula:

$$0.5\tau \gg 2t_{ex\to dev} \geq t_{tr} \quad (7)$$

The time tex→dev is roughly 0.2 of the time of the cylinder complete circle and $\tau \geq 10$ s as indicated above. Once in one cylinder complete revolution one image is formed, the printing speed is determined by the expression:

$$W = (5t_{ex\to dev})^{-1} \leq (5t_{tr})^{-1} \quad (8)$$

and the maximal possible printing speed is equal to $W_{max} = (5t_{tr})^{-1}$. The operating photoreceptors have roughly the following parameters: the surface potential $V = FL = 300$ V, $L = 20\mu$, $\mu = 10^{-7}$ cm^2/(Vs), then in according with (1) $t_{tr} = 0.13$ s and $W_{max} = 1.5$ s^{-1} = 5500 h^{-1}. The current electrophotographic printing machines, for example Indigo Platinum, have 4000 h^{-1} and there is a possibility to increase the printing speed. These data show that the transit time plays a significant role in achievement of the maximal resolving power of photoreceptors and it is also a governing factor in the realization of the maximal printing speed of electrophotographic printing machines.

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Toner transfer in multi-colour electrophotographic printing

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Keywords

Electrophotography, modelling, multicolour printing, toner, transfer

1. Introduction

In dry toner electrophotography, charged toner particles are transferred from a photoconductor onto paper with an electric field. The forces acting on toner particles are the adhesion forces between photoconductor and toner and, when paper is in direct contact, between paper and toner, and the transfer force arising from the electric field. A lot of work has been done to better understand adhesion between toners and surfaces (Feng, 2000; Rimai, 2003). However, during transfer the field is modified e.g. by the structure of paper and, in multi-colour printing, by the previously printed toner layer. Less attention has been paid to the variations of the field, which may lead to imperfect toner transfer, manifesting itself for example as a mottled print.

Most of the studies on the electrostatics of toner transfer have concentrated on the behaviour of the electric field in a transfer nip. Several results have been obtained from models, which assume the receiver to be homogeneous: A biased transfer roller system can be made robust against the variations of the resistance of the receiving media by controlling its resistivity (Ito, 2001); In an indirect toner transfer, decrease of toner charge density increases transfer field but a thick toner layer, to be transferred, weakens it (Chen, 2004); Paschen's discharge occurs more easily in the non-image area than in the toner image one (Furuya, 2001); The thinner the air gap, the lower the voltage needed to ionise the variations caused by rough paper surface are same order of magnitude than those caused by a single discontinious toner layer the air in a transfer nip (Tombs, 1998). The influence of paper properties on the transfer field has been considered much less. However, it is known that variations in caliper and filler content affect toner transfer uniformity and may lead to print density mottle (Provatas, 2004).

The objective of this paper is to show, how a previously printed toner layer together with paper modifies the electric field and how this can affect toner transfer in subsequent printing units. Especially toner properties are here in a focus. The approach is to utilize a rather simple model, which can be easily applied on various configurations. Naturally, this kind of approach clearly simplifies the transfer step. On the other hand, real paper surfaces, taken from crosscut micrographs, are used as an input for the model.

2. Toner transfer model and experiments

In order to analyse the effect of paper and toner layer structure on the electric field, and further on toner transfer, a model on the transfer stage was developed. The focus was on direct corona transfer, in which charges are brought directly on the surface of paper. When considering printing over a once printed sheet, there are four effective layers in the transfer nip: the paper; the toner layer already transferred, the air gap between the paper and the toner layer on the photoconductor; and the toner layer to be transferred. Each layer is characterized by its electrical permittivity and surfaces. In the model, the system is approximated locally as a capacitor with flat interfaces between the layers as illustrated in figure 1.

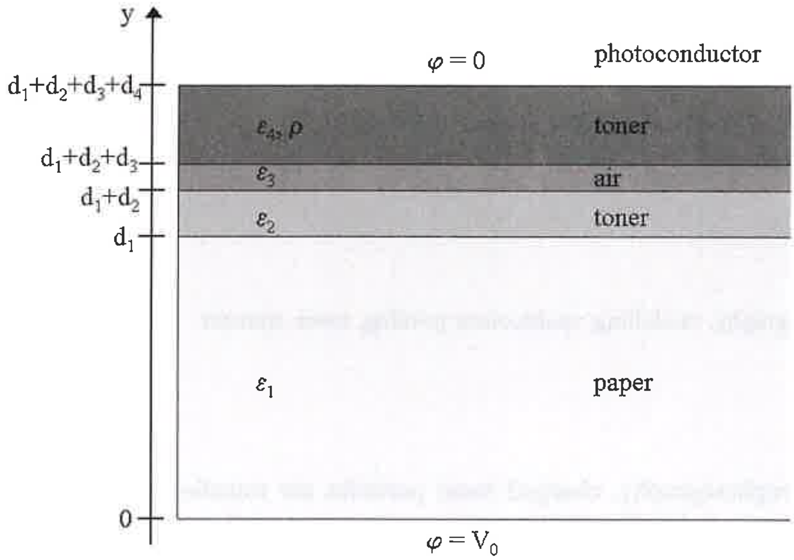

Figure 1: Geometry used for the capacitor model. Symbols d, ε, and ρ denote average thickness, permittivity and charge density, respectively, and the sub indexes refer to different layers

To make the model analytically tractable, the following assumptions were made:

- The motion of paper, and the charging of its bottom side are slow enough, so that the electric field can always be considered as static, corresponding to each momentary configuration.
- The resistivities of paper and toner are so large that there are no currents through the layers or along the surfaces.
- The potential at the lower side (facing corona wire) of paper and at the photoconductor are constants and given by $\varphi=V_0$ and $\varphi=0$, respectively.
- The toner layer on photoconductor is homogeneous and smooth, with constant permittivity ε_t and charge density ρ.
- Local permittivities are constants and should be interpreted as effective values.

Within these assumptions, the potential inside the toner layer attached to the photoconductor can be shown to be (Kallunki):

$$E(y) = \frac{1}{\varepsilon_t}\left(\sum_{i=1}^{t}\frac{d_i}{\varepsilon_i}\right)^{-1}\left(V_0 - \frac{d_t^2\rho}{2\varepsilon_t}\right) + \frac{\rho}{\varepsilon_t}\left(y - \sum_{i=1}^{t-1} d_i\right) \tag{1}$$

Here y is the distance measured from the lower surface of paper, d_i and ε_i denote the thickness and permittivity of the ith layer, $i \in \{1, 2, \ldots, t\}$, respectively, and ρ is the free charge density of the toner layer. There are all together t layers the toner layer on the photoconductor being the t:th one.

The validity of the capacitor model was considered by comparing the result (1) to a numerical solution of a corresponding two-dimensional problem, which was solved using the finite element method (Kallunki). The comparison was done both for Gaussian interfaces and for surfaces extracted from cross-section micrographs taken from a real paper. The main result of the comparison was that the simple one-dimensional approximation is accurate enough to calculate the electric field inside the toner layer. However, the approximation was found to overestimate the small length scale variations and in the calculations presented in this paper the variations of surfaces are neglected for length scales below two times the distance from the point at which the field is calculated. Comparing the calculated field to the transferred toner amount, which was extracted from a cross-section micrograph, further tested the applicability of the model. The transfer force due to the field showed a good correlation with the transferred toner amount: more toner was transferred on places with high field strength.

In this paper, the model is used to clarify how a previously transferred toner layer on paper influences subsequent transfer steps in a direct corona transfer system. Both transfer on a full-tone area and on a line pattern, printed earlier on paper, are considered. The spatial variations of the electric field are briefly discussed in the case of a smooth, coated paper and for a rather rough uncoated copy paper. The surfaces of the various layers used in the calculations are extracted from cross-section micrographs, taken from real paper sheets that were printed with an electrophotographic printer. Printings were done using a tailor-made printer based on Xerox DocuColor 40, in which toner is transferred directly from a photoconductor to paper. Charging was done using a corotron unit. Prints were not fused after printing. However, they were treated in an oven for 15 seconds at 105°C. This treatment enables the preparation of crosscuts but do not change the structure of the toner pile. In the calculations, the following values were used for unless stated otherwise: Permittivity of paper, air and toner layers $\varepsilon_p = 4\varepsilon_0$, $\varepsilon_a = \varepsilon_0$, $\varepsilon_t = 2\varepsilon_0$, respectively, charge density of toner $\rho = -10\ C/m^3$, surface potential of paper $V_0 = 2200V$, and toner layer thickness on the photo-conductor $d_t = 20\ \mu m$. The fields were calculated in the middle of the toner layer laying on the photoconductor.

3. Results

When considering multi-colour transfer, the toner layer, which has already been transferred on paper, modifies the electric field together with the paper. This leads to a decrease of the field, as shown in figure 2. The fields have been calculated with equation (1) using the surfaces of the crosscut image shown in the same figure. When calculating the field for the unprinted sheet, the same crosscut has been used but the toner layer on paper surface has been neglected. To study the effect of toner layer, the calculations have been done for three permittivity values of the toner layer: ε_t has been 1) a half of 2) equal to, or 3) a double of that of paper. These values are used to clearly illustrate the effect of dielectric properties although as large differences may not be accomplished easily in practise. Figure 2 indicates that a low permittivity of toner leads to large change in the strength of the electric field. On the other hand, for high permittivity the field strength inside the toner layer to be transferred is relatively low even without the pretransferred toner layer. The overall strength of the field could be partly compensated by increasing the transfer voltage, which, however, could lead to unwanted ionisation in the air gaps between paper and toner. In two-sided printing the already transferred toner is on the side, which will not be printed. In this case the model gives results similar to those presented in figure 2. Calculations with the model also show that increasing toner charge density decreases the electric field in accordance with the results obtained in (Chen, 2004).

There is a trend towards smaller toner particles and thinner toner layers. This leads to new challenges for the transfer stage, too. Here we consider the effect of a thickness change of the toner layer on the transfer field and keep all the other toner properties, as e.g. its charge density, constant. The resulting fields are shown in figure 3 for three different layer thicknesses. In the calculations both the toner layer thickness on the photoconductor and that on the paper surface were changed simultaneously. The transfer efficiency was kept constant at 82%, i.e., the toner layer thickness on the paper surface was scaled to be 82% of that on the photoconductor. Figure 3 shows that reducing toner layer thickness increases the transfer field. On the other hand, the variations of the field become larger indicating that the evenness of paper structure becomes more important when transferring thin toner layers.

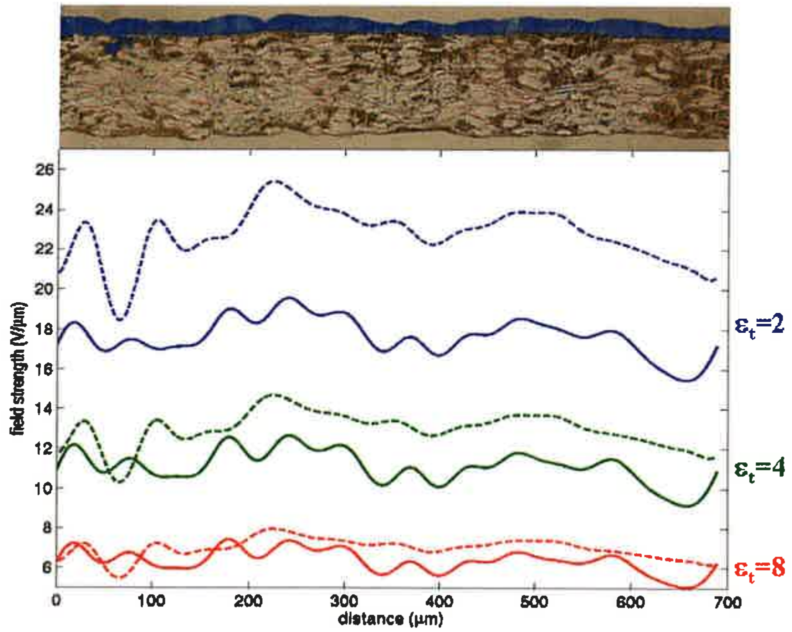

Figure 2: Electric fields for unprinted (dashed lines) and printed paper (solid lines). The image on the top presents the cross-section micrograph of a coated and printed, but unfused paper, which has been used as an input to the model. Values presented in the figure refer to the permittivity of the toner layer

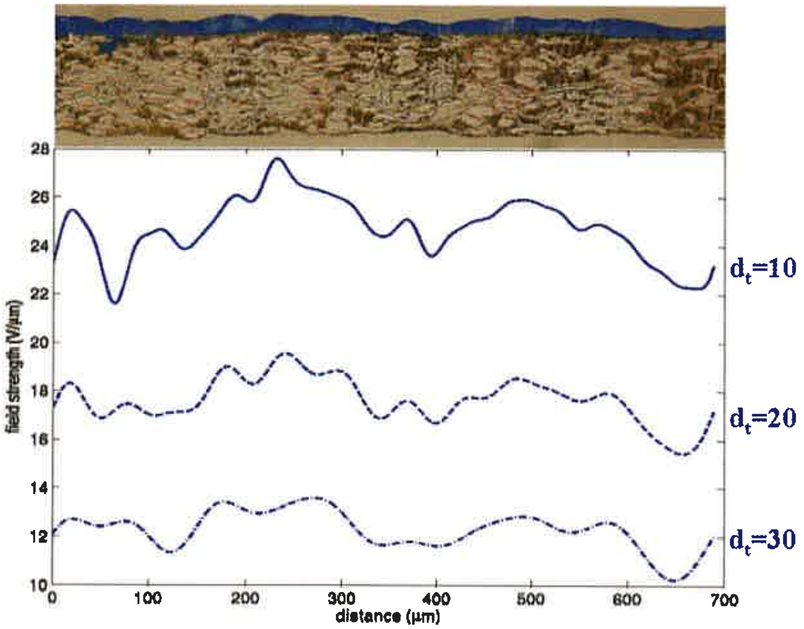

Figure 3: Dependence of electric field on toner layer thickness. Values presented in the figure refer to the thickness of the toner layer on the surface of a photoconductor. Permittivities of paper and toner are equal $\varepsilon_p = \varepsilon_t = 4\varepsilon_0$

Next we consider a situation, in which a continuous full-tone toner layer is transferred on a top of a non-uniform toner layer. In such case the electric field is locally lower in a spots with no toner, as shown in figure 4. Thus, toner transfer is more difficult on unprinted areas. Calculations also show that the thicker the already transferred toner layer, the bigger is the change in the field strength between printed and unprinted areas. The problem is most severe in the last printing unit, and as a practical consequence, the transfer voltage (or current) is usually increased in subsequent printing units. From the viewpoint of toner, a small permittivity leads to smaller field variations with respect to the mean value than large permittivity. Once again, the absolute field is lower when toner layer permittivity is increased.

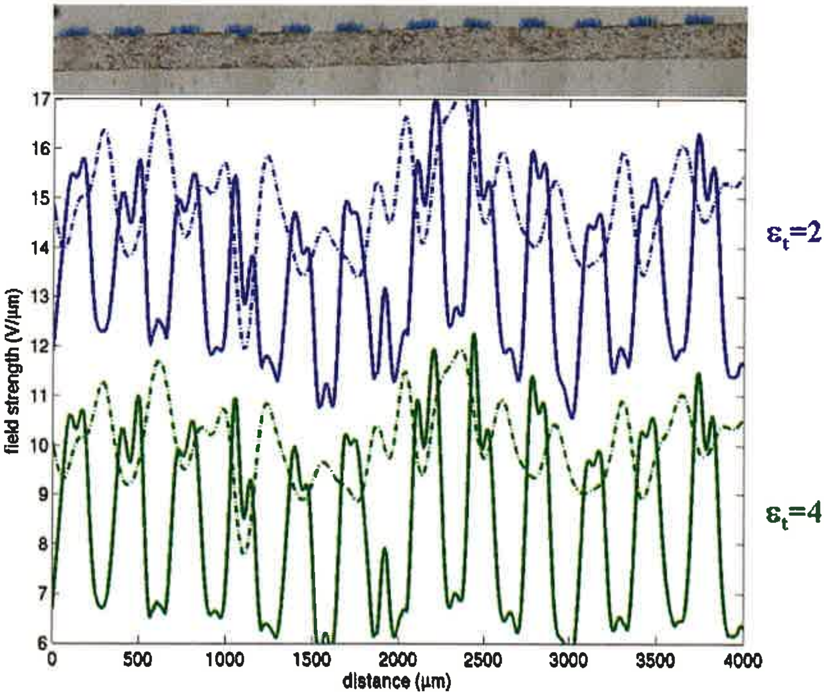

Figure 4: Variations in the electric field when printing is done over a discontinuous (solid lines) or on a continuous print with the same average toner layer thickness (dash-dotted lines). The cross-section micrograph corresponding to the discontinuous case is shown at the top. For illustration purposes, the micrograph image has been magnified two times more in the vertical direction than in the horizontal one. Values presented in the figure refer to the permittivity of the toner layer

The same phenomenon exists in two-sided printing. The variations in the already transferred toner layer affect the electric field on the other side. However, in this case local variations in the field strength are smaller since the distance between the variation and the toner particles to be transferred is larger, as shown in figure 5. Roughly speaking, only those regions of toner layer, whose size is comparable to the sheet thickness, will affect the electric field. In figure 5 this is seen as a similar shape of different curves, only the mean strength is clearly different. This should be compared to the case, in which the toner layer is at the side to be printed (see fig. 2). Then the variations in the toner layer thickness will affect also the local variations (shape) of the electric field.

There is a trend towards smaller toner particles and thinner toner layers. This leads to new challenges for the transfer stage, too. Here we consider the effect of a thickness change of the toner layer on the transfer field and keep all the other toner properties, as e.g. its charge density, constant. The resulting fields are shown in figure 3 for three different layer thicknesses. In the calculations both the toner layer thickness on the photoconductor and that on the paper surface were changed simultaneously. The transfer efficiency was kept constant at 82%, i.e., the toner layer thickness on the paper surface was scaled to be 82% of that on the photoconductor. Figure 3 shows that reducing toner layer thickness increases the transfer field. On the other hand, the variations of the field become larger indicating that the evenness of paper structure becomes more important when transferring thin toner layers.

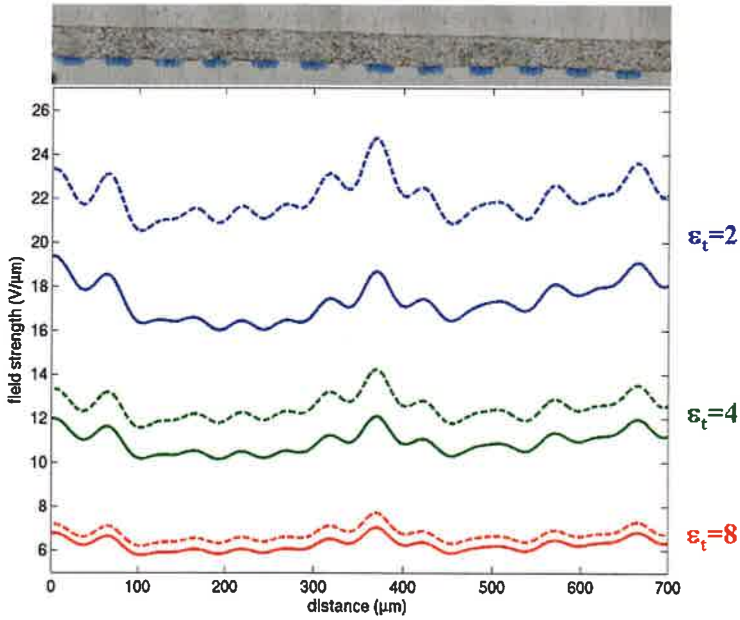

Figure 5: Electric field when printing on a sheet, whose other side has been printed discontinuously (solid lines). Dashed lines refer to the electric field modified by unprinted paper. The cross-section micrograph is at the top. For illustration purposes, the micrograph image has been magnified two times more in the vertical direction than in the horizontal one. Values presented in the figure refer to permittivity of the toner layer

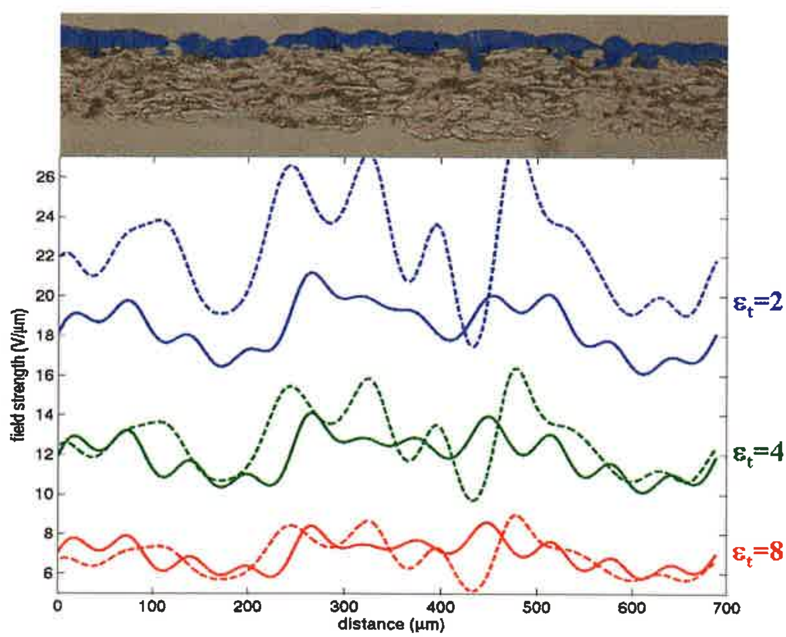

Figure 6: Electric fields for unprinted (dashed lines) and printed paper (continuous lines). The image on the top presents the cross-section micrograph of an uncoated, rough and printed, but unfused paper, which has been used as an input to the model. Values presented in the figure refer to the permittivity of the toner layer

4. Discussion

From the viewpoint of an efficient and uniform toner transfer, a high and uniform electric field inside the toner layer on a photoconductor is desired. Hence, the toner layer on paper should be thin and it should have a smooth surface. Thin toner layer decreases the electric field less than a thick one. In halftone area, the thicker the toner layer, the bigger are the variations of the electric field. A smooth toner layer surface causes less variation to the electric field than a rough one.

Both of the above mentioned requirements are closely related to the particle size of toner. With small toner particles it is possible to print thin and smooth toner layers. For a thin toner layer the strength of the electric field is larger. On the other hand, while toner particles are getting smaller, their detachment from the surface of a photoconductor becomes more difficult (Rimai, 2001). Thus, the requirements are to some extent contradictory. However, the effect of toner layer, which has already been printed, should be taken into account when toner detachment from a photoconductor is studied.

Permittivity of the toner layer influences transfer field directly. It is comprised both of the permittivity of toner particles and the air inside the layer. While the former can be modified by adding appropriate toner additives, the latter one depends on the packaging properties of toner particles, and once again, on toner particle size. For high field strength the toner layer permittivity should be low, which would be the case for a loosely packed toner layer.

When considering full-tone area, it could be advantageous to have toner with high permittivity on paper, whereas on the photoconductor surface a low permittivity is desiderable. This is clearly a contradictionary requirement. In principle, such situation could be achieved by fusing the toner on paper prior to the transfer of the next layer. Fusing removes air from the layer, which makes it denser and increases its permittivity. At the halftone area the situation is different: a high permittivity increases the variations of the electric field. In addition to this, high charging power together with a thin, discontinuous toner layer can result in the ionisation of air (May, 1997). Hence, a good choise is to have toner with permittivity close to that of paper.

Also paper properties influence the variations of the electric field. A rough surface of paper causes bigger variations than a smooth one. The importance of paper properties increases, when toner layer becomes thinner. On the other hand, a single discontinuous toner layer on paper causes variations of the same order of magnitude than a rough paper surface.

5. Conclusions

The effect of paper and toner properties on toner transfer has been studied using electrostatic modelling. We have used a one-dimensional static capacitor model, which has turned out to be a useful and simple-to-use tool for analysing the effect of several kinds of structural variations on toner transfer. To bring the analysis closer to real world applications, real paper surfaces have been used as an input for the model.

The model shows that a toner layer on paper decreases the electric field inside the toner layer on the photoconductor. The thicker the layer and the higher its permittivity, the bigger is the decrease. When considering printing on a once printed paper, the field is shown to couple both to the paper and the already transferred toner surfaces. The first printing diminishes the variations of the electric field for the rough paper whereas for a coated grade it makes them bigger. Thus, paper has a clear effect on the transfer field and its importance is emphasized for thin toner layers. On the other hand, the variations caused by a single discontinuous toner layer are of a similar magnitude than those caused by paper. Hence, when considering multi-colour printing, the toner layer, already on paper, has at least an equal effect on toner transfer than paper.

The model presented here could also be applied for studying how the non-homogeneous structure of the layers would affect the electric field. In this paper all layers have been assumed to be homogeneous. For example, one could consider non-uniform toner layers with spatial charge density variations or the effect of different structural changes of paper.

Acknowledgements

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Controlling fusing parameters by optical image quality in electrophotographic printing

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Abstract

Particle-based electrophotography is the premier digital printing method today. From the quality standpoint its competitiveness has suffered from print unevenness. The study addresses the issue to what extent improvements can be achieved by adjustment of variables in the fusing stage.

Four different contact fusing units were used in this work to introduce a wide range of parameters that influence the optical properties of the printed image. The differences in the optical properties measured within this range have assisted in investigating the quality improvements through additional external feedback control loop. Also, the paper grades and the colours used in this experiment have added value to differentiate the fusing quality.

1. Introduction

Fusing is the stage where the toner in electrophotography and other particle based digital printing methods is sintered, spread and penetrated into paper. As it is the last stage in the process, it dominates the final physical and optical print quality. There are two types of fusing technologies; contact and non-contact fusing. They could be used separately, or both installed in one machine in such combination to improve the image quality with desired speed.

Non-contact fusing methods such as radiant heat, hot air, oven fusing and flash fusing have different fusing parameters compared to contact fusing, and in turn the mechanism of fusing process will be completely different, especially in the absence of deformation in non-contact fusing (AL-Rubaiey H., et al., 2002). The experimental approach of this research is to control process parameters of contact fusing unit, only.

In any contact fusing method, the fusing energy is applied as pressure, and as conductive heat transfer and fluid flow phenomena. In this type of technology, three groups of parameters control fusing quality; toner properties, paper properties and process parameters (AL-Rubaiey H., et al., 2002), (Sipi K. M., 2002), as listed in Table I.

It is assumed that the toner on the peaks of the paper profile gets very glossy as a result of nip calendering. If the paper is very rough, the toner in the valleys of the surface does not get into good contact with the fixing roller, so the area remains matte. Since the calendering effect is proportional to the nip pressure, it is expected that reduced nip pressure results in reduced gloss and optical density variations. Therefore, reduced pressure should be compensated by increased dwell time (or nip width) to achieve the same level of physical fusing quality and to improve optical quality (Sipi K. M., 2002), (Chen, et al., 1997).

Table I: Three groups of parameters control fusing quality

Toner properties	Paper properties	Process parameters
• Specific heat capacity • Thermal conductivity • Surface energy • Glass transition temperature • Viscosity • Particle size	• Specific heat capacity • Thermal conductivity • Moisture content • Surface energy • Roughness • Porosity • Calliper (thickness)	• Hot roll surface temperature • Average nip pressure • Dwell time • Toner pile height • Ambient temperature • Nip width

Another way of increasing dwell time is to reduce the printing speed, but this is not the target, rather the target is to achieve high print quality with high printing speed. So, the nip width is one parameter to be controlled and optimised. The nip width is proportional to the thickness and elastic modulus of the elastomer layer (Johnson, J. L., 1998), therefore by increasing the thickness of a softer layer, the nip pressure is reduced and nip width is increased.

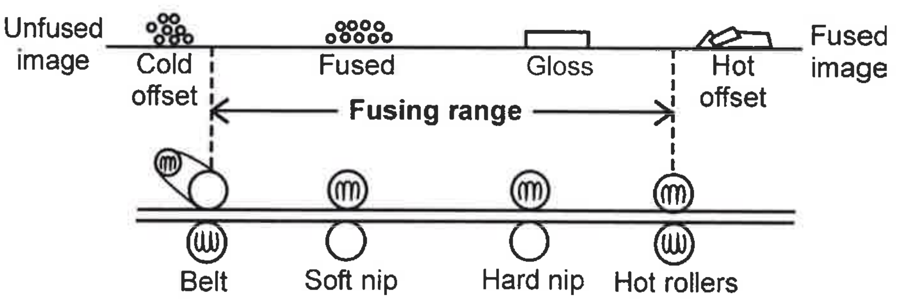

Figure 1: The experimental fusing units in acceptable fusing range

This paper is focused on the above adjustable fusing parameters to control optical image quality within acceptable level of physical quality such as image adhesion. Figure 1 shows the limitations of fusing range as a scale for the experimental fusing units.

From the equation (Chen, et al., 1997) [$K = f(Pt^2/MD, T/Ta)$], the fusing quality is a function of two dimensionless groups; (Pt^2/MD) and (T/Ta), where K is fusing quality, P is average nip pressure, t is dwell time, M is developed mass of toner per unit area on the substrate, D is average diameter of toner particle, T is fusing temperature, and Ta is the ambient temperature. For comparison between image quality of a hard and a soft nip, dwell time is a significant variable. Further adjustment of soft nip load and consequently the nip width is also possible (Prime, R. B., 1983).

2. Experiments

Four different contact fusing technologies were used in this work. They are described as following:

1st) Hot rollers; in this unit, both fixing and backing rollers are heated by tungsten-halogen lamps, with adjustable temperature and speed. It was used as a reference for the limitation near by heat set offset, because it is applying high pressure, and supplying high heating energy for both image side and back paper side.

2nd) Hard nip; in this technology, only the fixing roller image side is heated to a temperature of 165°C, and the contact area between fusing roller and back roller (nip width) is 4mm, with a nip pressure of 45kPa and dwell time of 40ms.

3rd) Soft nip; it is modified from the previous one by replacing the elastomer coated layer of the back roller with a softer one of different elastic modulus. This is to obtain softer nip with pressure of 30kPa, and in turn this modification produces wider nip (6mm) and longer dwell time (60ms) with constant load. The speed and temperature are kept the same as in hard nip. It is important to mention that the new elastomer coating material of the back roller has different thermal conductivity than the original one, but that will not affect the final temperature of fusing nip because this roller is not a heating roller, it is just a pressure roller.

4th) Belt fusing; as it is not so easy to obtain flat and wider nip between two rollers than in soft nip, belt fusing unit with nip width of 10mm was used for the other end of fusing latitude near by cold offset. The unit consists of a belt of high thermal conductivity wound around two rollers, the one far from the nip and the other forming the nip with back heated roller with adjustable pressure. In this design, the heating energy is supplied through the backside of the substrate by the heated back roller and partially to the image side by the belt transferring the heat from the roller far from the nip. The idea is to reduce the heating energy supplied directly to the printed image, for better quality. In these technologies, the latitude of fusing parameters is controlled by heat and cold offsets, and printed image quality. So, the range of process variables is flexible enough to study their influences on optical print quality.

Five paper grades were used in this experiment. The test target was designed to meet of the measurements requirements and further investigations of the results. At acceptable levels of fixing strength and image adhesion, optical image density, and gloss and its variation were measured.

Gloss variation was of prime interest. Preliminary experiments suggested that it responds far more sensitively to adjustments of fusing variables than optical density. Gloss variation was measured using modified gloss analyser at the 20° incident-reflectance angles for a minimum image area of 44mm × 46mm. The measurement is based on the concept of band-pass filtering of image. Three bands were used. The coefficient of variation in each range can be used as a measure for the strength of gloss variation.

The scale of gloss variation, which was used in Figure 3 is a measure for the size of unevenness and it is obtained by dividing the coefficient of variation from the band >5mm by the coefficient of variation from the band <1mm [(>5mm) / (<1mm)]. The scale is lowest for fine-grained and highest for coarse-grained structures.

3. Results and discussion

As a result of operating four different sets of fusing parameters within acceptable results of the physical fusing window, each of the four fusing units produces different density and glossiness. According to the density measurements, different grey scale reproductions were produced from the same image at certain grey scale %. In Figure 2, the higher level of densities obtained by hot rollers at each grey scale is due to heating energy being supplied from two opposite directions by both fixing and back rollers, which causes fast toner melting, and at the same time spreading widely under high pressure. As a result, image enhancement from a good level of coverage by high dot gain was obtained. From the black solid print, Figure 3 shows that the gloss variation of the image fused by the hot rollers is the highest. The gloss variation is an indication of print-surface unevenness. The rougher the print surface, the higher the gloss variation.

Reducing both energies, the heat and the pressure, and instead increasing the nip width as in belt fusing; less optical density in all grey scales indicates less dot gain as is evident from Figure 2, which in turn means high accuracy (grey scale image reproduction), and less gloss variation from smooth print surface. In belt fusing the optical image quality is improved.

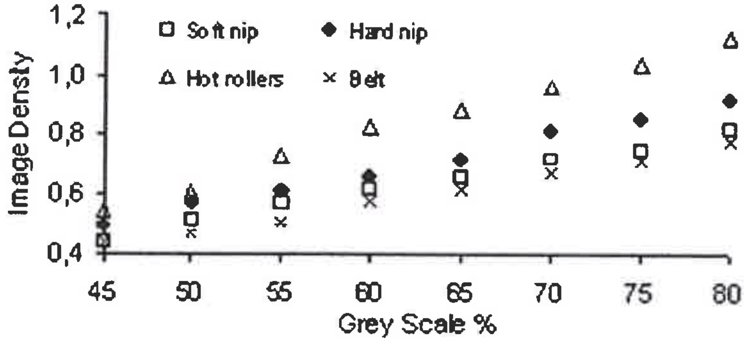

Figure 2: Grey scale densities printed on 100 g/m² coated paper

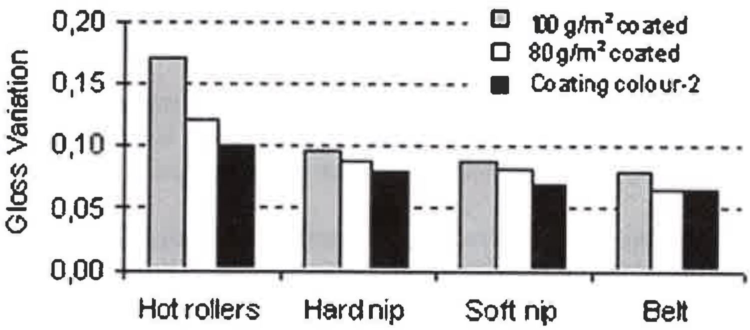

Figure 3: Gloss variation of black solid print

Between these two limits, the results from hard nip and modified soft nip show the critical fusing factors influencing optical image quality. Table II shows that even the average gloss of solid green and black prints are higher from the soft nip, but still -for both colours- the gloss variations are lower at all the wavelength reflectance ranges.

It is also clear from Figures 2 and 3 that the soft nip produces better optical image quality with less dot gain and lower gloss variation than the one produced by hard nip. The only difference between these nips is just replacement of the coating material of the back roller by a softer elastomer. As it was mentioned, this modification has increased the nip width and dwell time, and reduced the pressure. It is expected that with the soft nip, there will not be a considerable change in the fixing strength. Simply, the fixing quality is related directly to the nip pressure in one order of magnitude and to the dwell time in two orders of magnitude (Prime, R. B., 1983).

Table II: Gloss and its variation of solid prints on 80 g/m² paper

Sample	Gloss	<1 mm	1–5 mm	>5 mm	Scale
Hard nip/Green	9,4	60	17	6,5	0,11
Soft nip/Green	12	54	14	5,3	0,10
Hard nip/Black	2,8	47	14	5,7	0,12
Soft nip/Black	3,6	45	13	4,6	0,10

The results show that the image quality obtained by belt fusing is better. Its energy consumption is also lower and lifetime longer. Now, it is understandable to recommend an adjustable fusing system in industrial electrophotographic machines to allow different applications with desirable quality. The claim is not all quality attributes are controlled produced by the fusing stage, but as it is the final stage in the electrophographic process, therefore it has the final and definitely a crucial effect on achieved print quality.

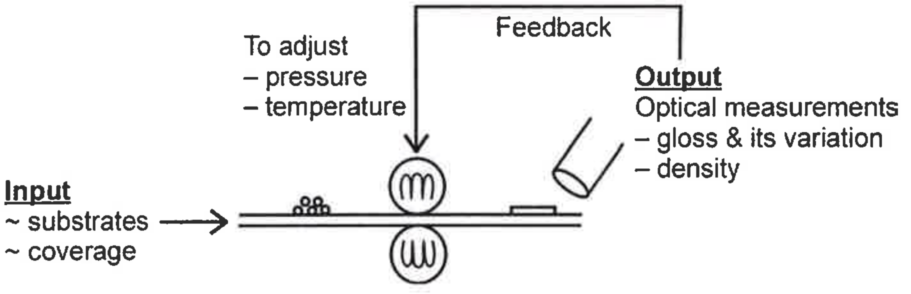

Figure 4: Controlled fusing unit

Some of the fusing parameters of this study that have clear influence on optical image quality could be adjusted within acceptable fusing range. To ensure high performance, these parameters could be adjusted automatically according to the density and gloss variation measured from the first print as functions of different substrates and image coverage.

Figure 4 gives a sketch of this adjustment. It is simply done by feedback control loop from the optical measurement system, back to the fusing system. Future research will address this issue.

4. Conclusion

The study focused on the role fusing configurations and fusing parameters have in controlling print unevenness. The influences proved to be considerable. This suggests that improvements can be achieved by adjustments of the parameters based on a feedback control loop in fusing units.

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Direct laser printing: New opportunities of competition with mechanical printing equipment

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Abstract

The suggested Direct Laser Printing Technology (DLP) is based on application of short laser impulses (~10 nsec) over ink layer 4-5 μm thick. The technology provides transfer of UV-ink drops 20 μm in diameter with 0,6 μJ energy consumption, similar liquid ink drops with 0,3 μJ energy consumption. The achieved results allow creation of high-speed printing devices.

1. Introduction and aims to the development

At present mechanical printing machines dominate in the printing market. "Computer-to-Print" equipment owns a small niche in this market due to low printing speed and high cost of supplies.

The reason for above is application of electrophotograhy principles, which stipulate creation of a hidden image on a photoreceptor, development with a toner, electrostatic transfer of the image to the paper sheet and its heat fixing.

Despite the fact that hidden image dot creation is only 10 nsec, subsequent operations add it up to 2-3 μsec. Taking into account high cost of toner and special paper limitations, market share of machines utilizing this technology can be easily understood.

The purpose of research, which resulted in creation of DLP, was development of a technology that can provide "Computer-to-Print"-based transfer of ink of any viscosity to the paper in 10 nsec per drop.

2. Theory

DLP utilizes Light-Hydraulic Effect (LHE) discovered by Nobel Prize Laureate A. M. Prokhorov, Russian Academy of Science corresponding member G. A. Askaryan in 1963 and Self Focusing Effect discovered by G. A. Askaryan in 1963.

The gist of LHE consists in the impact impulse in a liquid created by a short laser impulse. The duration of impulse allows creating high-density energy in small liquid volume. The short laser impulse does not boil the ink, but creates high pressure (up to hundreds of atmospheres) in its 0,5÷1,0 μm layer. This pressure leads to an explosion shock in other layers within the laser impulse spot and ink drop blowout from this spot.

Based on the above, shrinkage of the laser spot increases laser energy concentration in smaller ink volume, leading to higher LHE.

Shrinkage of laser spot is also achieved by self-focusing effect due to variation in refraction ratios inside ink and within the laser beam.

In order to understand LHE processes it is necessary to grasp the mechanism of interaction between laser radiation and liquid or viscous ink.

The analysis of high-power sound impulses generated by laser radiation in liquid showed that strong acoustic fields are generated on liquid surface in the conditions of high absorption as a result of optical-acoustic interaction. It is assumed that energy transfer occurs due to excitation of valence vibrations, and sound generation is stipulated by heat expansion of ink. Since registered duration of acoustic impulses is small (τ~5 nsec), thermalization of excitation occurs in less than 1 nsec.

Let us estimate the temperature in an ink cylinder volume after release of laser impulse energy, using the following formula:

$$T = \frac{E}{VC_V}$$

where E - energy, arising in volume V,
C_V - specific heat capacity.

The square of focused spot (S) can be expressed by the formula $S=\pi*\omega_0^2$, where ω_0 - laser beam radius.

Cylinder ink volume with (d) thickness can be expressed by the formula $V=S*d= \pi*\omega_0^2*2d$.

Heat capacity (C) for most viscous liquids approximates 4 kJ/mol°C.

Assuming that ω_0=10 µm, d=10 µm and impulse energy margin E_0=10 µJ, the following formula can be derived:

$$T = \frac{E_0}{\pi \varpi_0^2 dC_V} = 3{,}3 \cdot 10^{3\circ}C$$

Such temperature spike in such short time should be followed by thermal expansion of the radiated volume, which leads to an impulse wave. Thus, there is an opportunity to use LHE for high-speed DLP.

For better understanding of LHE ink drop transfer process we should mark the boundary between this effect and pure thermal interaction of laser beam with liquid.

The principle of creating a heat pressure impulse in liquid is widely used in ink jet printing machines, providing drop-on-demand printing. Such devices stipulate heating of all ink volume (e.g. in a capillary) therefore creating a superheated steam bubble. As a result a pressure impulse occurs and an ink-drop is ejected.

In market printing devices of this kind ink is heated by thermal resistances, despite the fact that many laser-created bubble effect patents where registered in recent 10-12 by leading office equipment firms.

Regardless of the source of heat steam a bubble is created in 2-3 µsec, and from the cost point of view it is efficient to create bubble effect using thermal resistance, not laser beam.

For more complicated solution - creation of digital printing machine - laser triggered bubble effect cannot be utilized due to low ejection frequency, low printing resolution and high dependence on ink type. Let us explain the latter statement.

Liquid ink should be used for bubble effect creation. If viscous ink is used it will start to burn during 2-3 μsec required to create a bubble by a laser beam. At the same time such a long laser impulse will lead to heat propagation in the ink layer behind the laser impulse spot, therefore not allowing to eject a drop with a diameter less than 50 μm.

LHE allows to create a pressure impulse in ink layer in 2-100 nsec, which is approximately two times less than bubble effect pressure impulse. Since time required to create pressure impulse is very small, the transferred into ink layer energy will not expand behind the laser impulse spot. Only the size of laser spot determines size of ejected ink drops. Moreover size of drops and impulse creation speed do not depend on ink viscosity.

3. Experimental setup

In the DLP development process we investigated a number of laser beam - ink interaction schemes.

The schemes per US patent № 6.270.194 and US patent 6.056.388 are of main practical interest [1, 2].

The scheme per first patent employs opportunity to eject ink drops from a thin ink layer deposited on a laser-transparent quill cylinder. Its outside surface is covered by a laser-absorbing layer, which is needed to level energy consumption on any color ink drop ejection. The absorbing layer (RF patent № 2174916) is an alloy of cylinder material and metal [3].

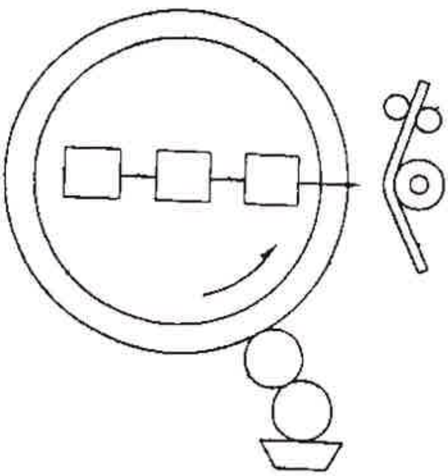

Figure 1: The scheme per second patent stipulates ink filling of cavities located on cylinder surface

Every scheme has its advantages and disadvantages. For example, a cylinder with plain outside surface is easier to manufacture than a cylinder with cavities. However, it is difficult to deposit level ink layer on a plain cylinder. Energy consumption is less for ink ejection from cavities. Ideally shaped dots are achieved when a laser-transparent cylinder with grid surface.

In fact final design of DLP should combine best elements from both schemes.

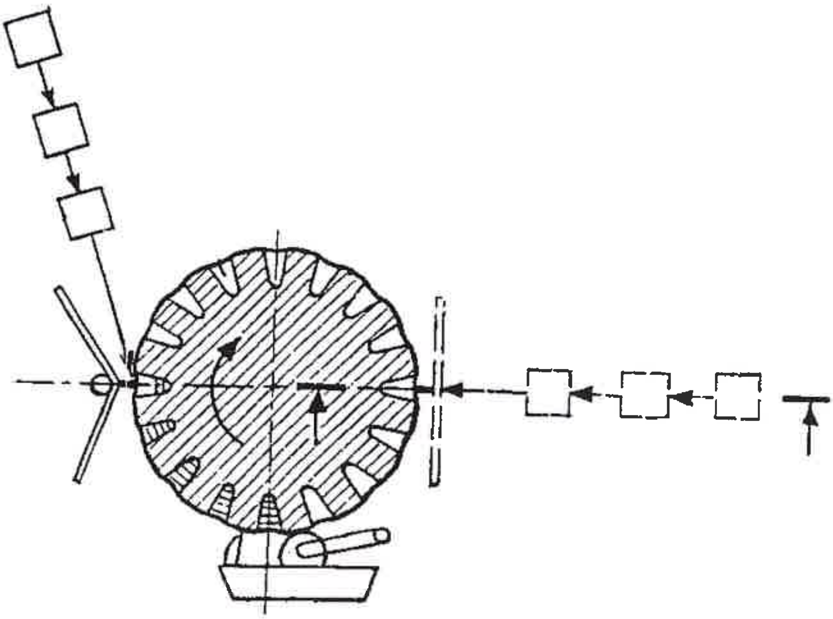

Figure 2

We confirmed experimentally that energy consumption for ejection of Ø20 μm viscous UV-ink drop from 4-5 μm thick layer equals 0,6 μJ, for a liquid ink drop of same size- 0,3 μJ.

4. Results

In order to understand the mechanism of laser impulse with ink interaction it was necessary to define the critical factor in the ink drop transfer process: whether it is energy exposure

$$H = \frac{E_H}{S}$$

where E_H - impulse energy, S - square of radiated surface) or irradiance

$$F = \frac{P_i}{S}$$

(where P_i – impulse power).

For the above purpose we used two experimental devices with Nd:YAG one-mode lasers. One laser was with a continuous wave-pumping and modulated q-factor, with impulse duration of 150 nces. The other laser was with an impulse wave-pumping, impulse duration of 15 nsec. Both lasers had equal energy impulse, but impulse power is tenfold.

Measurements of cut-off energy (E_T) required for even cross section area ink drop ejection showed that it is approximately equal for both lasers, despite the fact that peak power per square unit differed significantly. The results showed that energy exposure plays main role in the ink drop transfer process. In course of DLP research process we specified that increase of laser impulse frequency leads to reduction of peak energy required to eject drops from ink layer and reduction of drop size.

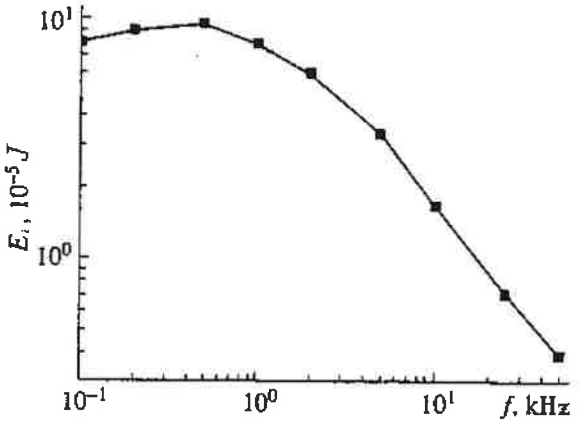

Figure 3

The graph shows correlation of laser impulse energy (E_i) per impulse with impulse frequency. It evidences that for frequencies >0,5 kHz E_i decreases smoothly. When the frequency is in the range from 2 kHz to 10 kHz, average impulse energy decreases approximately by a factor of 6, drop diameter - approximately by a factor of 3.

In course of the research process we found out that when there is an up to 0,8 mm gap between ink layer and the paper, shape and size of ink dots remains constant, with an approximately 1 mm gap, ink dot grows slightly.

5. Conclusion and resume of the results

The achieved reproducible results of our research demonstrate the opportunity for creation of experimental printing device based on DLP.

It is reasonable to start DLP realization with a small printing width, e.g. in a device for UV-ink printing on plastic cards. It will allow increasing speed of this process, and also eliminating ink ribbon, laminating ribbon and printing plates.

Further it is rational to proceed with the creation of DLP-based printing machines with wide printing width, e.g. for flexography. All technical implications for the above work already exist.

In future based on acquired experience it is possible to rollout the technology for high-speed wideband printing.

References

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2. S. N. Maximovsky, G. A. Radutzky, USA Patent № 6.056.388
3.S.N. Maximovsky, G. A. Radutzky, RF Patent № 2174916

5

Color science & management

A new method for comparing colour gamuts among printing technologies

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1. Introduction

In colour reproduction, it is generally important for different reasons to know beforehand the colour gamut of reproducible colours (Berns, 2000). Some industries applying industrial colorimetry, such as textiles, plastics, leather, paints, usually keep a data base with their colour gamut, which only occasionally, following commercial criteria and fashion, is reproduced in a sampler to allow the customers to judge the colour generating capabilities of the manufacturer. However, few enterprises study whether their colour gamut reaches the MacAdam limits (see Appendix) or whether it covers more or less homogeneously the Rösch-MacAdam colour solid (Berns, 2000; Kuehni, 2003). Pointer, in 1980, was one of the first scientists to study this problem (Pointer, 1980). In 2002, Pointer retook this subject, asking for the collaboration of all persons interested in the matter, to generate a large database of colour gamuts in current industry (Pointer, 2002). We are particularly interested in this subject, both in those aspects related to the comparison between the colour gamuts of different industries and the MacAdam limits and in those aspects related to how the colour solid is filled, whether homogeneously or leaving certain void regions.

In Colour Imaging there are other reasons why the computation of the colour gamut in colour devices is important, particularly the need for controlled colour management in input, display and printing devices (Green & MacDonald, 2002; MacDonald, Luo, 2002; Wandell, Silverstein, 2003; Kipphan, 2001; Smyth, 2003). Thus, most industries use colour charts to compute the colour profile of colour devices. For many years, for example, the ANSI IT8 charts have served as a reference to calibrate scanners and printing devices. Several works (Cheung, Westland, 2004) have studied the suitability and the efficiency of these colour charts depending on the device to be characterised. It is for this reason that, for instance, two versions of the ColorChecker chart are available for colour cameras: the classic one and the new DC chart. Similarly, many charts (ECI 2002, CIE 2.9 offset, etc) offer now an alternative to the ANSI IT8 7/3 chart for printing devices. The aspects taken into account in the design of these colour charts, such as linearization curves, primary and secondary colours and so on, are those that best characterise the colour device under study. Using these standard colours, the colour gamut of the device can be compared with the MacAdam limits, although few studies have analysed whether the rest of the colours fill homogeneously the Rösch-MacAdam colour solid. For instance, an exhaustive study of the differences arising from the use of different inks and substrates (paper, cardboard, etc.) in the different printing technologies (flexography, gravure, offset, electrophotography, inkjet, etc.) cannot be found in scientific literature.

For all these reasons, and following Pointer, we have developed a simple method to compare the colour gamuts of different printing technologies based on representing the reproduced colours in constant lightness L^* and hue h_{ab}^* planes. In particular, we focus in this work in the comparison of four printing technologies -electrophotography or laser, gravure, inkjet and offset- using the same class of paper and approximately the same characterization chart.

2. Methods

The printing devices selected for this analysis were three laser printers (HP 6600 Indigo, Xerox Docucolor 12 and HP 4600), one inkjet printer (HP 1220), one offset printing press (Heidelberg GTO 52 with Euro Offset) and one gravure printing press (HelioKlischograph K405), with the corresponding genuine cartridge units. Trying to get the most homogenous comparative among these printers we used plain paper as substrate (100 g/m^2 and matte or non-coated appearance), except to the gravure printing device, and we decided to print the ECI 2002 CMYK chart for laser, gravure and offset printers. On the other hand, we selected to print the TC9.18 RGB chart for the inkjet printer in order to benefit us from its internal driver model or RGB-to-CMYK conversion.

When it was possible, the spectral reflectance $\rho(\lambda)$ of the patches of each particular colour chart have been measured by a Minolta CM-2600d spectrophotometer (d/8 geometry) using the Minolta SpectraMagic 3.6 control software. The tristimulus values XYZ under illuminant D65 and the CIELAB descriptors $L^*a^*b^*C_{ab}^*h_{ab}^*$ are computed along with the H V/C Munsell descriptors of the sample. Taking also into account the MacAdam limits under D65 (Perales, et al., 2005), we can select the constant lightness L* and hue h_{ab}^* profiles in which the samples of each manufacturer (printing technology) and the MacAdam loci must be plotted. In other circumstances, for instance the gravure data, we use a GretagMacbeth SpectroScanT spectrophotometer (45/0 geometry) to get output data in CIELAB format under illuminant D50 in the corresponding ICC profile.

Once all the patches of each chart/printer are measured in turn, the CIELAB data are grouped in parallel ordering them by increasing lightness L* and hue-angle h_{ab}^*. CIELAB data are plotted into constant lightness (luminance factor) planes with a variance of $\Delta Y = \pm 5\%$. On the other hand, the same CIELAB data now ordered by hue are plotted into constant hue-angle planes with a variance Δh^* associated to the hue-angle range of the major hues of the Munsell notation (R, YR, Y, GY, etc). As reference hue-angle for each 2D profile in this case, we selected the corresponding value of each Munsell chip with V = 5 and C = 10 under illuminant C and according to CIE-1931 observer.

3. Results and discussion

With this methodology some studies can be done:

- calculate and graph the ICC profile data in several constant lightness and hue angle planes.
- compare colour gamuts with different categories of paper (uncoated, coated, recycled, etc) or other substrates in the same printing technology.
- compare among different CMYK and RGB characterization charts and to propose improvements to fill more homogenously the Rösch-MacAdam colour solid.
- search new colorants (pigments and inks) in all printing technologies to reach the borders of the MacAdam limits.

Next, we show some examples of this methodology.

3.1 Comparing among different printing technologies with the same paper

Figures 1 and 2 show a comparison between the colour gamuts of the three printers, using the same class of paper, according to several luminance factor (lightness) ranges. As it can be seen, none of the three printers reach the corresponding MacAdam limits, particularly for the lightest colours (section with Y = 70%). However, the colour sub-gamut of the lightness mid-range (Y = 20%) fills well enough the area of the MacAdam loci. Comparing among the three printers, it is obvious that the best one is the laser printer in the four constant lightness sections. The second place in this ranking is for the inkjet printer, although the colour patches of the TC9.18 RGB do not fill homogenously each sub-colour gamut of this printer. Finally, the offset printing machine shows the smallest colour sub-gamuts, especially for the dark colours (Y = 10%). Perhaps using a coated paper, with a grammage above 100 g/m^2, the colour gamut of this printing device could be significantly increased.

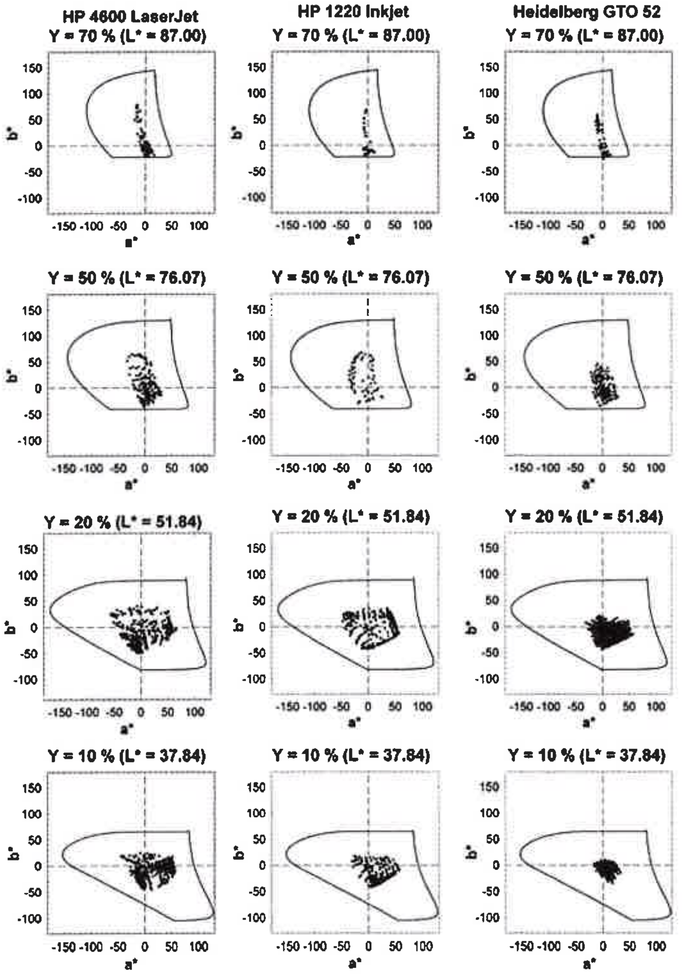

Figure 1: Samples of the ECI CMYK 2002 chart printed in a HP 4600 laserjet color printer (left side) and Heidelberg GTO 52 printing machine (right side) and the TC9.18 RGB chart in a HP 1220C inkjet printer (center) in several constant lightness planes. The outer loci are always the corresponding MacAdam limits

On the other hand, Figure 2 shows the colour gamuts of the same three printers for the Munsell Hue ranges. As it can be seen, none three printers reaches again the corresponding MacAdam limits. In general, the blue (B) and blue-purple (PB) MacAdam limits are relatively well filled for the three printers. But, in the other extreme case, the green (G) and purple (P) MacAdam limits are the worst filled by the colour sub-gamuts of the printers. Comparing among three printers, it is again obvious that the best one is the laser printer in the ten constant hue angle sections. The second place in this ranking is again for the inkjet printer. However, in this type of analysis, it is common for all the printers to leave empty or un-occupied sub-regions in these hue sections, especially around the achromatic axis, as can be clearly seen in particular with the inkjet printer. Examining each hue section, and taking into account the typical scheme of nuances in constant hue angle profile (Figure 3), it can be seen the following: there are more deep red colours in laser and inkjet printers than in offset printer, there are more strong blue colours in the laser printer but there are more bright blue colours in both inkjet and offset printers, etc.

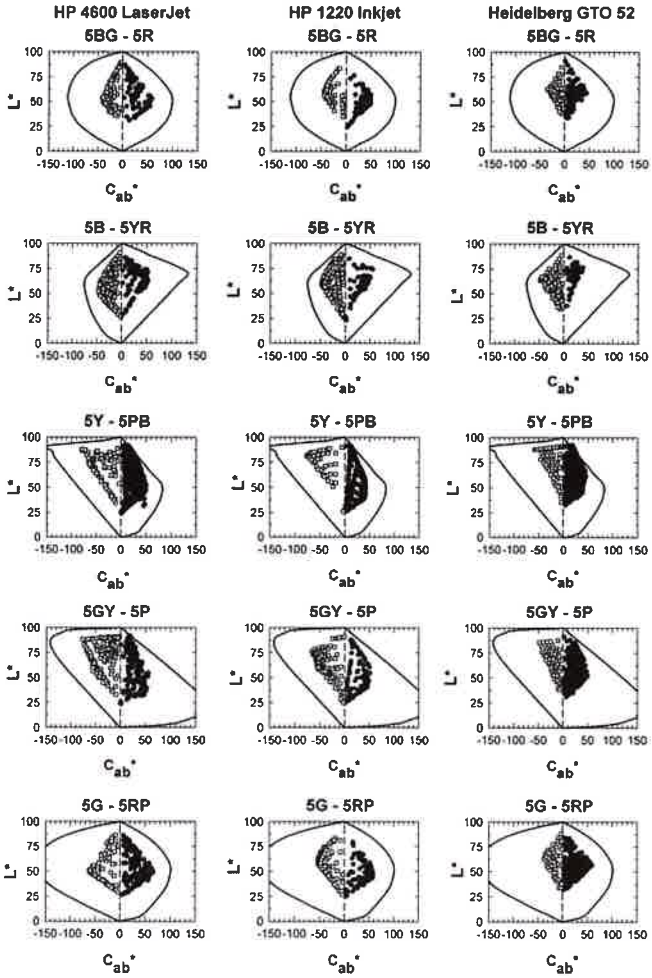

Figure 2: Samples of the ECI CMYK 2002 chart printed in a HP 4600 laserjet color printer (left side) and Heidelberg GTO 52 printing machine (right side) and the TC9.18 RGB chart in a HP 1220C inkjet printer (center) in several constant hue-angle planes. The outer loci are always the corresponding MacAdam limits

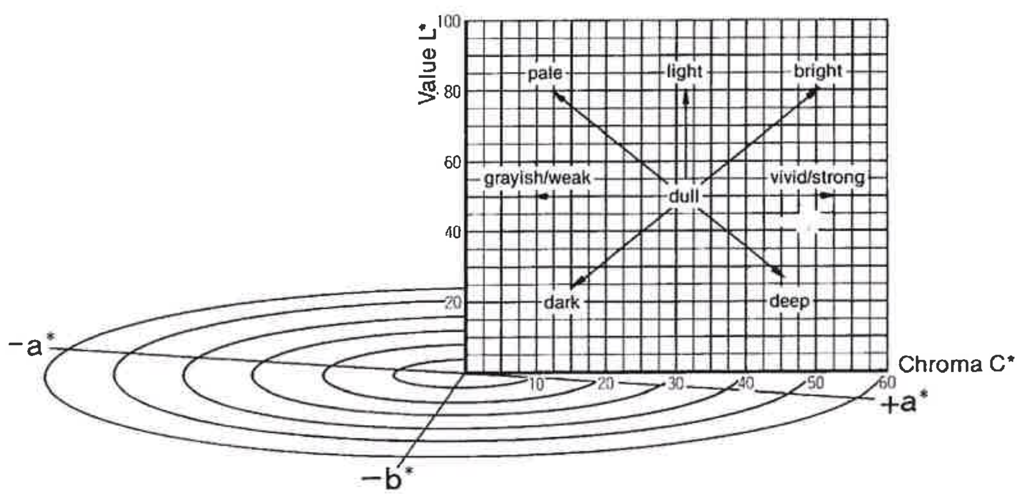

Figure 3: Nuance types in a constant hue-angle section in CIELAB colour space

In both cases and generalizing, it can be seen that the colour gamut of the laser printer is larger than the rest, above all for dark colours and red hue ranges. The last place of the ranking is occupied by the offset printer. In any case, as it also can be seen, none of the printer colour gamut reaches completely the corresponding MacAdam limits. Moreover, in some specific profiles, both constant lightness and hue angle segments, certain regions inside the colour solid remain empty, particularly around the achromatic axis.

3.2 Comparing the same printing technology with different substrates

Figure 4 shows the colour gamuts of the same web-fed gravure printing press with several substrates or transparent foils for the Munsell Hue ranges. As it can be seen, none colour sub-gamuts with printing technology reaches again the corresponding MacAdam limits. However, comparing with the Figure 2, associated to several printing technologies with paper as substrate, it can be seen clearly that the gravure technology is higher than the other ones (electrofotography, ink-jet and offset). Perhaps, the main reason of this significant difference among these printing technologies is due to the optical nature of the substrate: paper as reflective medium for the first ones, and transparent foil (cellophane, polyethylene, etc) as transmissive medium for the last one. Nevertheless, this analysis among these printing technologies is not almost right because it is necessary to take into account the optical influence of the reflective substrate of the final packaging materials.

In general, all the MacAdam limits are relatively well filled. The worst cases are the green (G) and purple (P) MacAdam limits, but this also was equal in the above printing technologies. Comparing among three transparent foils or substrates, the best one is the foil 1 in the ten constant hue angle sections. Examining each hue section, and taking into account the typical scheme of nuances in constant hue angle profile (Figure 3), it can be seen the following: there are more deep red colours in foil 3 than in other ones, there are more strong blue colours in the laser printer but there are more bright blue colours in foil 1, etc.

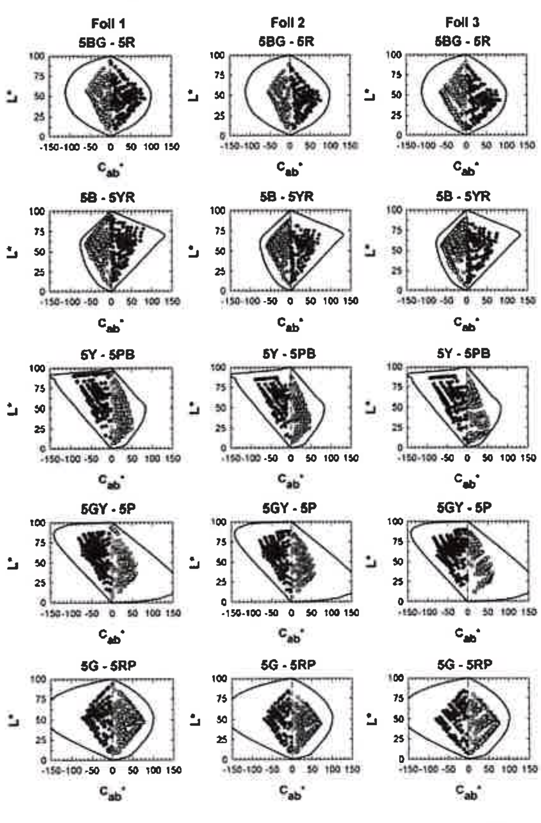

Figure 4: Samples of the ECI CMYK 2002 chart printed in a rotogravure press (HelioKlischograph K405) with several transparent foils in several constant hue-angle planes. The outer loci are always the corresponding MacAdam limits

4. Conclusions

As an example of the described methodology, which can be applied to any coloration technology (textile, paints, plastics, etc), we compared the colour gamuts of some printing technologies (electrophotography or laser, gravure, inkjet and offset) with the same class of paper and characterization chart (really the ECI 2002 CMYK for the laser, gravure and offset printing devices, but the TC9.18 RGB for the inkjet printer). We show in this comparison that in general the colour gamut of the laser printer is larger than those corresponding to other printers, as appear from both the constant lightness and the constant hue-angle 2D-plots. However, since we always include the corresponding MacAdam limits in the figures, and they are almost never reached for the analysed printers, we think that more research is necessary to obtain new dyes and pigments in printing technologies and paper industry for trying to reach the perceptible limits of the human eye. Therefore, we think that this new methodology, based on the exhaustive analysis of the colorimetric data in CIELAB colour space, could help to off-line quality control in all media print

Acknowledgements

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Appendix

Human colour perception is essentially tri-variant in nature. Colours are defined by three parameters: lightness, hue and colourfulness (chroma, purity, saturation, etc). This means that colours define a 3D structure named colour solid, in whose upper and lower vertex are the absolute or perceptual white and black, respectively. The colours shaping the intermediate frontiers, obviously with the maximum colourfulness, are called optimal colours and they were exhaustively studied by MacAdam in 1935. Due to this, the colour solid borders are also known as MacAdam limits. Although there are a lot of artistic attempts and preliminary scientific studies to graph realistically the human colour solid, few exhaustive works have arisen since 1935 based on MacAdam's data. We can highlight, as an exception, Pointer's paper from 1980, where different industrial colour gamuts are compared with the MacAdam limits. Since then, these data (Figure A1) have been shown sporadically in colour science textbooks (Berns, 2000; Kipphan, 2001; Kuenhi, 2003), but almost always in chromaticity diagrams, as constant luminance factor loci, with the same illuminants (A, C, D65 or E). However, we have developed recently a new algorithm for calculating the MacAdam limits for any lightness L*, hue angle h_{ab}* and illuminant (D50, F2, F7, F11, etc) or light source (Xe, metal-halide, etc).

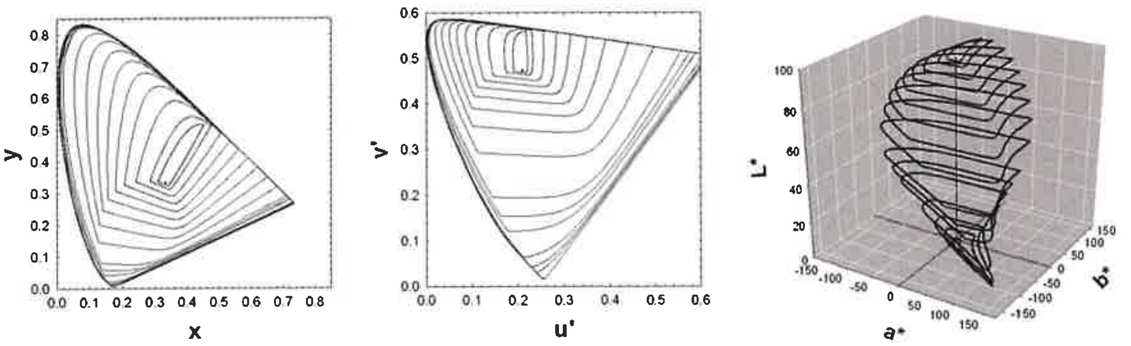

*Figure A1: MacAdam limits under illuminant E according to the CIE-xy (left) and CIE-u'v' (center) chromaticity diagrams and CIE-L*a*b* colour space (right)*

Rösch in 1929, but above all MacAdam (MacAdam, 1935ab), analyzed the theory of optimal colours proving that their spectral reflectance or transmittance can be only zero or one. There are two types of optimal colours (Figure A2): type 1, with "mountain"-like spectral profiles, and, type 2, with "valley"-like spectral profiles. As we know, although these colours are not present in nature, they are very important for Colour Science because they constitute the frontier of the human colour solid. Therefore the Rösch-MacAdam colour solid is the colour space derived from the colour-matching functions (Kuehni, 2003). Due to this, the MacAdam limits are used to analyze the colorimetric quality of colorants (Berns, 2000; Pointer, 1980, 2002) in any industrial application (textiles, paints, printing, etc).

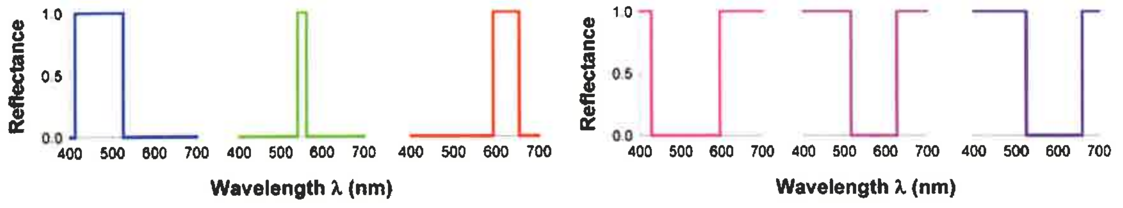

Figure A2: Six examples of optimal colours (left: type 1; right: type 2) with luminance factor Y = 20% under illuminant E and CIE-1931 observer

The combination of gravure or some ink-jet screening and the diffusion of light in the substrate lead to an experimentally confirmed increase of printable color hues

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Abstract

Light diffuses in every direction in paper and other substrates. This diffusion caused by the scattering of light inside the substrate leads in screens with dot area modulation (autotypic screening) as offset to the well known Yule-Nilsen effect. Actually the light diffusion in paper has also relevant consequences in the whole visible spectrum and therefore on the colorimetric values, as it was shown by many authors. Relevant: The light diffusion leads in autotypic halftone screening using very fine screens to a larger amount of colour hues than with the usual 60 l/ cm.

Still most interesting are the effects derived from the diffusion of light in the substrate if both, dot area and ink film thikness on the dot become greater with increasing tone as in gravure printing: The interaction between visible radiation-ink and film-substrate follows approximately the Lambert-Beer law; this means that with an increase of the ink amount on the substrate the light remission goes down exponentially. In other words, as a consequence of the light diffusion in the substrate; from tonal value of 100% to the lowest tonal values, the ink interacts with the light as if the ink would be distributed as a continuous film on the substrate. Some consequences of this behaviour:

- Some process control methods which suppose a continuous distribution of the pigments on the substrate as for example the "MiniTarget" control method leads to good results in gravure printing; the colour deviations are of about 2,5 ΔE units or lower.
- In the halftone overprinting of two or three inks the remission can be computed through an easy multiplication of the transparencies of each of the as halftone printed inks; the error is of about 4 ΔE units or lower. This model is useful for example for proofing or print simulations.
- Reduced "unwanted" light absorption, especially the absorption in the blue spectrum of magenta goes down; this means that a magenta halftone becomes "more magenta and less red-biased". In gravure printing for the same colour hexagon is possible a larger amount of colour hues as it would be possible with dot area modulation as in offset.

The same is valid for some versions of ink-jet printing.

Keywords

Gravure screening, increase of printable colour hues, ink-jet printing, light diffusion in the substrate

1. Introduction

It is well known that light diffuses in any direction in paper or another optically comparable substrate. This diffusion of light, also to the sides, leads to well studied effects in halftone prints with autotypic screening (screening with variable dot area but nearly constant ink film thickness). One of them is the since more than 50 years known Yule-Nilsen effect: in autotypic printing as offset, the densitometric measured dot area is quite larger than the ink covered substrate area. Actually the light diffusion in paper has also relevant consequences in the whole visible spectrum and therefore on the colourimetric values; as it was shown by Paul and Brune [PB, 1997] as well as by Naito, Lee and Kinoshita [NLK, 2004]. The basic aspects of these effects were explained by Hübler [Hü, 1992].

A short description of this effect: When a light beam hits the surface of the substrate we get through multiple scattering of the photons a "cloud" of photons inside the substrate whose concentration decreases with the distance to the beamed point. The remission is proportional to the photon concentration in this "cloud" under the surface as shown in figure 1 [FRGS, 1982].

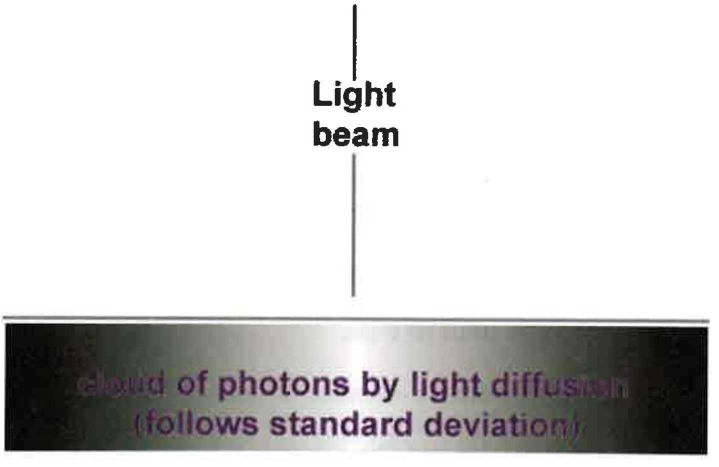

Figure 1

If the diffusion length (about 50 to 100μ) [FRGS, 1982] is much larger than the dimensions in the screen, a photon which diffuses in the paper may leave the paper anywhere inside the diffusion length, as shown in figure 2. It may leave the print through a printed or an unprinted area; the probabilities depend mainly on the dot area.

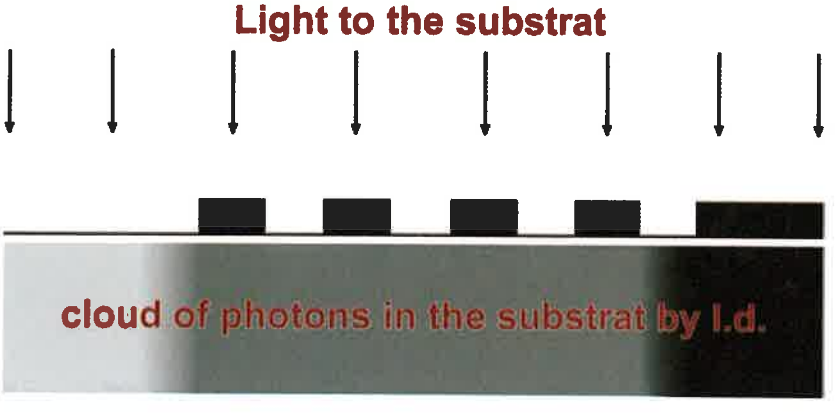

Figure 2

Therefore, many photons which come into the substrate through an ink dot may leave the print through an unprinted area; also many photons which get into the substrate through an unprinted area may leave the print through an ink dot as well. This means that a relevant amount of the radiation remitted by the print undergoes an absorption comparable to that of a solid tone with only one half of the present ink film thickness. A reduction of the ink film thickness to one half of the original thickness value leads to a large reduction of the "unwhished light absorption" of some pigments, especially magenta and cyan. Figure 3 shows this for magenta: There is a large increase of the remission in the blue, therefore magenta becomes "more magenta" or "less-only-red".

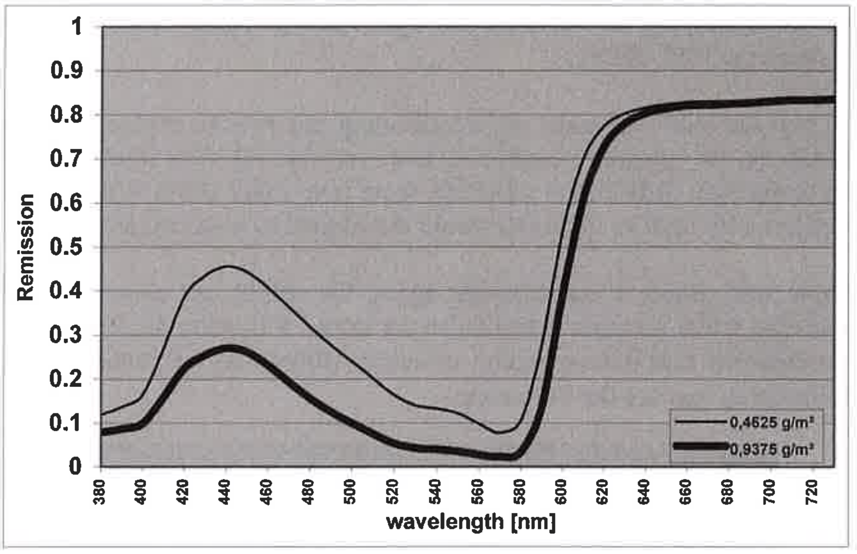

Figure 3

The consequence is a behaviour which reminds us of printing with continuous tones whose ink film thickness is modulated instead of dot area. The result is an increase of the number of possible colour hues, as shown by Paul and Brune [PB, 1997]. With the same inks and paper a very fine screening in offset allows to reach a larger volume in the colour space L*a*b*. The printable volume in the colour space L*a*b* may increase up to 15% (usual offset) or more (dry offset).

Still more interesting are the effects derived from the diffusion of light in the substrate in half autotypic printing, as gravure.

For a better understanding: In gravure printing when the tone values increase both together, the aperture and the depth of the cells will increase as well. This is valid for both: the dominating electromechanical engraving on copper and the uprising laser gravure on zinc. It is well known that at tone value of 60% to 80%, starts the so called "overflowing", this means that the ink flows on the substrate over the walls between the cells. Therefore for tone values over 80% there is a continuous ink film, whose thickness increases with the tone value.

Some consequences for transparent inks. Transparent inks are the four-colour-process chromatic inks cyan (C), magenta (M) and yellow (Y) and most of the special inks used for example in package printing. One evidently and well known (but very oft forgotten) consequence is the following one:

1. It is possible to modulate tone value in pictures up to 100%, (instead of up to 95-98% as in autotypic printing, offset for example) with a higher ability to preserve the draw inside the dark tones. For example the remission with black ink is one half or less as in autotypic printing with the same solid tone ink film thickness but a dot area of 98% or less.

A dot area up to 100% (instead of up to 95-98%) also means that it is possible to reach the whole colour saturation of the chromatic inks in the prints.

Another evident consequence for a tone value over 80% is the following:

- The interaction visible radiation-ink film-substrate follows approximately the Lambert-Beer law, this means that with an increase of the ink amount on the substrate the light remission goes down exponentially.

Less evident, surprising and relevant is that also for lower tone values, including the lowest ones, with an increase of the ink amount on the substrate the light remission goes down nearly exponentially in the whole visible spectrum [SH, 2002].

This behaviour of gravure prints far under the overflowing can only be explained as a consequence of the diffusion of light in the substrate, combined with variable ink film thickness on the dots. This means that thanks to the light diffusion in substrate, from tone value 100% to the lowest printable tone values the ink interacts with light as if the ink would distributed as a continuous film on the substrate.

To give an example was chosen a magenta ink again, the results are shown in figure 4; the little differences between the actual remissions and those computed following the assumption that the ink is distributed as a continuous film corresponding to colour differences of about 4 ΔE or lower. Some consequences of this behaviour are the following:

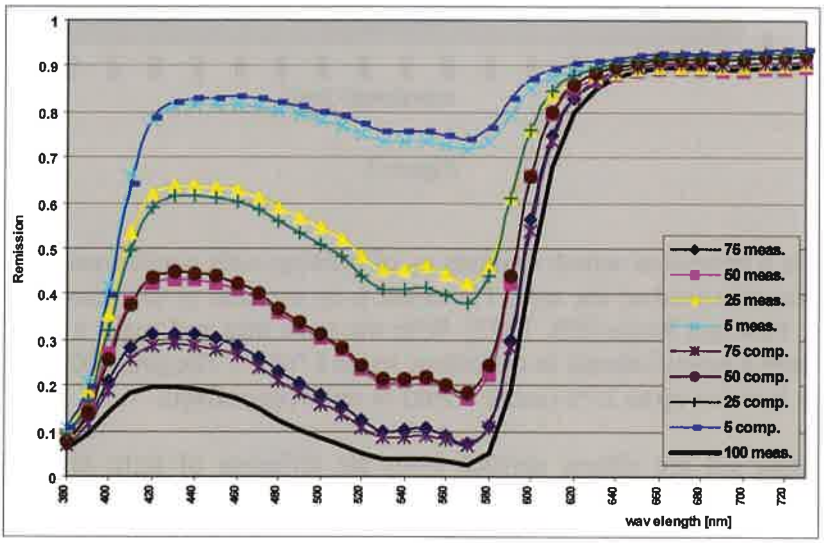

Figure 4

2. Some process control methods which suppose a continuous distribution of the pigments on the substrate as those which are based on the works of Viggiano and Wang [VW, 1993] or Künzli [Kü, 1998] [Kü, 2000] as the "MiniTarget" control method lead to good results in gravure; the colour deviations are of about 2,5 ΔE units or lower. This is also valid for some ink-jet versions.

3. In the halftone overprinting of two or three inks the remission can be computed by means of an easy multiplication of the transparencies of each of the halftone printed inks; the error is of about 4 ΔE units or lower. This model was used successfully for example for proofing or for print simulations.

4. Reduced "unwanted" light absorption, especially the absorption in the blue spectrum of magenta diminishes. This means that a magenta halftone becomes "more magenta and less red-biased". Increasing the tone value from the naked substrate to 100% you get a strong curved line on the xy-diagram, instead of a straight line. The result should correspond to a larger volume for the printable colours in the L*a*b*- space for a given hexagon defined by the values of C, MC, M, YM, Y and YC.

Together with item 1. this means that gravure printing should make it possible with the same basic tones (the same colour hexagon defined by the colour values of C, MC, M, YM, Y and YC) to get a larger amount of colour hues as in autotypic printing. Also for ink-jet it should be possible to gain a comparable effect.

Up to this point this paper is mainly a short version of earlier presentations [RG, 2005], but an important question is still missing. Is the assumption done in 4. a correct one? An experimental verification is needed. Again the assumption which should be verified:

- in gravure and in ink-jet printing it should should be possible for the same colour hexagon (defined by the colour values of its corners) a larger amount of colour hues as in autotypic printing.

2. Used evaluation method, or what does this mean "to get for the same colour hexagon a larger amount of colour hues as in autotypic printing"?

An easy answer to this question would be to measure gravure prints and offset prints with the same C-MC-M-YM-Y-YC-Hexagon. But this method is not possible because:

- It is very difficult to obtain gravure and offset inks with the same colour values for solid prints of C MC, M, YM, Y and YC; these difficulties are still greater with ink-jet.
- As a consequence of the light diffusion in substrate offset itself is not "completely" autotypic, especially with very fine screening.

The solution applied in this paper compares the amounts of hues of each printing method with the amounts of hues which would be possible for a "perfect" autotypic printing with the same C-MC-M-YM-Y-YC-hexagon. Actually, rather than a "perfect" autotypic printing would be a "reference" autotypic printing. The amounts of hues for the reference autotypic printing with the same C-MC-M-YM-Y-YC-hexagon would be computed by using the well known Neugebauer equations.

As an example: in a hypothetical comparison of the enlargement of the amount of colour hues between a given offset version and a given gravure version with slight different colours for C MC, M, YM, Y and YC. The measurements and computations show:

- For the offset version are 5% more color hues possible than for its own reference autotypic printing
- For gravure printing are 25% more color hues possible than for its own reference autotypic printing.

In such a case the gravure screenig would make possible to print 20% more colour hues than the dot-area-variable offset screening.

3. The result of measurements on gravure and ink-jet prints

3.1 Measurements on gravure prints

The measurements were done on prints from modern publication gravure presses, using electromechanical engraved cylinders with:

100 l/ cm - "Normal cell shape" (cup 4) for blaK
70 l/ gm - "Enlarged cell shape" (cup 2) for Magenta
70 l/cm - "Shortened cell shape" (cup 0) for Cyan
58 l/cm - "Normal cell shape" (cup 3) for Yellow

The measurements were done with a "GRETAG SPM100-II" spectrophotometer with digital data transfer to a "WINDOWS"- computer. The evaluation of the measurements was programmed and done under "Microsoft-EXEL" (standard Microsoft office software).

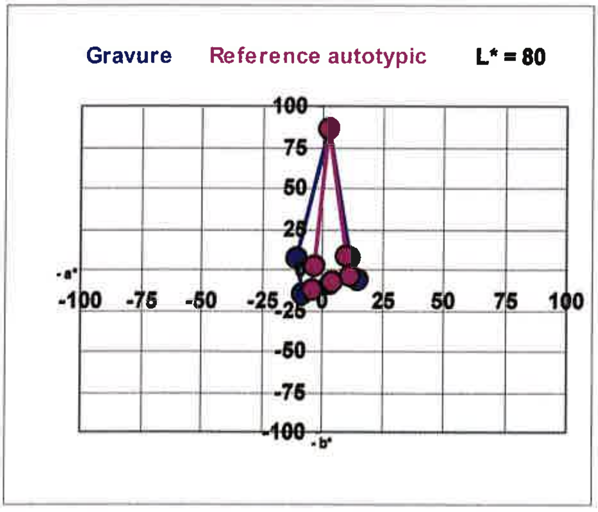

Figure 5

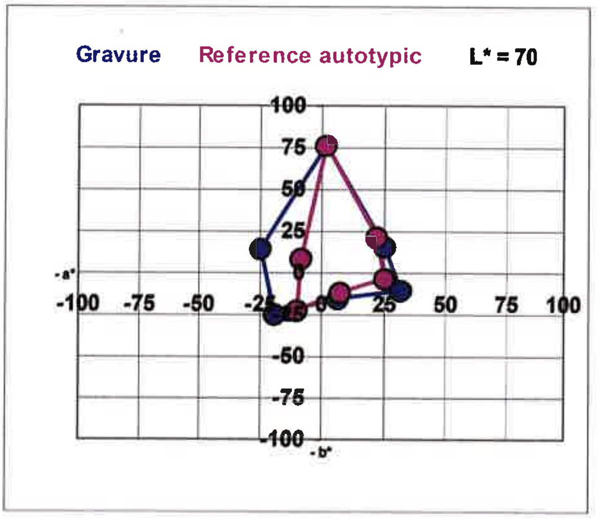

Figure 6

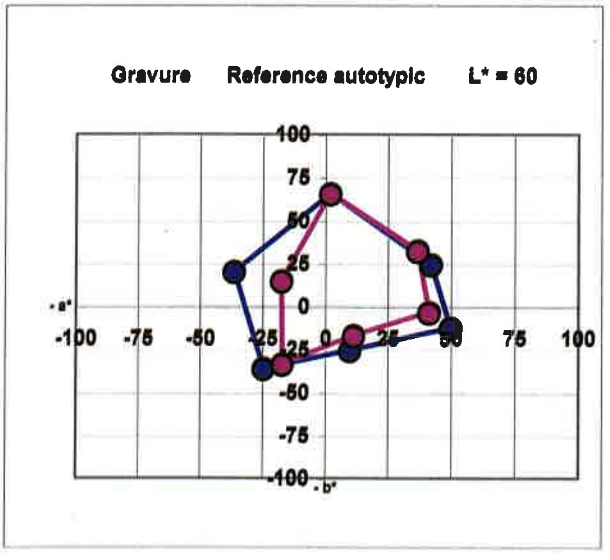

Figure 7

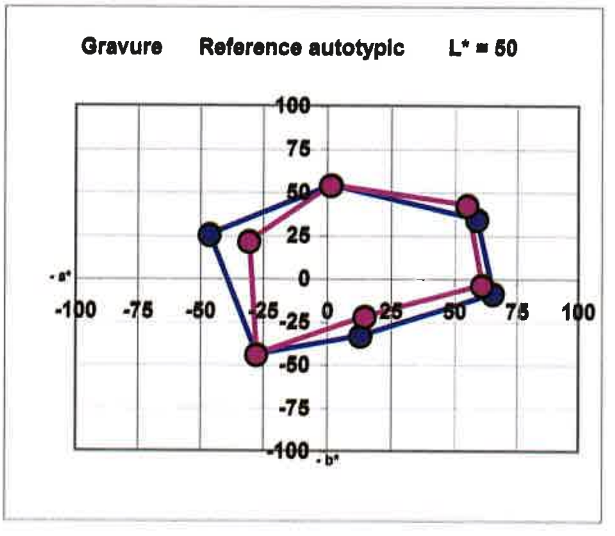

Figure 8

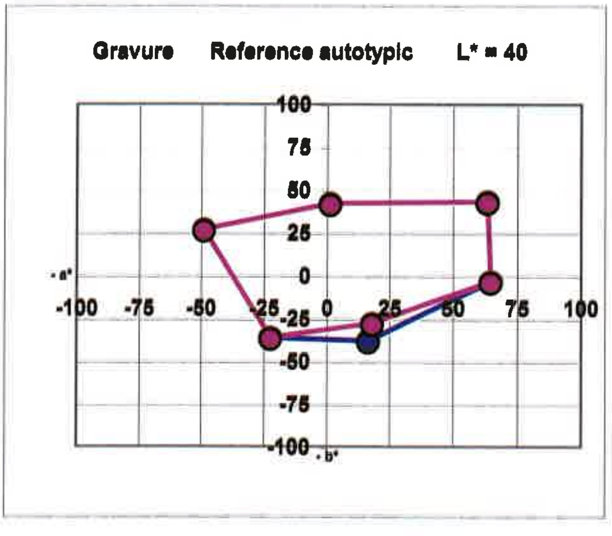

Figure 9

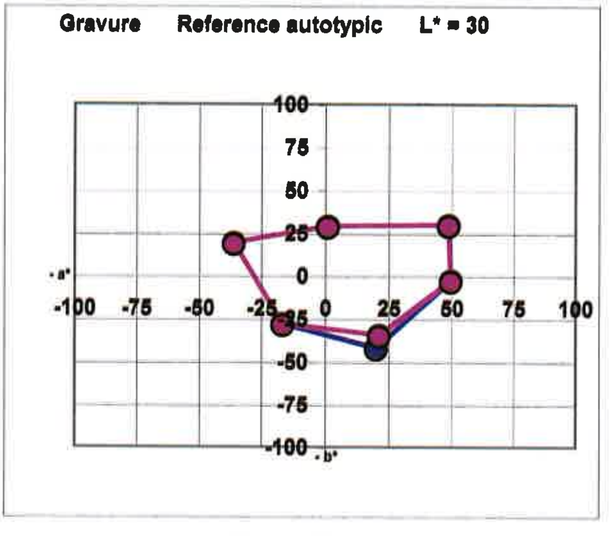

Figure 10

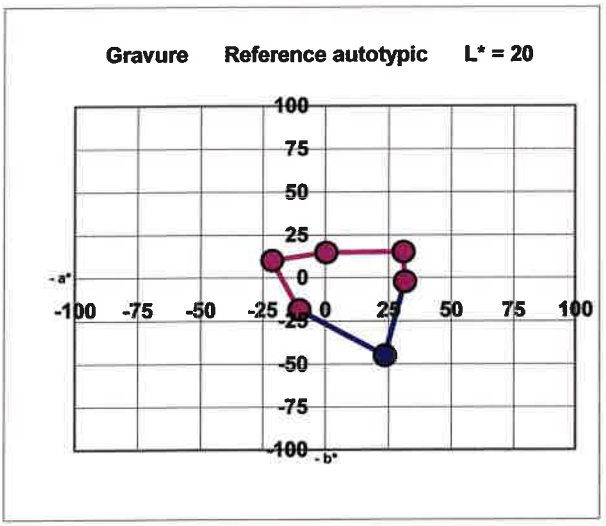

Figure 11

The following figures show as an example measurements done on prints on 70 gr/ m² SC - Paper. Each patch was measured on 12 different prints to compensate the sheet-to-sheet variations. Figure 5 to figure 11 show for different L* - Values the projection on a*b* of the hexagons of the printable colours for gravure and for the reference printing. The results correspond to:

- increasing tone values of C, MC, M, YM, Y and YC up to the maximal tone value in halftone printing, which correspond to the maximal chroma,
- then down for this maximal chroma tone with increasing tone value for K, up to the maximal tone value of K reaching the lowest printable L*, with a* and b* near to 0.

Figure 12 and figure 13 show the projection on L*a* for:
- increasing tone values of C and M up to the maximal tone value in halftone printing,
- then for this maximal tone with increasing tone value for black.

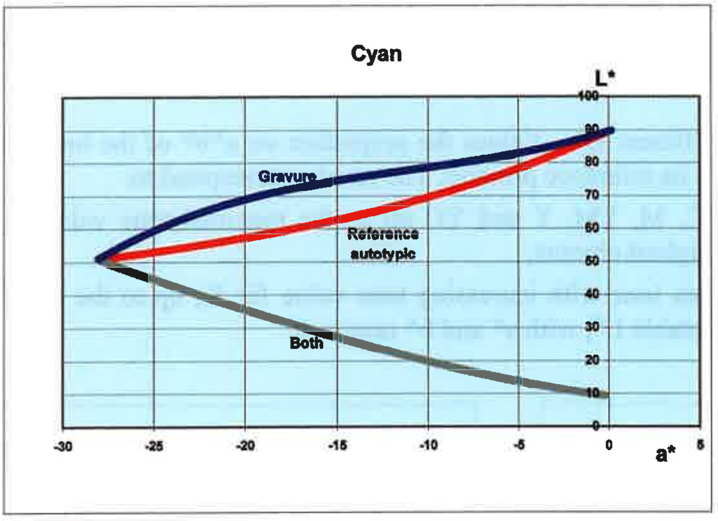

Figure 12

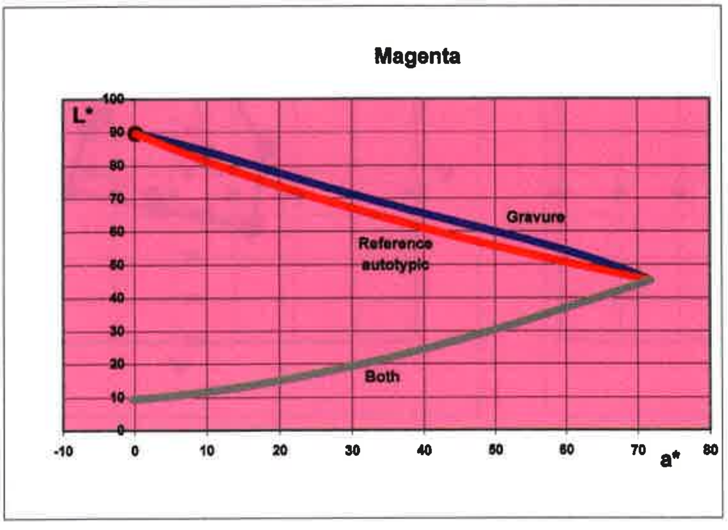

Figure 13

The comparison with its reference autoty pic printing, this means by using the Neugebauer equations with the same values for the corners of the C, MC, M, YM, Y and YC - hexagon shows for the gravure screening a volume in the L*a*b* about 26,4% larger than for the reference autotypic printing.

3.2 Measurements on ink-jet prints

These measurements were done on prints from a Creo/Scitex IRIS2Print continous ink-jet printer, designed to simulate conventional printing such as offset or gravure; this means designed for proofing. This high-end ink-jet printer is especially suitable for our research work on enlargement of the amout of printable hues because:

- It is easy to get every tone value for C-, M-, Y- and K- inks of the ink-jet printer. The C-, M-, Y- and K- channels of most ink-jet printers produce combinations of the inks on the substrate, which fit approximately the colour of offset inks.

- As a high-end printer for proofing it is designed (the design includes the inks and the substrate) to reach a large volume in the colour space.

- As a high-end printer for proofing it also has a high resolution, about 600 dpi.

- The Creo/Scitex IRIS2Print printed using the dot screen algorithm “GMG ColorProof Version 4” at 12 ppm (pixel per millimeter) and an anti-aliasing box-filter at a quality of 4 in a range between 2 and 8. The prints were done on the semi-matte “creo IrisPRO” Substrate with the “creo Iris Professional” C-M-Y-K inks.

Figure 14 to figure 21 show for different L* - Values the projection on a*b* of the hexagons of the printable colours for ink-jet and for its reference printing. The results correspond to:

- increasing tone values of C, MC, M, YM, Y and YC up to the maximal tone value in halftone printing, which correspond to the highest chroma,

- then down for this highest chroma tone with increasing tone value for K, up to the maximal tone value of K, reaching the lowest printable L*, with a* and b* near to 0.

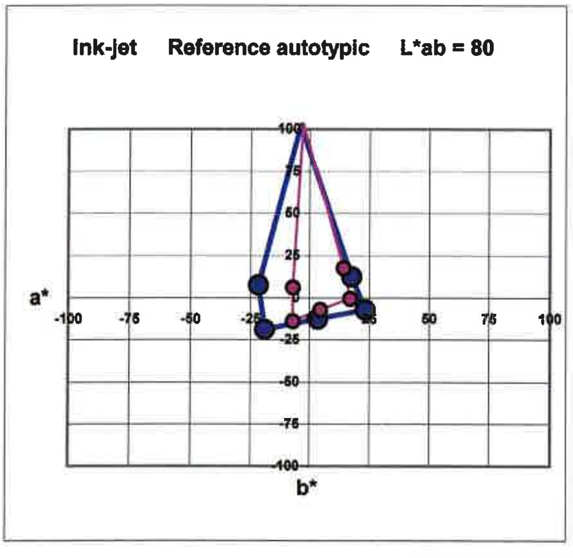

Figure 14

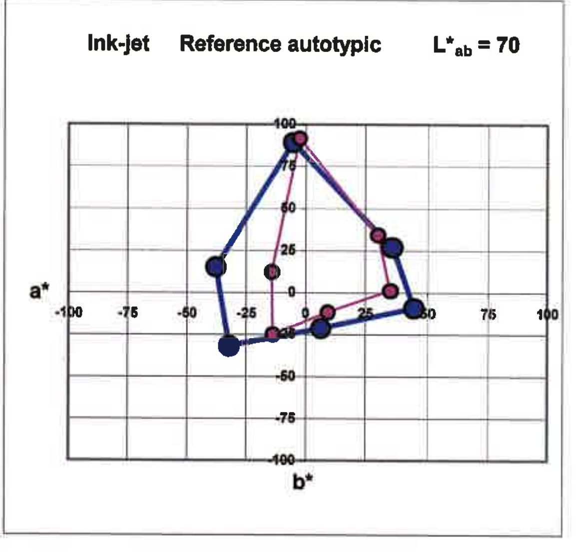

Figure 15

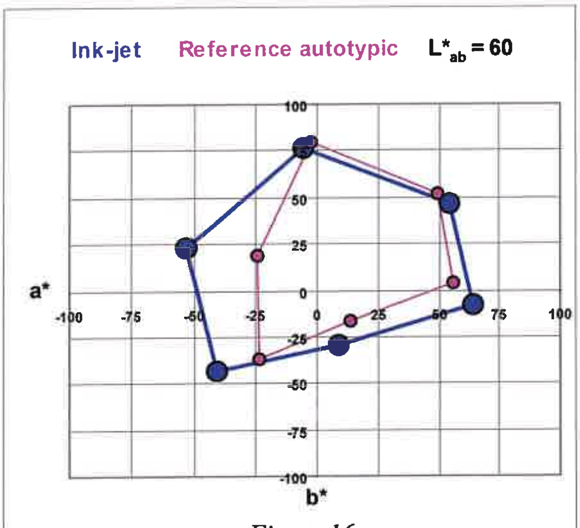

Figure 16

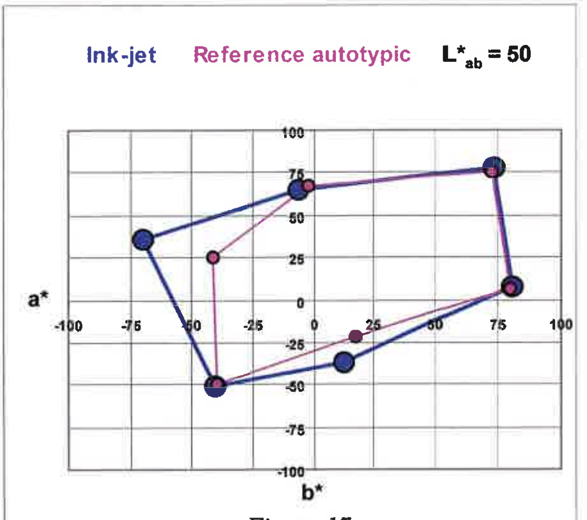

Figure 17

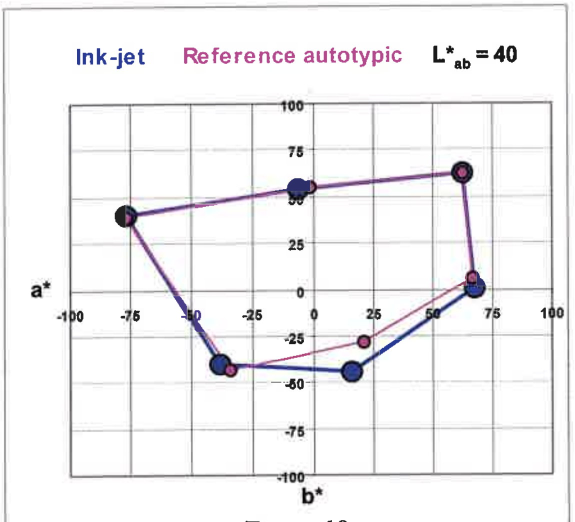

Figure 18

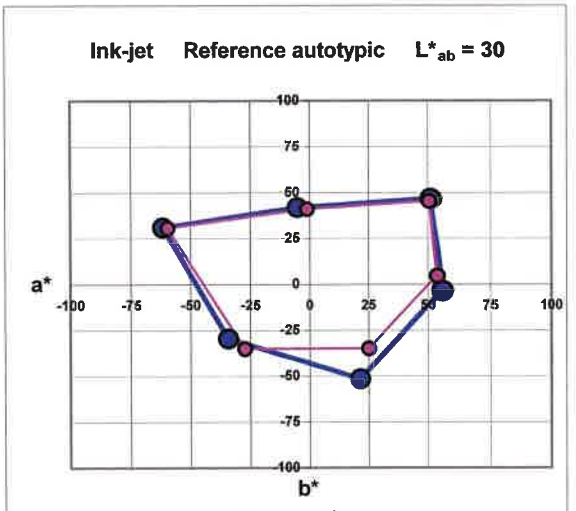

Figure 19

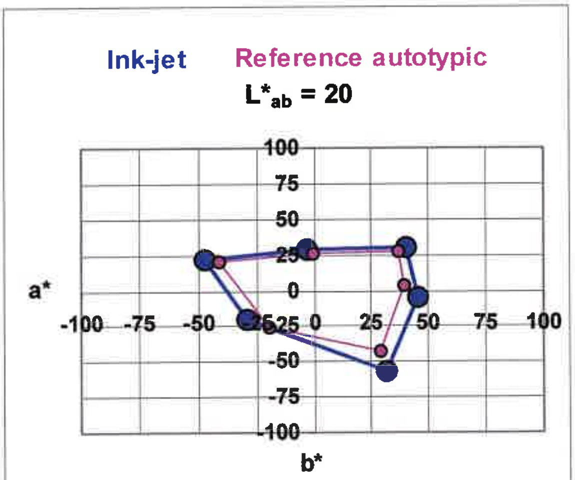

Figure 20

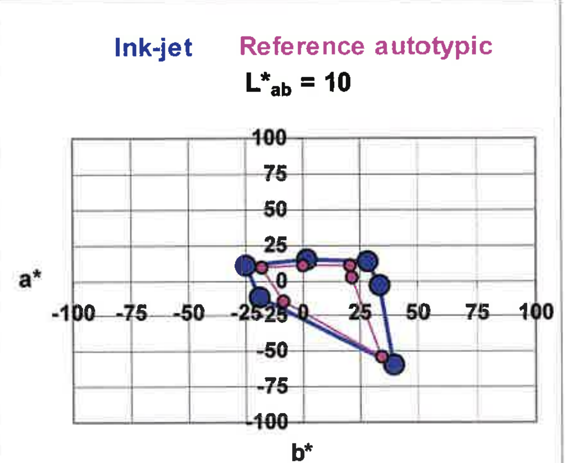

Figure 21

Figure 22 shows the diagramm L*C* for:
- increasing tone values of C up to the maximal tone value in halftone printing,
- then for this maximal tone with increasing tone value for black.

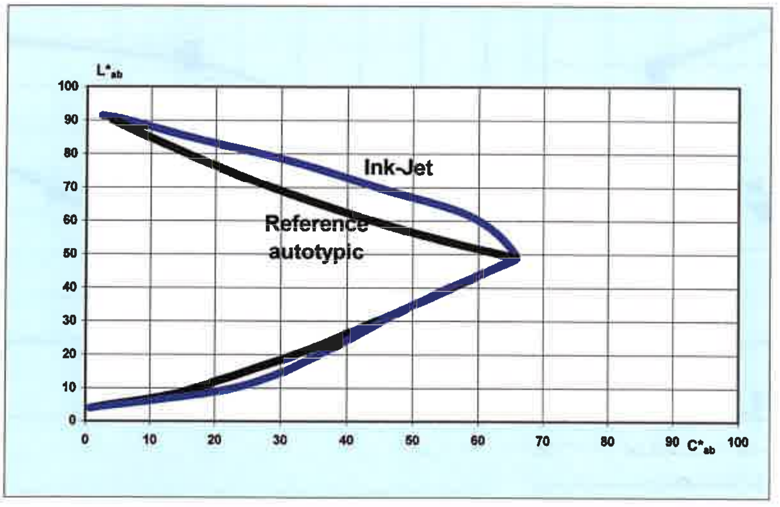

Figure 22

The comparison with its reference autotipic printing, this means by using the Neugebauer equations with the same values for the corners of the C, MC, M, YM, Y and YC - hexagon shows for high quality ink-jet printing a volume in the L*a*b* about 32% larger than for its reference autotypic printing.

3.3 Measurements on offset prints

These measurements were done only to compare the results for gravure and ink-jet with the results for offset. Actually, as said in the introduction, Paul and Brune [PB, 1997] as well as Naito, Lee and Kinoshita [NLK, 2004] have studied the effect of light diffusion in offset prints. But for a comparison it is advantageous to use exactly the same procedure and measurement equipment as with gravure and ink-jet.

The measurements were done on prints from modern sheet offset press, using CTP- positive "Fuji" photopolymer plates for violett laser. Screens: AM-60 l/ cm and FM based on 21 μ dots. The prints were done on a 135 g/ m² high gloss coated paper ("Zanders ikono new gloss"- Paper) with scale inks following the german standard described at the "MedienStandard 2004"- handbook [BD, 2004]; the paper belongs to the class 1 of this german standard.

As comparable measurements were published [PB, 1997] [NLK, 2004] now we give only a summary of the results: he comparison with its reference autotypic printing, this means by using the Neugebauer equations with the same values for the corners of the C, MC, M, YM, Y and YC - hexagon shows:

- for the AM-Offset a volume in the L*a*b* about 4,9% larger than its reference autotypic printing.
- for the FM-Offset a volume in the L*a*b* about 7.3% larger than its reference autotypic printing.

3.4 Summary of the results

It is interesting to compare the enlargement of the amount of colour hues between offset and gravure with slight different colours for C MC, M, YM, Y and YC for the commercially used screening. For offset the commercially used screening is today the 60 l/ cm screen, for gravure the electromechanical screening described in item 3. 1.

By using the method described in item 2. (what does this mean "to get for the same colour hexagon a larger amount of colour hues as in autotypic printing"?), the measurements and computations for gravure printing show a 21,5% larger amount of hues than offset. A comparison with ink-jet makes no sense because the corners of the hexagon show too different colour values. More research work to this effects in ink-jet printing seems necessary, testing another ink-jet equipment.

4. Comment of the results, proposal for further researches

As shown before, the interaction light and print for gravure and ink-jet screening has some interesting consequences:

- Some process control methods which assume as a continuous the distribution of the pigments on the substrate lead to good results, the colour deviations are of about 2,5 ΔE units or lower.
- In the halftone overprinting of two or three inks the remission can be computed by means of an easy multiplication of the transparencies of each of the halftone printed inks; the error is of about 4 ΔE units or lower. This model is usefull for proofing or for print simulations.
- Less "unwanted" light absorption. The result is a larger volume for the printable colours in the L*a*b*- space for a given hexagon defined by the values of C, MC, M, YM, Y and YC.

Specially the last one is relevant: commercial gravure prints may have a larger amount of colour hues (about 20-25% more) without needing unusual pigments or extremely fine screens.

This effects show that for every tone values, including the lowest ones, with an increase of the ink amount on the substrate the light remission goes down exponentially in the whole visible spectrum. Surely, such a behaviour of gravure prints can only be explained as a consequence of the diffusion of light in the substrate, combined with variable ink film thickness on the dots. But it may be very usefull and better to know for further developments how the diffusion of light in the substrate, combined with variable ink film thickness on the dots leads to this behaviour.

One way is to study the mechanisms of these effects by means of computer simulation. The paths of photons in the substrate could be simulated by using a Monte Carlo computing method for the scattering of photons. For a first trial the assumption would be enough that light underlies only absorption in the gravure screen dots. It is relevant for the simulation for gravure printing: when the tone values increase, the dot area and the ink film thickness will increase as well, up to the overflowing. After the overflowing there is a continuous ink film whose thickness increases with the tone value.

Literature

In this text are included information from literature, which can be found in the following list, and the results of new R & D work done in our group. In this research work have participated: Mr. A. Aziz, Mr. M. Fahoume, Mr. E. Hentschell, Mr. H. Mantler, Mrs. M. Marzahn, Mrs. K. Nahrgang, and Mr. S. Paus and also the both persons who present this article. This means that all these persons have participated in the work of this paper.

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Colour rendering of print samples at different illumination

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1. Introduction

In our research work we are studying influence of different lighting conditions on colour rendering of print samples using different indoor illuminants and daylight lighting induced by the switchable window. We know some CIE and ISO standards and recommendations regarding light conditions but in real life we see a lot of non-standard practical solutions based on insufficient financial sources, lack of knowledge or architectual proposals for energy sustainable building. In this paper we present the results of two research works.

First we studied illumination metamerism in different locations of a real printing house. Measurements of lighting conditions took place in prepress, facilities for mixing of inks, offset printing place, flexo printing place and reception room. Objective of this part of our work was to define the effect of illumination on appearance of colour, to evaluate colour differences ΔE^*_{ab} which appears between reference and sample and to define Colour Rendering Index (CRI) when illumination is changed. This paper also reports on how the variable transmittance of electrochromic switchable windows changes the colour rendering properties of the daylight passing through these windows. Chromogenic material used in switchable windows (eyewear, non-emissive displays ...) can change their optical properties between the fully transparent states through various degrees of coloration. Changes in Correlated Colour Temperature (CCT) and CRI are insufficient to describe the colour properties of this filtered light. We evaluate colour differences ΔE^*_{ab} on printed samples and strong distortion of colour appearance at higher coloration states of the windows.

2. Research methods

We began our investigation in advanced print house, specialised in high quality printed labels production. They use different print substrates, inks and print techniques and have very high requests on quality and standardisation of production process and their products. Preparation of the samples and all measurement took place in their building equipped with standard glass and indoor lighting with different light sources.

Measurements of switchable windows influence on colour changes are a continuation of projects, performed in past years at the University of Ljubljana and at the National Institute of Chemistry. For these measurements we used two types of electrochromic switchable windows, ink-jet printed colour samples, transmission densitometer and different spectrophotometers.

2.1 Investigation in the print house

For measurement of indoor illumination in the print house we used a spectrophotometer GretagMacbeth Eye-one. Results of illumination measurements on selected locations are shown in Table I. To evaluate the illumination metamerism a part of test chart IT8.7/3 (Figure 1) was printed on two colour offset machine on uncoated, woodless paper and defined as a reference (A). Simulation print out on ink-jet Epson Stylus 7000 PRO printer with default profile on selected paper was defined as a sample (B). All results of colour appearance measurements were compared with measurements under standard illumination D_{65}. Metamerism was quantified by Special Metamerism Index (SMI) based on CIELAB equation for colour differences (Table II). Correction factor was used to eliminate colour difference between reference and sample under the standard illumination (D_{65}).

A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13
A14	A15	A16	A17	A18	A19	A20	A21	A22	A23	A24	A25	A26
A27	A28	A29	A30	A31	A32	A33	A34	A35	A36	A37	A38	A39
A40	A41	A42	A43	A44	A45	A46	A47	A48	A49	A50		

Figure 1: Colour samples and codes (A for offset print sample)

2.2 Investigation of switchable windows

Two types of electrochromic switchable windows (Figure 2) were applied in this study, one commercial available and one from our lab. The transmittance spectra were measured with HP 8453 spectrophotometer (Figure 3).

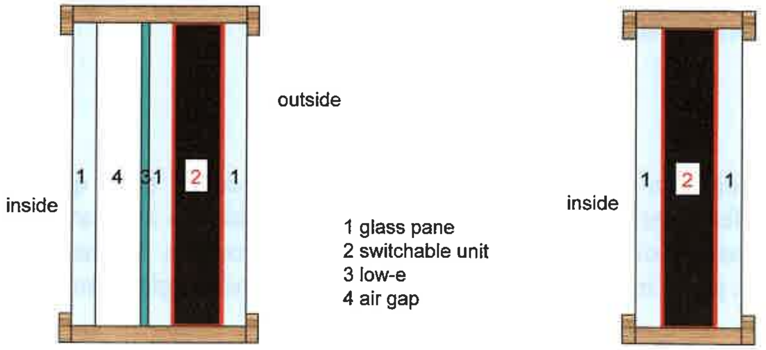

Figure 2: Shematic presentation of the electrochomic switchable window with thermal isolation and low - emittance layer (a) and basic switchable window used for our investigation (b)

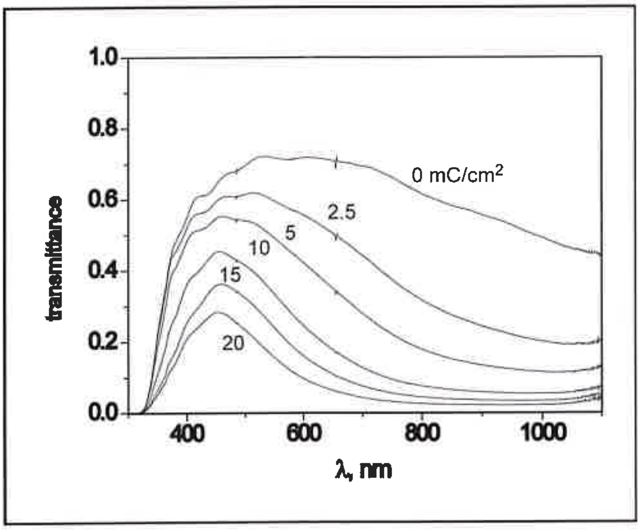

Figure 3: Transmittance spectra of the electrochromic switchable window in its bleached, colored and some intermediate states. The amount of the charge intercalated into WO_3 layer in millicoloumbs per square centimeters (mC/cm^2) is given

A set of ink-jet print samples (Figure 4) were chosen according to CIE recommendations. For measurement of colour rendering at variable transmittance of switchable windows a black box with different light sources (halogen, xenon and bluish filtered xenon lamps) outside of one hole for switchable window and second hole for Photo Research PR-650 spectrophotometer was built (Figure 5). White standard was used for calibration.

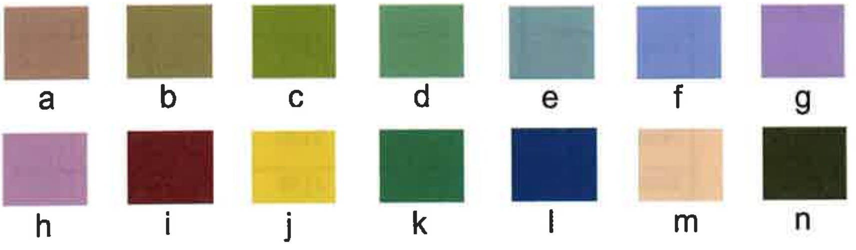

Figure 4: Sample colours according to CIE recommendations

First the theoretical differences in colour rendering, based on measured spectral power distribution (SPD) expressed as luminous transmittance (T_{vis}), CCT and CRI were calculated applying the CIE procedure (Figure 6). Measurements of colour rendering in a black box are necessary to confirm calculated colour differences. Results of measurement with halogen lamp are given in Figure 7.

Figure 5: Spectral measurement of colour samples using halogen lamp, switchable window and Photo Research PR-650 spectrophotometer

3. Experimental results

Table I: Correlated Colour Temperature (CCT), Illuminance and approximate CIE Illuminants on selected places in print house

Position	Time	CCT (k)	Illuminance (lux)	CIE Illuminant
Prepress 1	Morning	4380	228	F2
	Noon	4560	223	B
	Evening	4467	210	F2
Prepress 2	Morning	4097	143	F9
	Noon	4381	140	F2
	Evening	4180	123	F6
Prepress 3	Morning	4440	247	F2
	Noon	4654	253	B
	Evening	4517	211	F2
Position	Time	CCT (k)	Illuminance (lux)	CIE Illuminant
Colour mixing	Morning	4875	874	B
	Noon	5081	892	D_{50}
	Evening	5009	884	D_{50}
Offset printing	Morning	5619	2145	D_{55}
	Noon	5554	2177	D_{55}
	Evening	5638	2352	D_{55}
Gallus flexo printing	Morning	4974	2868	F8
	Noon	4962	3149	F8
	Evening	5172	1139	B
Reception room 1	Morning	2731	496	A
	Noon	2830	550	A
	Evening	2709	474	A
Reception room 2	Morning	2813	354	A
	Noon	3110	416	F12
	Evening	2769	311	A

4. Discussion

As we expected there were substantial differences in results of measurements in the print house and illuminant metamerism effect was anticipated. Calculations show that SMI and CRI compared to D_{65} are worse at illumination A (reception room) and F2 (prepress). Based on this it could be assumed that two samples which match under daylight would have different appearance if they would be observed under standardized illumination A. It could also be expected that there would be no bigger difference between reference and sample when illumination is changed from D_{65} to D_{50} (mixing of inks), D_{55} (offset) and F8 (flexo) because of their high average. SMI was worse at green and blue colours in most cases.

Table II: Special metamerism index (SMI) for 50 colour samples, standard illuminant D_{65} and illuminants F2, D_{50}, D_{55}, F8 and A (B for ink-jet print sample)

Colour sample	SMI				
	F2	D50	D55	F8	A
B1	2.004359	0.901188	0.64101	1.323188	0.526406
B2	1.747977	0.584517	0.920934	1.153238	0.559754
B3	1.331571	0.68103	0.533122	0.786839	43.94384
B4	1.992464	0.662901	0.703195	0.73103	0.719949
B5	1.115038	0.829799	0.848081	0.960881	1.617425
B6	1.423967	0.823477	0.894822	0.891121	1.153396
B7	1.705768	0.301228	0.211199	0.376979	1.234443
B8	1.995274	0.263203	0.538116	0.532252	1.478989
B9	2.558233	0.790795	0.553806	1.260473	3.808618
B10	1.833191	0.658715	0.089489	0.450719	1.099516
B11	1.859471	0.574675	0.160829	0.73174	2.38864
B12	1.769918	0.875156	0.39589	1.26931	2.915977
B13	1.373733	0.336875	0.231435	0.620847	0.946657
B14	1.79776	0.411477	0.818501	1.445093	1.070154
B15	2.373891	0.822282	0.323616	0.762184	1.965043
B16	1.674573	1.103676	0.86946	0.828525	2.482834
B17	1.613488	0.799676	1.011337	1.292642	1.274144
Colour sample	SMI				
	F2	D50	D55	F8	A
B18	1.431674	1.094662	0.922373	0.980775	2.526389
B19	0.726433	1.0269	1.424954	1.506829	3.055221
B20	1.381002	1.077671	1.172675	0.933392	2.272821
B21	2.898439	0.683055	0.704625	0.671538	2.561288
B22	1.655801	0.333623	0.328846	0.204665	0.915556
B23	2.260162	0.38756	0.176092	0.734671	1.637472
B24	1.612196	0.296079	0.210612	0.464819	0.263772
B25	1.881322	0.790405	0.387972	1.15999	2.601925
B26	1.850342	0.383725	0.336338	0.527529	1.652725
B27	2.273389	0.349698	0.682593	1.000316	0.736324
B28	2.142646	0.284488	0.420571	0.41374	1.549615
B29	1.983242	0.576904	0.116668	0.47864	1.383063
B30	2.701037	0.553287	1.15624	1.465632	0.633638
B31	1.804509	0.934026	0.754583	0.692923	2.328674
B32	2.017419	0.463075	0.729225	0.943055	1.259153
B33	1.43808	0.587459	0.822476	0.607877	1.797967

B34	0.85584	0.927454	1.025418	0.908342	1.700083
B35	1.023205	0.237883	0.232933	0.254641	0.711135
B36	2.796963	0.459967	0.392564	0.773465	2.066688
B37	1.729074	0.322724	0.244499	0.325264	1.306324
B38	1.197146	0.413485	0.377397	0.127041	1.118927
B39	1.937229	0.361239	0.285909	0.605262	1.767831
B40	0.991891	0.55762	0.390086	0.337041	0.653208
B41	1.741927	0.417031	0.563195	0.515605	1.068451
B42	0.780617	0.539641	0.42657	0.589547	2.491972
B43	1.502511	0.747018	0.561962	0.42388	2.698064
B44	0.841581	0.300725	0.126697	0.237059	0.470016
B45	1.932523	0.611236	0.382207	0.478433	1.4144
B46	1.209124	0.509988	0.102042	0.423718	1.615357
B47	0.730907	0.209776	0.891599	0.56243	0.440339
B48	1.046721	0.529443	0.325434	1.007054	1.100726
B49	4.197705	2.821767	2.14115	2.967984	5.115774
B50	1.898737	1.35043	1.781988	1.135126	1.585631
Average	1.732841	0.651214	0.606867	0.797507	2.473726

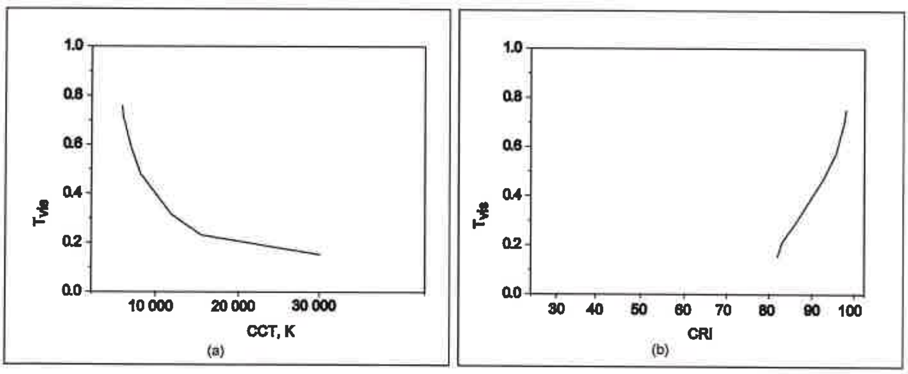

Figure 6: Calculated relations between T_{vis}, CCT (a) and T_{vis}, CRI (b) for electrochromic switchable window

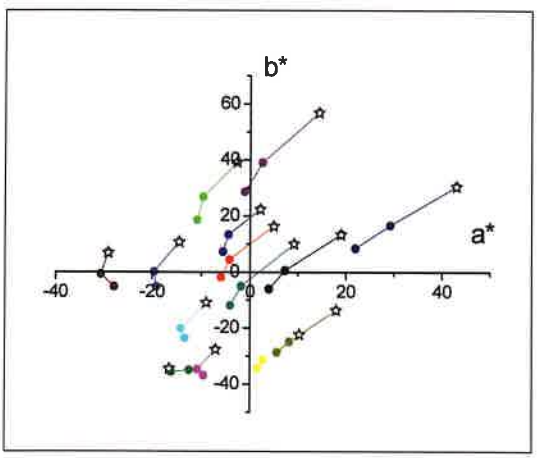

Figure 7:
Colour differences of 14 colour samples measured with halogen light source at three stages of electrochromic switchable window. Bleached stage is signed with star

Calculated differences of switchable window expressed as CRI cannot show how the object's colour is changing. The reflectance curves of colour samples were calculated and applied to define the objects. As the coloration of the device increases, the colour of each object moves along a path in the CIELAB space. A shift along the a* axis is greater than it is along the b* axis. All test samples with $b^* > 0$ change colour towards a smaller a* (they loose red hue). All colour samples with $b^* < 0$ change colour in the opposite direction i.e. towards a larger a* (increase in red hue). It could be expected that object appears dull when the switchable units are coloured. Indeed, the colour of some samples moves towards smaller L* and closer to the center of the (a*, b*) plane. For some colour samples the L* increases.

Measurements gave us similar results. Direction of colour changes is same as calculated in most cases. Reason for some differences is non-standard illumination with much lower CCT compared to theoretical calculations. Tests with xenon light source are not finished yet.

5. Conclusions

SMI and CRI are useful to find out properties of illumination in print house when conventional light sources are in use. It is important to achieve as close as possible standardised D_{50} illumination in all departments where colours are judged and compared. When non-conventional artificial light sources (e.g. LED) or coloured switchable windows for filtered daylight are used the calculation of SMI and CRI are not sufficient.

The colouring/bleaching process produces big differences in colour contrast. When viewed in such a light an array of colour objects changes their appearance. In these circumstances, the colour rendering becomes a very important problem for practice and in use. When using only colours that are shifted in the same direction in the colour space the effect is most likely compensated by physiological mechanisms, while this might not be the case for the colours shifting in different directions. At present, this complex problem has not been taken up in any kind of vision and colour research, known to the authors.

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Test charts and photometric tolerances for colour reliable image acquisition

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Abstract

Based on the research project named "Photometric tolerances for reliable colour image acquisition for digital studio photography" this article investigates the two main research goals. On the one hand individual test targets were compiled and utilised in order to improve the colour acquisition accuracy of digital studio cameras. On the other hand photometric tolerances were set up to indicate a pertinent deviation from the original lighting situation in order to warn the user when new profiling is necessary. Among several mathematical models for reconstructing tristimulus values out of the camera response the MPR-method (multi polynomial regression) can obtain the highest accuracy to evaluate the individual test targets. In addition to a popular test chart approximately 30 test targets comprising ceramics, textiles, wood, plastics and artwork were created and evaluated. It turned out that for almost all test charts the colorimetrical error could be minimized by 10 to 30%. For pastel colours the error was halved. Based on a reference lighting setting 14 deficient lightings were utilised in order to analyse the resultant colorimetrical error. It was found that allocating the chromaticity coordinates of the deficient lightings in a blue-red, a yellow-green and a green-blue region would yield in an almost linear correlation between the correlated colour temperature and the resultant colorimetrical error. Hence photometric tolerances were derived to easily indicate to the user the inevitable colorimetrical error connected with a colour drift when a new profile is required.

1. Introduction

ICC colour management has undergone a tremendous progress in the graphic art industry. Hence high quality digital studio photography plays a very important role to create digital images with adequate colorimetric accuracy for achieving and printing. For high quality reproduction nowadays every picture has to be modified in a cumbersome and time-consuming way because of inadequacies in the acquisition chain. Furthermore traditional colorimetric imaging is subject to the metameric problem (Berns, 2001). Without spectral capturing devices there is the need to optimise the interaction of test target selection, lighting and data handling.

In digital photography there are only a few test charts used very frequently like the Gretag Macbeth "ColorChecker" or the Color Solutions "DCAM target". Meanwhile the semi gloss version "Color Checker SG" is very promising due to the handy number of colour patches and an easy way to illuminate it free of gloss. Nevertheless there are a variety of objects to be photographed in a catalogue production like leather, various types of textiles, wood, fruits, ceramics, décor tiles and accessories. Therefore one test chart depicts always a compromise and cannot comprise all the colorants used in the specific scenery. Hence this article investigates the benefit using an additional test target tailored to the specific scenery.

A very important point to consider in high quality digital studio photography is the taking illuminant. Here the spectral composition of the light source as well as the constancy of the photometric parameters play a very important role. While it's mandatory in the graphic art industry to use D50 standard illumination (ISO 3664, 2000) the constancy will be considered in detail. Because of several reasons like degasification, aging or decomposition of the electrodes both scan lights and flashlights change their photometric and colorimetric properties over the time. The photographer therefore needs to know the degree of deviation between the reference setting, where calibration and profiling are based on, and the setting in the actual photo session.

2. Reconstructing tristimulus values

Evaluating individual test targets in an ICC colour management environment necessitates mathematical models for computing tristimulus values based on the camera response because typical software solutions concentrate on a few standard test charts. The following methods were scrutinised: the Wiener Inverse, the PCA (principal component analysis), the Pseudoinverse and the MPR (multi polynomial regression). Mathematical details can be found in Koenig (Koenig, 2001). The MPR-method can obtain the highest accuracy and will be used to evaluate the individual test targets. Eq. (1) shows the used polynom.

$$X = k1*R + k2*G + k3*B + (k10*R*R + k11*G*G + k12*B*B)/(R+G+B) \quad (1)$$

The Tristimulus values Y and Z are computed in the same fashion. The MPR method comes close to or even surpasses state of the art ICC profiling packages regarding the colorimetric reconstruction accuracy. It is noteworthy to mention that smoothness, which is a very important quality criterion too, was no accounted in this evaluation. Table I shows the colorimetric accuracy of the above-mentioned methods while reconstructing the "DCAM target" and the "ColorChecker24" test target.

Table I: Average colour difference for different mathematical methods

Targets		DCAM Profil	MPR linear	MPR non. lin.	Minimum Knowledge	Smooth Inverse	Wiener Inverse	Eigenvector Method
„DCAM-Target“	ΔE^*_{ab}	5.4	7.8	7.8	24.4	17.4	17.4	19.9
	ΔE^*_{94}	2.7	4.0	4	21.8	12.3	10.7	10.7
	ΔE^*_{00}	2.6	4.0	2.3	18.5	10.7	9.5	9.5
"ColorChecker24"	ΔE^*_{ab}	8.8	5.4	3.9	20.5	12.2	11.4	12.7
	ΔE^*_{94}	6.6	3.7	2.6	18.5	9.5	9.2	9.8
	ΔE^*_{00}	6.0	3.7	2.7	15.4	8.7	8.5	8.9

3. Individual test charts

In digital photography the most evident reason for not using well-known test charts like the IT8.7/1 (ISO 12641, 1998) for scanner profiling is the variety of different types of objects to be photographed. While flatbed or drum scanners mostly scan photographs or transparencies, which are limited in colorants used for imaging, digital photography is faced with a plethora of different lights and objects. A checkerboard array of colour samples should therefore represent the objects of interest. Here the spectral reflectance factor is of particular importance rather the tristimulus value. There is a range of further requirements for creating a test chart, which are sometimes contrary. On the one hand a glossy arrangement of colour samples would yield in a high colour gamut but on the other hand it is very difficult to illuminate such a target without glare. Useful criteria comprise the following: no fluorescence, homogeneous distribution of grey patches, "spectrally flat" greys, flat and stable composition, equally spaced in a perceptual uniform colour space, contain memory colours. The Figure 1 illustrates the effect of uneven reflectance factors and the resultant colour inconstancy.

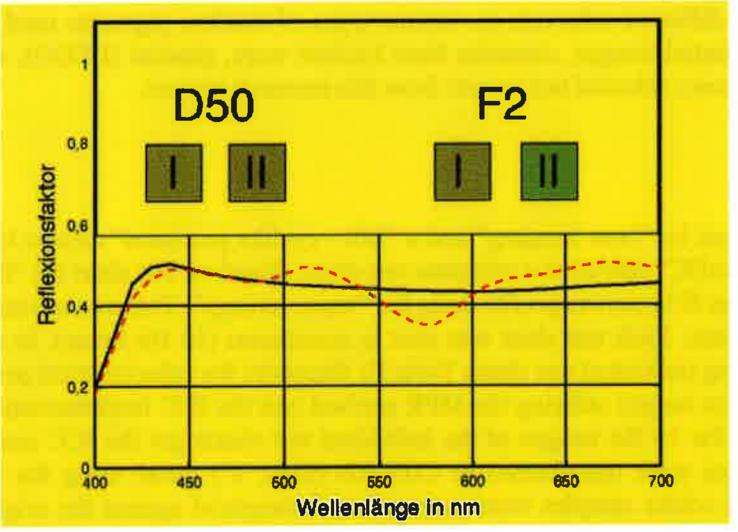

Figure 1 Different grey targets under daylight (D50) and office lighting (F2)

4. Classification in categories

Due to the trade off between complexity and manageability when creating individual colour test charts it is fundamental to classify the objects of interest. In this connection there are many possible ways to arrange the important types of objects into reasonable groups. In this study all types objects were grouped by their carrier (substrate), which is illustrated in Table II.

Table II: Classification of the individual test targets

Class	Examples
Wood	natural veneer, artifical
Chemical fibre	polyester (PES)
	polyamid (PA)
	polyacryl (PAN)
Natural fibre	cotton (W)
	linen (L)
Plastics	polyethylene (paperbags) polystyrene (packages) polyurethane (soles) silicone
Ceramics	sanitary decorative (kitchen, porcelain)
Artwork	historical pigments and dyes

Thus samples for each of the established groups were collected whereupon a stable non-fluorescent board provided a backing for any of the 30 test targets including approximately 2500 colour patches.

Samples comprising different colorants on various types of textiles, pigments used in fine art (gouache, acryl, pastel), self painted images, ceramics from kitchen ware, plastics (LEGO), wood from the do-it-yourself-store, etc. shows selected test targets from this research project.

Experiment

A flash light equipment by "bron imaging" and a "M6 - eyelike precision" camera by Jenoptik were used and the "ColorCheckerDC" served as a reference test chart. Based on this chart the "ProfileMaker" version 5 was used to create an ICC camera profile using the "repro settings". This was necessary to make sure that no alteration takes place. Each test chart was shot in succession (16 Bit linear). In order to visualize the benefit of incorporating individual test charts Table III illustrates the colorimetrical performance of both the usage of individual test targets utilizing the MPR method and the ICC implementation. In the case of the ICC implementation the 16 Bit images of the individual test charts got the ICC camera profile assigned. Afterwards the images were transformed to CIELAB (D50, 2°) mode using the absolute colorimetric transform. Finally all colour samples were averaged and compared against the original CIELAB values. Beside the classic CIELAB colour difference formulae the statistical analysis was further complemented by adding the CIEDE2000 and the ΔH colour difference metrics.

Table III: Colorimetrical accuracy of ICC profiling with and without an additional test chart

Test target	Profiling with „ColorCheckerDC"					Profiling with MPR in addition to the pertinent colour chart				
	ΔE^*_{ab} mean	ΔE^*_{00} mean	ΔH^*_{ab} mean	ΔH^*_{ab} max	ΔH^*_{ab} stddev	ΔE^*_{ab} mean	ΔE^*_{00} mean	ΔH^*_{ab} mean	ΔH^*_{ab} max	ΔH^*_{ab} stddev
5	4.8	2.8	2.9	10.1	2.8	3.5	2.1	2.3	6.9	2
9	10.4	3.9	4.6	14.9	4.1	4.1	2.8	2.7	7.8	1.9
10	8	3.3	3.7	7.9	2.7	7.4	2.5	2.1	5.8	1.4
14	5	2.4	2.2	6.5	1.7	5.3	2.7	1.4	5.4	1.4
23	5.8	2.8	2.9	25	3.5	4.8	2.2	2.3	8.6	1.8
27	4.6	2.3	2.7	8.3	2	4.2	1.9	1.6	4.8	1.1
28	3.5	1.3	0.5	0.7	0.2	2.7	1.4	0.5	1.2	1.4
32	5.9	4.4	1.6	5.4	1.2	5.8	4	1.5	8	1.7

The statistical analysis in Table reveals for some chosen colour targets that the incorporation of the extra test chart outperforms the standard ICC implementation in almost every case. The results ranges from minor improvements to a significant decrease of the colorimetrical error, especially in pastel tones.

5. Photometric tolerances

A very important point to consider in high quality digital studio photography is the taking illuminant. In theory the taking illuminant should be identical to the illuminant used for later viewing but this is often practically not possible. While in the graphic art industry D50 standard illumination is mandatory (ISO 3664, 2000) for viewing and evaluating prints the taking illuminant should spectrally resemble D50. This could be controlled by first measuring the radiant flux and secondly compute indices of metamerism. Beside the spectral composition of the light source the constancy of the photometric parameter will be considered in this study. Because of several reasons like degasification, aging or decomposition of the electrodes both scan lights and flashlights change their photometric and colorimetric properties over time. The photographer therefore needs to know the degree of deviation between the reference setting, whereupon the calibration and profiling was based on, and the setting in the actual photo session. For this reason broadband filter foils were utilised in order to modify the reference illumination towards equally distributed deviations in the CIE xy chromaticity diagram.

These so-called "deficient lightings" as well as a partition into three pertinent colour regions (blue-red, yellow-green, green-blue) are illustrated in Figure 2.

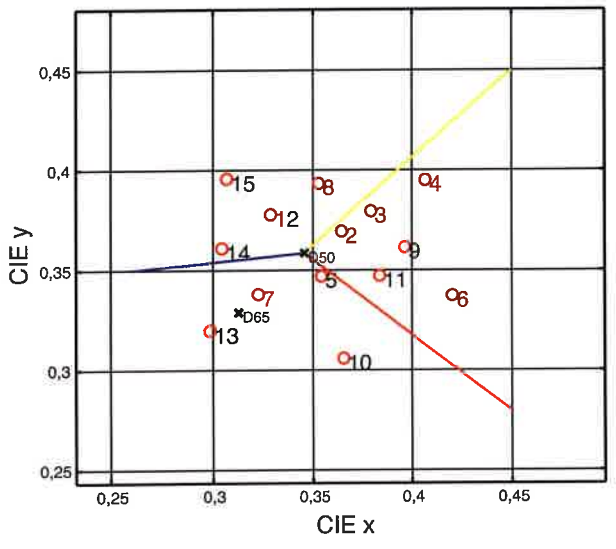

Figure 2:
Chromaticity coordinates of the 14 deficient lighting conditions

Experiment

All test charts were captured under the reference light and the 14 deficient lighting conditions. Because of different absorption properties of the filters it was necessary to alter either the lighting intensity or the exposure setting in the camera in order to achieve reasonable utilisation of the dynamic range. Therefore two methods were used.

Method I

The first method uses for each lighting setting a simple amplification for all RGB values. The amplification factor was derived by the decrease of the highest saturated channel. This procedure assures that at least one channel uses the full dynamic range. Using this method a colour shift will remain because the relative relations among the channels stay the same. This procedure reflects practical situations where throughout a photo session only the level of light will be considered.

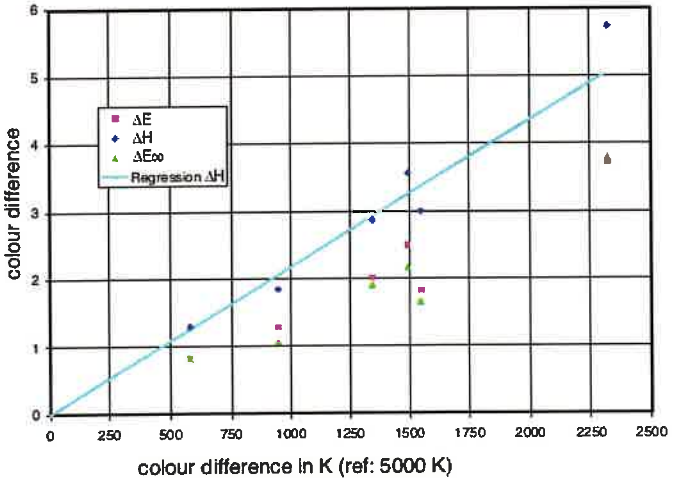

Figure 3:
Colour differences for lighting conditions in the red-yellow region (Method I)

Method II

The more practical second method accomplishes the colour shift by applying a histogram equalisation. Here the RGB channels are amplified individually based on their response of the reference white sample in the "ColorCheckerDC". This procedure resembles a white balancing that is frequently used in digital photography. Thus this method reflects the common way of white balancing each picture individually even if was shot in the same session.

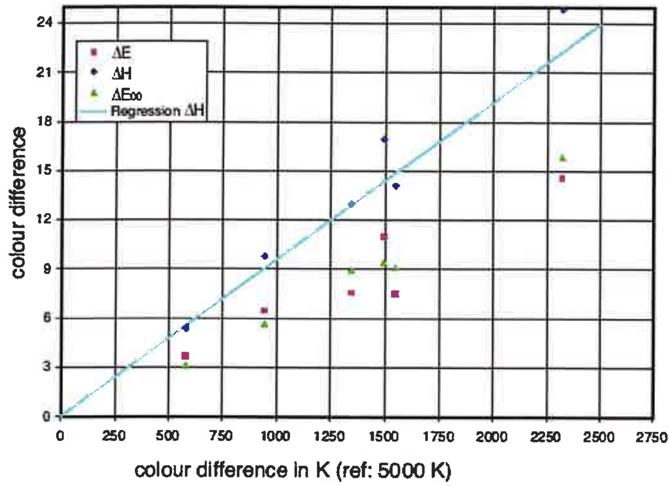

Figure 4:
Colour differences for lighting conditions in the red-yellow region (Method II)

The Figure 3 and Figure 3 illustrate the deviation relative to the reference lighting using the CCT (correlated colour temperature) and the resultant colorimetrical error for method II and I. Here the most evident thing to mention is the almost linear relationship between the easily accessible photometric unit CCT and the associated colorimetrical error using ΔH, ΔE^*_{ab} and ΔE^*_{00}. It is noteworthy that prior evaluations, conducted in this research project without sectorizing the colour shift of the deficient lighting, didn't reveal this simple relationship. Further it can be clearly seen that "method II" shows up smaller colorimetrical errors than "method I". This is due to the white balancing algorithm, which maps the camera response to the actual lighting setting. Based on the Figures 3 and 4 as well as the deviation statistics of practical offset print runs (Traber, 2001) representing a typical high quality printing condition the photometric tolerances in Table IV were put together.

Table IV: Colour difference regarding (Schlaepfer, 2002) and associated photometrical tolerances

Colour difference	Colour difference sensation	Red green region in K	Blue red region in K	Green blue region in K
≤1	very small	100	150	150
>1 to 3	small	300	500	450
> 3 to 6	normal	600	1000	850
> 6	large	> 600	> 1000	> 850

6. Conclusion

This work considers the usage of additional object specific test targets that were compiled and utilised in order to improve the colour acquisition accuracy of digital studio capturing devices. Regarding the used classification (textiles, wood, artwork, plastics, etc.) no significant differences were found. In other words it could not been stated that the improvement by additional usage of test charts depends much on the groups established in this study. The author suspects that the spectral composition of the test samples and therefore the amount of camera metamerism are assumed to be the predominant reasons.

Furthermore photometric tolerances were set up to indicate a pertinent deviation from one original lighting situation in order to tell the user when new profiling is necessary. First a simple relationship between the CCT, stating the difference between the reference and the modified lighting, and the resultant colorimetrical error was investigated. It turned out that there is no such simple relationship. But it was found that allocating the chromaticity coordinates of the deficient lighting conditions in a blue-red, a yellow-green and a green-blue region would yield in an almost linear correlation between the CCT and the resultant colorimetrical error.

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Colour management of special plastic print media in practice of a printing company

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Abstract

Today, customers expect a more colourful appearance, not only from traditional printed matter, but also from specialized print media, like securities, excise tax stamps, plastic cards or card-format identification documents: personal ID cards, diving licenses, student ID cards etc., which are the main products of the State Printing Company. Customers insist on identical brand colours, in order to show consistency of quality. Consistency of identical colours on security documents is compulsory. The media used in manufacturing of these products is usually security paper or plastic. The colours of the original can undergo major changes during printing and preparing these materials. In order to provide a solution to this complex scope of problems, the company introduced the digital colour management system in 2000, mainly in order to make production of plastic cards a more economic activity, and to reduce impacts and loads on the environment.

This paper is dealing with the most important effects of this process and compares some of colour gamuts concerning plastic card production.

1. Introduction

Colour management is a matter of concern in printing ever since process colour printing has been introduced into practice. The first three-colour printing experiments were made using photo mechanically prepared printing forms in 1893 (Vogel-Albert). However the colour rendering quality of three and then four-colour printing had a lower level than of the former 6 or 8-colour chromolithographic and heliogravure technologies offered, and the situation remained the same for long time. Nevertheless, lower costs of the new printing processes ensured wider masses of people could afford to buy colour publications, and the increased demand provided resources for improvement from the very outset.

Development efforts aimed at an improved colour rendering within closed technological systems finally led to effectual results by the last third of the 20th century. The use of more and more advanced masking procedures in photomechanical colour-separation and that of analogous and then digital devices in colour separation followed by the so-called High-End systems, the introduction of synthetic inks and print carriers with more compact surfaces, as well as the improvement of presses have all made it possible to print full-colour products up to the highest quality requirements.

But the printing industry had to face a new challenge - the spreading of digital technologies over wide portions of industry, combination of the print processing of images with other media, as well as out-of-printing office pre-press solutions have definitely made printing reproduction an open process. Digital materials (images, texts, figures, etc.) received for pre-press workshops of printing offices from heterogeneous sources could not provide the expected quality in terms of colour rendering on account of the different colour management systems applied on various devices during their digital processing. The problem was solved with the introduction of digital colour management systems. International standardization work is under way concerning various issues of colorimetric and colour difference measurement, as well as of definition of industrial colour tolerance values. Established in 1993, the

International Colour Consortium (ICC) set as a goal to coordinate worldwide efforts made to standardize digital colour management technologies.

In addition to the mentioned general spread of open systems, State Printing Company's problem basically consisted in the great diversity of the special materials (print carriers, inks, printing and finishing processes) used throughout its production technology.

2. Digital colour management system at the state printing company

2.1 Importance of colour management

Colour management of the technological process of plastic card production is the most complex one at the company. Over the course of the production process, starting with graphics and image components originating from heterogeneous sources, and ending with the integrated card as an end product; the colours of the artwork undergo multiple modifications.

The main steps of the technological processes are the following:
- Design (open input),
- Preparation of proof, approval,
- Printing (colour sequence, trapping),
- Application of cover foil (thermal impact, compressing force),
- Additional operations that will not modify colours any longer (die-cutting, hot stamping, personalization, etc.).

Before introduction of the colour management, the sample deemed to be acceptable by the customer came into being as an end product through proofing series, produced on the presses and frequently repeated form corrections, which was a very expensive method, wasting both valuable raw material and machine time.

Summarizations of the main reasons for introducing the CMS were the following:
- Open input for the design,
- Several card body structures are available according to the end user's demand,
- The features of the materials constituting the card body affect colour rendition and colour gamut differently,
- Application of expensive special basic materials,
- Colour modification of plastic card production technology,
- Demand for high quality,
- Short lead-time requirements for the products,
- Manufacturing waste is harmful to the environment.

2.2 The procedure of colour management of plastic card production

2.2.1 ICC profile determination

ICC profile determination includes making test prints for the combinations of available prepress facilities (traditional and CTP), printing machines, inks, print medias and overlay foils as well as defining the colour profiles and the colour gamut that can be reproduced by the proof equipment, and then reducing the colour gamut of the proof equipment according to the finished test prints. It includes storing this gamut by combinations of the materials and the technological line and defining the colour gamut of the calibrated monitors used in printing preparation.

The process begins with the test chart selection. Then the printing plate is made using colour separated films and the appropriate exposition-program in the traditional way, or directly using the CTP device. The test print is made on a selected printing press using the appropriate setting, printing blanket, inking, colour sequence, raw materials (media). It's very important that all the parameters of the test print are to be identical to the future printing run parameters, therefore the test print must be made with the parameters that can be maintained during printing run, even when the setting quality is perhaps higher than the continuous print quality. While the plastic cards are printed on so called core foil, the next step is the laminating of the core foil together with the overlay foil. This happens at 120-160 bar pressure and at 140 degrees, which can significantly alter colour. This modification also depends on the type of overlay foil.

The printed image on the constructed card body is what's read into the Spectrolino colour-measuring device. The characteristics (the reproducible colour gamut) of the printing system and the colour profiles of the printing system are determined by GretagMacbeth ProfileMaker software. The colour profiles can be modifying using the Profile Editor.

Application of the digital colour management systems requires naturally permanent maintenance. If any of the elements of the technological system is replaced, the system-specific ICC profile will also change. This requires a repeated determination of system characteristics.

2.2.2 Application of the established ICC profiles

The established ICC profiles application starts with checking the data files received for prepress. Then the appropriate colour profile is selected according to the materials and the technological line required for card production. On a calibrated monitor, the difference can be seen between the image expected by the customer and the image that will be produced by the printing press. The digital data file of the image can be modified to fit the colour gamut used be the output device. The modification can be checked using Photoshop software. This way, the result expected by the customer can be guaranteed, even at the cost of compromise due to the limitation posed by the technology. By calibrating the proof device with the printing system, we get a digital proof sample for the client's approval. After approval, another proof needs to be made for the print-shop operation which simulates the print image of the card prior to its assembly without any colour distortion under the influence of heat and compression.

In the interests of cost-effective and quick manufacture, all information regarding the printing, raw materials, the type of ink, and the printing machine to be used, must be available to the operator at the prepress. The images arriving from various sources can be checked and modified only with these appropriate ICC profiles.

3. Determination of reproducible colour gamut of plastic card production

Determination of reproducible colour gamut of plastic card production is very important not only for technology but for sales of cards on the market in a cost effective way too. When the appropriate gamut is known, it can be determined that the brand colours or other spot colours are in this gamut or they are out of this gamut. So number of spot colours and which colours need to print can be set before the printing company contract with the customer determining a price calculation. Other case the additional spot colour printing can be waste of the printing company.

3.1 Means of examination

Experimented materials:

Core foil	Lucchesi	PVC 2911
Overlay foil	Lucchesi	JS 2922: non-laserable

	Lucchesi	JS 2910: laserable
Ink	J+F	Process colours
Machines:		
Printing press	Heidelberg	Printmaster GTO 52
Lamination	Oakwood	Single stack
Colour management device:		
Testchart	GretagMacbeth	CMYK Testchart 6.02
Measurement	GretagMacbeth	Spectrolino/spectrscan
Software	GretagMacbeth	ProfieMaker 4.1

3.2 Reproducible colour gamut

3.2.1 Colour gamut changing of core foil after lamination with non-laserable overlay foil

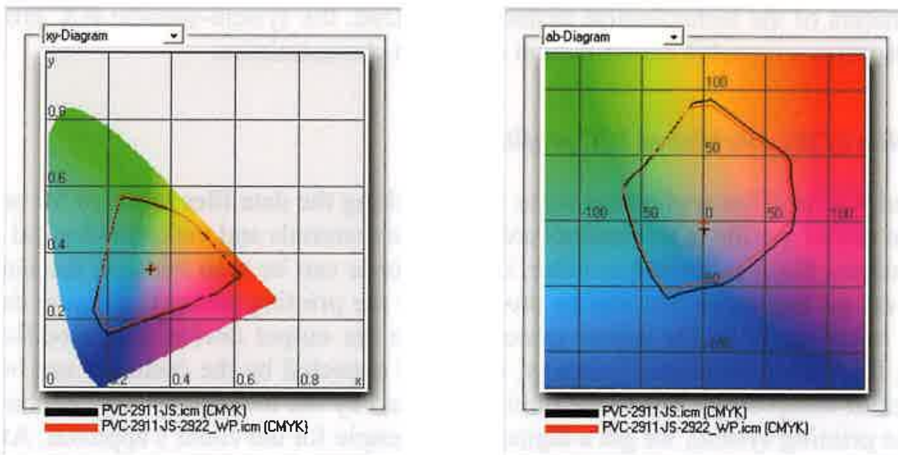

Figure 1: Colour gamuts of core foil and with non-laserable overlay foil laminated together core foil

The difference in both the size of the colour gamut and the position of the white dot is well visible. (Figure 1), (Table I) The cause of the colour difference is the distortion and expansion of printed dots under thermal impact and pressure. Also, high temperatures are instrumental in inducing the colour changes of the ink.

Application of the non-laserable overlay foil the size of the reproducible colour spectrum decreases by blue, magenta and orange colours. It is on a-b diagram remarkably better.

The white point shifted to the direction of the yellow colours, so the reproduced picture can be converted slightly warmer.

Table I: The greatest ΔE values between core foil and after laminating with non-laserable overlay foil

Field	ΔE	Field	ΔE
2G31	8.68	U20	7.24
2K35	7.99	2I33	7.22
2J34	7.65	2G31	7.17
P20	7.58	2J34	7.13
L14	7.54	2C27	7.00

Average value: 3.22 Maximum value: 8.68 Minimum value: 0.30

3.2.2 Colour gamut changing of core foil after lamination with laserable overlay foil

The overlay foils are quite different in a technological point of view. The functions of the non-laserable overlay foil are only to protect the core foil and contribute to the card thickness. In addition the laserable overlay foil partakes with its transparent grey colour in the personalization of the card. The laser beam burns for example, the owner's photo in the foil of a personal identity card.

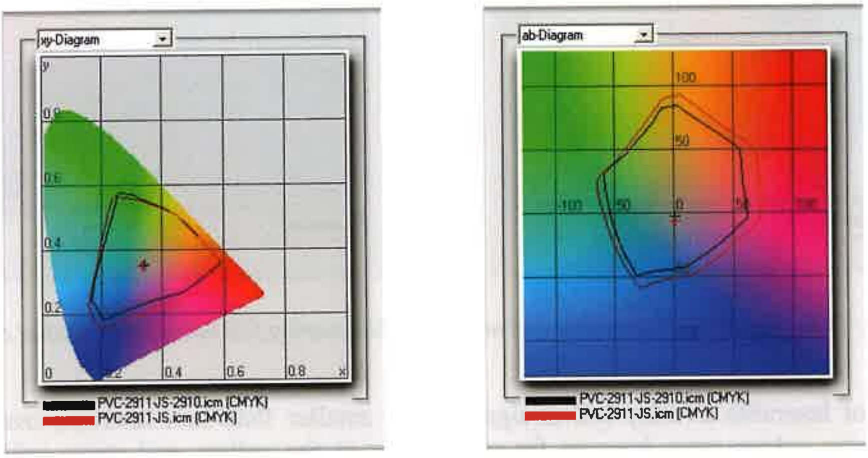

Figure 2: Colour gamuts of core foil and with laserable overlay foil laminated together core foil

The primary cause of the colour difference is the distortion and expansion of printed dots under thermal impact and pressure. Also, high temperature changes the colour of the ink, but it is the transparent grey basic colour of the overlay foil that is mainly responsible for such changes. The white point shifted to the direction of yellowish green colours, so the reproduced picture can be converted slightly warmer by light colours. The colour gamut at greens slightly, but at the others significantly decreases. (Figure 2), (Table II)

Table II: The greatest ΔE values between core foil and after laminating with laserable overlay foil

Field	ΔE	Field	ΔE
U4	20.14	2G31	19.25
B10	19.85	J4	19.14
U10	19.59	W11	19.14
B9	19.38	C16	19.04
B14	19.34	U15	19.03

Average value: 11.71 Maximum value: 20.14 Minimum value: 1.24

3.2.3 Colour gamut difference of laserable and non laserable overlay foils

As it mentioned the overlay foils can be quite different in a technological point of view. They protect the core foil and contribute to the card thickness and laserable foils partake in the personalization of the card too. The laserable foils have a transparent grey colour so it is very important for the operator in charge of the pre-press to know exactly the whole technological process of a particular work, because the difference in colour reproduction is significant. (Figure 3), (Table III) The difference in both the size of the colour gamut and the position of the white dot is visible. Because of the greyness of the laserable overlay foil, the white point is significantly shifted as well compared to the non-laserable overlay foil.

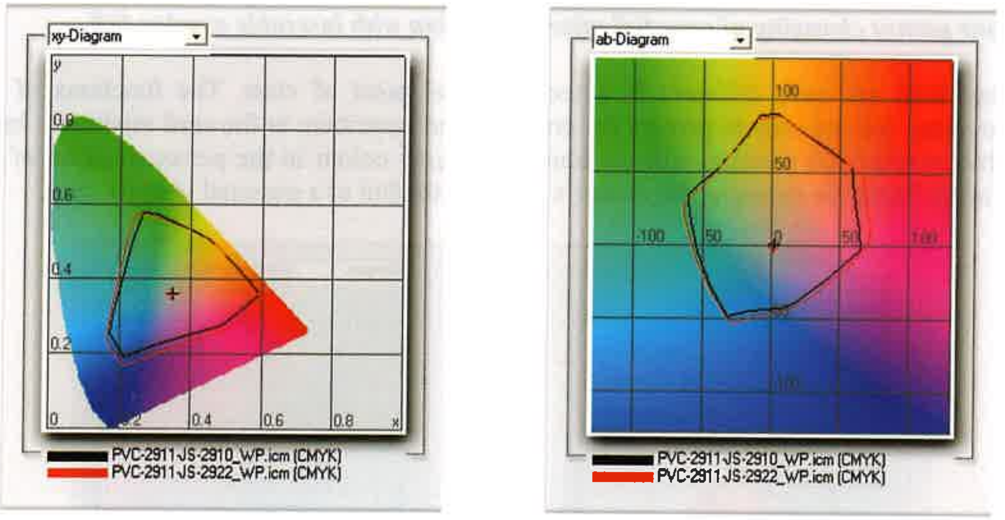

Figure 3: Colour gamuts of laserable and non-laserable overlay foil laminated together core foil

Colour gamut of laserable overlay foil is significantly smaller than non-laserable overlay foil. The magenta and cyan colour areas become far smaller but at the yellow and green colours its colour rendering is better.

Table III: The greatest ΔE values between laserable and non-laserable overlay foil laminatum

Field	ΔE	Field	ΔE
2H32	18.85	B14	18.09
U4	18.61	2G31	18.01
D21	18.52	B9	17.97
C16	18.50	C15	17.84
B10	18.41	I10	17.79

Average value: 10.87 Maximum value: 18.85 Minimum value: 0.77

3.2.4 Colour gamut difference of coated paper and with laserable and non laserable overlay foil laminated plastic card

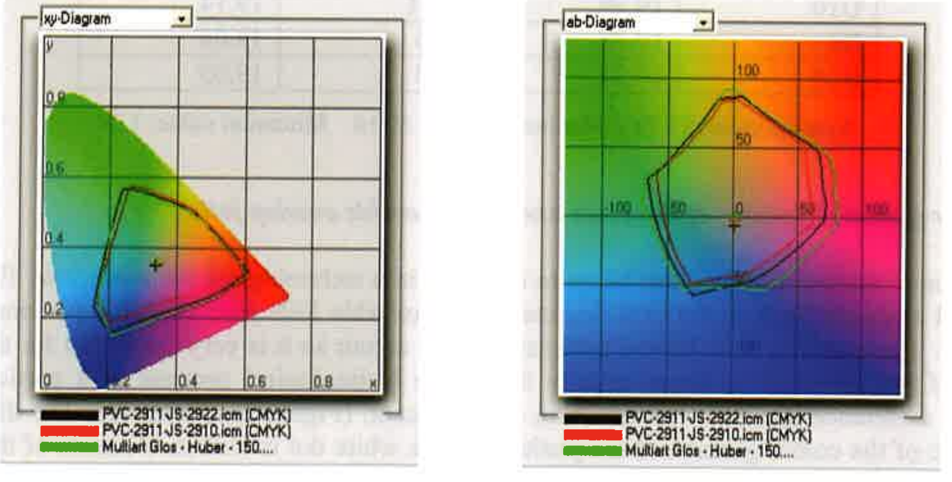

Figure 4: Colour gamut difference of coated paper and with overlay foils laminated plastic cards

The issue of a plastic card usually happens with a sales promotion. The marketing-mix is composed of a range of advertisements on various medias. So it is useful to make a comparison between colour gamut of plastic card production and the colour gamut of an offset print on coated paper. So can arise which spot colours of plastic cards can be printed without serious compromise in process colour printing and which ones would be better as spot colours print in a leaflet too.

The difference in both the size of the colour gamut and the position of the white dot is significant. It must be considered in pre-press of marketing materials. (Figure 4), (Tables IV-V)

Table IV: The greatest ΔE values between coated paper and non-laserable laminatum

Field	ΔE	Field	ΔE
A23	31.93	A21	29.00
A22	30.98	A24	28.62
2G31	30.48	D20	28.41
2J34	29.41	A20	28.36
O16	29.12	A17	28.24

Average value: 19.70 Maximum value: 31.93 Minimum value: 2.67

Table V: The greatest ΔE values between coated paper and non-laserable laminatum

Field	ΔE	Field	ΔE
2J34	39.87	H5	33.96
2K35	37.24	Q15	33.89
H4	35.58	O4	33.83
A16	35.01	U10	33.09
A22	34.20	A23	32.95

Average value: 20.54 Maximum value: 39.87 Minimum value: 3.57

The following pictures try to show it what does the colour gamut difference mean in practice of a mentioned sales promotion, and plastic card production. More details can be discussed at the conference.

Figure 5: The source RGB file - it is used at on-line media too, and an offset print on coated paper

Quite a big difference between the pictures (Figure 5) while RGB and CMYK colour space have different gamuts in CIE Lab system too.

Figure 6: The core foil print and with laserable overlay foil laminated together core foil

The difference between the two pictures (Figure 6) shows why there needs to be another proof to be made for the print-shop operations with the image of the card before its assembly.

4. Conclusion

Information technology that is in permanent progress today is continuously leaving its mark on, as well as improving, printing technologies. Utilization of various applications makes everyday work easier and, in addition, results in reduced lead times and enhances quality in all fields of the printing industry. Colour printing has come to the forefront in every area of the printing industry, including the security documents and prints that are the major products of State Printing Company.

We have been looking for, and have finally found, ways and means how to introduce a system into the routine work processes, by which quality can be proven and supported using exactly measured and carefully managed data. Visual appearance of the prints is a matter of subjective judgment, but a single and common language can be brought into existence using up-to-date colorimetric devices. The immense diversity of both hardware and software with different chromatic characteristics is a great problem to all of us. Colour management is the way, through the use of which a system can be set up to obtain results always correct in colour, no matter whether in the pre-press phase, or in the phase of processing.

State Printing Company has been using GretagMacbeth's ICC standard colour management system since 2000, to optimize colour reproduction technology in plastic card production, while this is the area where colour modification is the greatest, and have to place manufacturing colour communication on objective grounds. The introduction of a digital colour management system has also made it possible to shorten production time, and decrease pollution.

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The influence of monitor white point chromaticity on color appearance

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Abstract

In cross media reproduction, it is important to be able to predict the appearance of colors under a wide range of viewing conditions. This research focuses on comparision of printed images with CRT displays. If a simple corimetric match is made between a printed image and a CRT display, the perceived color in the image typically do not match. This is due to differences in viewing conditions between the two displays. Such differences include changes in luminance level, white point chromaticity, and surround relative luminance. The aim of this research was to collect and evaluate additional corresponding-colors data using pictorial images presented in well-controlled viewing conditions. In this work, the influence of monitor white point chromaticity on color appearance is presented.

Keywords

Color appearance, cross-media imaging, monitor white point

1. Introduction

Digital colour imaging is one of today's most exciting and fastest growing fields. At first sight, it might seem that the endless flexibility provided by having signals in digital form should make all the problems easily solvable. The complexity of the situation arises from the different input, monitoring, and output media involved, and the different objectives required for different applications. It is often difficult or impossible to successfully exchange digital color images among different types of systems. The use of well-established measurement methods, along with color-management applications and image file format standards, should allow the open interchange of digital images among systems (Giorgianni, 1998).

The reproduction of color images in an ever-widening array of media is challenging for a variety of reasons. That include physical limitations of devices, colorimetric calibration and characterization of devices, viewing conditions, intent and preferences. If a simple colorimetric match is made between a printed image and a CRT display, the perceived colors in the image typically do not match. This is due to differences in viewing conditions between the two displays. Such differences include changes in luminance level, white point chromaticity and surround relative luminance.

Conventional CIE XYZ colorimetry is useful for specifying color appearance under agiven set of viewing conditions and for determining whether two colors will match in a viewing configuration. However, two colors, which are a corimetric match, can appear qiute different if viewed under different viewing condition (Mandić, 2002). Therefore, in recent years, researchers have tried to develop more comprehensive color appearance models, which are able to predict color appearance accurately across a range of viewing conditions (Fairchild, 1998). Color appearance models were derived from the results of physical experiments using simple scenes (e.g. single colors against a variety of different viewing environment. To determine whether these models are useful for realistic color reproduction, their performance must be evaluated for complex images. The aim of this research was to collect and evaluate additional corresponding-colors data using pictorial presented in well-controlled viewing conditions. The two most commonly used media, CRT-displays (soft copy) and printed images (hard copy), were included in this research using four complex images. The viewing conditions varied in white point chromaticity of monitor.

2. Experiment

Four printed images containg pictorial information were used as the originals. One scene was a natural scene (grass and sky), the other contains saturated colors from the majority of hues (masks), third was skin and fourth one neutral scene (snow-neutral tones). These images were continous tone images printed on mat papers using a large format printer at 254 dpi. The original hardcopies were captured by an Agfa scanner at 72 dpi to provide RGB data for processing the CRT reproduction. The scanner and CRT display were calibrated and characterized using Macbeth software ProfileMakerPro 4.

The experiment was taken in dark room. Printed hard copies were illuminated and viewed under just light source that simulated CIE Standard Illuminants D50. Reproduction was displayed on Mitsubishi monitor at 72 dpi and had the same physical size as the originals. The CRT white point was set to the chromaticity coordinates close to 5000K (CIE Illuminant D50), 6500K (CIE Illuminant D65) and 9500K. Each soft copy or hard copy image had a 5 mm white border, which was the reference white for chromatic adaptation purposes.

A total of five observers, all experienced in using Adobe Photoshop, took part in the entire experiment. All the observers had normal color vision as evaluated by Ishihara plates and a Farnsworth-Munsell 100-hue test. Observers sat approximately 25′′ from the printed originals and CRT screen. The printed originals and CRT reproduction were placed 90° from each other with respect to observers in an L-shape arrangement. All experiments were carried out in a darkened room, so that only the print or CRT images occupied observer field of view. Observers adjusted the rendition of the scene to match the color appearance of the print.

The CRT image adjustments were accomplished using Adobe Photoshop. Observers were allowed to use any of the color adjustment tools in Photoshop, but were not allowed to perform spatial manipulation of the images. The length of each experimental session was left to the discretion of the observers. Each experiment began with the same starting-point image, uncorrected scans, and the matching was perform for all images with one monitor white point, then with another monitor white point. Every time the monitor was calibrated.

After observers completed the various matching tasks, the resulting images were saved for later processing. The images were segmented into several number of object region, depend of image context.

3. Results

The actual prints used in the experiment were measured using a Gretag Spectrolino 45/0 spectrophotometer (Hunt, 1991). Measurements were made on the prints by sistematically sampling the same image regions and then averaging the tristumulus values.

Results are presented in Tables I-IV, and test images and the region that were measured are shown in Fig. 1-4. After measuring, CIELAB metric lightness (ΔL), chroma (ΔL) and hue (ΔH) were, calculated between the printed images and images displayed on CRT. Color differences ΔE_{94} and ΔE_{00} (Luo, 2000) were calculated for each region of image, and for three different white point of monitor, D65, D50 and D95.

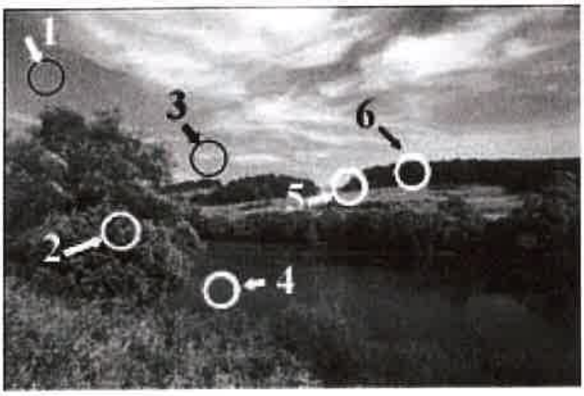

Figure 1: Test image 1

Table I: Data for image 1

Image 1		ΔL	ΔC	ΔH	$ΔE_{94}$	$ΔE_{00}$
1 sky	D65	0,2	8,7	2,9	3,2	2,1
	D50	4,6	0,6	0,1	4,6	12,8
	D95	5,8	4,5	01	6	11,8
2 green	D65	0,9	7,3	0,2	2,9	7,6
	D50	13,2	17,9	0,3	15,2	17
	D95	17	16,2	0,2	18,2	18,9
3 cyan	D65	0,5	19,6	0,1	6,2	3,9
	D50	4,9	1,3	2,6	5,2	12,4
	D95	6,4	2,3	2,7	6,6	11,6
4 blue	D65	1,6	3,3	0,1	2,1	1,4
	D50	5,7	4,3	2,8	6,3	10
	D95	6,2	2,5	2,7	6,5	10,3
5 green	D65	6,3	7,2	0,2	6,8	6,3
	D50	12	14,7	0,3	13,7	16,4
	D95	14,6	12,6	0,2	15,6	17,3
6 dark green	D65	1,4	25,9	0,2	13,4	8,1
	D50	5,6	23,7	2,5	13,3	16
	D95	5,3	21,2	2,5	11,8	17,6

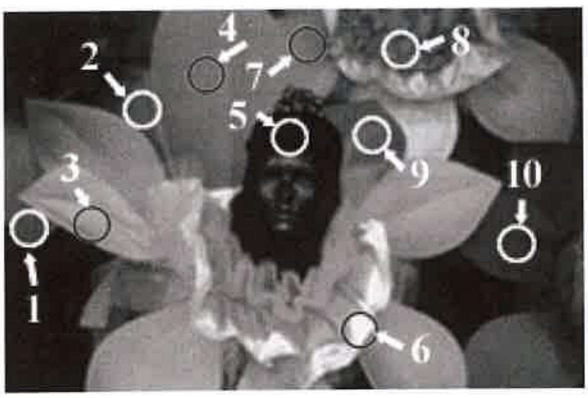

Figure 2: Test image 2

Table II: Data for image 2

Image 2		ΔL	ΔC	ΔH	$ΔE_{94}$	$ΔE_{00}$
1 violet	D65	9,2	13,4	3	11,2	10,5
	D50	3,7	18,1	0	8,6	8,1
	D95	6	2,7	3,1	6,5	5,6
2 blue	D65	4,2	15,6	0,2	6,8	5,1
	D50	2,2	16,7	0,2	6,1	3,6
	D95	5,9	7,3	0	6,6	6,8
3 yellow	D65	2,2	15,4	0	4,7	3,6
	D50	10,7	6,6	0	10,8	8,3
	D95	5,1	7,1	0,1	5,4	4,7
4 orange	D65	1,7	1,7	0,2	1,7	8,9
	D50	8,2	4,6	0,1	8,2	7,2
	D95	4,9	2,5	0,1	4,9	6,1
5 black	D65	3	19,3	0,2	13,1	13
	D50	9,1	11,3	0,4	12,4	10,3
	D95	7,6	20,2	0,4	15,2	14
6 white	D65	6,9	7,3	1,8	9,1	13,8
	D50	7	9,1	2,2	10	11,3
	D95	6	6,2	1,8	7,9	11,7
7 magenta	D65	0,5	7,7	0,2	2,7	7,3
	D50	7,7	5,1	0,3	7,9	10,8
	D95	3,6	1,8	0,1	3,6	5,1
8 red	D65	7,5	5,4	0,1	7,6	8,3
	D50	11,4	1,3	0,2	11,4	13
	D95	7,9	4,4	0	8	7,6
9 brown	D65	5,5	17,7	0,2	7,8	6,9
	D50	0,3	13,3	0,2	4,1	4,2
	D95	3	7,8	0,2	3,7	6
10 blue	D65	2,1	2,2	2,8	2,7	11,3
	D50	5,1	6,4	2,7	5,6	11,2
	D95	1,6	6,1	2,8	3	12

The research was concentrated on the relative appearance attributes of lightness, chroma and hue, because imaging systems are typically limited to three degrees of freedom in color reproduction. Lightness, chroma and hue represent the most intuative dimensions that observers typically use to describe complex colored stimuli. The results of these experiments show that some of the observers were producing matches more closely represented their preference rather than an accurate reproduction of the printed image.

Figure 3: Test image 3

Table III: Data for image 3

Image 3		ΔL	ΔC	ΔH	ΔE_{94}	ΔE_{00}
1 white	D65	2	12,8	1	8,8	12,4
	D50	4,4	19,2	0,9	12,5	15,7
	D95	2,2	14,9	0,8	9,9	12,4
2 blue	D65	2,8	2,6	2,9	3,5	4,4
	D50	1,2	10,6	2,9	4,3	2,6
	D95	1,6	1,5	2,9	2,5	5
3 black	D65	5,8	6,1	0,7	7,6	10,9
	D50	3,7	7,8	1,1	7,3	10,1
	D95	3,2	7,2	1	6,6	10,1
4 skin	D65	1,4	7,9	0,2	3,1	3,5
	D50	2,4	10,8	0,2	4,6	3,6
	D95	0,2	6,9	0,1	2,4	2,1
5 blue	D65	4,2	6,9	0,2	5,1	5,1
	D50	7,1	2,7	0,1	7,2	6,2
	D95	2,8	0	0,1	2,8	4,1

Figure 4: Test image 4

Table IV: Data for image 4

Image 4		ΔL	ΔC	ΔH	ΔE_{94}	ΔE_{00}
1 grey	D65	2,4	13,9	1,9	10,7	11
	D50	7,8	17,7	2,2	14,8	14,2
	D95	8,1	16,2	2	14,3	13,6
2 snow	D65	10,7	10,2	2,1	12,7	16,6
	D50	9,8	13,5	0,7	12,9	15
	D95	10,2	12,3	0,7	12,8	14
3 black	D65	1,1	6,6	0,4	5,5	8,9
	D50	4,8	14,4	0,2	11,4	14,9
	D95	4,3	12,4	0,1	10,1	14
4 grey	D65	9,5	11,9	2,5	12,2	13,8
	D50	14	14,5	0,3	16,5	15,3
	D95	14,2	13,1	0,3	16,3	14,4

3. Conclusion

Psychophysical experiments were carried out to assess the influence of monitor white point on image appearance. The largest color differences were noticed in white and black regions, due to the difference of media. The smallest differences in chroma and lightness value were when matching was done with monitor white point D95. The accuracy of matching between hard and soft copy depend of image content. Our further research will be oriented to influence of other parameter and development of transformation that will give the optimal start point.

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Prepress and workflow

Creation of an industrialised newspaper production system[1]

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Abstract

One of the basic requirements of human development is the creation of visions. In times of a very rapidly changing social as well as industrial environment, it is essential to think ahead beyond the necessities defined by everyday business in order to maintain and strengthen competitiveness. Visions form the normative frame for a company's development within a defined period of time in the future. A reliably described as-is state is necessary as a starting point in order to assure on the one hand that the visions contain a high degree of innovation and on the other hand that no unachievable objectives are expressed. If a vision is to be developed for a larger application area, as for example an industrial sector, it is necessary to elaborate this vision based on a generally accepted as-is state and by means of a terminology customary in this trade. This paper deals with the preconditions and possibilities of a visionary description of an industrial newspaper production system under consideration of a higher degree of automating, closed loops and continuous process control.

1. Introduction

The branch of trade is biased by the conception that printing houses are producing like craftsman but with more sophisticated production equipment. Although this prejudice could be justified, it is necessary to think ahead beyond the next step in order to get an idea of how future newspaper production can be structured.

Changing reception behaviour of the newspaper readers, paired with general problems relating to market conditions, has led the medium newspaper and associated production enterprises to financial and structural problems. Subsiding run lengths, a collapsing ads market, special interest markets migrating to other distribution channels [KPMG05], loss of turnover to a considerable extent in the last five years on the one hand, and penetration of free newspapers in cities as well as the establishment of a multiplicity of new newspaper titles in recent years on the other hand, determine strategic considerations in both publishing and newspaper printing houses.

Subsiding run lengths automatically lead to rising production costs per edition. If these costs cannot be compensated, for instance, by printing additional products, production itself must become more cost-effective.

Suitable instruments for achieving this are automation, standardisation and, both a better understanding as well as control of the production process. Since reaching a higher degree of automation and introducing standards are always accompanied with investments, forecasts are necessary for which production steps automation or standardisation create streamlining effects.

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[1] The paper is initiated by the currently running Ifra project „Create a vision of an integrated, closed-loop controlled and intelligent newspaper production system from data input to distribution, which ensures standardised high-quality and industrialised production", see www.ifra.com

Gathering relevant information from the production process is complex and thus expensive. An exclusive view on the environment of one production step and/or small control loops goes along with the risk of neglecting effects in preceding and/or subsequent production steps. Gaining comprehensive knowledge of the entire production chain and modelling it as abstractly as possible offer an approach to determine effects influencing the whole production process and to detect potential starting points for investments in automation and standardisation.

A vision gives an ideal image of an enterprise or a branch of trade and sets the normative framework for branch goals and strategic decisions. An essential precondition for the development of an appropriate vision is a comprehensive knowledge of the current state of the domain in focus. Another precondition is the possibility to describe the current state in an abstract and general way. This implies the existence of a common model of the domain as well as taxonomy and terminology to describe it. Based on these conditions, the final constraints for the development of a vision are objective targets. These determine the guideline for the development.

2. Methods

A common model of the actual state of newspaper production is currently not available. Therefore the first step in the direction of an industrialised newspaper production vision is the description of its current state by means of an abstract model.

At this point the restrictions of the model focusing on achieving the objectives have to be discussed. It is essential for the model to provide taxonomy as well as terminology capable to describe both the current state and the prospective stages of development. Furthermore, granularity and degree of abstraction have to be defined in order to limit the complexity of the model to a degree reasonable for the problem's conceptual formulation. Additionally, a clear guideline for the design of the model has to be derived from the objectives. This is also a prerequisite for the model to be capable of providing a basis for the development of a visionary state. Finally, a basis for further discussion has to be pre-defined to set a normative framework for the design process. In the following the constraints are discussed in greater detail.

The essential taxonomy and terminology are provided to the greatest possible extent by the branch-specific standardisation activities. Hence, the development of a new linguistic approach for the intended model is not necessary and would contradict the claim of generality. The standards, both in use and under development, have to be respected and introduced to the process of modelling. Furthermore, the specific nature of the application of standards in heterogeneous domains with various stages of development has to be considered. For instance, the prevailing "lingua franca" of the branch of trade, the Job Definition Format, provides a comprehensive taxonomy and terminology applicable to all production processes of the Graphic Industry. It is well defined for most processes of commercial printing, but lacks newspaper-specific elements. In contrast to this, the standardisation efforts of the newspaper industry like IfraTrack[2] and AdsML[3] contain the "language" of the publishing houses and newspaper printing floors. Attention has to be paid to overlapping of definitions as well as gaps. It is to be expected that these standards will be harmonised in the near future. Therefore, a comprehensive and self-contained taxonomy and terminology can be assumed as given for the model. In terms of granularity and degree of abstraction, the constraints are set by various intentions. It is mostly the objectives that determine the depth of abstraction. For the concrete task of creating a vision, the difficulty arises that both granularity and degree of abstraction are not determinable at the

[2] IfraTrack is a specification for the interchange of status and management information between local and global production management systems in newspaper production, see: http://www.ifra.com/

[3] AdsML is an initiative supported by Ifra, an international association for media publishing, and the Newspaper Association of America (NAA) with the aim of creating the first comprehensive, global standard for end-to-end advertising workflow, see www.adsml.org

beginning of the design process since the objectives are naturally not entirely clear then. They will substantiate during the course of development.

The main objective, the development of a vision of an industrialised newspaper production, can be understood as an umbrella covering a multitude of single objectives. For this reason it is necessary to decompose the general objective into subsumable targets. These bias both the characteristic and the direction of the process of development and should lead to a balance between the extreme poles of extrapolation of the current structures and a reissue from scratch. The concrete objectives are assumed to be in the range of more efficient production, improved quality of the product, reduction of waste, etc. Problems arising here come from polytely.

Figure 1: "Black box" model

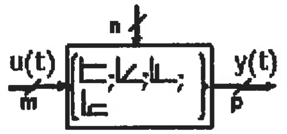

Figure 2: Principle of control unit design for multivariable systems

The metaphor of the newspaper production process as a holistic closed loop control system, promoted by Ifra as a result of former research projects, frames the current research on this demanding model.

The starting point for the creation of such a vision is the evaluation of the present state of research, in this case, on newspaper production. Since a common abstract model of newspaper production is currently not available but necessary as a basis for the development of a vision, it has to be created first. At the moment, business process models are the most widely used form for describing the workflow management of a venture. Having the demand for efficiency in the model in mind, present business models can serve as base. While a process is understood as transformation and/or transport of Matter, Energy and/or Information[4], a business process is generally a sequence of business duties belonging together, performed for the purpose of achieving an output. "The *output and result of the business process is called an achievement, which is both requested and accepted by an internal or external "customer". A substantial contribution to the creation of value of the enterprise is also frequently required of a business process [...]. Business processes are directly subject to economical views"*[5]. The basic statement, derivable from these definitions, is that a business process is determined by an input, an output and a transformation of the observed object described by a more or less complex transition equation[6]. Depending on granularity, this equation can become arbitrarily complex or impossible to form. In order to reduce complexity at this stage of development, the application of the auxiliary means provided by the system theory[7], first of all the "black box" approach, is a well proven method. The advantage of this approach is that the behaviour of a system is described only by its input and output variables as well as the feedback of the system to its environment. The internal processes are temporarily hidden in the "box", which is a favourable way to explore systems whose inner structure is perceptible only to a limited degree or can be described only with phenomenological terminology. Since business processes can be described by means of black boxes, this approach can be used to develop a network of boxes representing business processes that describe the current stage of newspaper production. Connections within the network can be set up, applying the rules for

[4] definition by DIN 66201

[5] translation of a definition of business processes by Scheer in [SCH02] page 3

[6] The input-output-models discussed here follow the system-to-system-relations described by [LUH02]. It is a matter of rather ideal and mathematical models. The transformation equation is defined structurally. Luhmann calls these extremely technical models or factory models. With respect to the hypothesis of the closed-loop-controlled-system model, the feedback model, described by cybernetic approaches e.g. by WIE48], is applied to enhance the system model towards the ability to describe side effects and long distance effects.

[7] Here the definition of a „concrete system" by [LUH02] page 60 is taken as a basis. The system theorist describes the systems that have been established in reality as it is.

interconnection provided by the system theory and the mathematical calculation rules provided by the information theory. Taking the constraints discussed above into consideration, the network to be developed should show the behaviour of a control loop. The advantage of this procedure is the concentration of the developmental work on feedback and side effects as well as long-distance effects. Another result of this step is expected to be a better understanding of the determining parameters. Determining parameters are understood to be parameters that intensively influence subsequent processes or give a strong feedback to preceding production steps. Newspaper-specific examples for such determining parameters are screen ruling, dot shape, screen angles, dot gain and the like. Definiteness of these parameters across the entire branch of business is a visionary aim that has to be integrated into the model. The discussion of this network should set most potential parameters into focus for the further development. Naturally, this leads to an iterative process. If during a subsequent step of development the importance of a parameter is modified or other parameters gain attention, the causes have to be reported back and heeded in an updated version of the system model.

In order to control the response of the system to parameter modifications, knowledge about signal coupling, controllability and observability are essential. Under the condition that the regarded system is quasi-stable and the influence of parameters' modification keep it in a steady state but must not lead to a positive feedback of the overall system, the stimulus threshold of the variation of determining parameters has to be defined[8]. The qualitative description of the behaviour of a system cannot provide methods for this task. Consequently, the concrete transition equations of the particular subsystems become important. Past experience has shown that the formation of transition equations becomes difficult relatively fast because of the complexity of the open multivariable controlled systems. The further away a subsystem is located from the area of influence of the main production process, the more difficult the development of the transition equation becomes. Means of structural analysis provide a remedy by utilising structure matrices, as they are known from control unit design. The results offer predications about the structural controllability of the subsystem itself and, by applying interconnection rules, also for the whole system model.

With the existence of such an abstract model describing the current state of newspaper production as well as containing capabilities to estimate or at best calculate the benefits of automation and improvement of processes, the groundwork is laid for the development of visionary variants. With regard to the behaviour of control loops, one or only a few of the manipulated variables of the system should be changed. The intention is to anticipate the effects of an increased degree of automation or adjustment of processes at a certain point at the process chain on the whole system. A prediction should be derived from the system of whether the modifications cause positive effects for all subsystems or whether a positive feedback causes problems for ambient processes. That way various visionary variants can be developed. If the process of improvement has started from different points and has led to different variants, each of which is capable of causing more effective production for the focused domain, the mutual interference of these approaches has to be investigated. If no negative side effects appear, a potential vision has arisen. Eventually, Occam's razor[9] facilitates the decision of whether the vision is applicable to the branch of trade or not. Bearing this in mind, methods to count the costs for standardisation and automation as well as lifecycle costs have to be applied. Such methods are helpful for instance [Bux96] when calculating the costs incurred by the introduction of standards into the production. The difficulties of such calculations result from both limited knowledge and the cost-intensive ascertainment of the concrete costs, which are broken down into single positions in the production chain. The result of this is further demand on the model, to provide for this type of costs to the greatest extent possible.

The final step, once the model is approved, is the derivation of medium-term and long-term strategies for the branch of trade with regard to the realisation of the vision.

[8] A first-rate source for the definition of the ranges of important parameters is the revised ISO 12647-3:2004.

[9] William of Ockham (1285-1349) formed the basis of methodological reductionism, also called the principle of parsimony or law of economy.

The multitude of methods presented above limits the scope of discussion when putting it into practice, in particular when developing a vision of a prospective industrialised newspaper production.

3. Discussion

The future state of newspaper production, aspired as a vision, has to describe a steady-state system with the aim of more cost-effective production. Consequently the attention has to focus on economic parameters to the same degree as on technological parameters.

Naturally, the first step when modelling a system is the definition of the system's borders. For a newspaper production system, a sufficient approach is to limit the focus on the processes from product definition to its deposition on the loading ramp. Although the product newspaper seems to be looking the same each day, the final structure of each issue is defined at a point in time very close to the editorial deadline. The structure differs slightly for each issue and involves variations both for characteristics as well as responsibilities of the production processes. Therefore, it is necessary to shift the system's border to an early point in the production chain as mentioned above.

The next and, within the context of this paper, most important step is the identification of the most significant processes of newspaper production. As a common model does not yet exist, it has to be developed first. Two approaches are available to achieve this. To begin with a bottom-up modelling approach, the subsystems can be developed starting from an abstract description of the system. As this description is not available and is supposed to be very complex, the more pragmatic top-down approach will be adopted. Its advantages are manifold, beginning with the already available terminology and taxonomy provided by various standardisation activities and partial models resulting from previous research projects up to the knowledge of the trade written down in standard works like [KIP00][10]. Considering the economic focus as well, the most promising starting point for modelling is the application of the already determined business processes of newspaper production. Based on intensive analyses of relevant literature as well as discussions of the research results with experts, a set of business process descriptions has been worked out. The obtained business processes cover different sections of the process chain and also represent different views with different levels of abstraction. Therefore, the collected business processes (BP) had to be broken down into a hierarchical structure representing the dependencies as well. A four-level-deep structure evolved. Starting from the top, the levels are as follows: business processes of the first order represent the predominantly economic view on the whole process, i.e. correlate with a cost-centred structure, and then, they are assigned to the "conventional" definition of the value chain for printed matter, prepress, press, postpress as well as traditional process structures like procurement, logistics, distribution, etc. The first attempt adopted this given classification. If, however, the results are not promising and the resulting approach is not the most feasible, this classification will not be pursued further. The processes of the second order are sub-processes of the BP of the first order. They are organised according to the principle of working groups. Representative examples are business processes such as "ad sales", "single copy sales" and so on. A value chain model of the second order business processes is shown in figure 3. The third stage contains processes that are comparable to a workstation and perform exactly one operation in the production chain. Their physical representations are usually a machine and/or a software application. In this context, business processes such as "image processing" or "imposition" can be mentioned. Finally, business processes of the forth order are characterised by open and closed loop control systems that are representative for basic technological processes, for instance automatic colour control systems or web travel control systems. The last years have seen the most research effort dedicated to processes of this order. The processes of the fourth order are accompanied by mathematical-physical models and are therefore most conveniently described as a closed loop control system.

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[10] For a description of the newspaper production workflow see p. 189.

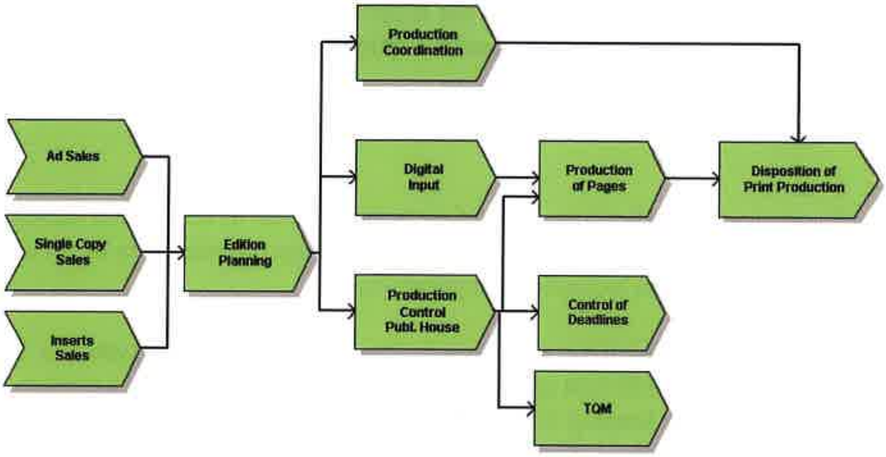

Figure 3: Strongly simplified value chain model showing the predecessor/ succesor relationships for the most important business processes of a publishing house (developed using ARIS toolset)

Each of the four hierarchical stages is characterised by different parameters. Their focus trends to shift from a technical view to an economic view the higher the stage of hierarchy, and vice versa. Also, depending on the direction, parameters are compressed or extended.

The next challenging task is the formation of the network out of the systems and the different flows. These flows serve as containers for the determining parameters of the system. The first approach pays especially attention to the most important flows, i.e. flows of material and information. Other flows, such as energy, auxiliary means, supply and dumping, appliances, tools and inspection devices, play a secondary role and are included as available. The hierarchical alignment of the business processes is reflected in the serial or parallel connections of the particular systems. These connections represent the flows of material and/or information between the single systems. Since the particular systems are described as a black box in terms of system theory, their behaviour reflects the transformation of the flow object between input and output. This facilitates both the evaluation of feedback of the particular system to its environment as well as to preceding and subsequent processes, and the determination of side effects and long-distance effects. The interlinking of flows between the particular systems with the determining parameters forms a basis for the next step. In order to determine the entire system with regard to its stability, controllability and observability in terms of automation theory, means of control unit design can be applied.

The controllability of systems is sustainably influenced by control parameters. The importance of clearness of parameters has already been discussed further above. Besides the business processes influencing the system, it is the process-controlling parameters that are of decisive importance. A trade-binding collection of these parameters can be found in the revised version of ISO 12647-3:2004. According to control theory, parameters are characterised not only by a clear identification and the assignment of a reference value, but also by the declaration of tolerances representing the control range. Furthermore, binding measurement methods as well as standard conditions of measurement have to be agreed upon. The newspaper printing standard offers not only these, but also models and procedures to adjust printing production to the standard. Although a trade-wide introduction of ISO 12647-3:2004 is still a vision, it shall serve here as a description of the as-is state from which advancements can start.

Due to the complexity of the system model for recording and further development, sophisticated tools are essential. The demands on such a development environment are exceptionally high. Besides the demands from the IT point of view such as support of teamwork, versioning and the management of huge amounts of data, an intuitive user interface is indispensable. The interface has to be adapted to the design process for both technological process chains and as the implementation of technological information.

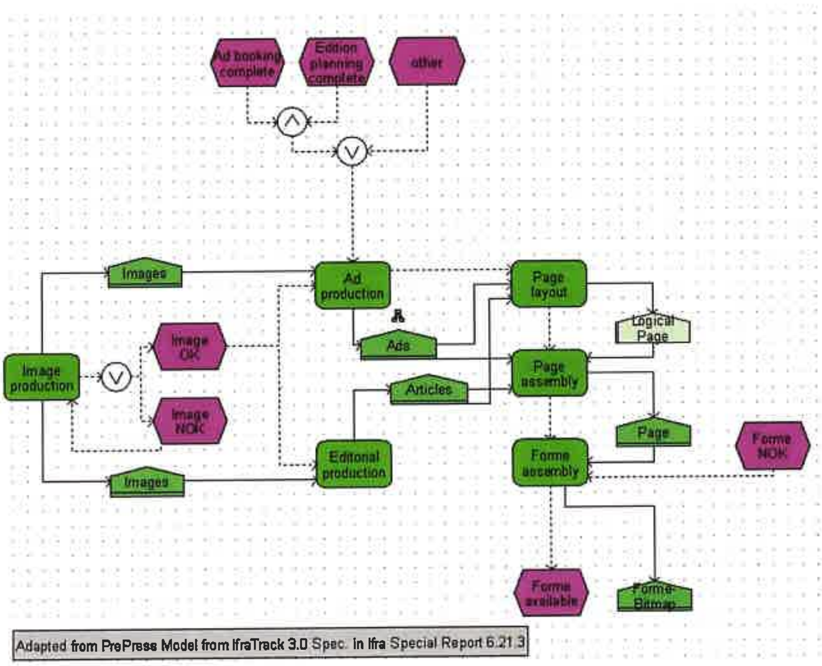

Figure 4: Sample of an eEPK model of processes in prepress (developed using ARIS toolset)

Furthermore, different views on the processes, depending on the development objective, have to be provided (see figure 4). Eventually, essential for the development of a vision, the application should be able to manage different strands of development. Therefore the capabilities have to go beyond simple version control, so that at least the comparison of different strands of development is possible. Ideally, an economic evaluation with regard to the determining parameter and/or the relevant quality figures should be possible for each process of the model. Another still insufficiently solved problem is the estimation or even better, the calculation of costs for introducing both automation and standardisation. For the latter, the above-mentioned approach by [Bux96] can be used. For the discussed system model and in consideration of the imperative to introduce more than just one standard, Buxmann's approach has to be improved towards to an extended heterogeneous standardisation model.

The differences of the results of evaluations have to be presented in a plausible way in order to assist in deciding on the most potential strategy.

Finally, the issue of changing occupational images of the trade should also be addressed briefly. A higher degree of automation, which is naturally accompanied with a transfer of process control to control technology, puts increasingly different demands on the operator. Observing the whole production chain, the production of ads and editorial contents is, to an increasing extent, transferred to suppliers, such as ad agencies, or contents are published directly from databases. This way, the knowledge and skills of the staff have to become increasingly information-technological and automation-focussed. Although this leads to higher efficiency and to cost reductions, this development causes specialised printing skills or even specific newspaper printing skills to be lost. [IFRA2.37] Therefore, when putting the vision of an industrialised newspaper production into practice, particular care has to be taken in the adoption of the job profile, especially with regard to the training of competences in newspaper-specific issues as well as technical automation and information knowledge.

5. Conclusion and outlook

The discussion of the approach presented above leads to the unanimous assessment that an abstract model of a common newspaper production system is highly needed and possible to create. The present state of the developing model is audited both by authorities of the production management of printing houses and suppliers of management software. If the model has progressed to a state where it is accepted as a potential starting point for further development, the transition equations of the particular sub-systems have to be developed, providing they are not already available. This implies that there is a demand for research projects both in the technical and the economical field. However, for most parts, no new projects have to be initiated. It is often sufficient to re-evaluate the results of currently running as well as already completed projects, especially of the major standardisation projects of the branch of business such as the JDF project of the CIP4[11] consortium or the AdsML initiative, with respect to the implications for newspaper production. They supply the terminology for the well-defined discussion of problems and, consequently, the basis for the communication between applications and sub-systems of the production system. The newspaper standard ISO 12647-3:2004 contributes the pool of values for the achievement of trade-wide comparable standards of quality. When these specifications are realised in the trade as well as in the describing model, a significant step has been taken towards an industrialised newspaper production.

Finally, a few more aspects should be discussed briefly. It is safe to assume that, on account of the changing reception behaviour of the readers, the publishing houses have to broaden the production competence regarding valuable editorial contents and advertising contents towards multi-channel distribution. The production of printed matter, mainly the newspaper as the original stomping ground with well-established trademarks, will continue to be as it has been for at least a couple of years. Other distribution channels will be explored and exploited, probably as a joint work with presently competing media suppliers. Therefore, both publishing houses and printing houses have to attune to adjust the workflows, above all for premedia and prepress production steps. The awareness must prevail that the processes of these production steps establish the basis for the quality of both products and production for all subsequent steps, all distribution channels and therefore also the newspaper. Possibly, radically new production methods will arise and entail completely new procedures and applications. Therefore, the standardisation of the interfaces between the particular systems gains outstanding importance. In a prospective newspaper production system, the production managers are aware that all processes are subject to permanent change. The resulting requirements are met by the introduction of the especially qualified position of a process manager. The most important elements of production, i.e. the employees, will have to gain a thorough comprehension of the processes at the periphery of their actual workspace. They will be aware that the quality of their work influences both the quality of the subsequent work steps and, eventually, the product. Therefore they will be able to use provided instruments and inspection devices in a reasonable way to achieve the best results possible.

The approach is in so far visionary as the system of newspaper production within the borders discussed above will be both understood and managed in its entirety. This means that particular systems will be broken down into their underlying mathematic-physical and/or economical models and basic functions. All effects, most importantly the long-distance effects, resulting from the interlinking of the determining parameters will be described in the model. The linking of all elements in the production process will be completely standardised and the model derived its terminology, taxonomy and grammar from these standards. Adjustments on processes and the introduction of automation will be assessable and, at best, calculable with regard to their effects on the entire system. The abstract model shall serve as a basis for the derivation of enterprise-specific models. These shall provide means for the decision makers to decide about investments and the development of long-term strategies for their enterprise.

[11] CIP4 - International Cooperation for the Integration of Processes in Prepress, Press and Postpress Organization, see www.cip4.org

Acknowledgements

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Closed loop control of inking in newspaper presses

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1. Introduction

Inaccurate grey balance is a common quality problem in newspaper printing. In image reproduction generally, correct grey balance refers to the case in which grey objects are rendered neutral grey in the image and do not appear to be tinted with any hue. Grey balance is a significant factor in the visual quality of images, since the human visual system, though less sensitive to changes in chromaticities of saturated colour stimuli, is able to detect even comparatively small deviations from the neutral grey. Relatively small grey balance shifts may cause images to appear disagreeably unnatural, while the effect of similar shifts of purer colour stimuli to the perceived image quality may be negligible. Grey balance therefore has a high priority when controlling colour reproduction characteristics of newspaper presses, as well as other kinds of imaging systems.

Newspaper printing is a large-scale industrial process susceptible to many kinds of disturbances. During the make-ready phase of a printing run the ink feed must be adjusted according to the material being printed, so that the desired ink densities are achieved across all printed pages. However, the densities tend to drift from their proper levels throughout the printing run, as the printing process is affected by disturbances such as temperature changes and wear of the printing plates. Necessary adjustments to inking have traditionally been made manually by the printers based on visual evaluation or manual density measurement of print samples.

Closed loop control systems automatically adjusting inking based on on-line density measurement offer a means to reduce the labour-intensiveness of printing and to improve the colour consistency of the printed products. To accomplish this, the control system must be able to compensate for the drifting of ink amounts and other process variations that occur in newspaper presses by adjusting inking.

Although examples of commercial implementations of closed loop inking systems exist for other types of printing presses, until quite recently no suitable on-line measurement device was available for newspaper printing. The relatively high printing speeds and the large number of webs used in newspaper printing set special requirements for on-line measurement devices. The closed loop controller discussed in this paper relies on a recently released commercial densitometric on-line measurement device, the development of which has been previously presented by Heikkilä and Juhola (2001). The main principles of the closed loop control algorithm and its parameterisation are presented below, followed by results from its testing.

2. Principles and parameterisation of the closed loop control algorithm

The ColorSpector on-line measurement device (Data Engineering) measures intensities of light reflected from two thin grey bars printed across the pages at three different wavelength regions (corresponding to the spectral power distribution of light emitted by the red, green, and blue LEDs in the measurement device). Densities can be easily calculated from the intensity values. The control algorithms described here use intensity values directly, however. Therefore intensity values are also mainly used in this text.

One of the grey bars is a 1-ink grey (a black halftone), while the other bar is a 3-ink grey composed of cyan, magenta, and yellow halftones. The measurement results for the 1-ink grey bar can be used as a basis for controlling the feed of black ink. The contributions of cyan, magenta, and yellow, however, must be separated from the intensity values measured from the 3-ink grey bar. This is done in a separation step that predicts the intensities of separate CMY halftone components (as if they were printed separately) from the intensities of the 3-ink grey bar.

A block diagram of the closed loop control algorithm of inking is shown in Figure 1. The output of the press at time t, $y(t)$, is the intensity of light reflected from the grey strips on newspaper pages, as measured by the ColorSpector online measurement device. Intensity values relative to paper white are used. The task of the closed loop control system is to compensate for the disturbances, $d(t)$, by adjusting the inking so that the intensity (and thus density) of the grey bars is kept steady at the target, or reference, value $r(t)$. When successfully done, this guarantees that grey balance is maintained across all pages throughout the printing run.

The Controller block in the diagram depicts the main control algorithm. This block calculates the required adjustment to inking, $u(t)$, based on the current and previous errors, $e(t)$, between the target intensities and the measured intensities of printed grey strips. The controller is implemented as a classic PI controller.

The inking adjustment is calculated separately for each ink and inking zone. However, in practice the effect of adjusting inking at a single zone also affects the ink flow to the neighbouring zones to some extent. The Precompensator block compensates for these inking zone interactions, calculating a modified set of inking adjustments, $u_{pc}(t)$. This approximately inverts the effect of inking zone interactions, ideally cancelling them out.

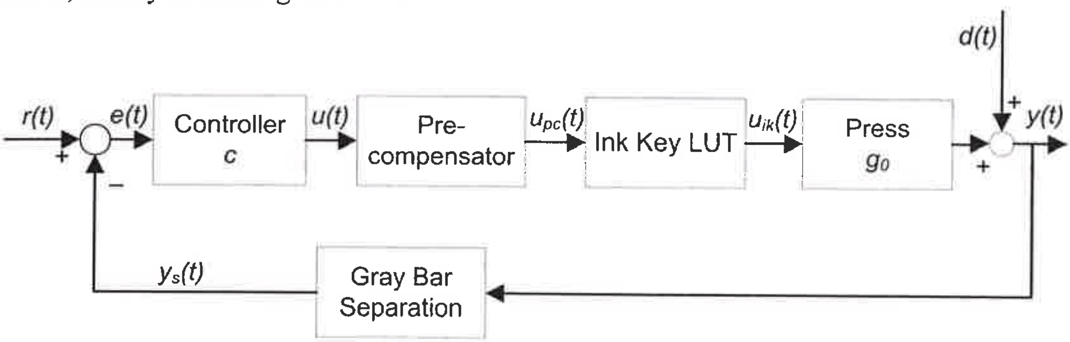

Figure 1: Flow diagram of the closed loop control system

The Controller and Precompensator blocks give the inking adjustments in relative intensity units. These intensity changes need to be transformed into corresponding adjustments of ink key positions. This is done via look-up tables for each ink in the Ink Key LUT block.

The contributions of the cyan, magenta, and yellow inks to the measured intensities of the 3-ink grey bar must be separated from each other, in order to control each ink individually. This separation is performed by the Grey Bar Separation block in the diagram.

The main control algorithm is a straightforward implementation of a PI controller, from the family of classic PID controllers. The output of the controller is calculated as a sum of proportional and integral terms:

$$u(t) = K_p \left(e(t) + \frac{1}{T_i} \int_{t=t_0}^{t_c} e(t)\,dt \right) \qquad (1)$$

The first term is linearly proportional to the current value of the error between the target and measured values of the grey bar intensity, or the predicted intensities of the cyan, magenta, and yellow halftone components of the 3-ink grey bar. The second term is proportional to the integral of the error from a given start time t_0 to the current time t_c, thus incorporating the error history into the equation.

The equivalent transfer function, calculated by Laplace transform, is:

$$C_{PI}(s) = K_p\left(1 + \frac{1}{T_i s}\right) \quad (2)$$

The parameterisation, or tuning, of the controller involves setting the values of the parameters K_p and T_i such that desired behaviour of the closed loop system is achieved. Since the system behaviour depends on the responses of both the controller and the press, the controller tuning must obviously be based on the characteristics of the press. Specifically, the step response of the press is used as a starting point in tuning the controller. The parameterisation procedure for this block therefore requires creating a step of suitable size at the press input by adjusting ink keys on a number of zones simultaneously, and measuring the resulting temporal change in the intensity of the 1-ink grey bar for black, or separate cyan, magenta, and yellow components of the 3-ink grey for these inks.

Typically compromises have to be made between the stability and speed of the controller. Figure 2 shows a modelled example of the step response of the closed loop system with varying gain K_p of the controller; press response and other controller parameters are constant. With low gain it takes the controller a long time to take the intensity value $y(t)$ to the new target level $r(t)$. With high gain, on the other hand, the target level can be reached faster but at the cost of overshoot and oscillations. Similar changes to the behaviour of the closed loop system can be induced by variations in the press step response. This needs to be taken into account in the controller design and parameterisation: the controller must be sufficiently robust to possible modelling errors of the press response.

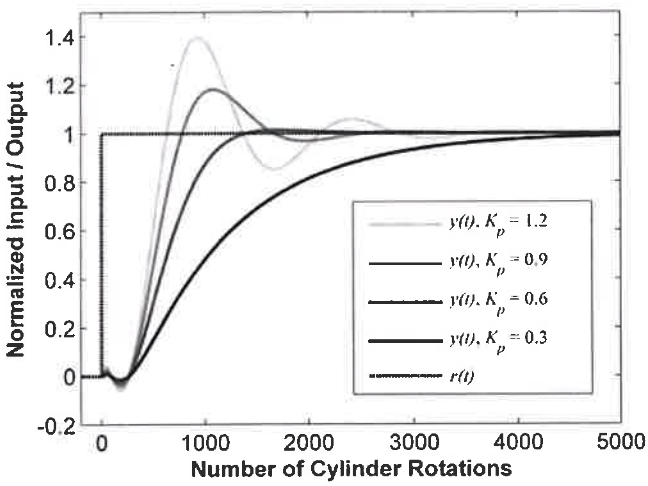

Figure 2: Modelled closed loop system step response with varying parameter K_p values

The effect of adjusting inking at a given ink zone to the ink flow to the neighbouring zones can be mathematically modelled by a convolution function:

$$u_c(x) = s(x) * u(x) = \frac{1}{M}\sum_{m=1}^{M} s(x-m)u(m) \quad (3)$$

Although the inking zone interactions naturally take place within the Press block of the diagram, in the notation of Equation 3 their effects are conceptually calculated as effective ink key positions. This serves the purposes of the pre-compensator, which compensates for the inking zone interactions before they occur in the press. Convolution of the actual ink key positions $u(x)$ with a convolution mask $s(x)$ representing the inking zone interactions yields the effective ink key positions $u_c(x)$. Inking zone is denoted by x, and M is the number of inking zones. In practice it is usually sufficient to consider interactions between neighbouring zones only.

The required precompensator must perform deconvolution to counter the effects of inking zone interactions. This is done by finding a convolution mask that approximately cancels the effect of convolving with $s(x)$. When applied to the controller output $u(x)$ the precompensator gives modified ink screw positions $u_{pc}(x)$. The press then, due to ink zone interactions, effectively convolves $u_{pc}(t)$ with $s(t)$. This results in the effective ink screw positions that are approximately the same as the original $u(t)$ from the PI algorithm.

In practice $s(x)$ can be estimated based on ink spreading to neighbouring zones, measured from printed test pages. This is done by introducing a step adjustment of suitable size to a single zone in the centre of the test page, and measuring the steady-state intensities of a grey bar at that zone and its neighbours before and after the step.

During each control round the controller decides how many intensity units each of the inks should be adjusted. These intensity adjustments need to be transformed into corresponding adjustments of inking expressed as changes in the ink key positions. This transformation is implemented as four look-up tables, one for each of the CMYK inks. The look-up tables are built by simply fitting a line to a set of experimental data. It is thus assumed that an approximately linear relationship between the ink key steps and intensity changes exists in the proximity of the chosen operating point. When ductor control is to be used, separate look-up tables have to be built for ink screw (or ink pump) and ductor adjustments.

The ColorSpector measurement device uses red, green, and blue LEDs to measure the intensity of light reflected from printed newspaper pages at three spectral channels, corresponding to the wavelength regions of the LEDs. Thus each measurement gives three intensity values, denoted here by R (red channel), G (green channel), and B (blue channel). Any of the three values of the intensity vector for 1-ink gray, $[R_{g1}\ G_{g1}\ B_{g1}]'$, can be directly used as the press output value for the control of black ink. However, each element of the intensity vector measured from the 3-ink gray bar, $[R_g\ G_g\ B_g]'$, bears some contribution from each of the cyan, magenta, and yellow halftone components of the gray bar. Therefore a separation transform is needed to allow the chromatic inks to be controlled in individual control loops.

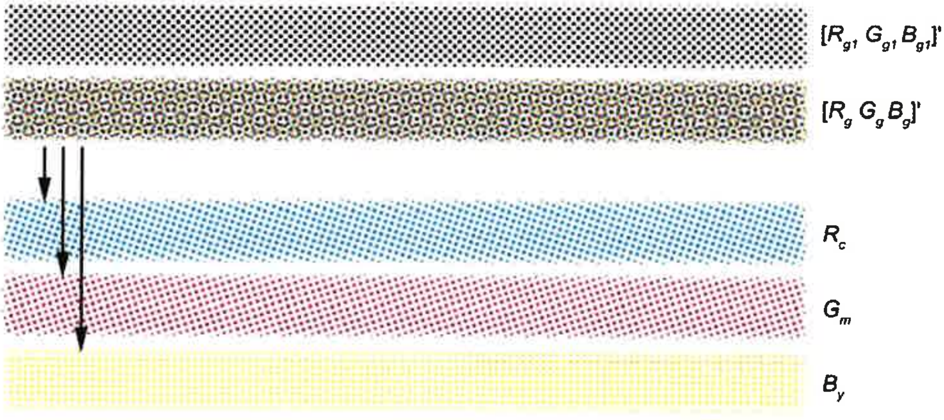

Figure 3: Principle of 3-ink grey bar separation

The principle of the separation of the 3-ink grey bar is shown in Figure 3. A transform matrix of the kind shown in Equation 4 is used to predict from the three intensities of the 3-ink grey bar the intensities R_c, G_m, and B_y, that would have been measured from the cyan, magenta, and yellow components, respectively, of the grey bar if they had been printed and measured separately.

$$\begin{bmatrix} R_c \\ G_m \\ B_y \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \end{bmatrix} \begin{bmatrix} R_g \\ G_g \\ B_g \\ 1 \end{bmatrix} \qquad (4)$$

R_c indicates the red channel intensity of the cyan halftone, G_m the green channel intensity of the magenta halftone, and B_y the blue channel intensity of the yellow halftone. Parameterisation of the separation transform calls for specification of the values for the elements a_{ij} of the transform matrix. The parameterisation is done by fitting the parameter values to a set of experimental data measured from the 3-ink grey bar and separately printed CMY components.

3. Testing of the closed loop control prototype with a press simulator

The controller was first tested with a simulator software application developed for this purpose. First simulations concentrated on finding any problems in the implementation of the control algorithms. The emphasis then turned to testing the behaviour of the controller and the simulated closed loop system with different types of control parameter settings and simulated disturbances and modelling errors. After a satisfactory system performance and understanding of the effects of different kinds of parameter choices had been achieved in the simulations the controller was installed in a newspaper printing plant. With the system installed and working automatically, the performance of the system was tested in separate test printings as well as in normal production printing.

The first examples show the simulated system behaviour under different kinds of disturbances with nearly optimal controller parameter values. Naturally, there can be several criteria for deciding what is an optimal behaviour of the system. Typically tradeoffs have to be made between control speed and robustness. Here the parameters were chosen so that the control was as fast as possible without significant oscillations.

It can be seen in Figure 4, which shows the response to two opposite step errors for black ink, that the controller takes the intensity values of the 1-ink grey bar smoothly back to the target level of 0.5. The thick line depicts the intensity of the grey bar and the thinner line is the position of the black ink screw (also in relative intensity units). The ductor controls were fixed to produce the target intensity of 0.5. The controller was set to react to any deviations from this value by adjusting the ink screws only. The ink screw positions are given as relative positions around zero, so that with ductor set to 0.5 and all the screws to 0.0 the output steady state intensity without disturbances would be 0.5. This was the case at the beginning of this example at 2000 seconds. A step error of 0.1 intensity units was then introduced at 2040 seconds. The disturbance was identical across the neighbouring inking zones. Therefore the controller response was also the same at each zone, the inking zone interactions having no effect in this case.

The initial controller response to the step error is determined by the factor K_p in the proportional term of the PI controller. Because a rather conservative value of 0.6 was used the initial ink screw adjustment corresponds to 60% of the magnitude of the current error. The effect of the integral term then kicks in and the adjustment is increased as the error persists. When the press simulator starts to respond to the control after the dead time the error starts to decrease. The ink screw settles on the proper position to compensate for the disturbance and the intensity of the grey bar returns to the target level.

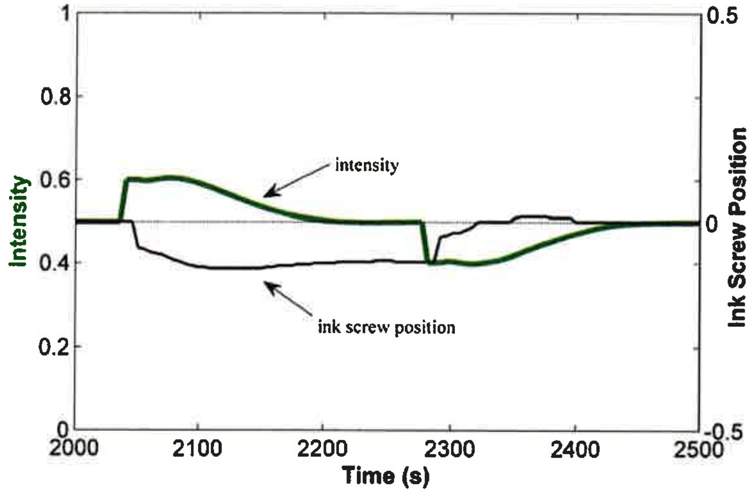

Figure 4: Simulated closed loop control system response to step errors for black ink

At 2280 seconds the previous step error is removed, effectively causing another disturbance to the system. As the system was adapted to compensate for a disturbance that was suddenly removed a step error in the opposite direction results. The controller then takes the intensity back to the target level by readjusting the ink screw.

Instead of sharp step errors, slow drifting of the output intensities is more likely to be encountered in practice during printing runs. The simulated system response for this kind of disturbance is depicted in Figure 5. At 700 seconds the intensity of the 1-ink grey bar is steady at the target value of 0.5. The effect of the drift type of disturbance starts at 720 seconds. The disturbance grows linearly at a constant rate from there to 1020 seconds, after which it stays at 0.1 units. The intensity would thus have been 0.6 at that point without control. The controller, however, starts to adjust the screw more and more as the disturbance grows. Due to the relatively fast rate of increase of the disturbance relative to the delay in the press response the intensity of the grey bar does rise above the target value, although the controller is pulling it back in the opposite direction. When the drifting stops after 1020 the controller is able to take the intensity all the way back to the target level. The drifting encountered in practice is likely to be so slow that it can be compensated well before the effects on printed pages can be detected visually.

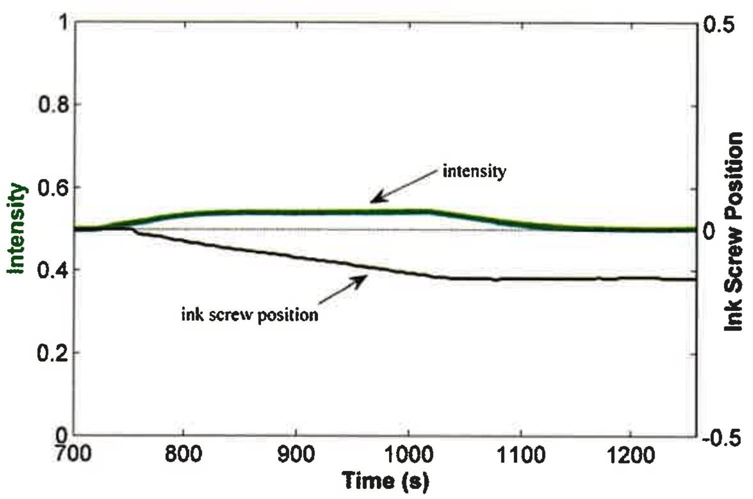

Figure 5: Simulated closed loop control system response to drift for black ink

So far the disturbances used in simulations have been identical over all inking zones. In the next example (Figure 6) a positive step error is introduced at zones 1-5 and a negative step error at zones 6-10. This sample starts from an even intensity profile across the page, the intensity at all zones being at the target value of 0.5 before 2500 seconds. The step error with magnitude of +0.1 intensity units is then introduced at 2520 seconds at zones 1-5. A step error with magnitude of -0.1 intensity units is simultaneously introduced at zones 6-10. The visual effect is to make one half of the grey bar too light and the other half too dark. The controller then brings the intensities on both sides smoothly back to the target intensity, thus restoring the desired appearance of the printed pages with uniform density across the page.

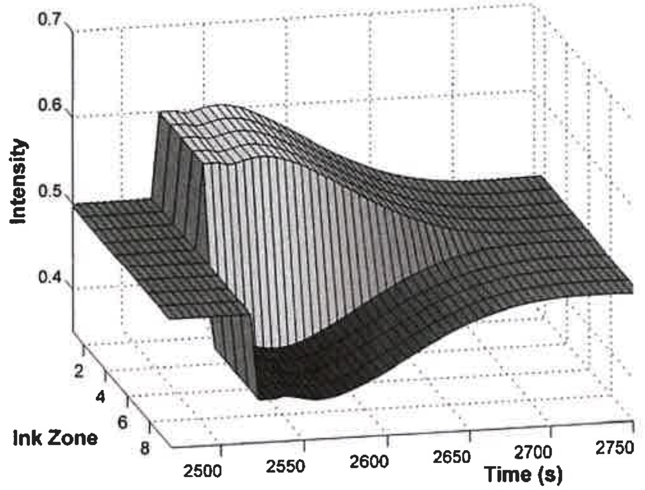

Figure 6: Opposite step errors creating a sharp edge between neighbouring inking zones. Simulated closed loop system response for black ink

The need for the precompensation of inking zone interactions is not directly evident from the graph of intensity values. Precompensation is needed, however, to achieve a grey bar with a smooth intensity profile after a disturbance with a sharp edge between inking zones is introduced to the system. This can be seen in the graph depicting corresponding ink screw positions in Figure 7. The ink screw positions required to achieve the even intensity profile of the previous figure can be best seen by examining the cross-section in the front part of the figure (after 2700 seconds). The effect of precompensation algorithm is most evident on both sides of the steep edge between zones 5 and 6.

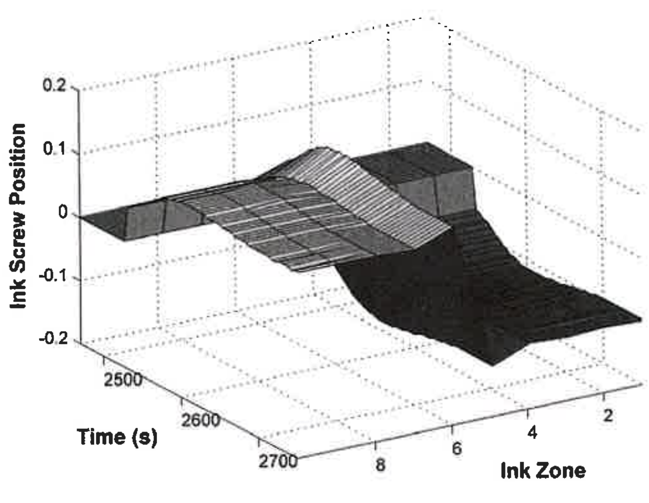

Figure 7: Opposite step errors creating a sharp edge between neighbouring inking zones. Ink screw positions in relative intensity units

Figure 8 provides yet another look at the data from the simulations, this time concentrating on the control of the cyan, magenta, and yellow inks. The thick lines depict the intensity values measured (simulated) from the 3-ink grey bar at three different wavelength regions (corresponding to the red, green, and blue LEDs in the online measurement device). The thinner line shows the position of the magenta ink screw. In the beginning of this timeline the intensities are at their target values. At 3240 seconds a step error affecting magenta ink only is introduced. The effect of disturbance is most evident on the green measurement channel but is not restricted to it: the blue channel intensity of the 3-ink grey bar is also considerably affected, and a slight change takes place on the red channel intensities. If the control was based on direct measured values, the inking would in this case have erroneously been adjusted for all of them. Here the separation algorithm, however, correctly isolated the adjustment need to the magenta ink. Thus only the magenta ink screw was adjusted, and this compensated for the disturbance and all three intensity values of the 3-ink grey bar returned to their target levels.

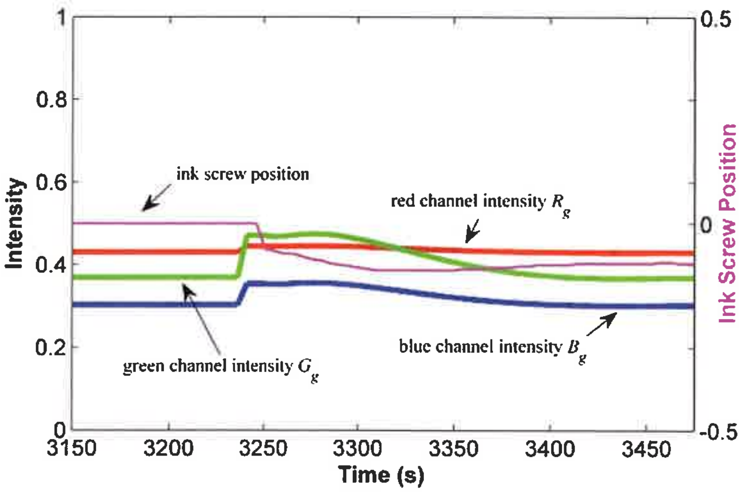

Figure 8: Step error for magenta ink. Simulated intensities of the 3-ink grey bar at red, green and blue channels, and the position of the magenta ink screw

4. Testing of the closed loop control prototype in a newspaper press

The behaviour of the closed loop system was examined in test printing runs in a newspaper press. In these tests different types of disturbances were created manually by adjusting certain ink screws on the press control desk to see if the closed loop control system could correct the resulting deviations from the target densities. In the test printings the control parameter values were also varied to gain practical experience of their effect on the system behaviour. The ability of the system to maintain the density levels during a longer time span was tested in the production printing of the Helsingin Sanomat newspaper. Representative examples of the closed loop system behaviour from these printings are shown below.

The first examples from the test printings involved only black ink. Data from the control of all CMYK inks in the test printings are then presented. Finally, data from the closed loop control of black ink in the production printing will be shown.

Figure 9 shows the response of the closed loop control system to a step error caused manually on several zones. The measured intensity of the 1-ink grey bar and the black ink screw position from a single ink zone are plotted in the figure. The manual error was made at approximately 20 seconds. The ink screw was closed by approximately 10 steps. The step error made by the printer at the press input did not cause a sharp step in the output intensities as it was subject to the input-output delays of the press. Since the controller was active when the error was made it could adjust the ink screw position before the full effect of the error was evident in the measured intensities. It can be seen in the plot that the intensity remains at the target level for some time after the error was made. The controller naturally makes no adjustments during this dead time, the intensity error being zero. After the dead time the closing of the ink screw by the printer starts to cause less black ink to end up on the printed pages. This in turn makes the grey bar lighter, increasing its measured intensity. Now the magnitude of the error term in the controller starts to increase from zero. This causes the controller to adjust the ink screw, opening it to allow more ink to flow onto the printing plate, thus making the grey bar darker. The first adjustment by the control program was done at ~70 seconds. The adjustment does not immediately affect the printed pages, the intensity still increasing due to the earlier manual error. As the error increases the controller opens the screw more. At ~190 seconds the adjustments made by the controller start to bring the intensity down towards the target value. The intensity of the grey bar is eventually brought back to the target value.

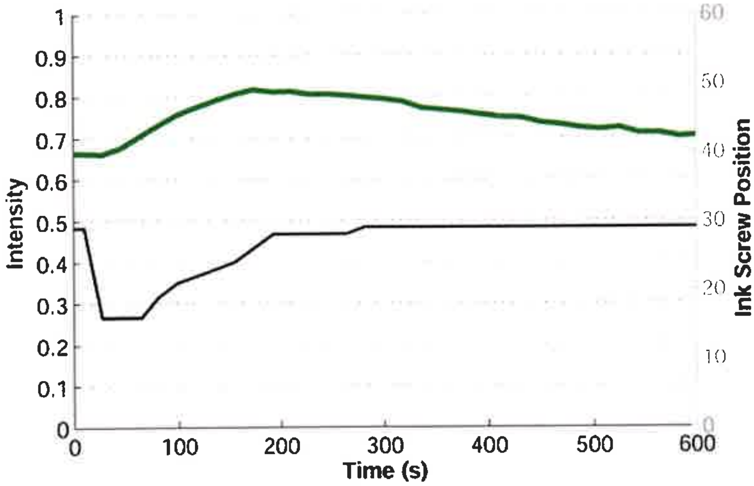

Figure 9: Closed loop system response to manual step error, 1-ink grey bar intensity (thick line) and ink screw position (thin line) from a single inking zone

The system response in the previous example was relatively slow, due to a conservative choice of PI controller parameters. System response with more aggressive parameters is shown in Figure 10. The closed loop controller was turned off when the manual error was made by the printer. The controller was turned back on only after the steady state value after the disturbance was reached. From the controller point of view this is seen as a sharp step at the output, so this example effectively shows the step response of the closed loop system. The step error has taken place before the zero of the timeline in the figure and the controller was turned on within the range from zero to 20 seconds. The controller, once turned on, sees the intensity of the grey bar being ~0.57 units and thus below the target value and immediately closes the ink screw. As the error is not immediately corrected, due to press delay, the integral of the error grows and the controller increases the ink screw adjustment. The controller behaviour is more aggressive than before and the target intensity value of ~0.63 is reached sooner. There is even slight overshoot before the output settles on the target. The controller took the ink screw position below the final level and then opened it again once the intensity got closer to the target. This is in line with the simulated and modelled system behaviour, and allows the target intensity to be reached faster.

In Figure 11 the system response to a step error for magenta is shown. The three thick lines depict the intensities after the separation step. The results from the test printings indicate that the separation algorithm of the grey bar was reasonably accurate. In the current example a step error for magenta ink screw (whose position is indicated by the thinner line) was done manually at ~10 seconds, the screw being opened from ~35 to ~55. The resulting darkening of the 3-ink grey bar is reflected only on the separated green channel intensities, as it should be. The red and blue lines show only the typical noise. The controller, using these separated values as the basis for control, correctly adjusts only the magenta ink screw and manages to bring the separated green channel intensity back to the target value of ~0.71 intensity units.

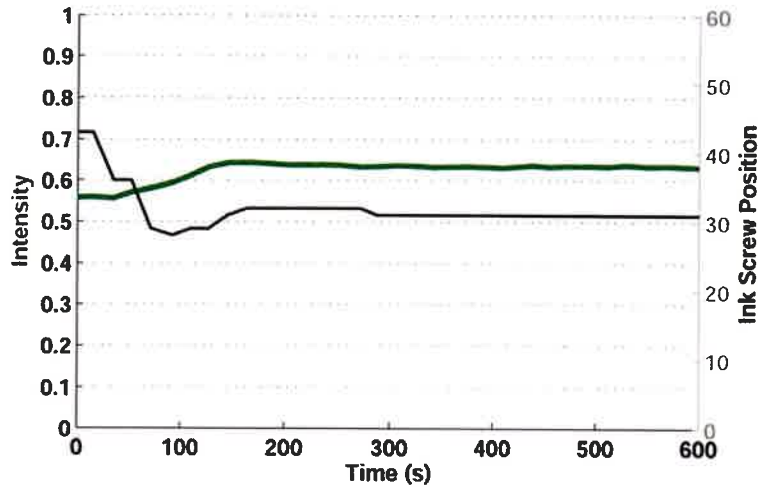

Figure 10: Closed loop system response to manual step error, 1-ink grey bar intensity (thick line) and ink screw position (thin line) from a single inking zone

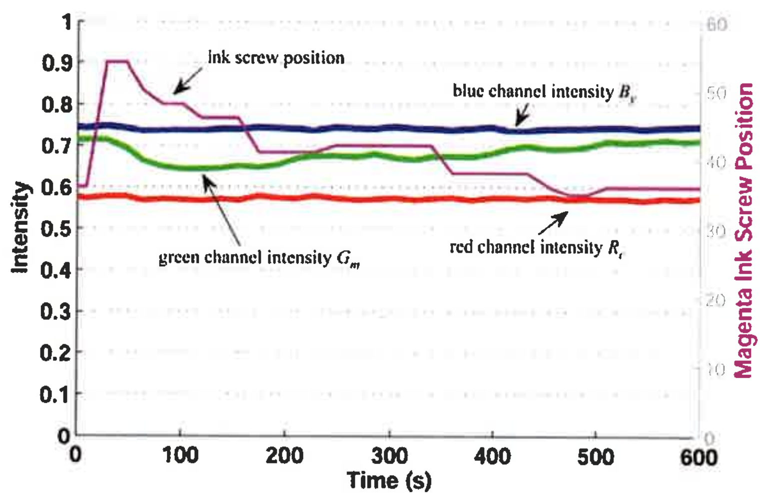

Figure 11: Closed loop system response to manual step error, 3-ink grey bar separated intensities and magenta ink screw position from a single inking zone

Let us then examine the system response at multiple ink zones simultaneously. Figure 12 shows the system response to a yellow step disturbance. The printer manually closed the yellow ink screws between zones 10 and 15. As evidenced by the lighter bump in the graph at these zones, this disturbance increased the intensity of the "yellow bar" predicted by the separation transform based on the intensities of the 3-ink grey bar. The controller then started adjusting ink screws to correct the error. It can be seen that the intensities were returned to approximately same levels where they were in the beginning of this example. Note that the target intensity profile across the 20 inking zones that the controller tried to maintain was set according to the measurements done after the printers had manually set the proper density levels. The closed loop control can in this case be considered successful since the differences in the original intensity profile were maintained.

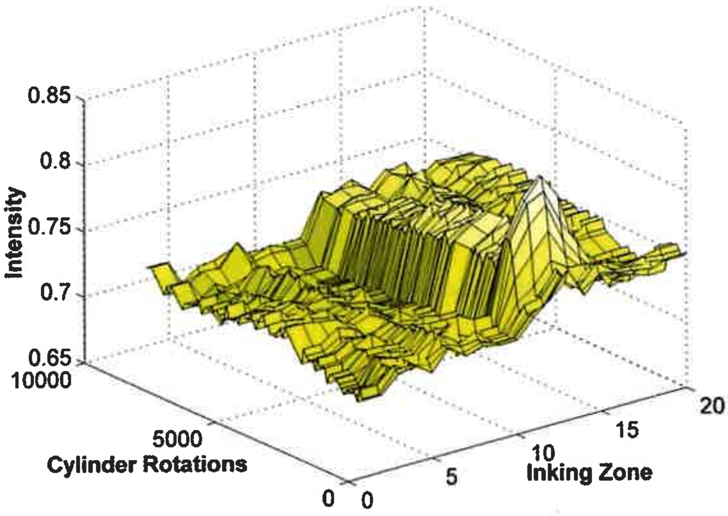

Figure 12: Closed loop system response to manual yellow step error at multiple inking zones, separated blue channel intensity of yellow from 20 inking zones

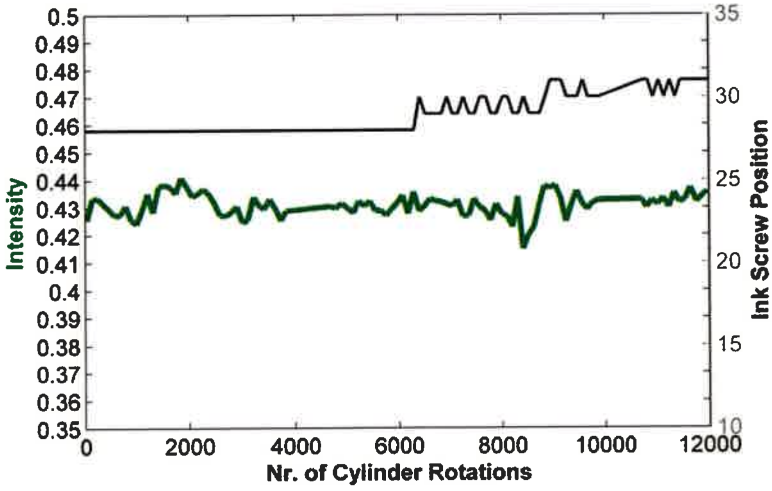

Figure 13: Ink screw position (thin line) and intensity (thick line) of 1-ink grey bar at inking zone 24 during production printing, inking controlled by the closed loop system

Finally, the long-term performance of the controller in maintaining the density levels was studied in production printing. After the proper density levels had been achieved after the start-up the control program was taught the prevailing intensities of the 1-ink grey bar as the target values that should be maintained. The closed loop control was then turned on at 10 inking zones, corresponding to the width of a newspaper page.

Figures 13 and 14 show the black ink screw positions (thin lines) and intensities of the grey bar (thick lines) at zones 24 and 25, respectively, during the production printing as examples of the behaviour of the closed loop system. It can be seen that the variation of the intensity values stays comfortably within 0.01 intensity units. In this range the intensity difference of 0.01 corresponds approximately to the density difference of 0.01, a change so small that it would not be observed visually. The ink screws were adjusted only slightly from their original positions (3 steps maximum in both of these examples), so the print quality would in this case have been acceptable even if no screws were adjusted.

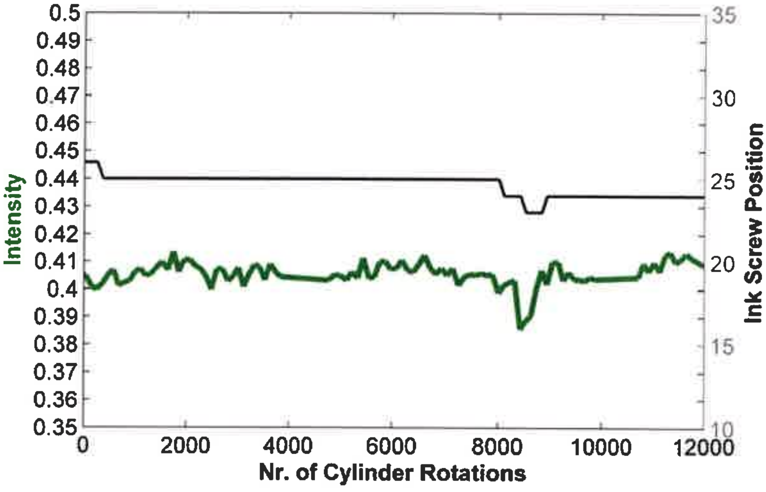

Figure 14: Ink screw position (thin line) and intensity (thick line) of 1-ink grey bar at inking zone 25 during production printing, inking controlled by the closed loop system

Finally, Figure 15 provides a 3-dimensional view to the intensities at all of the zones controlled by the prototype program. It is evident that the original intensity profile of the grey bar across the page was maintained fairly accurately throughout the production printing run. The closed loop controller was not seriously challenged at any point, as can be seen by studying the ink screw positions of these zones during the printing in Figure 16: only slight adjustments were needed and none of the screws was adjusted beyond a few steps away from their original positions. Statistical analysis of measurement data from multiple printing runs over a longer time period would be required to gain more information about the performance of the closed loop control. At this point it can be said that the system output, the ink densities on the printed pages, remained at correct levels and that the control prototype showed no unexpected behaviour.

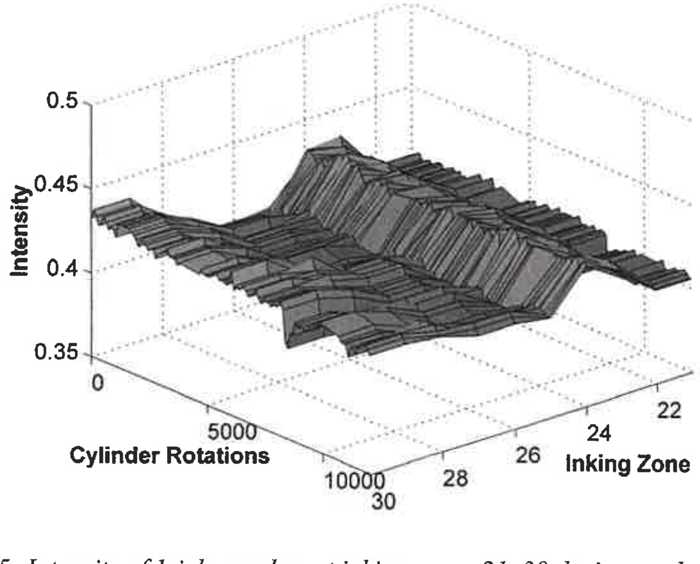

Figure 15: Intensity of 1-ink grey bar at inking zones 21–30 during production printing, inking controlled by the closed loop system

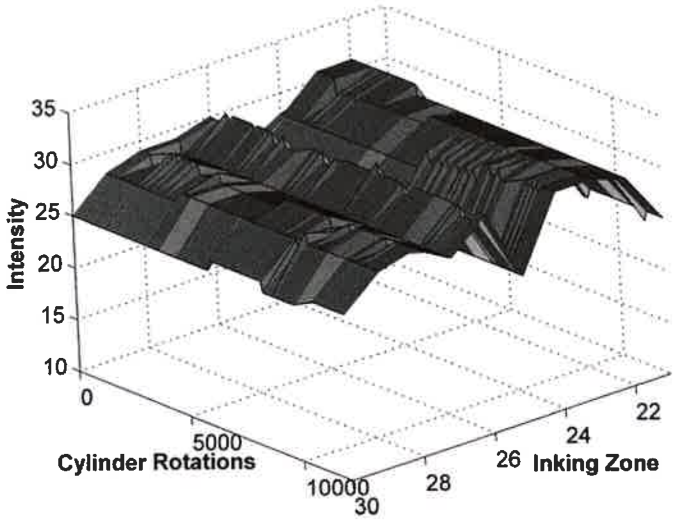

Figure 16: Ink screw positions at inking zones 21-30 during production printing, inking controlled by the closed loop system

5. Discussion

The examples shown above, although containing just a small portion of all data, are representative of the performance of the control program in the test printings. Same kinds of effects were generally experienced in genuine test printings as in simulated printing runs. Various parameter value combinations were experimented with in the test printings, the results being mostly predictable: for example, more aggressive PI control parameters resulting in a faster response but also inducing oscillatory behaviour, even instability in a few extreme cases. With some experimentation proper parameter values, resulting in satisfactory system behaviour, could be found.

It is typical in process control development that iterative work is required. In order to enhance the performance of the closed loop control system the behaviour of the system must be observed in practice and parameter values and possibly the algorithms adjusted to overcome any shortcomings. It should, however, be possible to develop an automated parameterisation program utilising on-line measurement of specific test pages that would deduce the response of the press by adjusting the inking controls and continuously measuring printed pages. The parameterisation program would then automatically analyse the results and arrive at parameter values that would give satisfactory results in the closed loop control of inking. While it is to be expected that some modelling error is always present, such a parameterisation scheme would remove the need for time-consuming manual parameterisation work and likely provide a more accurate model of the press characteristics. This would be useful in further research and especially from the point of view of simplifying the installation procedure of commercial closed loop control systems.

One major factor governing the press response to adjustment of inking is ink consumption at that particular zone. In the tests a single set of global PI controller parameters was used for all zones, implicitly assuming that the press response would be reasonably typical at all zones. Problems may arise, however, if excessive amounts of ink are fed to zones with very low ink consumption, for instance. In that case it would take a very long time for the excess ink to be consumed, making that zone quite unresponsive to controls for a long time. Avoiding considerable overshoot thus seems an appropriate approach when tuning the controller.

The above considerations are connected to the robustness of the closed loop control system to modelling errors. Generally, some of the speed of the closed loop control system can be sacrificed to guarantee that the system performance is still acceptable when the press response deviates from what was assumed when the control parameters were set. On the other hand, improved knowledge about the behaviour of the press reduces the uncertainty in parameterisation, and less margin needs to be reserved for variations of press response.

6. Conclusions

Algorithms for closed loop control of inking in newspaper printing were developed and implemented. The controller prototype program was first put through a round of laboratory testing using a press simulator software, which was developed to simulate the response of the press to commands given by the controller under different types of disturbances. The controller prototype was installed in a newspaper press for further testing and development in genuine conditions. The performance of the controller in the tests was encouraging after proper parameter values were found.

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Quality assured digital media interchange between press and post press using JDF

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1. Introduction

This technical paper describes work done by using JDF as architecture for quality assured information exchange. Whereas much QA work in the graphical arts industry has been focusing on technical aspects, the work described in this paper emphasises the logistical and commercial challenges of the workflow. The objective for the activities is to ensure that the JDF standard is operable for MIS to MIS communication, and to use it for quality assurance.

The work described in this paper has been done in the KDI Project ("Kvalitetsikker Digital Informasjonshandtering"), a three year project supported by The Research Council of Norway. The project does research in quality assurance in the printing industry, particularly the areas of colour management (not reported here) and in business processes.

2. Background

Today the traditional value chains in the graphical art industry are distributed. A few years ago most newspapers had their own printing press. Today one or a few newspaper presses prints all the local newspapers and national newspapers are printed by several printing houses. This increases the requirements for Quality Assurance of the processes.

In the area of technical Quality Assurance much work has been done, and several tools and products exist. The use of architecture such as ColorSync and the concretisation into ICC profiles has made colour management possible and more and more used. In this and other technical areas much progress has been made, although improvements in tools and a more general deployment will be welcomed.

In the area of general workflow management, especially in the handling of logistical and commercial metadata, the results are less prominent. Paper based workflows, post-it notes and telephone messages are still common. The KDI project, in cooperation with the CIP4, is aiming at defining and enabling a quality assured information exchange using JDF.

3. A typical workflow

The example of a value constellation described in this paper includes Hjemmet Mortensen Publishing House (HMF), Hjemmet Mortensen Printing House (HMT), Gan Printing House (GT), Lundeby PostPress (LB) and several other partner delivering inserts to magazines. These inserts can come from other companies in the graphical art industries, but also items such as garden glows, sun-glasses etc are handled as inserts to different magazines.

The process of documenting the work flow used was far from easy. Although the formal relationship between Publisher, Printer and Post-Press was clear, the actual workflow is a bit tingled up and sometimes informal and versatile.

A typical scenario is as follows. HMF monthly magazine "Home and Garden" is scheduled for April. The body will be printed by HMT while the cover is printed by HMT's subcontractor GT. LB do the binding, inserts, packing and distribution. In addition to the regular magazine, a printed inserts from a 3rd party, offering subscription, will be added for all retail copies (not sent to subscribers), while a set of gardening glows and a bag of seeds will be packed with all copies for the south of Norway.

All elements needed for the finalised products (notice the plural, although this is "THE April Number" as seen from the readers point of view, there are four products, two for retail and two for subscribers) arrive directly to LB. If all goes well, all pallets arriving are marked with information about magazine and issue.

4. JDF compatibility

The JDF 1.2 specification covers 550+ pages. Few, if any vender claiming "JDF compatibility" Implements the entire specification. Doing so would not be practical. A printing machine and a plate setter do different tasks, and a requirement that both should implement the same functions, although one of them could not use it, does not make sense. CIP4 therefore define "Interoperability Conformance Specifications" (ICS). These are subsets of JDF suitable for certain tasks or for certain areas of the production chain.

The KDI project focuses on the interchange of information between processes in the value chain between organisations or between different organizational units within one company. Much of this communication will be between Management Information Systems (MIS) of different companies. In the near future data will be sent from a customer to a vendor as a JDF file. The JDF file will be parsed by the receiving MIS which updates its database with the information from the JDF file. The human operators of the MIS should never see JDF files, all information should be kept in the MIS database, and shown through the MIS user interface. JDF is simply an interchange format. When "MIS 1" needs to update "MIS 2" a JDF file is generated and sent. The MIS vendors therefore needs a MIS to MIS ICS specification from the CIP4, to be able to programme there MIS software to have this specified capability.

While some information may be equally important for all users of MIS system (such as customer name, product name and delivery time and place) at different steps in the value chain, some information is specific to a process. Different process information is required between prepress and press verses between press and post-press. The notion of one "MIS to MIS ICS" therefore, is somewhat optimistic. In the KDI project one of the sub goals has been to define a press-MIS to post-press-MIS ICS that satisfies the information flow in work flows similar to the one described in chapter 3.

5. Defining the elements of Press-MIS to Post-Press-MIS ICS

Once JDF was chosen as the architecture for quality assured handling of digital content, the next KDI process was to define what information would be necessary to order and process products of the type delivered by LB.

The concrete result of this process is an Excel workbook with several worksheets as shown in Figure 1.

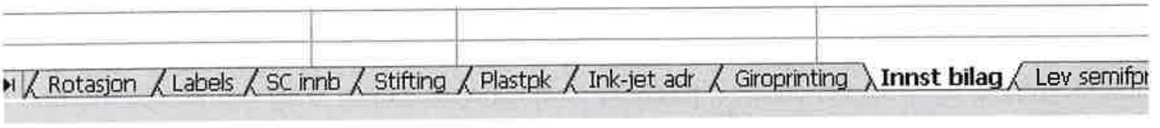

Figure 1

Each of the worksheets contain several information types, like the Norwegian name of the attribute, the English name, a reference to relevant JDF resources and so on (Figure 2).

Field Name	JDF Element	Atteribut	Comments
Insert ID/serial number			
Version			
Method of attachment (?)	InsertList	BlowIn/BindIn	> do not cover all our needs
Total number of pages	LayoutIntent	Pages	If Insert is a folded, trimmed and stitched sheet e.g
Format	LayoutIntent	FinishedDimensions	(measured in points= ??mm)
Advertiser	Contact	ContactTypes	
Product code			
Product name			
Description	**InsertingIntent**	GlueType	(permanent, removeabel)
	InsertingIntent	Method (BindIn, BlowIn)	= loose or fixed
Placement in product	**InsertingParams**	InsertLocation	(look up; capter 7.2.89)
dispersion			
Number of inserts ordered	**PhysicalResource**	AmountRequired	
Number of inserts received			
Accomplished number of copies	**PhysicalResource**	AmountProduced	
Weight in gram	**PhysicalResource**	ResourceWeight	
Approved dummy-attachment			
Approved dummy-attachment			
Deadline for ordering			
Status of deliverance			
Deadline for deliverance of			
Received date from finisher			

Figure 2

As an example, InsertList is defined by JDF 1.2 under “7.1.9 InsertingIntent”.

The resource specifies the placing or inserting of one component within another, using information that identifies page location, position, and attachment method. The receiving component is defined by a ProcessUsage attribute of “Parent”. All other input components are mapped to the Insert elements by their ordering in the ResourceLinkPool.

Once this workbook had been compiled and reevaluated, contact was made with the CIP4 organisation for quality assurance, and for discussions on the fields not mached in the JDF standard.

Once the parameters to be used for QA had been chosen, ranges for acceptable values were defined. Then rules were defined, what to do when values are within range and what to do when they are out off range. JDF does not offer any help in this prosess. JDF does not know if 20000 copies is a reasonable volume. Or 2000. JDF does not now what to do if it is 20000 but should be max 5000. The framework helps to describe the QA parameters in a standardised form when interchanging information. What to do with this information is still up to the MIS system or the human operator.

6. Results of the activities

Anyone visiting DRUPA 2004 knows that "everybody and his brother" are JDF compatible. None of the "JDF compatible" MIS vendors we talked to at DRUPA had any JDF based MIS to MIS communication to show us, nor concrete plans for such communication. What was shown was how the MIS (a "JDF controller / agent" in CIP4 terminology) could communicate to some printing press or other device (a "JDF Device / Machine" combination). This is of cause interesting. But it does not solve the quality assurance issues in MIS to MIS communication.

The project did present its ideas and results at the CIP4 meeting in Heidelberg in January 2005. The workflow described in chapter 3, "A typical workflow", was reported to have emphasised the need for sub-contracting in JDF 1.3. It was also discussed in the MIS to MIS working group, and with vendors of finishing equipment. Currently the KDI project is co-championing the issue of subcontracting in the CIP4 MIS working group.

Among the participants in the KDI project are the two MIS vendors Novavision and MPS Graphics with their respective products PrintViz and eGraph. As part of the project, these MIS vendors have implemented a JDF based MIS to MIS "proof of concept demonstrator" workflow. The demonstrator lets an operator enter a job in one of the MIS systems, describing the job to be done. Once finished the operator ask the system to generate a JDF that is sent to the other system. This file is imported by the other MIS, and all information from the file can be displayed in this system. Although this is still just a proof of concept implementation, once JDF 1.3 is released and the MIS to MIS ICSes are defined, this "proof of concept" shows that full standardisation of MIS to MIS communication with JDF is feasible.

The KDI project shows that JDF can do more than controlling equipment, and although this is of high importance, it is not the only use of JDF. The workflows defined in the project and the specification of fields and values suitable for Quality Assurance based on JDF shows that the implementation of MIS to MIS ICSes in MIS system could increase the quality level of graphical production.

7

Inks and inking

The development of a six colour ink system for enhanced colour gamut

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Abstract

This paper reports on the development of a six colour ink set for the rendition of multi coloured images. The six colours are defined as green shade yellow, red shade yellow, green shade blue, violet shade blue, a blue shade red and a yellow shade red which allow darkening without desaturation of the colours. An image containing custom test forms was printed using offset lithography and measured using a scanning spectrophotometer. Photographic images were also printed with the ink set as well as the CMYK and Hexachrome ink sets. The colour gamut produced by the ink set was large, achieving over 95% of pantone colours. The colour gamut excelled in the violet blue region of colour space but showed some deficiency in the green region of colour space. A strategy for the future development of the ink set is made based on the experimental findings.

Keywords

Colour, gamut, ink

1. Introduction

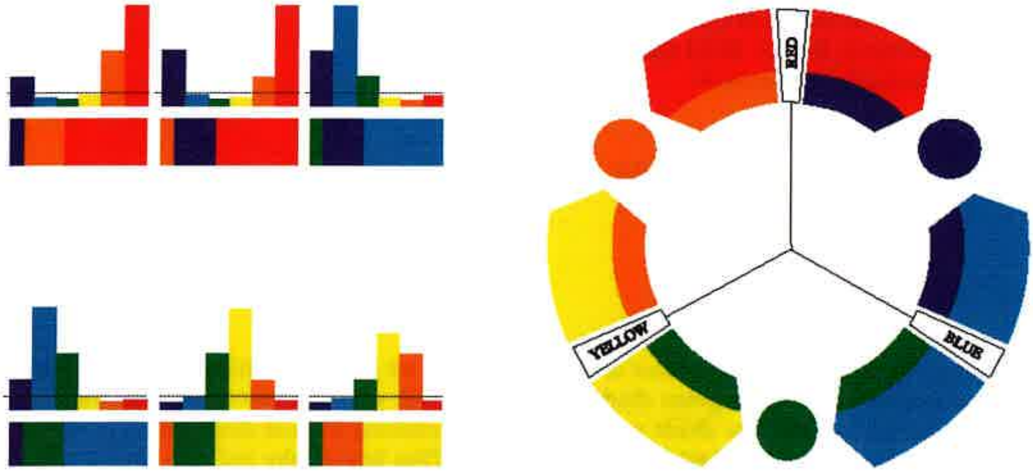
The limited colour gamut of CMYK is well documented [1, 2] and as such there is scope for improving the rendition of colour by printing. In order to widen the colour gamut numerous commercial products have been launched, e.g. Hexachrome [3] and Opaltone [4]. Both these system provide more or less a standard CMYK with the addition of other colours (Green & orange for hexachrome, RGB for Opaltone) to produce the increased colour gamut. Darker colours are achieved by the addition of black to the underlying colour. This not only reduces the lightness of the colour but also reduces the saturation of the colour as the darkening is applied across the entire colour spectrum, making deep, strong colour difficult.

An alternative approach is to utilise a base set of colours which naturally darken each other without loss of saturation. This strategy has been employed in the production of the ink colour system for the printing and packaging industry and is based on the 'bias' or 'leaning' of established ink colours. The ink colours selected are a green shade yellow, red shade yellow, green shade blue, violet shade blue, a blue shade red and a yellow shade red (henceforth named the Wilcox 6 or W6), Figure 1. These six colour represent a set of inks whose reflectance is dominant over the range within the visible spectrum, Table I.

Table I: Peak reflective wavelength of the six colours

Violet-blue	Green-blue	Green-yellow	Orange-Yellow	Orange-Red	Violet-red
400–440 nm	420–490 nm	490–550 nm	550–590 nm	590–620 nm	610–670 nm

As the printed colour relies on light absorption, then the mixing of any of these colours will lead to the common colour (e.g. the green in the blue and yellow) to become dominant. For example, the addition of the violet shade-blue to the red shade-yellow produces a dark green which has not been reduced in saturation as would be the case with a black darkened green.



(a) - The spectrum for a variety of colours from the 6 inks with reflective distinct wavebands

(b) -The colours illustrated in a "colour bias wheel"

Figure 1: The principals of colour mixing used in the 6 colour ink set

While this concept is effective in mixing paint, colour printing relies on the transparency of each ink film layer and therefore there is a need, as part of the development, to establish the gamut that could be obtained by overprinting halftones of these inks. Further details of the colour theory including full spectral data for the inks used in the formulation and the application to printing is available, ref [5].

There are two practical applications for the use of the enhanced colour set in the printing industry. It could be used as a standard set of ink colours for the printing of separated images on a six colour press. It could also be used as a standard ink set from which spot colours are mixed; eliminating the need to keep a large inventory of ink colours. The methodology used in the development of these applications is given in this paper.

2. Method

The pigment types for the ink were selected from commercial organic pigments and these were incorporated into a lithographic ink vehicle. The formulations for the inks were not optimised for their printing performance (in terms of rheology, tack etc) for each colour as the primary objective was to assess the role of ink colour on reproducible gamut.

In order to fully examine the printable colour gamut obtainable in a six colour print a series of test forms was designed. The test form design was a balance of the printable area, the available press time, the ease of data manipulation and the number of colour combinations required in order to obtain a well defined colour gamut. To produce the full subtleties of tone when each combination of ink is combined would ideally require each ink to be printed at 10% tone intervals with every other ink (although certain combinations may not occur in practice it was decided that every combination should be examined for experimental completeness). Given the 6 colours the possible number of combinations is significant.

The requirement for each halftone patch needing to be a minimum of 6mm x 6mm for accurate spectrophotometric measurement imposes a minimum total print size. Under these constraints, the sheet size / number of plates becomes excessive. As a result a series of 4 test forms was produced which each contained 4096 patches laid out in a logical order. Each test form consisted of a solid, zero coverage and an additional two tonal values in pairs; 80% & 50%, 70% & 30%, 60% & 20% and 40% & 10%.

As 6 colours were being printed, the choice of screen separation angle was important as there is increased scope for moiré patterning between the halftone screens. The screen angles chosen were set such that the shade for each pair of colours (e.g. green shade yellow and red shade yellow) were at the same angle. The angles used were 45 degrees for the blue, 75 degrees for the reds and 105 degrees for the yellows.

In addition to the test forms, test images were printed which contained a number of standard images which allowed a visual assessment of the print quality. The images included a flesh tone, an image of food similar to that which would be used in the packaging industry and an image containing saturated colours. These were placed before a number of observers and a scoring system was used to assess each image when compared to its CMYK alternative and Hexachrome. The test images for the W6 were separated using a skilled operator from the packaging pre press industry who used intuitive judgements to obtain the colour separations given the 6 base colours. Subsequently, this may not be the optimum separation. Separations for the CMYK and Hexachrome set were made using Adobe Photoshop and Hexwrench respectively.

The test forms and test images were printed at 70 l/cm on a Heidelberg Speedmaster 10 colour offset lithographic press printing to 100 gsm coated paper. Fifty sheets were taken at the end of a 300 sheet run print run for each form / image. The print sequence used was Violet (darkest then lightest colour), Reds (darkest then lightest colour) and finally yellows (darkest then lightest colour). The press was set-up such that each of the ink colours at the densities shown in Table II (measured through filter with the maximum response). These target densities were chosen by the operator and experienced viewers on the basis of the test images. The densities of the process inks and Hexachrome set were set according to recommended industry standards.

Table II: Ink densities for the six colours

Orange-Yellow	Orange-Red	Violet-blue	Green-yellow	Violet-red	Green-blue
1.22	1.05	1.25	0.73	1.09	1.38

Measurement of the patches on each test form was carried out on a Gretag-Macbeth Spectrolino by sectioning each form into A4 sections. Three test samples were taken from each test in order to provide a reasonable sample. The variation between these three samples were found to be within a delta of 0.6.

3. Results

All observers stated that the images printed with the W6 were significantly more vivid and saturated than those produced from CMYK. The most noticeable features found by the observers included brighter reds, deeper cleaner violets and smoother transitions through the mid tones to shadow. Overall the images were found to be significantly better compared than the CMYK equivalent. In many areas of the images the W6 ink set was found to offer a significantly more vivid image than the hexachrome ink set. Some limited areas of green were more vivid and possessed more smooth transition with the hexachrome ink set, although some observers noted the green rendition of plants and trees produced "artificial" looking greens.

The tone gain of each separation (measured with the colour ANSI colour filter which produced the highest density) for all the colours is shown in Figure 2.

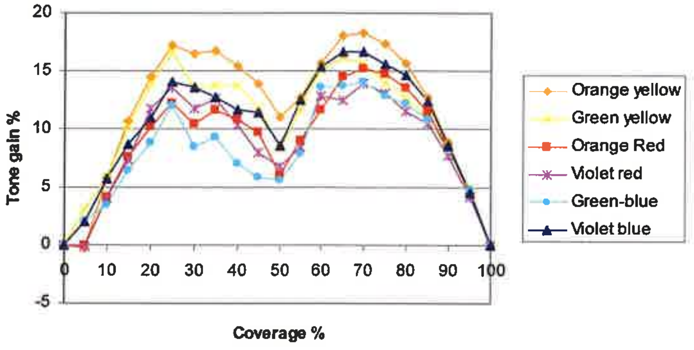


Figure 2: The tone gain obtained for each ink colour in the W6 Set

The comparable tone gain curves for the standard CMYK process set and the Hexachrome ink set are shown in Figure 3 & 4. All show similar behaviour with a reduction in tone gain around the 50% coverage, although the tone gain for the Hexachrome and process colour inks is lower. The relative higher tone gain with the W6 may be due to either non optimised rheology which lay lead to excess gain through ink spread or insufficient pigment loading necessitating excess ink transfer in order to obtain the target densities.

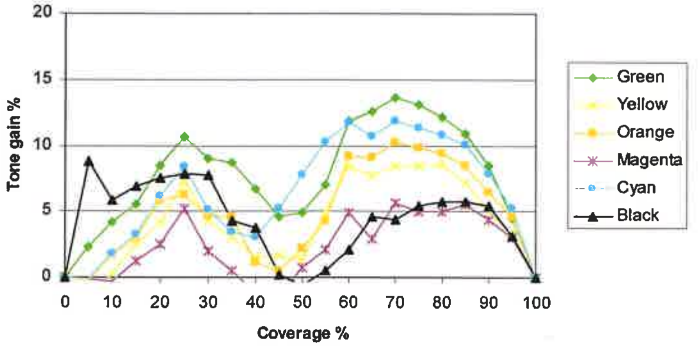


Figure 3: The tone gain obtained for each ink colour in the Hexachrome ink set

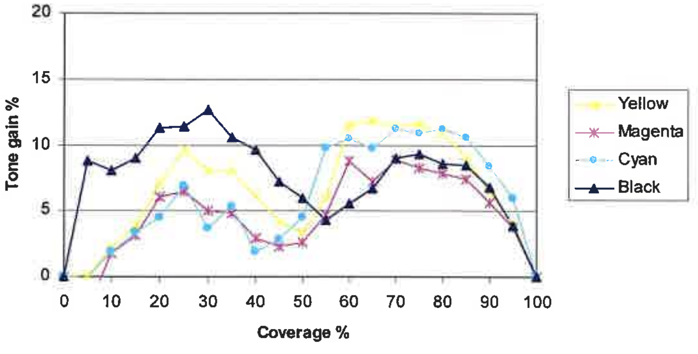


Figure 4: The tone gain obtained for each ink colour in the 4 colour ink set

As any colour space is three dimensional, the printed colour gamut of the ink colour system are best shown in the 2D plane of the paper by examining the orthogonal views of the L*a*b* colour system.

In each case the measurements are compared to the colour gamut available in the pantone colours for coated paper. The comparison is made compared to the pantone colours since ultimately a major advantage of the ink system would be an ability to reach a high proportion of the pantone colours. Examining the a*b* plane, Figure 5, shows that colour gamut matches of the Wilcox 6 (W6) most of the pantone colours, being only some what deficient in the green region.

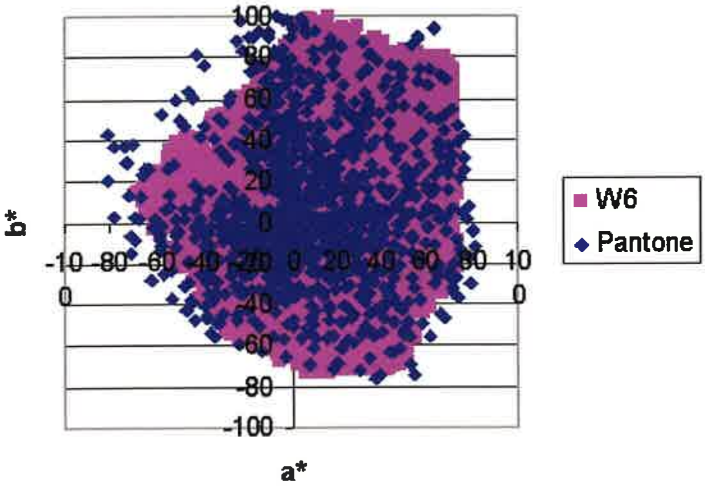


*Figure 5: A comparison between the Wilcox 6 ink system colour gamut and the Pantone range of colours in the a*b* plane*

This small deficiency in the green can also be seen when one examines the view of the L*a* colour, Figure 5, where some of the pantone light green colours are beyond the W6 colour gamut. Some of this may be associated with the limited number of test patches in the test forms and the tone gain on press which would tend to darken colours. The colour gamut may be improved through increased testing in this region with lower percentage values and tone gain compensation.

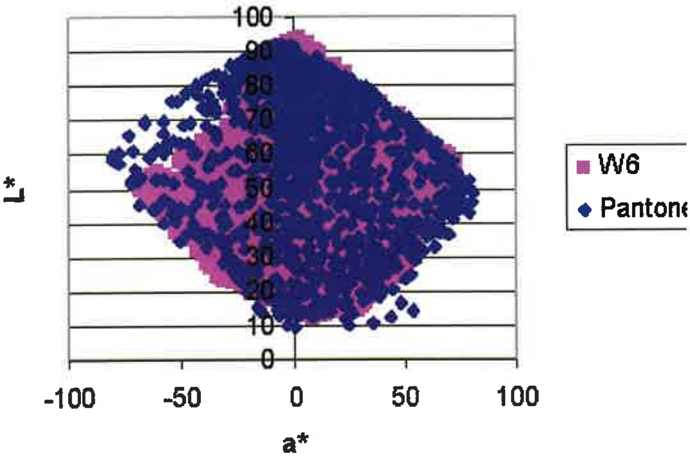


*Figure 6: A comparison between the W6 ink system colour gamut and the Pantone range of colours in the L*a* plane*

When the L*b* plane is examined, the wide colour gamut produced by the colour set is easily seen, Figure 7. Only some selected very dark blues are not covered by the colour gamut of the W6.

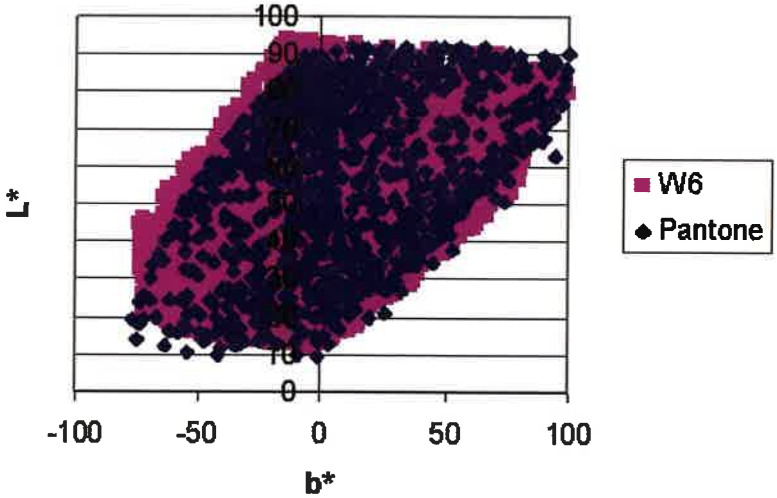


*Figure 7: A comparison between the W6 ink system colour gamut and the Pantone range of colours in the L*b* plane*

Notwithstanding, some minor deficiencies in the light green area of the colour space (some of which may be attributed to the lack of data in this region) the colour gamut produced the ink system is large and readily achieves over 95% of pantone colours. This statistic was calculated by examining the number of colours which lie within the colour gamut of the Wilcox 6.

When the W6 is compared to the Hexachrome, the increased gamut available in the blue and violet areas of the print are apparent by examining the a*b* colour gamut, Figure 8. The small area of deficiency in the green can also be seen in Figure 8.

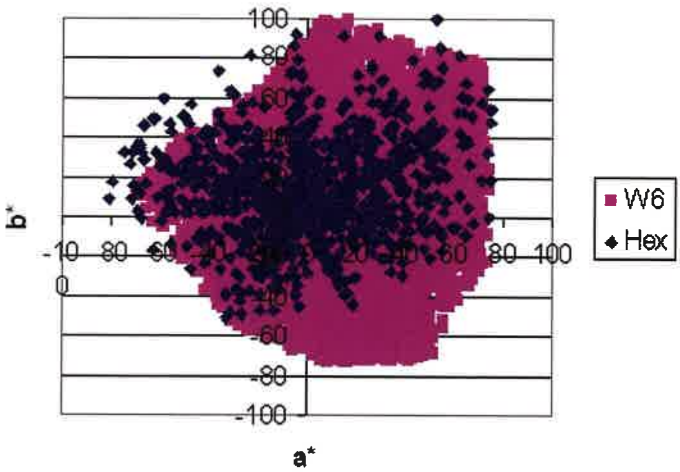


*Figure 8: A comparison between the W6 ink system colour gamut and the Hexachrome ink set in the L*a* plane*

The smaller gamut of the W6 set in the light green region of colour space can be seen in Figure 9 while its enhanced capability in blue / violet region of colour space is also evident in the L*b* plot, Figure 10.

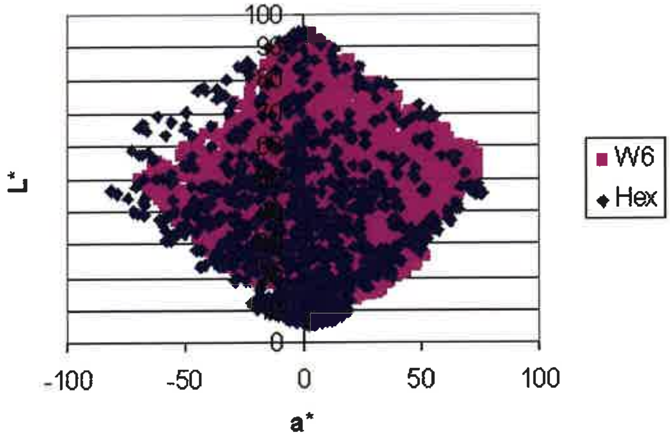


*Figure 9: A comparison between the W6 ink system colour gamut and the Hexachrome ink set in the L*a* plane*

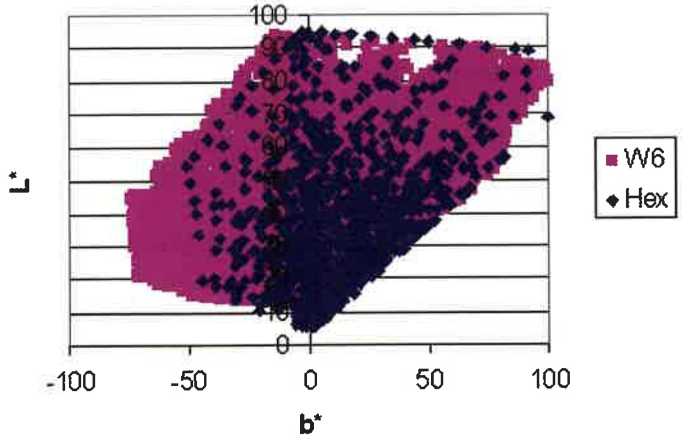


*Figure 10: A comparison between the W6 ink system colour gamut and the Hexachrome ink set in the L*b* plane*

4. Discussion

The ink set offers a number of distinct advantages over comparable ink systems used in commercial printing. There are however a number technical and economic challenges which need to be addressed before the ink set is widely adopted. Instances of it use in the packaging industry are already available.

The basic economic challenge to the ink system are associated with the number of printing units required to print the job, the additional ink cost, the additional pre press costs and the time associated with developing a fingerprint for any press / ink / substrate combination. These may be significant issues in the 4 colour offset lithographic commercial printing sector where print is increasingly seen as a commodity and not a service. The use in the packaging market where multi coloured presses are more common and the correct rendition of food colour offers significant commercial advantage.

A major technical challenge in further developing the ink system is the development of software which will provide the correct separations without the need for highly skilled operators. This should either be a Photoshop plugin or a stand alone package. This will allow the six colour set to be incorporated into current prepress workflow with minimal interruption. Amongst the parameters which need to be identified in such a system is the optimum reproduction of colours within the colour gamut which could be produced by mixing in a number of combinations, e.g. neutral greys. An alternative to the custom production of software is to utilise current commercial software such as that produced by Special Colour, [6]. This would provide a more direct to print market route for the ink set but may need further refinement in order to provide the optimal separations.

An obstacle to the commercial exploitation of the ink system is the requirement for an additional black separation for text, line art etc. Although it may be possible to obtain a black whose colour is correct using the 6 colours (by overprinting the three darkest colours for example), there are a number of disadvantages to this. These include ink use, ink cost, register between colours and ink drying problems with high ink builds. Thus in many practical applications, the ink system is effectively a 7 colour system which has implications on the number of presses on which the system can be used. A means of overcoming this in the system is the sacrifice of a colour in order to accommodate a black for line work and text reproduction. In most cases the green-yellow would be sacrificed in order to accommodate the black although there may be cases where one of the other colours is sacrificed. Any software developed would need to allow any colour to be sacrificed automatically and predict colour on a "what if" scenario.

5. Conclusions

A six colour ink system which can be used in the printing industry for the reproduction of wide gamut images has been tested and developed. The system is based on darkening colours using complimentary colours with the bias of colour without the addition of black, thus allowing the darker saturated colours to be reproduced. The 'bias' or 'leaning' of colours is also incorporated into the darkening process. The primary findings of the investigation are:

- The 6 colours selected yields a large colour gamut achieving over 95% of pantone colours.
- The colour set excels in the deep violet and orange regions of the colour space, but shows some deficiency in the light green region. Some of this may be attributed to excess tone gain and colour
- Darker saturated colours are possible.

Further research is required to establish the detail of the colour gamut, compensating for the tone gain on press and to investigate the colour gamut using black in combination with the W6 set where the ink set must be used on a 6 colour printing press.

Acknowledgements

The authors would like to thank Heildelberg UK, Brentford and Technograv, Derby for their assistance in running the experimental trials.

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Non-destructive methods in the study of IJ ink - substrate interaction

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1. Introduction

The quality of ink-jet prints depends to a large degree on the interaction between printing substrate and Ink-Jet ink. The penetration of printing ink should be low in order to retain high optical colour density (Glittenberg et al., 2003, Muck et al., 2004). The surface of the paper also plays an important role: the absorption capacity for printing inks should be controlled. It should not dust and should have a suitable level of smoothness as well as other properties necessary for good operability and printability (Lyne et al. 1985, Baudin et al. 2001).

The scope of the study was to investigate the radial and vertical distribution of Ink-Jet printing ink, both on and beneath the paper surface, on different types of papers, as well as to determine the impact of the paper surface on print quality.

The aim of the study was to find non-destructive methods that can give a rapid and accurate insight into the Ink-Jet ink penetration in z-direction of the substrate.

2. Materials and methods

2.1 Types of paper

Four completely different types of paper were used:

- Z - Zweckform Photo Paper, recommended for Ink-Jet prints, one-side coated, high glossy, (130 g/m^2, 170 μm),
- K - Carton board, one-side coated multilayered white board, (300 g/m^2, 430 μm),
- I - ICP Permanent Paper made at the Pulp & Paper Institute in Ljubljana, which corresponds to standard ISO 9706, no surface treatment, (70 g/m^2, 110 μm),
- T - Three-ply tissue paper with a low percentage of secondary fibres, (60 g/m^2, 185 μm).

The test forms were printed with magenta water soluble dye-based ink. Only for the photoacoustics measurement black ink was used too.

The reason for the use of such a wide range of papers in the study is to test the limits of non-destructive measuring techniques applied.

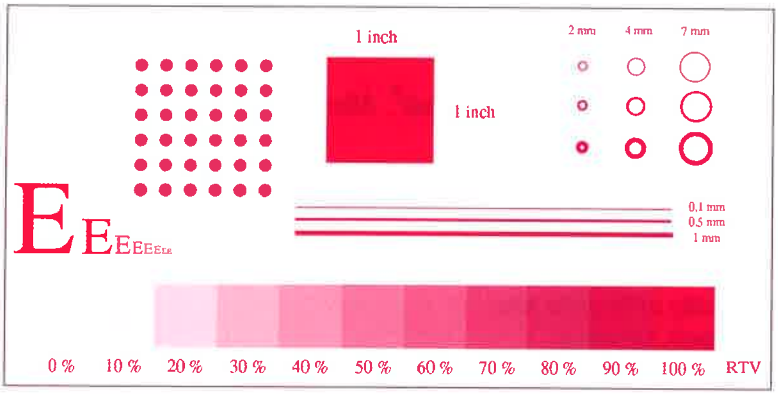

Figure 1: Part of the printed test form

A part of the printed test form is shown in Figure 1. The Canon BJC 8500 ink-jet printer was used, printing quality 1200 dpi and color intensity 100%.

2.2 Tests on the paper surfaces before printing

2.2.1 Penetration - dynamics analyser (PDA) is an analytical instrument designed for the investigation of penetration dynamics of liquids into solid samples, such as papers. The analytical technique employed is based on recording the change of intensity of ultrasonic signals transmitted by solid samples, while one of their sides is in contact with a liquid (sample is immersed into the water bath).

The sample, 55×80 mm in size, was fixed on the sample holder and inserted vertically into the clamp of the immersion device and fixed with screws (Penetration-Dynamics Analyzer Emtec PDA coating). The measurement was controlled automatically by computer during the adjusted time.

2.3 Non destructive methods

2.3.1 Slit - scanning densitometer is used in qualitative and quantitative evaluation of thin layer chromatograms. It was used for investigation of both radial and vertical distribution of different spots of printing ink.

Non-homogeneity of the paper influences the signals from different tracks and different lines of the models.

The testing conditions for measurements were remission mode and a wavelength 580 nm.

2.3.2 Confocal laser scanning microscopy (CLSM) represents a non-conventional method for non-destructive study of interaction of Ink-Jet inks and printing substrate. It was used in the investigation of three-dimensional paper structure, the determination of pore volume (Goel et al., 2000, Auran et al., 1999) and the evaluation of ink penetration in z-direction (Hoang et al., 2001).

The spots of printing ink were observed and measured with the CLSM. The scan area was 460 µm × 460 µm, air objective with numerical aperture 0.6, laser beam wavelength 458 nm and resolution in z-direction 2.7 µm. The sample preparation, i.e. cutting the samples in z-direction was done virtually, by computer software.

This software calculated the number of slices necessary to pass from the most fluorescent to the non-visible part of the ink. The measurements were done on printed samples covered by immersion oil.

2.3.3 Photoacoustics and photoacoustic spectroscopy are non-destructive methods for the study of optical and thermal properties of a printed area at different depths beneath the sample surface. This implies the examination of ink penetration into the paper structure. The physical principles of indirect photoacoustic effect and its possible applications in the field of graphic arts are already well established (Kaplanova et al., 1992, 1994, 1997, Drzkova et al., 2004).

Magenta and black Ink-Jet prints on all examined substrates were measured together with appropriate blank paper. Samples were cut from these sheets, 11 mm in diameter and mounted on plexiglass backing using two-sided adhesive tape for photoacoustic measurement. As a reference, the "carbon black" was used. A diode pumping solid-state 20 mW laser (Suwtech, 532 nm) was used for all photoacoustic measurements as the light source. Light beam (diameter ~ 1 mm) impinged on the surface of sample placed inside a cylindrical photoacoustic cell. Generated acoustic signal was detected by a capacitor microphone Brüel and Kjaer type 4166 and preamplified. Output signal was fed to a DSP lock-in amplifier Stanford Research Systems model SR830. The laser light was modulated using the internal oscillator of the lock-in amplifier. All measurements were controlled and processed by computer.

Optical spectra used for optical density and whiteness determination were measured by a reflection spectrophotometer Eye-One.

Paper roughness was evaluated by Parker Print Surface Roughness tester (model 58-04-00-0001). Each result is an average of at least five measurements.

2.4 Destructive method

2.4.1 Cross section analysis of prints was made by microtome. The slices were then examined by optical microscopy (OM). This is a destructive method which enables a detailed access to the undersurface migration of printing ink through the inside layers of the printing substrate.

We prepared samples with four-component epoxide resin. The slice thickness was 30 µm.

3. Results

3.1 Sample analysis before printing

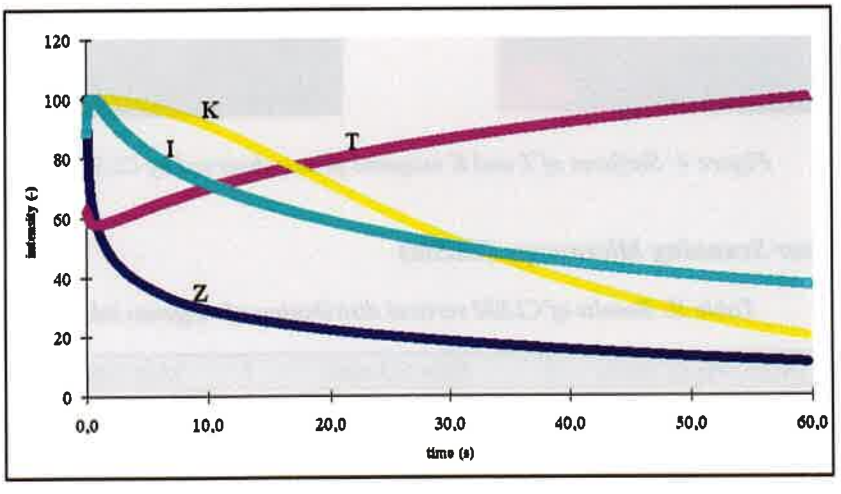

Figure 2: The change of relative intensity in time for different samples

3.2 Study of the of ink distribution

3.2.1 Slit - Scanning Densitometer

Table I: The average peak area and RSD measured by densitometer in remission mode, for magenta ink printed on all four samples

	Z_1	Z_2	K_1	K_2	I_1	I_2	T_1	T_2
average	47802,4	48468,8	41904,5	41602,4	40114,8	38897,3	25010,0	24899,8
stdev	411,6	546,5	1637,7	1501,5	1133,0	577,1	2730,0	2242,4
RSD	0,9	1,1	3,9	3,6	2,8	1,5	10,9	9,0

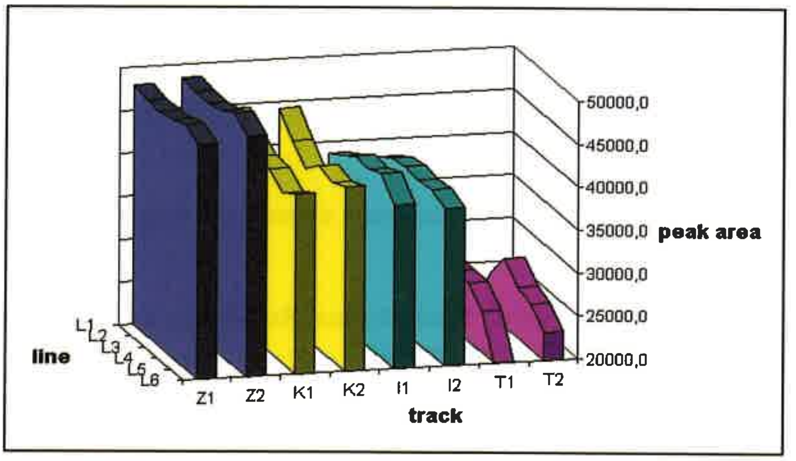

Figure 3: The peak area of the magenta prints measured by densitometer in remission mode on all four samples

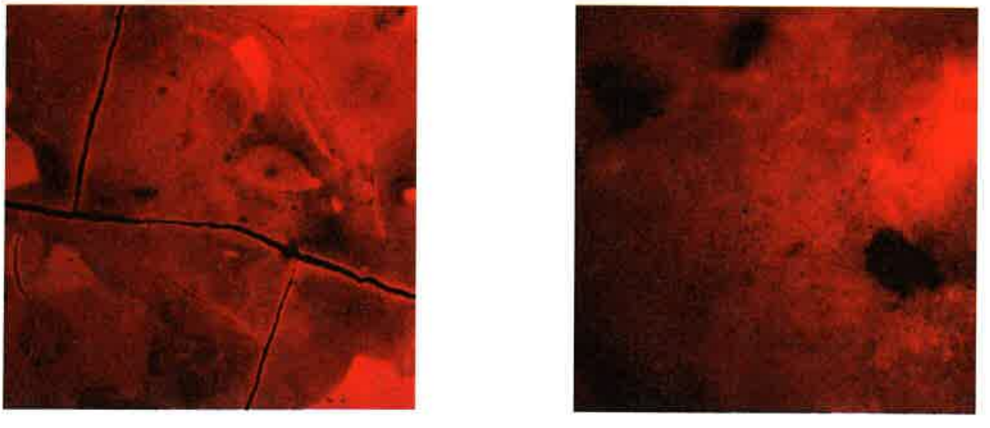

Figure 4: Surfaces of Z and K magenta prints observed by CLSM

3.2.2 Confocal Laser Scanning Microscopy (CLSM)

Table II: Results of CLSM vertical distribution of magenta ink

Sample	Aver. Nu. of slices	Slice tickness	Max. ink thickness (μm)
Z	32,23	0,73	23,53
K	32,64	0,74	24,15
I	32,12	0,80	25,96
T	89,51	0,81	72,50

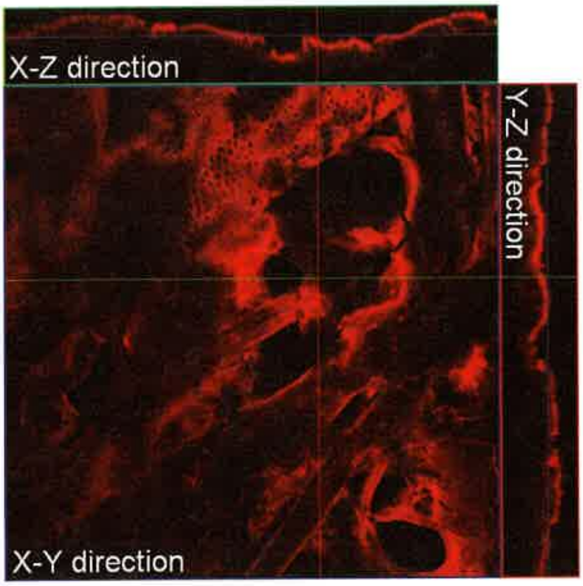

Figure 5: The printed surface of I sample evaluated by CLSM software (virtual slice)

3.2.3 Photoacoustics and photoacoustic spectroscopy

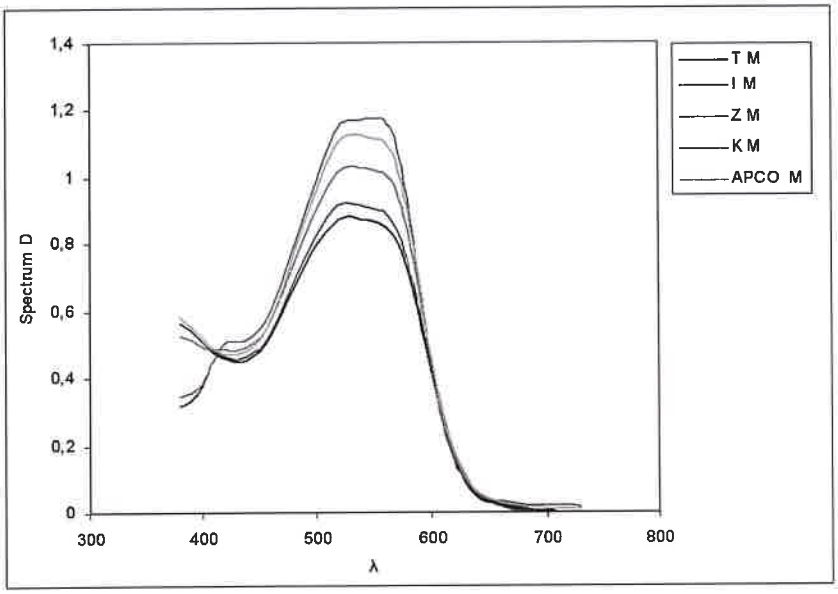

Figure 6: Density spectra changes for all different substrate type

Table III: Results of vertical distribution of magenta ink

Sample	Real sample thickness (μm)	Sample thickness of microtome slice (μm)	Ink thickness of microtome slice (μm)	Real Ink thickness (μm)
Z	170	250	30-50	20-34
K	430	-	-	-
I	110	170	60–100	39-65
T	185	280	100–120	66-79

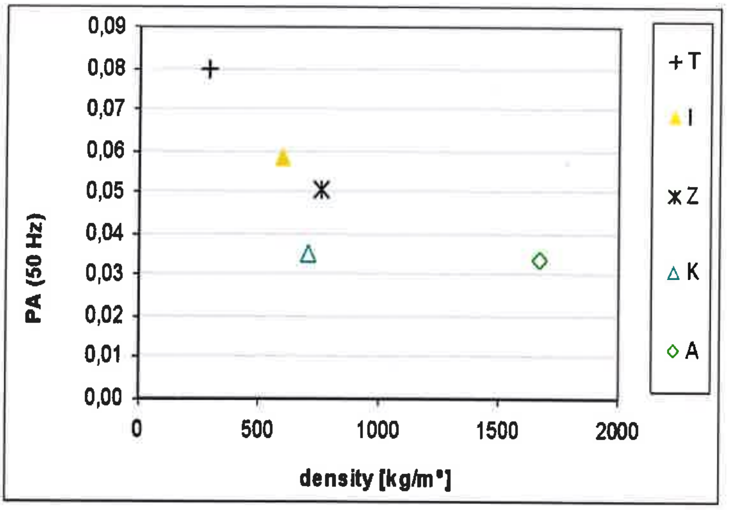

Figure 7: Dependence of normalized photoacoustic signal on effective density of substrates

3.2.4 Cross section analysis and Optical Microscopy (OM)

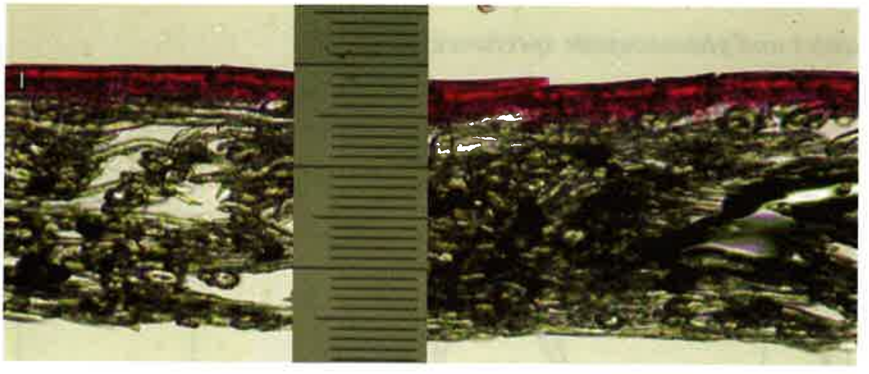

Figure 8: The microtome cross section analysis of Z sample with added micrometer measuring tool

4. Discussion

Sample analysis before printing

The results of the penetration test on the I and K samples showed three successive phenomena: wetting, penetration and impregnation, i.e. complete penetration) (Figure 2). The K sample shows a gradual penetration curve, which means that its surface is more hydrophobic than the surface of I sample.

The Z sample has the steepest penetration curve. The sorption of liquid is almost instantaneous. Undesirable phenomena such as ink show-through might occur.

The T sample (tissue paper) shows a curve typical for hygiene papers: the fibers swell up, so the slope of the curve is positive.

Study of the ink distribution

In the remission mode of Slit - Scanning Densitometer (Figure 3) the highest intensity of magenta is on the Z sample and the lowest on the T sample. The colour on the Z sample remains on the paper surface, contrary to expectatios based on PDA results.

Ink Jet inks are homogeneously distributed on the Z sample. This is proven by the lowest relative standard deviation (RSD) value (Table I). Such characteristics were expected from the paper producer's specification which guarantees a brilliant colour reproduction. The T sample has the highest RSD value - around 10, because of its rough surface structure. The RSD value for the K sample is higher than for the uncoated I sample. This can be explained by the type of coating of the K sample, which is excessively hydrophobic. After the drying process, dye-based ink remains on such a surface in a non-homogeneous layer. Therefore, the K sample is not suitable for Ink Jet printing. Figure 4 shows the surfaces of Z and K magenta prints observed by CLSM. Stack size in μm is as follows: x, y, z values are 146.2, 146.2, 24.7 for Z sample and 206.8, 206.8, 12.4 for K sample.

The Confocal Laser Scanning Microscopy measurements of vertical ink distribution were done on the edge of printed area of each sample. Virtual cutting in z-direction slices was done by software. The maximum depth of penetrated ink was calculated using the number of slices from the top of the printed area (the most fluorescent part of the magenta dot) to the lowest visible ink trace in the sample (Table II).

Figure 5 shows the example of printed surface evaluated by CLSM software (virtual slice) for I sample. The stack size is 206.8, 206.8 and 31.3 μm for x, y and z-directions, respectively.

The deepest ink penetration is into the T sample and the shallowest in the Z sample (Table II2). These results correspond to those of Slit Scanning Densitometer. On the Z sample ink forms a layer on the paper surface; the optical density of such a layer is high. Ink thickness for T and I samples is higher, because ink penetrates deeper into the uncoated substrates (Table II).

Photoacoustics - Figure 6 shows that density spectra are different for each type of substrate. This means that different colour will be perceived on different media.

For modulation frequency range, where the absorbing layer is thermally thin, i.e. the signal arises from the whole thickness of the layer, the photoacoustic signal is influenced by structural and thermal properties of the substrate, the so-called sample backing. The theory predicts the decrease of the photoacoustic signal with increasing density of the backing. The effective density of individual substrate was determined from thickness and grammage. This is supported by the dependence of the normalized photoacoustic signal on effective density of substrates. Only for the K sample the value of normalized photoacoustic signal is lower than the values of substrates with similar effective density. This result corresponds to the value for APCO, whose effective density is considerably higher. This reflects the real structure of the K sample, as the main effect on its upper side density comes from coating layer, as is also the case with APCO. With increasing modulation frequency the influence of the substrate is less important, while the impact of the absorbing layer (i.e. the impact of ink density) becomes more significant. The low frequency photoacoustic signal from tissue paper differs depending on the compactness of its three layers. The more closely the individual layers of tissue are set, the stronger the photoacoustic signal is.

The comparison of normalized photoacoustic signal for low modulation frequencies with optical density reveals character of substrates: values for substrates with similar properties are clustered together (Figure 7).

Cross section analysis and optical microscopy. The K sample (carton board) could not be cut by microtome (is too thick), therefore optical microscopy could not be done either; all the analysed samples caused various difficulties in cross section analysis (as the magenta dye ink is water soluble, the microscopy evaluation of the prints should be done as quickly as possible after the sample preparation).

The study of the cross sections of cut samples enables a real insight into the ink distribution in z-direction (Figure 8). The measurements of ink distribution on cross sections show that the results of all applied non-destructive methods - slit scanning densitometer, photoacoustics and CLSM, are in correlation with this destructive method (Table III). The correlation is particularly high for CLSM of Z and T samples.

5. Conclusions

At this point of the study we assessed the relevance of information obtained by different, non-destructive and destructive measurement techniques. Each of these methods, and their limitations, are important in the study of ink - paper interactions, as well as in the impact of substrate on print quality.

A detailed study of obtained results shows a good correlation among the applied non-destructive methods: slit scanning densitometer, photoacoustic spectroscopy and CLSM. Besides the correlation among the non-destructive methods, the correlation with the results of the destructive method is almost proved. The results of cross section analysis by microtome and optical microscopy gives the picture of real ink distribution in z-direction of each Ink Jet print. Therefore, the correlation of the results obtained by non-destructive methods with those obtained by a destructive method is of the greatest importance for the future use and application of studied methods.

We proved the reliability of slitt scanning densitometer, photoacoustic spectroscopy and CLSM in the analysis of Ink Jet inks distribution in z-direction.

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A new methodology for the use of a printability tester for the simulation of flexographic halftone printing onto film substrates

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Abstract

An experimental investigation has been performed to optimise a methodology for obtaining halftone test prints using a printability tester. A test image containing two gradation scales was printed onto a film substrate using UV cured ink. Initial problems due to poor ink transfer from the plate to the substrate were overcome by modifying the configuration of the printability tester was modified to increase the tension in the substrate. Neither the anilox nor the plate was cleaned between printed samples. Spectrophotometry measurements of the printed samples showed a significant increase in density occurred between the first print and subsequent prints, as the ink transfer from the plate, which occurred after approximately 6 prints. The stabilised density and halftone reproduction of the prints were similar to those produced on a commercial printing press under the same nominal conditions, showing that this method is suitable as an alternative to full-scale press trials.

Keywords

Flexographic, IGT F1, Polypropylene, UV ink

1. Introduction

In flexographic printing the raised surfaces of the plate are inked by an anilox roll. At the entrance of the printing nip, the ink on the printing plate contacts with the substrate. For porous substrates, some of the ink is hydraulically impressed into the substrate, and is considered to immobilised (DeGrâce and Mangin, 1987). The remainder of the ink is split between the plate and the substrate at the exit of the nip. For non-porous substrates a small fraction of the ink can penetrate into the asperities of the substrate, however this ink is not considered to be immobilised and is available for splitting (DeGrâce and Mangin, 1983). Studies examining these ink transfer mechanisms from plate to substrate (DeGrâce and Mangin, 1987), (DeGrâce and Mangin, 1987), (Fetsko and Walker, 1955), (Walker and Fetsko, 1955), and (Fouche and Blayo, 2001) have focused on solid prints. The ink splitting between the plate and the substrate is largely dependent on the thickness of the ink film carried by the plate, the ink properties and the process conditions such as the press speed.

In order to further understand the transfer of ink from the printing plate to the substrate in the flexographic printing process, a standard method was required to print halftones in a controlled manner, producing a comparable print to that obtained using a full-scale press. Printability testers have been developed to allow the compatibility between inks and substrates to be evaluated, prior to their use on the printing press, and as such have predominantly been used for the printing of solids and solid overprints. The IGT F1, manufactured by IGT Testing Systems, is a printability testing device designed to simulate the flexographic printing process. To produce a print the anilox roll is engaged with the plate and ink is applied to the anilox using a pipette. The anilox is rotated a set number of times in contact with the plate to transfer ink to the raised image regions of the plate. A doctor blade removes the excess ink on the anilox to prevent excess inking of the plate. The impression roll is then engaged with the plate before bringing the substrate in contact with the plate surface. Rotating the plate cylinder pulls the substrate carrier through the printing nip. The impression cylinder and anilox are both driven from the rolling contact with the substrate carrier and plate respectively. Ink is continuously transferred to the plate from the anilox. At the end of the print cycle the impression cylinder and anilox are disengaged from the plate. A schematic of the IGT F1 is shown in Figure 1.

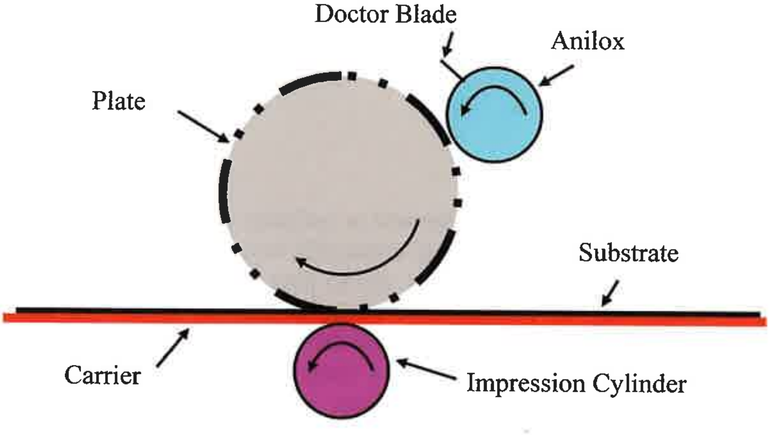


Figure 1: Schematic of the IGT F1

Like a flexographic printing press, the IGT F1 utilises an impression cylinder, plate cylinder and an anilox roll. The maximum print width is 40 mm. However, unlike on a printing press, the substrate is mounted onto a substrate carrier using an adhesive tape at either end. The substrate carrier is rigid, but contains cushioned layer on the side nearest the plate onto which the substrate is attached.

2. Experimental methodology

The experimental investigation was performed using cyan UV ink, and a polypropylene film substrate to examine the ink transfer from the plate to the substrate, at three set printing forces of 10N, 35N and 75N. Use of a non-porous substrate eliminated immobilisation as a mechanism of ink transfer, ensuring that all of the ink transfer was due to ink splitting, and the use of UV cured ink ensured the loss of mass from the prints after printing was negligible. This enabled the volume of ink transferred to the substrate during printing to be quantified, details of which can be found in (Hamblyn, 2004).

The configuration of the IGT F1 is such that, the plate cylinder has a diameter approximately double that of the anilox roll. IGT recommended the use of two consecutive identical test images on the plates, where the second print coincides with the second rotation of the anilox roll. Measurements are taken on this second print, as the anilox roll has had an extra rotation for the ink transfer to stabilise producing a more consistent print. A test image containing two nominally identical halftone gradation scales with dot sizes ranging from 2% to 100%, and line ruling of 100 lpi was used (Figure 2). The first gradation scale on the test image and hence the first to be printed is labelled as 'G1' while the second is labelled as 'G2'.

A conventionally imaged plate, with a thickness of 1.70 mm, was used during the investigation. Although this is a thinner plate than supplied with the instrument, 1.70 mm plates provide good tonal reproduction. Thicker plates, which are generally used to print solids, can result in high tone gain, when used for halftone printing due to excessive deformation of the dots as they pass through the printing nip (Bould, 2001). Analysis of the gradation scales, G1 and G2, using a white light interferometer, showed little difference in the dot sizes between the two strips.

2.1 Modification of IGT F1 configuration

Initial prints had a visually poor solid density and had halftone dots that were irregular in shape and size. It was observed that the substrate was not separating from the plate correctly, with the substrate lifting from the carrier, before the forces generated by the rotation of the plate and linear movement of the substrate carrier reached a sufficient level to split the ink. Since the substrate was attached to the carrier using and adhesive tape at either end, the tension within the substrate was insufficient to overcome the elasticity of the ink.

To improve the quality of the prints, the configuration of the IGT F1 was altered by removing the substrate carrier and draping the substrate over the impression roll (Figure 3). However, it was necessary to add a mass at each end of the substrate to provide enough tension to split the ink film at the nip exit therefore preventing the substrate from adhering to the plate. Various masses were assessed, but a 60g mass at each end was found to provide optimum performance, as it gave sufficient tension to the substrate. The revised configuration was more similar to the principle employed by a web fed press, and resulted in an improved print quality with visually fewer defects in the solid ink film and halftones.

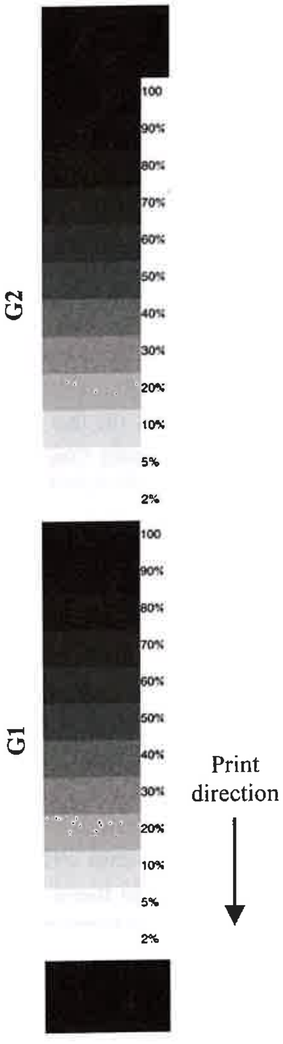


Figure 2: Test image

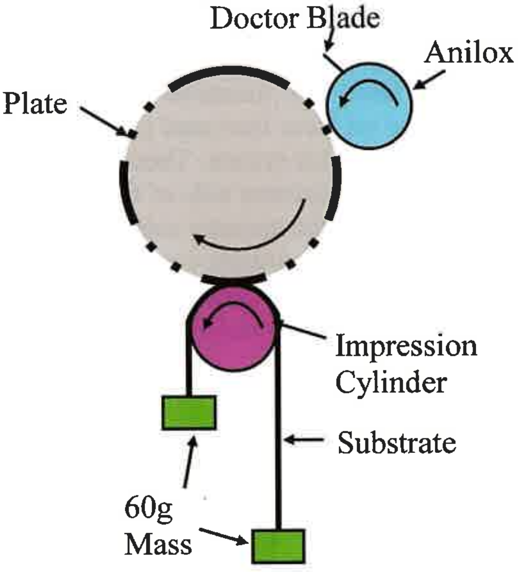


Figure 3: Modified operation of the IGT F1

A visual assessment of the prints showed that the uniformity of the ink film had been greatly improved, although, a lower solid density was printed than was obtained using the substrate carrier. This was attributed to a thinner and smoother ink film being applied. The solid density was also less than 1.2, which is below the level used commercially in flexographic printing, where the solid density of cyan typically ranges between 1.4 and 1.8, and was lower than those achieved during a print trial on a commercial press under similar conditions (Hamblyn, 2004). This was thought to be related to the cleaning of the plate and the anilox after each printed sheet. During a print run on a traditional press the anilox continuously rotates within a chamber or bath filled with ink and the plate is in continuous contact with the anilox. Therefore a fresh supply of ink is constantly being transferred to the plate. This prevents the ink from drying on the plate, and within the cells of the anilox due to the evaporation of the solvent. However, the IGT F1 has no provision for this and therefore the standard procedure when using an IGT F1 is to clean the anilox roll, doctor blade and plate surface on the completion of each printed sheet with a suitable solvent. Not only is this time consuming but also the solvent used for cleaning can affect the surface energy of the plate.

While the cleaning procedure between sheets cannot be avoided when using an IGT F1 with a water-based or solvent-based ink, UV cured inks do not suffer from solvent loss and therefore do not dry on the anilox or the plate. The use of a UV curing ink removed the need for cleaning between sheets. Further trials were performed without cleaning the plate or anilox between printed sheets, which improved the sheet-to-sheet consistency. Because not all of the ink is transferred from the plate during printing, the multiple prints allowed the remaining layer of ink on the plate to reach a consistent level. This would result in the surface energies of the plate having less influence on the ink transfer and result in consistent ink splitting between the plate and the substrate. Also due to the greatly reduced and more controlled time taken between printed samples, the variations in ink viscosity would have less affect on the print. Continuously printing would allow the ink to reach a level of constant shear and a more stable viscosity. This will also affect the filling and emptying of the anilox cells and hence the amount of ink supplied to the plate. On a traditional printing press the first few prints before the press has stabilised are inferior.

2.2 Force calibration

The forces within the anilox-plate and plate-substrate nips were examined using thin film sensors, which measure a change in resistance within the sensor as a load is applied. The data is then captured and stored on a computer. The sensor was drawn through the anilox and printing nips at 0.3 m/s, whilst recording the applied force. The forces were measured at three locations across the width of the plate. A difference in force was measured between the operator and machine sides of the instrument that increased as the set force increased (Figure 4). The spindles for the anilox roll and impression cylinder operated on a cantilever system. Therefore a small misalignment of the spindle will result in more force being applied to the operator side of the plate. The forces measured in the centre of the nip were nearly identical to those on the operator side of the plate. The differences shown in Figure 4 may have been a result of not using the substrate carrier, which could cause a greater displacement of the impression roll on the operator side of the print. This could also have been compounded by using a thinner plate (1.70 mm) than the instrument was design for.

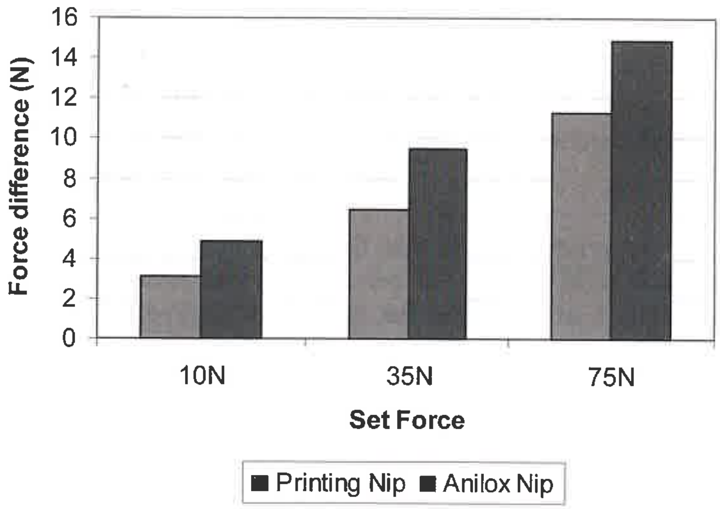


Figure 4: Difference in force measured between the operator and machine sides in the printing and the anilox nips

The measured printing forces within the printing nip from the operator side of the plate are shown in Figure 5. For the set force of 10N the measured force was higher than the set force. However, for both the 35N and 75N settings the measured force was significantly lower than the set force. This may have been due to the relatively small contact area within the nip due to the small diameter of the impression cylinder. This small area may have been insufficient to correctly compress the semi-conductive material within the sensor, during the contact time.

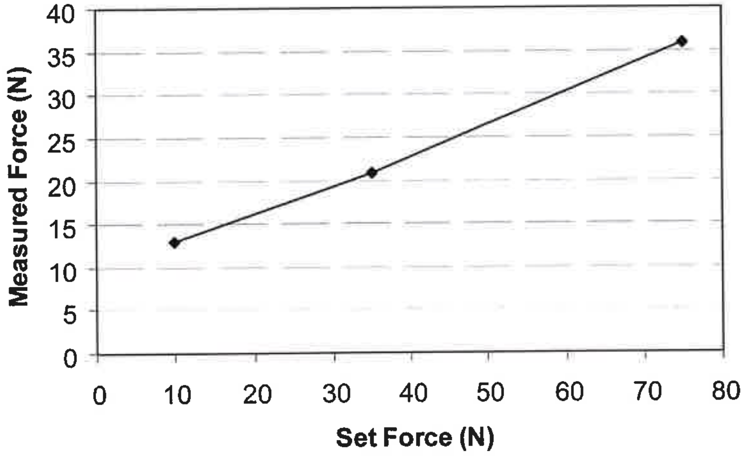


Figure 5: Relationship between the set printing force and the measured force

The differences in the forces measured between the operator and machine side of the instrument (Figure 4) resulted in differences within the prints. Figure 6 shows the differences in optical densities measured on the print with a set printing force of 10N. The densities on the operator side of the print where the force was greater were higher than those on the machine side. The differences in density between the two sides increased as the printing force was increased. Due to this difference within the prints, a template was used for all subsequent spectrophotometry measurements to ensure measurements were taken in the same region of the halftone patch, therefore reducing the effect of positioning errors.

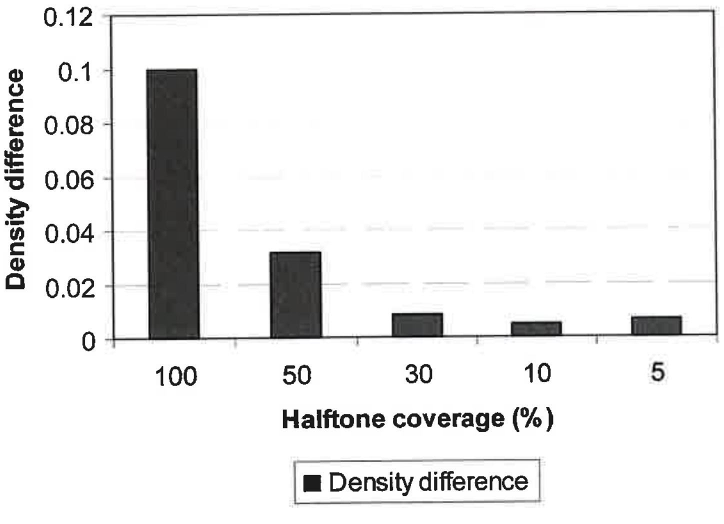


Figure 6: Difference in density between operator and machine sides of the prints for a set force of 10N

3. Results

3.1 Densitometric analysis

Figure 7 shows the effect of printing 12 consecutive sheets with no cleaning of the plate or the anilox roll between prints, for a set printing force of 10N. This was evaluated for both gradation scales on the plate, 'G1' and 'G2'. The densities of the solid and halftone prints increased with each sheet printed, stabilising after 4 sheets. The increase in the solid density between the first and fourth printed sheets was approximately 0.45. For the halftones the increase in density was lower and appears to be nearly insignificant. After 4 printed sheets the solid density produced was close to that achieved on a commercial press under similar conditions. The solid densities produced from the two gradation scales on the plate were virtually identical and achieved stability at the same point. Initially the print from the first gradation scale, G1, had a marginally lower solid density than that of the second gradation scale, G2. However once the print had stabilised after the forth sheet was printed, G1 had a slightly higher density. With the printing force set at 10N, little difference was observed between the halftone densities produced from the two gradation scales. However, as the printing force was increased the densities from G1 increased more than those from G2.

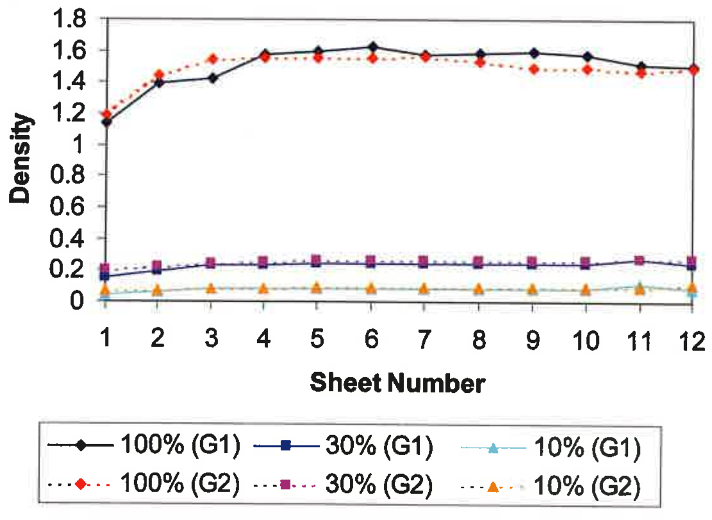


Figure 7: Effect of 12 consecutive prints on the printed density of solid and halftones

3.2 Colorimetric analysis

Figure 8, shows the average a* and b* components of the printed colour for the 5%, 10% and 30% coverage dots and the solid print, based on an average of 6 sheets printed with a set force of 75N. The printed colour was more saturated for the halftone dots from the second gradation scale, G2, while the solid prints were identical in hue and saturation. For a printing force of 10N, the a* and b*values followed the same profile as for the 75N curve. However for the 10N curve the difference between the two gradation scales was negligible. The greater increase in saturation on the prints for the dots in the G2 gradation scale at higher printing forces suggests these dots on the plate were carrying more ink, and therefore spread to a greater area during printing. This was not considered to be a stability issue as 6 sheets had been printed previously, and the difference in colour saturation between the two gradation scales was far greater than the differences observed between consecutive printed sheets. This may be related to the time taken to change substrate samples between prints, which may have affected the filling of the anilox cells, potentially resulting in a lower volume being present for the first gradation scale. Due to the differences between the gradation scales and in-line with the recommendations from the instrument manufacturer, only the second gradation scale, G2, was considered for further analysis.

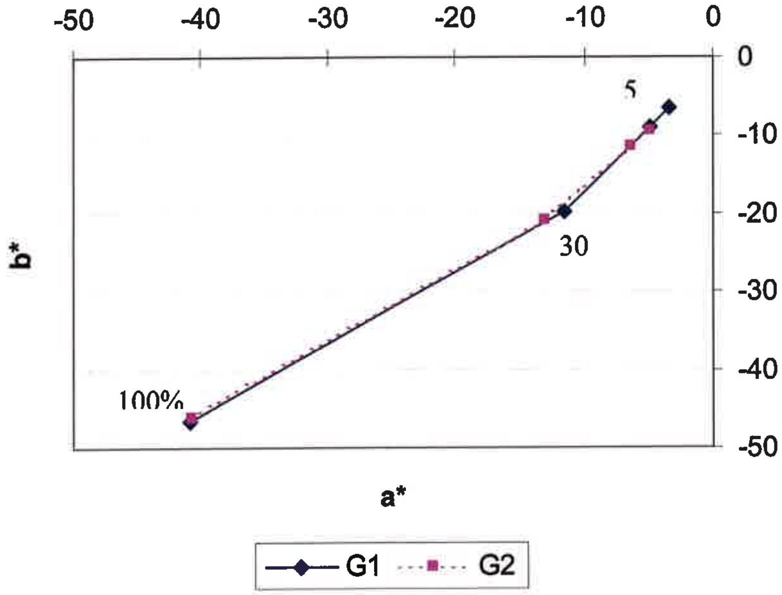


Figure 8: Colour components of a and b* of the first and second gradation scales contained within the test image printed at 75N*

The colour difference (ΔE) for the 75N prints was calculated using the CIEL*a*b* values relative to the first sheet printed for the second gradation scale, G2. This is plotted in Figure 9 for the Solid, 30%, 10% and 5% halftones. A ΔE of 1 is considered to be visible by most observers. The colour difference between the first sheet printed and the subsequent sheets was greater than a ΔE of 1 for all of the halftones considered, and would therefore be visible to the human eye. This shows less ink was being applied to the substrate during the first printed sheet than for the subsequent prints. For the halftones the printed colour reached stability following the sixth sheet. For the solid print, the ΔE increased until the seventh sheet, resulting in a ΔE of 9.8 between the first and seventh sheets. The ΔE decreased between sheet seven and sheet twelve, which suggests the ink transfer for the solid print had not stabilised. Examination of the L* a* and b* values showed small drift in a* and b* values between sheets nine and twelve, however the largest changes in ΔE after sheet six coincided with large changes in L*. This may have been due to variations in the lay of the ink film rather than the quantity of ink transferred to the substrate. The large differences in the ΔE of the halftones were not observed in the densitometric analysis. This highlights the limitations in using density for quality control.

4. Discussion

The change in ink transfer observed over the initial prints during this investigation is typical of the flexographic printing process. For the first printed sheet, the ink film thickness on the plate is relatively low. This leads to a thin layer of ink being transferred to the substrate, and low saturation of the printed colour. Since not all of the ink is transferred from the plate to the substrate, the remainder left on the plate after printing increases with each subsequent print. As this ink film thickness increases, the quantity of ink transferred to the substrate also increases due to changes in the ink split. This increase in the ink transferred to the substrate increases the saturation of the printed colour and sometimes also results in a small change in hue. After a number of printed sheets have been produced the ink film thickness on the plate stabilises and hence the ink transfer from the plate also stabilises resulting in a consistent print between sheets.

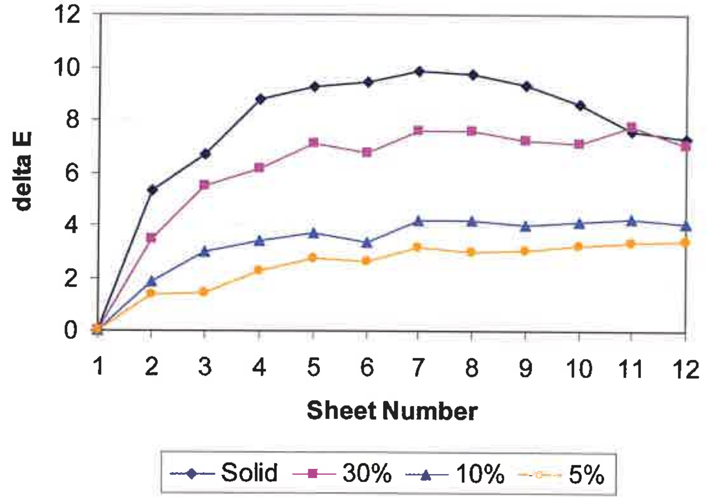
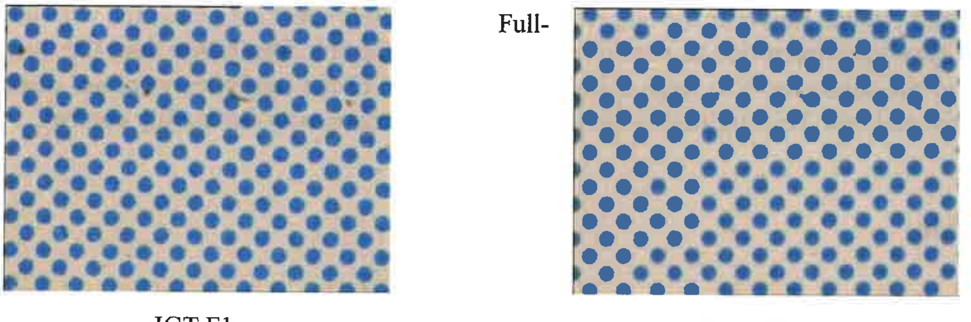


Figure 9: Effect of consecutive printed sheets on colour difference relative to the first sheet

Therefore by cleaning the plate and the anilox after printing each sheet the quantity of ink transferred to the substrate remains lower than achieved using a commercial press and identical plate, substrate and anilox properties. The ink transfer is also more likely to be affected by the solvent used for cleaning due to its effect on the surface energy of the plate, resulting in variations between sheets. The experiments showed 6 sheets were required to be printed on the IGT F1 before the ink transfer became stable.

This investigation has also shown that in order to produce consistent halftone prints, it is necessary to modify the configuration of the instrument. Using the modified method the solid density was comparable with those produced on a full-scale press. White light interferometry and image processing also showed the reproduction of the dots produced on the IGT F1 were of similar quality as on a full-scale press. This is shown in Figure 10, which compares halftone dots from prints made with the modified configuration of the IGT F1 and a commercial flexographic printing press under similar printing conditions. The images were captured using a stereomicroscope and show similar dot profiles for both cases. Therefore results obtained using the modified IGT F1 configuration are comparable with those obtained from a commercial printing press.



IGT F1 Full-Scale Press

Figure 10: Printed halftone dots captured using a stereomicroscope

5. Conclusions

As a result of this investigation, the following conclusions have been drawn:

- A revised methodology has been developed for producing halftone prints on an IGT F1 printability tester, using UV ink and film substrates.

- Densities similar to those obtained on a commercial press could be obtained on a commercial press could be obtained by not cleaning the plate and anilox roll after each print.
- Densitometric analysis showed that 4 copies were required for the ink transfer to stabilise. Greater variation was observed from the colorimetric analysis, where a minimum of 6 prints was required to obtain equilibrium. Therefore density cannot be used in isolation as a means of process control.
- The stabilised prints were comparable in solid density and dot formation to those produced on a full-scale flexographic printing press, operating under similar conditions.

Acknowledgements

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8

Advances in print & packaging

Behaviour of some custom programmed screening elements in various printing systems

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Abstract

Most commercial graphic arts reproduction systems use screening or printing elements for coverage and-or applying the inks to the substrate. In that way the specific reflectance of some area is changed, so various shades of gray or in the separation principle various shades of color are obtained. Standard screening systems combine adequate rulings with screening elements that are usually round, square, various eliptical shapes, in some specific situations lines waves or special technical shapes are used (1). They are usually presented as modules in RIP system. Todays purposes are more wide, and some specific or custom designed elements can be programmed and applied in various fields of use. According to their shape, their usage has to be considered with more care, because not only reproduction, but also the specific message could be poor.

Keywords

Coverage, dot gain, individualisation screening elements, linearisation curves, PS programming

1. Theoretical part

Postscript programming opened the way for describing various shapes, curves, as well various objects that can be mathematically described. In this work seven various shapes are developed in correlation to the "standard" shape, the round one (picture 1). All of them were programmed to fulfill the continous range of coverage from non-covered area to the solid tone.

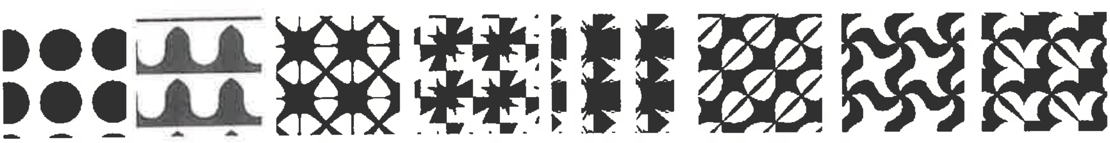

Figure 1: Programmed shapes of screening elements, labeled as R1-R8, at 0,5 coverage

For the purpose of examinations they were reproduced as a standard offset Matchprint proof, and printers copies on the semicoated (les absorbing substrate K1), and rather absorbing printing substrate K2. Scanned picture if reproduction is showed on fig. 2.

It is evident from the fig. 2 that that the reproduction with such custom designed elements is possible, but we must differ them from the "standard" reproduction using round, square elliptical or some specific technical shape inserted as a module in the RIP system. PS programming (2) allows us to define or construct any possible shape, element or object mathematically described as curves. It is allowed their use in usual way, but their usage correspond to apply them also in various artistic purposes, they can carry a special message, change their size, they can incorporated in security documents and personalisation (3). It can be also seen from fig.2 that the density distribution and density range differ in given examples. From some prior examinations it was decided that ruling in that situation over 20 lin-cm has no sense. It depends of course on the complexity of the element and the quality of the reproduction system used.

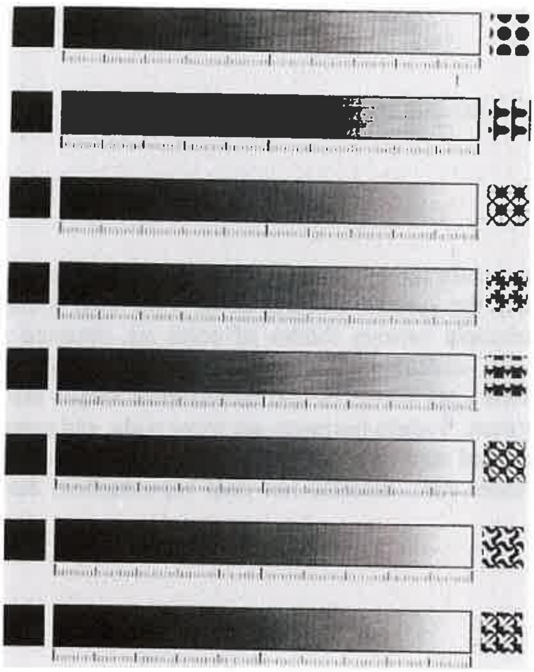

Figure 2:
Scanned printed sheet

An example for the programmed element and its imposition in the chart is given as following:

/r4 *Wheat Ear*
/r5 *Hanger*

```
/polje [{r4} {r5}] def
/L 7 def %linijatura
/K 45 def %kut
/polumjer 50 def
/siva 0.9 def
gsave
250 300 translate
/j 0 def
7 {
siva 0.1 sub
/siva exch def
siva setgray
0 0 moveto
0 0 polumjer 0 360 7 div arc
0 0 lineto
50 10 add
/polumjer exch def
closepath 7 45 polje j get bind setscreen fill
360 7 div rotate
/j j 1 add def
j 1 gt {/j 0 def} if
} repeat
grestore
showpage
```

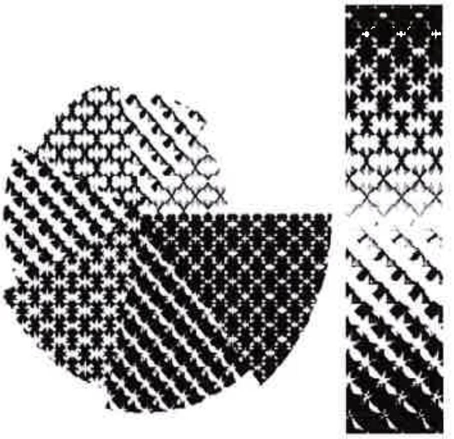

Figure 3: Example of programmed element and its applying to the chart

2. Experimental

To get some information for reproduced elements dot gain values were determined in reference to film round element coverage (Table I for Matchprint, table II for paper quality 1, table III for paper quality 2).

Table I: Coverage of Matchprint printed elements vs film coverage

film cover.	Matchprint			coverage				
	M R1	M R2	M R3	M R4	M R5	M R6	M R7	M R8
10	11	19	22	19	14	32	22	26
20	24	27	34	45	29	44	34	35
30	36	42	43	54	42	53	45	46
40	48	50	54	61	57	59	54	61
50	59	61	62	65	61	67	63	68
60	66	66	70	73	70	73	69	74
70	78	74	78	79	79	79	77	80
80	85	83	86	88	87	87	86	87
90	92	92	94	96	94	96	93	95

Table II: Coverage on T1 paper quality vs film coverage (Dsolid 1,48)

film		paper T1		coverage				
coverage	T1 R1	T1 R2	T1 R3	T1 R4	T1 R5	T1 R6	T1 R7	T1 R8
10	29	32	34	34	36	36	27	36
20	47	53	61	62	62	58	59	49
30	64	67	76	70	65	72	72	72
40	73	77	84	81	74	83	82	82
50	83	84	91	86	83	89	87	91
60	89	89	94	92	92	93	93	93
70	93	93	97	96	95	97	95	97
80	95	97	98	99	97	98	98	99
90	98	99	99	100	100	100	100	100

Table III: Coverage on T2 paper quality vs film coverage (Dsolid 1,37)

film		paper T2	coverage					
coverage	T2 R1	T2 R2	T2 R3	T2 R4	T2 R5	T2 R6	T2R7	T2 R8
10	27	27	28	32	38	32	26	32
20	45	46	52	50	48	51	53	50
30	60	66	67	71	67	69	71	69
40	72	75	80	78	71	81	84	77
50	80	82	88	83	81	87	87	88
60	88	89	93	90	87	93	93	92
70	92	92	96	93	93	97	95	95
80	95	97	98	98	96	98	96	98
90	99	99	99	100	99	100	99	100

According to tables, elements build their specific reproduction shapes, a term corresponding to reproduction curves. The round element has an optimal shape with lower dot gain, but elements R4 and R8 are more complex with a higher dot gain. It appears that the gain curve is not sufficient for estimating the reproduction of an element. Its specific shape, "free edge", or complexity would be very important not the only responsible factor for achieving the range of reproduction of tones, although the whole imaging system corresponds.

An optical estimation has to be done to determine useful beginning of the reproduction, and the place pretending to the solid tone with the loss of basic characteristic of elements. This could be determined as an basic density range. On film and Matchprint reproduction all elements reproductions are approximately more accurate with a rather longer density range, but on paper imaging (e.g. for R8) the reproduction is considerably lower and useful density range is lower, so the first useful element appears e.g. at 20 percent coverage, or more, and ends at approximately 60 percent of useful coverage. Presented pictures are 14 times enlarged.

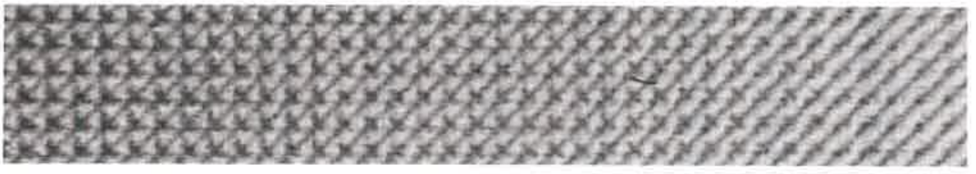

Figure 4: For element R8 areas from 20 to 10% coverage (T1)

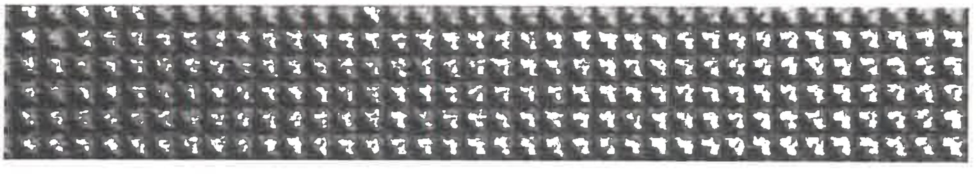

Figure 5: For element R8 50% coverage (T1)

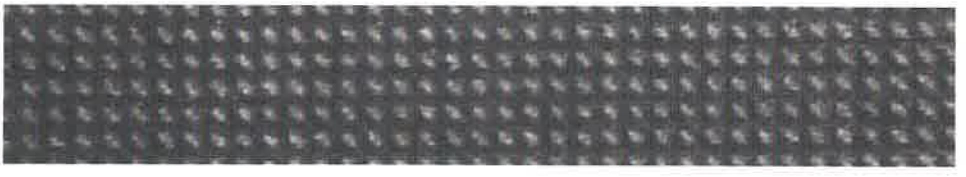

Figure 6: For element R8 areas from 60 to 70% coverage (T1)

From figures 4, 5 and 6 is obvious that the useful range of reproduction has to be carefully chosen for the reproduction system used for each element. If not, such custom designed element will lose their specific information or message, and the whole reproduction becomes out of sense.

3. Conclusion

Custom designed screening elements are rather new area of interest provided by PS programming. Their usage and application can vary wide from standard reproduction to very specific artworks, effects and design. Applying appropriate shape of element to nonadequate magnification, color, relief, substrate or any possible magnitude, unexpected and unpredictable effects can occur. Of course knowledge about matherials, colorants, technology is necessary, but also knowledge about behaviour of programmed elements in various situations, its possible range, the point of maximum gain, the point of useful appearance and ending an other imaging characteristics in reproduction process.

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Investigation of corrosion in print production

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Abstract

The phenomenon of corrosion is present in the processes of graphic reproduction; however, it has never been a great concern in discussions and research. Nevertheless, an *ad hoc* poll showed that 8 out of 10 printers can indicate, or at least are aware of the effect of corrosion in printing processes, some of them experiencing problems on printing machines.

Corrosion in the process of printing can be caused by a number of different reasons. They seem to be more evident with the use of ecological inks and fountain solutions. This paper deals with investigation of corrosion processes on construction steel in contact with different electrolytes (normal and distilled water, electrolytes of different conductivity and pH value), as well as aqueous solutions of surface coatings of high gloss and standard offset papers. During the period of four months changes in the mass of steel specimens were measured (loss of material), as well as changes in pH values and conductivity of the examined electrolytes.

Formation of corrosion products on the surface was identified by changes of spectrophotometric remission in the visible portion of the spectrum for steel. After four months of exposure to electrolytes, corrosion products on the surface of steel were determined by FT-IR spectral recordings.

This investigation gave an insight into dynamics and mechanisms of corrosion under conditions close to those in printing production, thus facilitating better understanding of the entire process.

Key words

Corrosion, fountain solution, FT-IR, spectrophotometry

1. Introduction

Metallic corrosion is a pervasive phenomenon, which can be noticed in contact of metal with the aggressive environment, but can be also caused by other reasons - pitting, stress corrosion, cavity corrosion, roaming currents etc. Very often corrosion is combined with erosion, thus multiplying undesirable effects. Not all metals are equally affected by corrosion, however, iron and its alloys (mostly steel) - as dominant materials in many areas - are to a great extent subject to deterioration caused by corrosion.

According to the type of the process, diverse methods of protection have been developed, like anticorrosive primer layers, corrosion inhibitors, cathodic protection etc. They, solely or in combination with other methods, more or less prevent corrosive dissolution of metals, or can - at least - decrease the rate of corrosion.

Printing industry is not an exemption to this. Metallic parts of printing machines and other equipment are - due to the requirements of the production process - exposed to different aggressive liquids and solutions, which can cause material destruction on the solid/liquid interface. Most significant case, however, is influence of the fountain solution to the metallic parts of offset printing machines. It is, therefore, necessary to consider different aspects and examine influence of fountain solutions on metallic corrosion in printing technology - including chemical, electrochemical and mechanical investigations.

In addition to its primary function, fountain solution has a number of secondary, although not less important roles in the offset printing system. Along with other ingredients, most of commercial solutions contain inhibitors with the aim of preventing corrosion. However, under dynamic conditions of the printing process, surface coating of the paper is entering the fountain solution, particles being either released from the surface, or dissolved in contact with the solution. Although intended to cover non-printing areas of the printing plate, it is distributed from the offset cylinder to other machine parts, where it can remain deposited.

Although in a very short time, fountain solution is therefore polluted by dissolved particles, thus having the composition and characteristics changed. This can reflect to the quality of printing, but, if deposited, can gradually cause deterioration of ball bearings, metallic rollers and other movable machine elements.

2. Theoretical background

Corrosion is spontaneous transformation of metals into its compounds, resulting in unintentional degradation, wear and loss of material (Potter, 1968). Corrosion effects can be identified by different methods, emerging from the nature of the process and characteristics of the products involved.

Spectral analysis is based on measuring of the radiation energy absorbed by or emitted from the basic particles of the matter. Different frequencies of radiation are giving emission spectrum of the respective matter. Changes in energy levels are caused by different reasons and have different values, and by this are emerging in diverse section of the spectrum of electromagnetic radiation (Laćan-Šuprina 1976).

Due to the structure of the crystal lattice, smooth and even surface of steel has high degree of reflection in the visible portion of the spectrum (380-700 nm). By formation of corrosion products, which are - as a rule of a rough granular structure - incoming light is scattered and the reflectance is gradually decreased (Zorović, 1972). In compounds formed as corrosion products, iron is, together with other elements or ions (oxygen, hydrogen, hydroxyl group, etc,) bound with chemical links of different energy level and, accordingly, their spectral emissions in the visible spectrum will be different.

Atoms in molecules are not static, but in the state of permanent vibrations. Each molecule is characterized by a specific mode and frequency of vibrations, depending on the atomic mass and strength of links among them. Wavelengths of molecular vibrations are positioned in the infrared portion of the EM spectrum (2,5-45 μm or 4000-220 cm^{-1}). Molecules can absorb radiation energy from this part of the spectrum and transform it into the vibration energy, if the frequency of radiation corresponds to the vibration frequency within the molecule. By comparing the incoming and outcoming electromagnetic radiation through the IR spectrum, absorption spectrum of the corrosive product can be obtained. Furthermore, by comparing absorption spectra with those of known standards, presence of certain molecules in the corrosion product can be determined and mechanism of their formation explained (Van der Maas 1970; Misković 1975).

3. Experimental

An extensive number of methods have been developed for investigation of corrosion, ranging from mechanical, over chemical to electrochemical investigations. However, most of experimental work in this investigation was intended to determine state of the surface and identify corrosion products by specific experimental methods. All experiments were performed under standard laboratory conditions and on room temperature.

3.1 Steel specimens

Experimental specimens were prepared from carbon steel according to DIN Ust 12 (C_{max} 0,12%, Mn_{max} 0,50%, P_{max} 0,04%, S_{max} 0,04%), measuring 60 x 47 mm. Surface was treated with sand paper T400 and T 800 and then highly polished with the polishing paste. After chemical treatment in dimethyl ketone and 10% sulphuric acid, specimens were washed out, dried and immersed into the electrolyte. Uniformity of surface treatment was tested by spectrometer, showing the same results of spectral emission.

3.2 Solutions

For testing of corrosion 8 different electrolytes were used: distilled water, normal (tap) water, solutions buffered to pH 4, 5, 6 and 8, as well as aqueous solutions of standard offset paper and high gloss printing paper.

The latter two solution were prepared with strips of paper (dim. 460 x 60 mm), 10 of which have been immersed into 500 ml of distilled water for 15 seconds. In such a short time merely primary penetration occurs, therefore surface compounds from the paper can dissolve only. In this way, real process of paper/fountain solution interaction can be simulated.

All solutions (electrolytes) prepared for this investigation had volume of 350 ml. Initial values of electrical conductivity and pH were measured by standard instrumental methods, giving the fol-lowing results:

Table I: Initial values of pH and conductivity for examined electrolytes

Specimen/solution	pH	Conductivity ($\mu S/cm^{-1}$)
Specimen # 1 DW	6,82	1,8
Specimen # 2 NW	6,25	832,0
Specimen # 3 Buffer pH 4	3,99	393,0
Specimen # 4 Buffer pH 5	5,01	563,0
Specimen # 5 Buffer pH 6	6,05	408,0
Specimen # 6 Buffer pH 8	7,99	188,0
Specimen # 7 GP solution	9,92	205,0
Specimen # 8 OP solution	7,62	272,0

Abbreviations
DW = distilled water
NW = normal water
GP = high gloss paper
OP = standard offset paper

3.3 Methods

Spectral reflectance from the surface of steel was measured in the visible portion of the spectrum (380-700 nm) by X-Rite spectrophotometer Swatch Book and furthermore processed by Colour shop 6.2 software. Before each measurement, spectrophotometer was calibrated according to the white standard.

Method of measuring spectral adsorption by Fourier Transformation Infra Red Spectroscopy (FT-IR) has been also applied for this investigation, using Perkin-Elmer spectrometer 1720-x. Corrosion products were pressed for this purpose and recorded by technique of pure KBr pastilles at room temperature. Steel specimens were taken from the electrolyte before measurement, dried in the air, without removing corrosion products.

Spectrophotometric measurements of the steel surface were done before, as well as after 7, 14 and 28 days, while FT-IR spectrometry of corrosion products was performed after total of 126 days.

4. Results

Corrosion products emerging on the surface of steel are of rough, granular structure and have - as a rule - larger volume. Since they are falling down from the surface, mass of steel is consequently decreasing. By means of precise balance rate of corrosion can be determined, i.e. dynamics of the process. Results of Δm as a function of time are shown on Fig. 1.

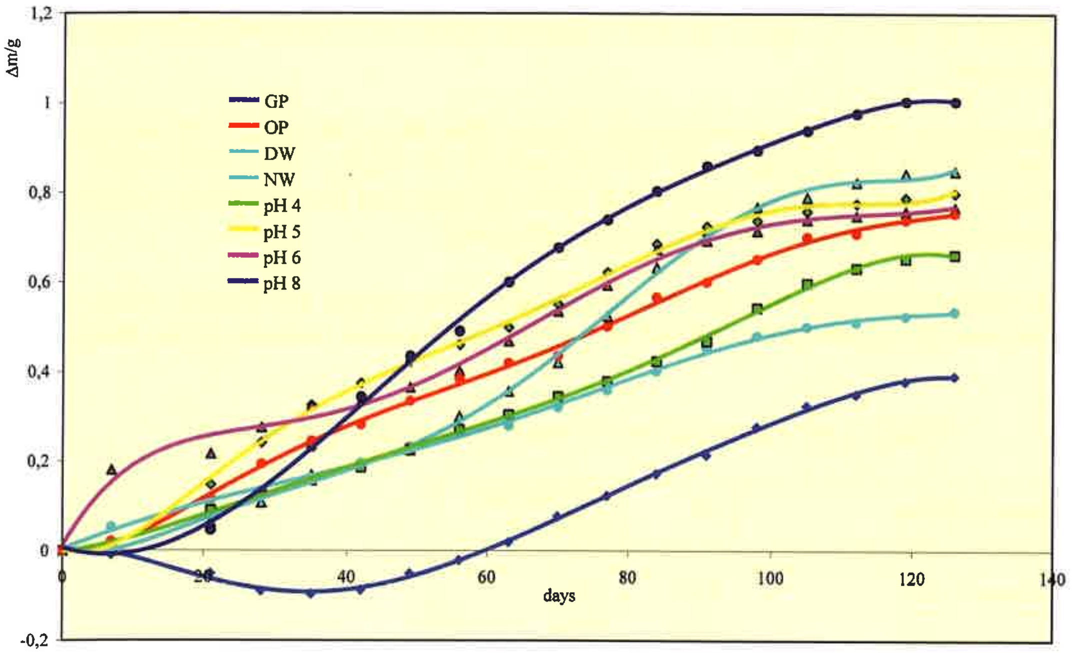

Fig. 1: Loss of material of the steel specimens in electrolytes depending on the duration of the corrosion process

In the observed period, steel specimen immersed into buffer solution pH 8 showed greatest loss of material. Dynamic of the corrosion process measured in buffer solution pH 6 was much higher in the first 21 days than in other electrolytes. Contrary to previous expectations, specimen exposed to the aqueous solution of surface coating of high gloss paper, showed increase of mass in the first 35 days.

By measuring the values of the electric conductivity of solutions as a function of time, dynamic changes of the concentration of dissociated ions was indirectly examined. pH values measured are indicating influence of the ratio of H^+ and OH^- ions on the corrosion reaction, as well as acting of buffers in the system.

Electrolytes 1 to 6 have known composition and properties, therefore only results of conductivity and pH measurements for solutions containing surface coatings of papers are presented (Fig 2).

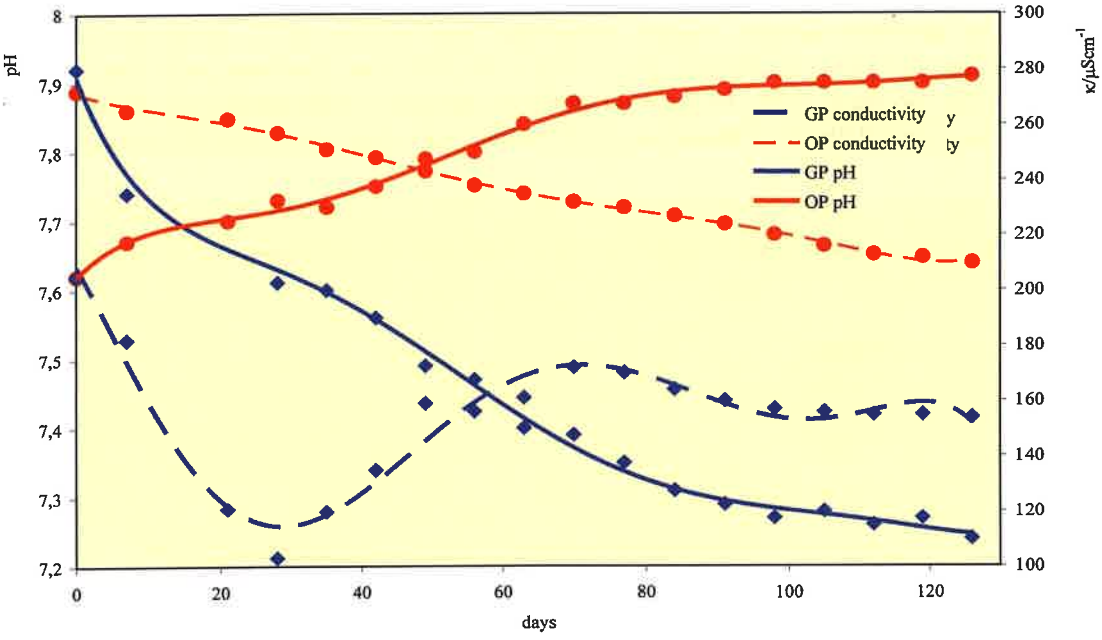

Fig. 2: pH and conductivity of paper coating solutions depending on the duration of the corrosion process

Before the beginning of the corrosion process, even and polished surface of steel has rather high degree of reflection (0.55), equally in the entire visible portion of the spectrum. However, smallest traces of corrosion products on the surface will disperse the incoming light, so generally, total reflectance will be lower (Fig. 3).

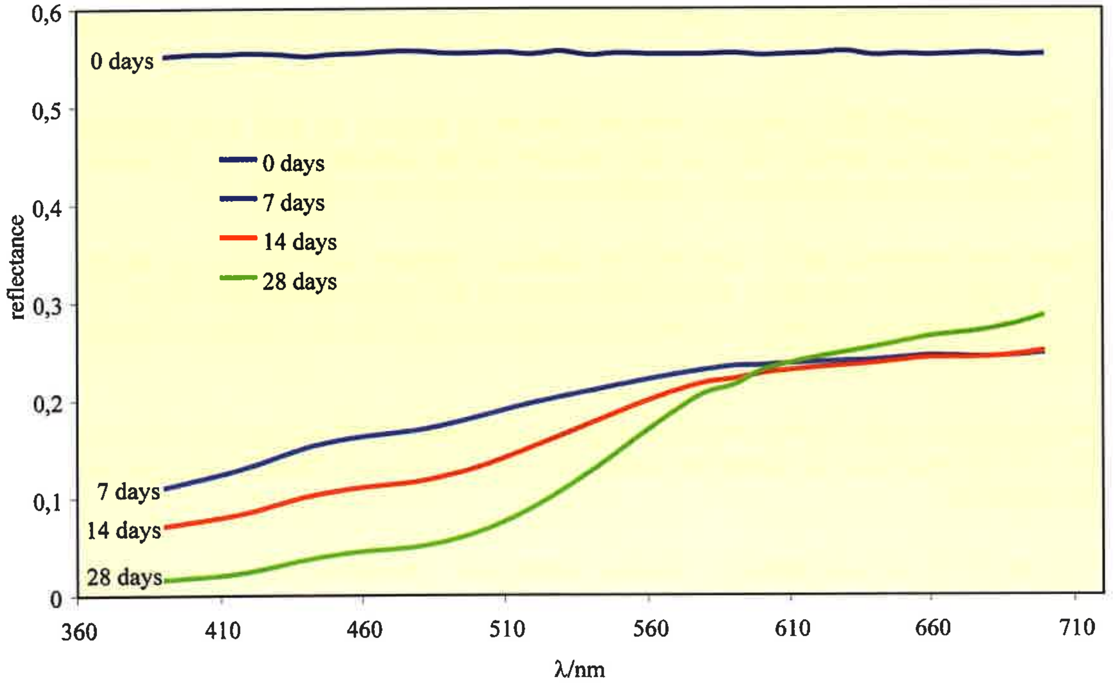

Fig. 3: Spectral reflectance from the surface of steel specimens in the visible portion of the spectrum before and after 7, 14 and 28 days of exposure to solution of surface coating of the high gloss paper

After 7 days corrosion products formed on steel in the aqueous solution of surface coating of standard offset paper have absorbed radiation equally along the entire portion of the spectrum. In the next period, compounds created on the surface of steel are more and more absorbing incoming light in the blue section of the spectrum. After 14 days no obvious changes in reflectance have been indicated, therefore it can be assumed that the formed corrosion products are of the same crystal structure (Fig. 4).

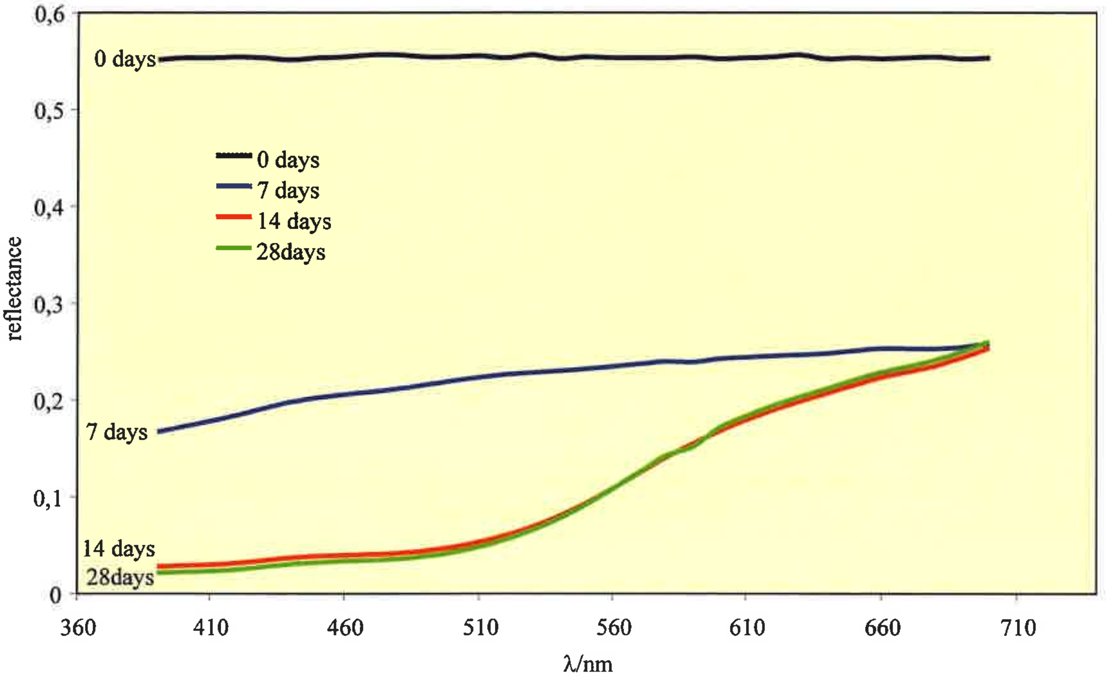

Fig. 4: Spectral reflection of the steel specimen surface in the visible portion of the spectrum before and after 7, 14 and 28 days of exposure to aqueous solution of surface coating of standard offset printing paper

FT-IR analysis proved that corrosion products formed in normal, as well as in distilled water are giving almost identical results. Most of the recorded bands indicate presence of lepidocrocite and magnetite, which was also confirmed by measurements in the FAR range (Fig. 5).

At different concentrations of H^+ ions diverse corrosion products will be present, which is obvious from Fig. 6 with FT-IR recordings of corrosion products for buffered solutions of pH 4, 5, 6 and 8. Electrolyte buffered to pH 4 shows the presence of goethite, besides equal shares of lepidocrocite and magnetite.

Buffered electrolyte at pH 5 gives corrosion product consisting mostly of goethite with magnetite only in traces. Corrosion process in electrolyte buffered to pH 6 resulted in lepidocrocite and only a smaller share of magnetite.

However, at pH 8 - in a moderately alkaline electrolyte - corrosion process is most intense, and products containing lepidocrocite and haematite were identified, while magnetite can be indicated in traces only.

Water solutions of paper surface coatings are, however, giving a composite structure of corrosion products. FT-IR results are showing a composition of lepidocrocite and goethite, as well as a presence of haematite and traces of magnetite (Fig 7).

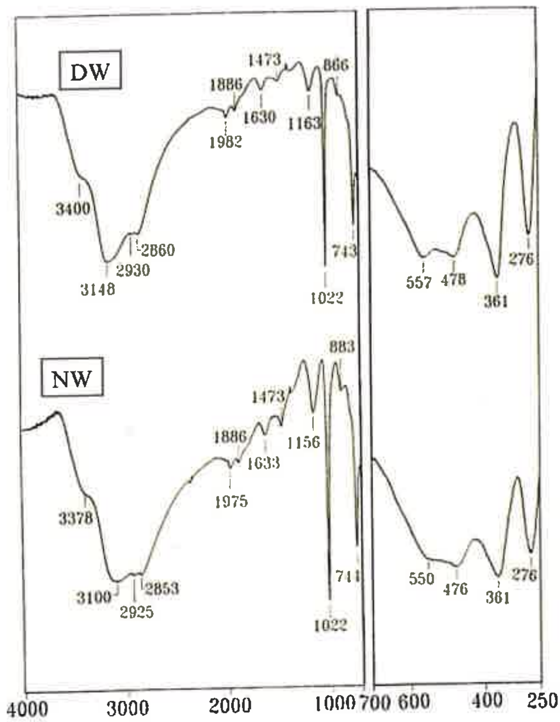

Fig. 5:

FT-IR recordings in MEAD and FAR range of corrosion products formed in distilled (DW) and normal water (NW)

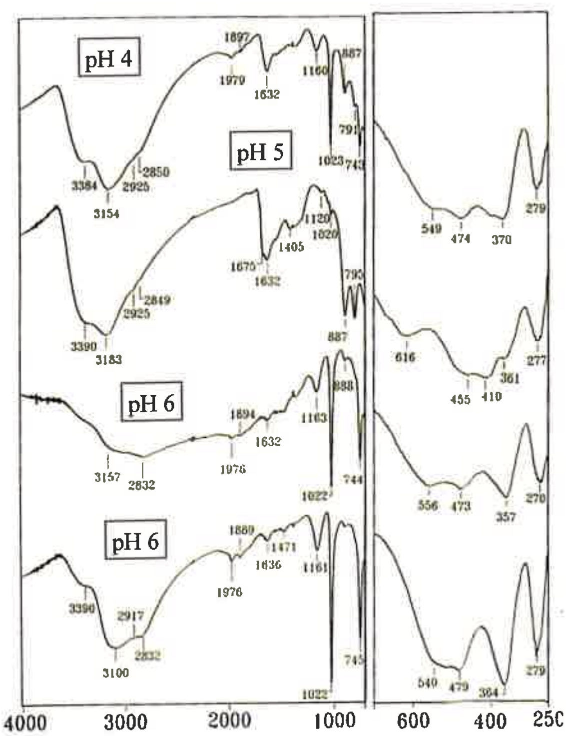

Fig. 6:

FT-IR recordings in MEAD and FAR range of corrosion products formed in buffered solutions of pH 4, 5, 6 and 8

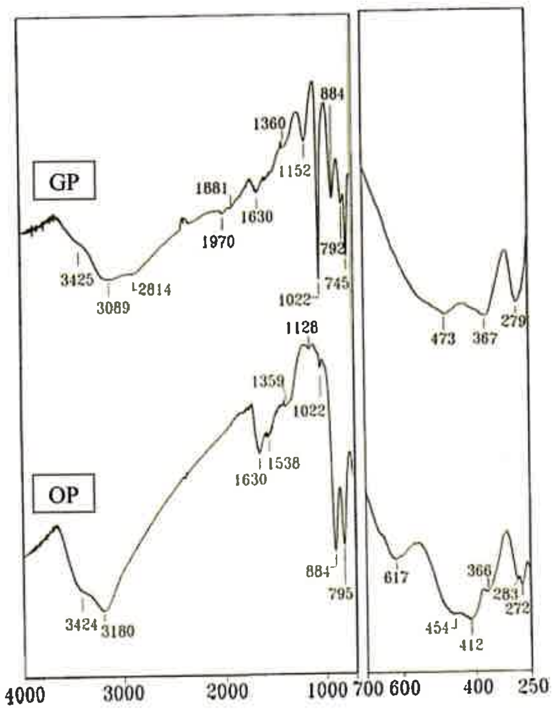

Fig. 7:

FT-IR recordings in MEAD and FAR range of corrosion products formed in water solutions of surface coatings of high gloss printing paper (GP) and standard offset paper (OP)

5. Discussion

Results obtained by the experimental methods applied in this investigation can elucidate the rate of corrosion and mechanisms of formation of corrosion products in the examined systems.

Steel specimens - besides iron - include also traces of other elements with different redox potentials. Therefore, when immersed into electrolyte, micro galvanic cells appear, which are actually causing dissolution of metal and its corrosion. It is clear that the course and rate of corrosion, as well as products emerging, are related to the composition of electrolyte. Elementary iron from the steel transits into Fe^{++} ions. They, in further secondary and tertiary reactions form oxides and hydroxides of different composition and crystal structure.

During the process of corrosion, ions in secondary and tertiary reactions are bound to ferrous ions or are exchanged with ions of different conductivity. Therefore, conductivity cannot remain the same as in the initial state. Aqueous solution of surface coating of standard offset printing paper (OP) shows linear decreasing of electrical conductivity, while measured pH values are continuously growing during the corrosion process, i.e. solution is becoming more alkaline. On the contrary, pH of aqueous solution of surface coating of high gloss paper in the observed time is decreasing from initial value (9,92) to almost neutral. Electrical conductivity in this case is decreasing in the first 30 days and than increasing until 60th day. After that, further changes cannot be noticed (Fig. 2). This proves that steel has been exposed to different corrosive environments, which resulted in diverse state of the surface (Fig. 4) and corrosion products (Fig. 7).

Spectrophotometric measurements proved that the corrosion process results in products of different crystal structure, as well as of different composition, both as a function of time. Each single crystal shape has specific absorption of light in the visible spectrum. The utmost reflectance was registered on all specimens in the first 7 days. In the following observed period, the total reflectance is decreasing considerably slower, while spectral composition of the light remitted is obviously changing. After 7 days of exposure, corrosion products on steel specimens immersed into the solution of high gloss paper absorbed much more light in the blue portion of the spectrum. After 28 days the share of the red portion of the spectrum is much more represented in the total reflectance. This clearly indicates formation of corrosion products of different crystal structure (Fig. 3).

Although the complete quantitative analysis of corrosion products has not been preformed, FT-IR recordings proved that steel specimens in the investigated systems are giving different results, with the following four ferrous compounds identified (Table II):

Table II: Compound represented in corrosion products of investigated systems (relative presence)

	DW	NW	pH 4	pH 5	pH 6	pH 8	GP	OP
Lepidocrocite	◆	◆	◆	◇	◆	◆	◆	◇
Magnetite	◆	◆	◆	◇	◈	◇	◇	◇
Ghoetite			◈	◆			◆	◆
Haematite						◆	◈	

Explanation of symbols

◆ Higher presence

◈ Lower presence

◇ Traces only

Most of the bands recorded for distilled water, as well as for normal water indicate high presence of lepidocrocite [γ-FeO(OH)], which is a typical product of under-water corrosion. It can be most clearly identified at 1022, and 743 cm^{-1}. Presence of magnetite [ferrous-ferric oxide (Fe_3O_4)] is detected at 557 cm^{-1}. Both results are confirmed by measurements in FAR range, where bands at 361 and 276 cm^{-1}

can be attributed to lepidocrocite, band at 557 cm^{-1} to magnetite, while both crystals share the band at 478 cm^{-1} (Fig. 5). Results obtained for corrosion in distilled water are in accordance with earlier investigations and literature references (Music, 1993).

Results of FT-IR measurements of corrosion products formed in the buffered electrolytes are showing greater variety of present compounds. For the solution of pH 4 lepidocrocite was detected at 1023, 743 cm^{-1} in the MEAD range and at 370 and 279 cm^{-1} in the FAR range. Equal share of magnetite was determined at 549, 474 cm^{-1}, while measured values at 887, 791 cm^{-1} can be at-tributed to goethite, another product of FeO(OH) composition.

While in buffered solution of pH 5 the measured values mainly correspond to goethite, with only traces of lepidocrocite identified at 1022 cm^{-1}, for electrolyte of pH 6 bands at 1022 and 744 cm^{-1} indicate greater presence of lepidocrocite (confirmed at 357 and 270 cm^{-1} in the FAR range). Band at 556 cm^{-1} can be attributed to the presence of magnetite, while values of 556 and 473 cm^{-1} indicate both, lepidocrocite and magnetite in the corrosion product.

However, in moderately alkaline environment (pH 8), corrosion products formed on the surface of steel, besides lepidocrocite, also include haematite (Fe_2O_3), the most common ferrous oxide. Shoulder of the curve at 479 cm^{-1} can be attributed to both, lepidocrocite and haematite. Traces of magnetite can be also indicated here (Fig. 6).

Recordings of FT-IR measurements obtained for corrosion products on steel in aqueous solutions of surface coatings of both papers are indicating a more complex structure. Solution containing surface coating of the high gloss paper (GP, Fig. 7) resulted in a mixture of lepidocrocite (1022, 745 cm^{-1}) and ghoetite (884 and 792 cm^{-1}), while shoulder of the curve at 553 cm^{-1} can be attributed to haematite. In aqueous solution of surface coating of the normal offset paper (OP, Fig. 7), most of the bands recorded in MEAD and FAR ranges are corresponding to goethite, only the band at 1022 cm^{-1} shows the presence of lepidocrocite, while the FAR band at 283 cm^{-1} indicates the traces of magnetite (Briston, 1998).

6. Conclusion

Spectophotometric measurements in the visible portion of the spectrum are suitable for detection of corrosion in initial phase only, depending on the dynamics of the process, up to the first 7 days under described laboratory conditions. After that time corrosion products emerging defecting from the surface, therefore such analysis is not a real indicator of the dynamics and the course of the process. However, in initial phases formation of corrosion products can be detected on the metal surface, even without analysis of the product in the electrolyte, which usually evaporates in the printing machine. Such a method, although not accurate enough, could be suitable for simple detection of corrosion under production conditions.

Exposure of steel to normal and distilled water will give the same corrosion product, which indicates the same mechanism of their formation; however distilled water as corrosive environment seems to be much more aggressive. According to values of electrical conductivity, fountain solution is significantly much closer to normal water (600-700 $\mu S/cm^{-1}$), but has higher hardness. Minerals contained in normal water will not influence the chemism of corrosion, but will have an effect on dynamics. In addition, pH values of solutions significantly affect the corrosion rate, but chemical process depends on the composition of electrolytes, which was proven in cases of water solutions of paper coatings.

Coatings have their multifunctional role on the surface of printing papers. Their composition and characteristics are different, depending on the type of paper and production method. During the process of printing wet friction occur between the offset and impression cylinders. Small particles from paper surface are entering the fountain solution, some of them being soluble. Such dissolved compounds of different chemical origin, together with the fountain solution (which is of a compo-site character itself), results in an extraordinary complex corrosion system. Under real printing conditions, fountain solution should not act as a corrosion medium. However, during the process, starting parameters are changing, and the solution becomes significantly more aggressive. In pre-venting corrosion in the process of printing, it is necessary to control properties of inks, papers and - particularly - fountain solutions entering the system, since they can significantly influence the effect of corrosion of printing machine elements.

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A colour separation strategy for reproduction of printed dynamic images on paper substrate

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Abstract

Dynamic images printed on paper that can change from one image to another makes it possible to include more information to the printed product and it also adds more attention to the print. In this paper, two different colour separation strategies for dynamic image reproduction are investigated. The colorants used consists of a static ink set and a dynamic ink set, where the dynamic colorants can obtain two different optical states. The required colour changes in the dynamic image are given by the two input images. A spectral model based approach is used for predicting the different ink combinations in the two different states. The spectral colour printing model is based on Yule-Nielsen modified Neugebauer equations and Kubelka-Munk theory. This model is then applied for the computation of the colour separation functions from CMYK to static and dynamic separations. Thermochromic inks are used as dynamic colorants and the printing method is screen printing.

1. Introduction

Dynamic images printed on paper can be obtained by combining dynamic ink-layers with static ink-layers. The dynamic ink-layers can be brought to different optical states where they change color or become more or less transparent revealing underlying static ink, thus changing the image. The dynamic images are controlled by a thin film of conducting polymers, developed by Acreo, which is printed on the backside of the paper substrate. The printed conducting polymer-film can be printed using traditional printing techniques like gravure-, offset-, flexo- and screen-printing. The possibility to print dynamic images adds more attention to the final printed product. There are many different possible future applications, for example dynamic billboard commercials, intelligent packaging, and dynamic labels.

The reproduction of dynamic images requires new methods for the pre-press process. The dynamic images will be reproduced with more printing primaries than ordinary four process color printing, so-called multi-color printing. And the additional requirement to be able to shift between two or more images sets completely new demands for the whole color separation process. The objective with this study is to derive a color separation strategy for dynamic image reproduction from a set of static and dynamic colorants.

2. Dynamic image reproduction

The goal with this project is to derive colour separation models for dynamic image reproduction with two input images where some of the colorants have different optical states, and the colour transitions are predefined by the input images. The dynamic image in the first state consists of a combination of static and dynamic inks in their colored state and the image in the second state consists of static inks and dynamic inks in their translucent state. Each image element in the dynamic image is thus a function of dynamic ink layers, static process-ink layers and the current image state given by Eq. 1:

$$Dynamic\ Image\ Pixel = f\left(I_s, I_{d,State}, State\right) \tag{1}$$

where I_s are the static process-ink layers, $I_{d,State}$ are the dynamic ink layers with two different states; in state 1 they exhibit color, and in state 2 they turn transparent revealing the underlying static ink layers, and *State* that indicates if the dynamic inks are activated or not. In this study four thermochromic inks, $C_tM_tY_tK_t$, are used as the dynamic ink set, where C_t=thermochromic cyan, M_t=thermochromic magenta, Y_t=thermochromic yellow and K_t=thermochromic black. They change color in response to temperature, and are colored in their cool state and almost translucent in their warm state. The static ink set consists of the four standard process-inks $C_pM_pY_pK_p$, where C_p=process cyan, M_p=process magenta, Y_p=process yellow and K_p=process black.

3. Predicting static and dynamic primaries

A spectral model based on Kubelka-Munk theory and Yule-Nielsen modified spectral Neugebauer model was used for predicting spectra of different ink combinations in the two states. The halftone colours are predicted using the Yule-Nielsen modified spectral Neugebauer equation (Yule and Nielsen, 1951). For dynamic colour halftoning the reflectance spectra of the inks are also dependent of the current state, represented by Eq. 2:

$$R_{State}(\lambda)=\left[\sum_{i=1}^{N}a_iR_{i,State}^{1/n}(\lambda)\right]^n \qquad (2)$$

where R_{state} represents the resulting reflectance spectrum of the halftoned printed area, a_i represents the fractional area coverage estimated using the Demichel equations (Demichel, 1924), $R_{i,state}$ represents the reflectance spectrum of the current ink in a given state, N represents the number of colorants and n represents the Yule-Nielsen-factor which is derived from the best fit of the model to the training data set.

The static and dynamic primaries were predicted using the Kubelka-Munk model (Kubelka, 1948), described by Judd and Wyszecki (Judd and Wyszecki, 1975) and Niskanen (Niskanen, 1998) among others. Modifications of this method has been used by Stollnitz (Stollnitz, 1998), for modeling multi-ink-layers images reproduced with custom inks, and Hoffman (Hoffman, 1998), for modeling multi-layer toner images, among others. The modified equation for N dynamic ink layers is represented by Eq. 3:

$$R_{p1\ldots N,State}=R_{N,State}+\frac{T_{N,State}^2R_{pN-1,State}}{1-R'_{N,State}R_{pN-1,State}} \qquad (3)$$

where $R_{p1\ldots N,State}$ represents the reflectance spectrum of the dynamic ink layers in the current state, $R_{N,State}$ represents the reflectance spectrum of the top dynamic ink layer, $T_{N,state}$ represents the transmittance spectrum of the top ink layer in the current state, $R_{pN-1,State}$ represents the reflectance spectrum of the second top dynamic ink layer in the current state and $R'_{1,State}$ represents the reflectance of the back side of the ink layer. The reflectance spectrum of N ink layers is predicetd by treating the reflectance spectrum that has been modeled for the (N-1) ink layer as the substrate reflectance spectrum for the next ink layer. This process is further repeated for all remaining layers in order to model a final reflectance spectrum for a multi-layer sample. Since the Kubelka-Munk model does not take into account the reflection losses at the sample boundaries, the measured reflectance spectra have to be compensated for this illumination loss. This is done by applying the Saunderson correction equations (Saunderson, 1942). A more detailed description of the method was presented at TAGA 2005 (Johansson, 2005).

4. Colour separation strategies

Two different colour separation strategies have been invesigated. The first method is used for reproduction of a dynamic image changing from colour to grayscale, where the ink set consists of thermochromic cyan (C_t), thermochromic magenta (M_t), thermochromic yellow (Y_t) and process black (K_p). The colour separation method for dynamic image reproduction changing from colour to grayscale starts with the input image represented by RGB which is then converted from $C_3M_3Y_3$ to $C_4M_4Y_4K_4$ according to Nakamura equations (Nakamura, 1989):

Input Image

$$C_3 = 1 - R_1 \quad M_3 = 1 - G_1 \quad Y_3 = 1 - B_1$$

$$K_4 = R\min(C_3, M_3, Y_3)$$
$$C_4 = \frac{C_3 - K_4}{1 - K_4} \quad M_4 = \frac{M_3 - K_4}{1 - K_4} \quad Y_4 = \frac{Y_3 - K_4}{1 - K_4}$$

Output Dynamic Image

$$K_4 = K_p \quad C_4 = C_t \quad M_4 = M_t \quad Y_4 = Y_t \tag{4}$$

where C_3, M_3, and Y_3 are the original CMY components, C_4, M_4, Y_4, and K_4, are the new CMYK components and $0 \leq R \geq 1$. R, in this case, is set to 1. The new CMYK components are then used to calculate the final fractional area coverage according to Demichels equations and the final reflectance spectrums for the two different states, $R_{State1}(\lambda)$ and $R_{State2}(\lambda)$, are then predicted using the spectral printing model. The separation C_4 is reproduced with cyan thermochromic-ink, M_4 with magenta thermochromic-ink, Y_4 with yellow thermochromic-ink, and K_4 with black process-ink.

Input Image 1

$$C_{31} = 1 - R_1 \quad M_{31} = 1 - G_1 \quad Y_{31} = 1 - B_1$$

Input Image 2

$$C_{32} = 1 - R_2 \quad M_{32} = 1 - G_2 \quad Y_{32} = 1 - B_2$$

$$K_{41} = R\min(C_{31}, M_{31}, Y_{31})$$
$$C_{41} = \frac{C_{31} - K_{41}}{1 - K_{41}} \quad M_{41} = \frac{M_{31} - K_{41}}{1 - K_{41}} \quad Y_{41} = \frac{Y_{31} - K_{41}}{1 - K_{41}}$$

$$K_{42} = R\min(C_{32}, M_{32}, Y_{32})$$
$$C_{42} = \frac{C_{32} - K_{42}}{1 - K_{42}} \quad M_{42} = \frac{M_{32} - K_{42}}{1 - K_{42}} \quad Y_{42} = \frac{Y_{32} - K_{42}}{1 - K_{42}}$$

$$K_t = K_{41} - K_{42} \quad C_t = C_{41} - C_{42} \quad M_t = M_{41} - M_{42} \quad Y_t = Y_{41} - Y_{42}$$

$$K_{42} = K_p \quad C_{42} = C_p \quad M_{42} = M_p \quad Y_{42} = Y_p$$

Output Dynamic Image

$$K_{tot} = K_t + K_p \quad C_{tot} = C_t + C_p \quad M_{tot} = M_t + M_p \quad Y_{tot} = Y_t + Y_p \tag{5}$$

The second method is used for reproduction of a dynamic image changing from a dark colour image to another lighter colour image, where the ink set consists of thermochromic cyan (C_t), thermochromic magenta (M_t), thermochromic yellow (Y_t), thermochromic black (K_p), process cyan (C_p), process magenta (M_p), process yellow (Y_p) and process black (K_p). Again the separation process starts with the $C_3M_3Y_3$ to $C_4M_4Y_4K_4$ conversion given in Eq. 4 for input image 1 represented by $R_1G_1B_1$ and input image 2 represented by $R_2G_2B_2$, as illustrated in Eq. 5. The amount of $C_pM_pY_pK_p$ for the static separations is then determined by the $C_{42}M_{42}Y_{42}K_{42}$ separations for image 2 and the amount of $C_tM_tY_tK_t$ is determined by substracting the $C_{42}M_{42}Y_{42}K_{42}$ separations from the $C_{41}M_{41}Y_{41}K_{41}$ separations for image 1. The final output image then consists of four static separations ($C_pM_pY_pK_p$) and four dynamic separations ($C_tM_tY_tK_t$). The final fractional area coverage is again calculated according to Demichel's equations and the final reflectance spectrums for the two different states, $R_{State1}(\lambda)$ and $R_{State2}(\lambda)$, are then predicted using the spectral printing model.

5. Experimental setup

Eight different inks, process- and thermochromic, were printed on an uncoated paper using screen-printing. The printing parameters are collected in Table I.

Table I: Printing parameters

Press	Semiautomatic flatbed screen press, American
Line Screen	80 lines per inch
Mesh	120 threads/inch with a 15µm thread diameter
Ink	UV-curable process inks (C_p, M_p, Y_p and K_p) with printing base, Encres Dubuit Thermochromic pigments (C_t, M_t, Y_t, and K_t,) mixed with base, Encres Dubuit
Substrate	Uncoated card, Opalin 220g

Four standard UV-curable process inks: cyan (C_p), magenta (M_p) and yellow (Y_p) and four thermochromic inks: cyan (C_t), magenta (M_t), yellow (Y_t) and black (K_t) were used in the study. The thermochromic inks all have an activation temperature of 31°C where they turn almost transparent. The colour transition is reversible. The particle size of the thermochromic pigments is about 6 micron as compared to normal pigments that have a particle size of 0.1-2 microns (Kipphan, 2001). Thus, the thermochromic particle is about 3-4 times larger than an ordinary pigment particle.

In order to characterize the static and dynamic ink-set a test target was designed to contain sample ramps for each of the static process-inks and the dynamic thermochromic-inks. Each ramp consists of eleven steps from 0% to 100% area coverage in 10% intervals. The training target used for evaluating the accuracy of the spectral printing model consisted of a total of 480 colour paches of primary, secondary and tertiary ramps also consisting of eleven steps from 0% to 100% area coverage in 10% intervals.

The printed samples were measured in their both states with a spectrophotometer with an optical geometry of 45°/0°. Measurements were done with D50 illuminant, 2° observer and UV filter. The adopted spectral range was from 400 nm to 700 nm at 10 nm intervals. The spectral data of the patches were obtained by averaging four measurements on each patch. To transform the thermochromic ink to the warm state a radiator was used together with an aluminium plate to separate the test prints from the radiator and make the heat distribution more even. The temperature was set to 40°C. The temperature was measured against the paper on top of the plate.

6. Results

The spectral reflectance factors of the four static primaries (C_p, M_p, Y_p and K_p) and the paper substrate (black dotted line) are plotted in Figure 1.

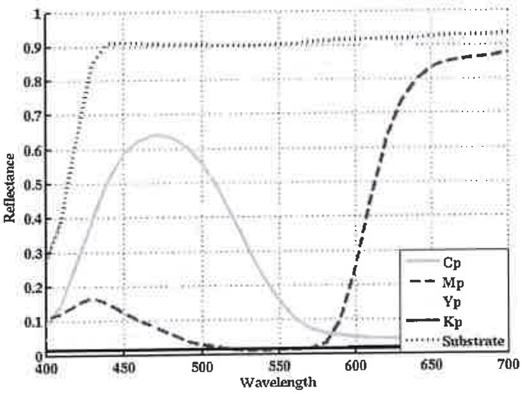

Figure 1:
The reflectance spectra of the four static primaries

The spectral reflectance factors of the four dynamic primaries (C_t, M_t, Y_t and K_t) in state 1 are plotted to the left in Figure 2, and the corresponding curves for the inks in state 2 are shown to the right. As can be seen, the thermochromic inks do not turn completely transparent in state 2, they still exhibit colour, especially the thermochromic yellow ink.

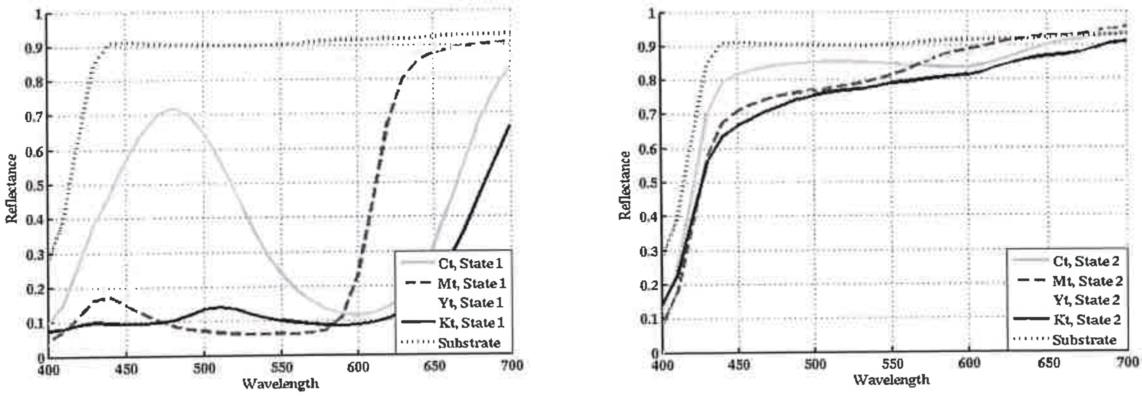

Figure 2: The reflectance spectra of the four dynamic primaries in state 1(left) and state 2 (right)

The reproducible colour gamuts for the standard process inks (solid line) and the thermochromic inks (dashed line) are shown in Figure 3 in the a*b*-plane of the CIELAB colour space. The combination of the four standard process inks yields a gamut volume of approximately 309740 cubic CIELAB units in comparison the volume of 87541 cubic CIELAB units for the four thermochromic inks. Thus, the reproducible colour gamut with the thermochromic inks is approximately 30% of the gamut of the standard process inks.

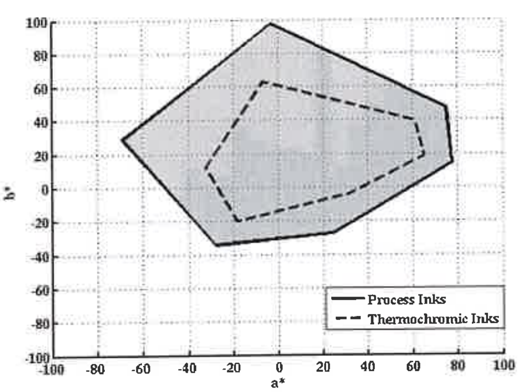

Figure 3:
*Reproducible colour gamuts with standard process inks (solid line) and thermochromic inks (dashed line) shown in the CIELAB a*b*-plane*

The accuracy of the model was evaluated by spectrally measuring the 480 patches in the training test-target in their both states, and compare the measurements with their corresponding model predictions. The model performance is summarized in Table II.

Table II: Summary of model performance

Separation	**Average ΔE^{*}_{ab}**		**Average Spectral RMS**	
	State 1	**State 2**	**State 1**	**State 2**
Solid Colour Layers	8.79	4.70	0.031	0.016
Halftoned Colour Layers	7.32	5.01	0.036	0.035

The model performance is acceptable even though it would probably be improved with a more stable printing method than screen. The ΔE histograms for the training set in the two different states are shown in Figure 4.

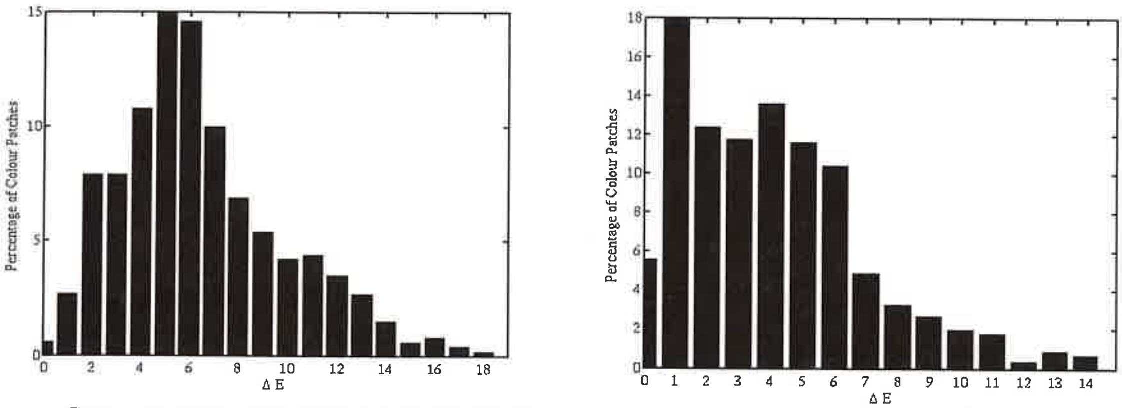

Figure 4: Histogram of the ΔE errors for the training set in state 1(left) and state 2 (right)

The prediction of a dynamic image changing from colour to grayscale was tested with the TC3.5 CMYK test target. First, a prediction of the test target reproduced with the $C_pM_pY_pK_p$ ink set based on the spectral printing model was made. Then, the colour separation method from CMYK to $C_tM_tY_tK_p$ was applied and the resulting predicted images in state 1 and state 2 were calculated. Figure 5 displays the histogram of the ΔE errors for the TC3.5 CMYK colour patches for this separation technique in state 1 (left) and state 2 (right).

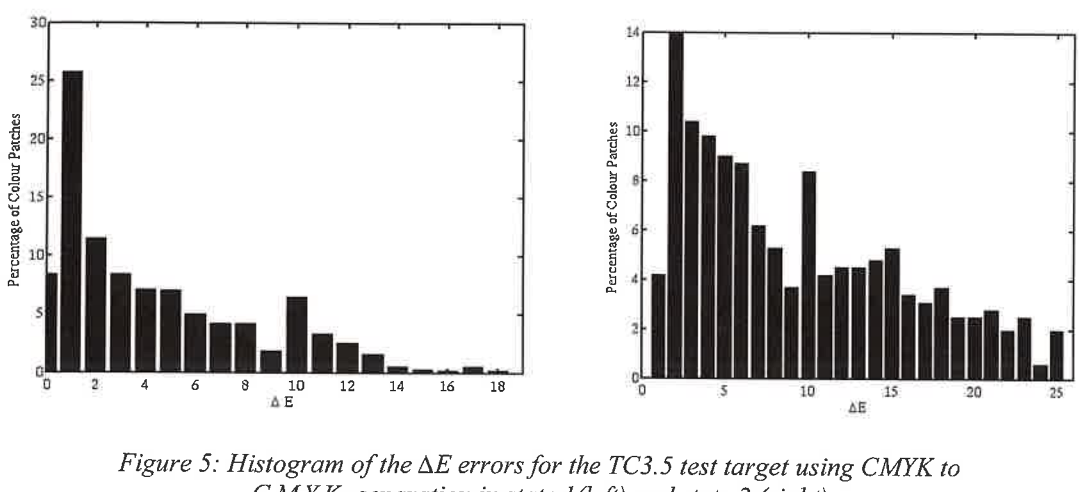

Figure 5: Histogram of the ΔE errors for the TC3.5 test target using CMYK to $C_tM_tY_tK_p$ separation in state 1(left) and state 2 (right)

The prediction of a dynamic image changing from a darker colour image to a lighter image was tested with a part of the TC2.9 CMYK test target containing 169 different patches. First, a prediction of the test target reproduced with the $C_pM_pY_pK_p$ ink set based on the spectral printing model was made. Then, the colour separation method from CMYK to $C_pM_pY_pK_pC_tM_tY_tK_t$ was applied and the resulting predicted images in state 1 and state 2 were calculated. Figure 6 displays the histogram of the ΔE errors for the TC2.9 CMYK colour patches for this separation technique in state 1 (left) and state 2 (right).

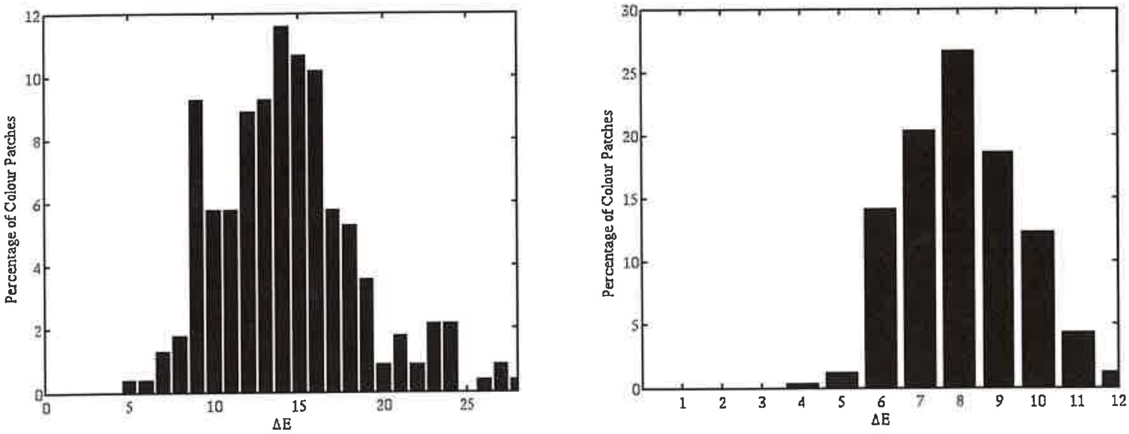

Figure 6: Histogram of the ΔE errors for the TC2.9 CMYK test target using CMYK to $C_pM_pY_pK_pC_tM_tY_tK_t$ separation in state 1(left) and state 2 (right)

Figure 7 shows an example of a predicted dynamic image in the two different states, where the image in state 1 is reproduced by a combination of process and thermochromic inks in the cold state, and the image in state 2 is reproduced by a combination of process and thermochromic inks in the warm state.

Output Image (State 1) **Output Image (State 2)**

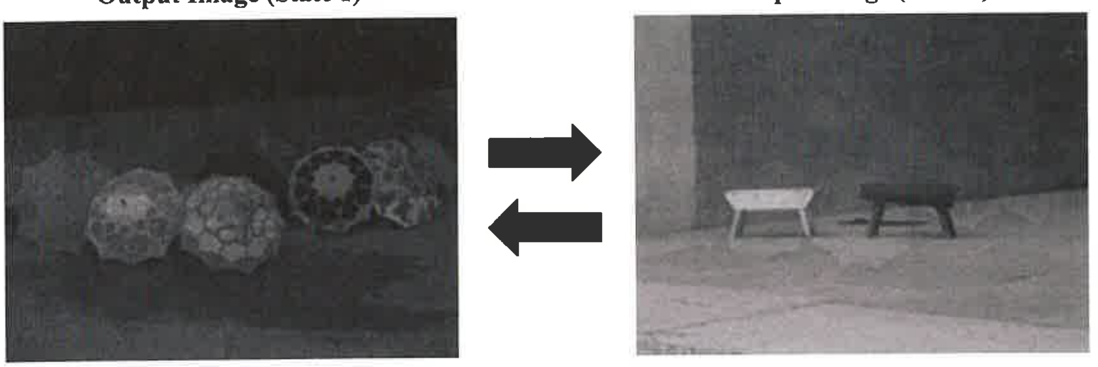

Figure 7: Example of a predicted dynamic image in state 1 (left) and state 2 (right)

7. Conclusions

Two color separation strategies for dynamic image reproduction with static and dynamic ink sets has been presented. The colour separation methods are based on a spectral printing model that predicts the reflectance spectra of the static and dynamic ink layer combinations based on Yule-Nielsen modified spectral Neugebauer equations and Kubelka-Munk theory. The first method is used to reproduce dynamic images that changes from colour to grayscale and the second method us used to reproduce dynamic images that changes from colour to colour. The results show that it is possible to change the printed dynamic image between two different images even though the quality of the colour reproduction is highly dependent of the quality of the thermochromic ink. The second colour separation approach is currently restricted to handle dynamic image reproduction where input image 1 is darker than input image 2. A further development of a colour separation model for dynamic image reproduction without such restriction would require the dynamic ink set to include a white opaque colorant that can cover parts of the print in state 1.

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Optimisation of folding box board coatings for electrophotographic printing

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Abstract

Nowadays, folding box manufacturers are being confronted more than ever before with declining printing order runs. The reasons for this are the demands for order-related just-in-time delivery, higher individuality and intensified market segmentation. A suitable technical solution that reacts to the trend of short runs is digital package printing. The most important techniques are ink-jet printing and electrophotography. The present project focuses on the latter. Digital package printing presses employing electrophotographic printing techniques are currently available as dry-toner systems (e.g. Xeikon, NexPress) and as liquid-toner systems (e.g. HP-Indigo). These machines can be effectively used to digitally print packages, but they place different and sometimes unspecified requirements on the print substrate. In addition, the properties of printed paperboards for manufacturing packages are unknown or only very imperfectly known.

This project aimed at providing optimised coatings for paperboards for the digital printing of packages. It was also important for quality assessment to consider the parameters relating to the usability of printed paperboards in the production of folding boxes (finishing suitability).

Successive stages of work were devoted first of all to studying the surface properties of industrially manufactured board samples that are relevant to optimum print quality, then correlating these properties with the print qualities that can be achieved using these samples and ultimately developing target values for the surface properties of paperboard. Based on these results, coating formulations were then developed, applied to a base board and tested on a laboratory scale. The coating formulations were then optimised step by step by varying the different components of the coating formulation (pigments, binders and additives). Ultimately, the optimised coating formulations were then verified by trials conducted under practical conditions on a pilot coater. The coated board samples were then reprinted using digital printing presses and the print quality was evaluated.

This report sets forth the individual studies and the results obtained. The final section compiles the essential findings of the research work and presents future approaches for further optimisation of boxboard coatings.

1. Introduction

Nowadays, folding box manufacturers are being confronted more than ever before with declining printing order runs. The reason for this is the demand for order-related just-in-time delivery. This tendency can be observed throughout the entire sector, irrespectively of whether the folding boxes are being used to package semiluxury foods and beverages, cosmetics or other consumer goods. A technical solution that is virtually predestined to provide a answer to the problem of declining printing runs is digital package printing. There are two important arguments that speak in favour of using this method to print short and very short print runs. On the one hand, it is the cost factor: when printing approx. 5,000 packaging units, digital printing methods are more cost-effective than conventional ones [1]. The second point is the time factor: although the output of digital printing presses is lower than that of conventional printers, the total time required to print short runs is less, since no time is lost making the printing plates nor is much set-up time involved.

In the narrow sense, digital printing is understood to mean printing methods that do not require physical printing plates. The most important techniques are ink-jet printing and electrophotography. The present project focuses on electrophotography. Digital package printing presses employing electrophotographic printing techniques are currently available as dry-toner systems (e.g. Xeikon, NexPress) and as liquid-toner systems (e.g. HP-Indigo).

The heart of any electrophotographic printing unit is a cylinder coated with a semiconducting material that is termed the photoconductor drum. The individual process steps (especially for the Xeikon dry-toner system) are as follows:
1. Create a uniform positive charge on the photoconductor drum by a charge corotron;
2. Produce a latent image by partial exposure of the photoconductor drum with a character generator (LED array or laser). The desired print now exists as a negative charge pattern on the photoconductor drum;
3. Develop the latent image with a positively charged powdery toner (printing ink);
4. Transfer the toner to the print substrate which was previously negatively charged by the corotron. The toner is transferred by a forme cylinder blanket in the NexPress and HP-Indigo printers, unlike the Xeikon process;
5. The printing process concludes with a fusing step in which the toner forms a film and is fused to the paper. Liquid toner systems do without this fusing step.

When paperboard is used as the printing substrate, problems frequently occur with toner transfer and toner fusion. These findings are based on test prints carried out at the research institute, in which it was not possible to print all grades of paperboard with the same high quality level. Most grades exhibited substantial unevenness in ink distribution (cloudiness) in full tone areas (Figure 1).

Figure 1:
Cloudiness of full tone areas due to poor toner transfer

Another critical process parameter in dry-toner systems is fusing the toner to the print substrate by heat and pressure. When liquid toner systems are used, the problems that arise relate in most cases to toner adhesion. To improve toner adhesion, the paperboard is commonly pretreated with a primer immediately before being printed. This, however, means higher printing and time costs.

Adequate print quality and a printed image that is suitable for use in the packaging sector thus make it indispensible that the paperboard comply with certain basic requirements.

These basic requirements include the following:
1. Uniform electrostatic charging of the print substrate (only for Xeikon);
2. Flatness;
3. Heat resistance (only for Xeikon and NexPress);
4. A surface finish suitable for toner adhesion.

The printed board must fulfill the following minimum requirements so that it can be used as raw stock to manufacture packagings:
1. High print quality;
2. Abrasion-resistant surface;
3. Creasability and foldability;
4. Gluability.

Although digital printing presses such as Xeikon, NexPress and HP-Indigo are available as high-performance printing presses for digital package printing, they place changing and sometimes non-specific requirements on the print substrate. The properties of printed paperboard for use in packaging (in particular for producing folding boxes) are likewise unknown or only incompletely known. The circumstances alluded to above largely explain why there has been so much hesitation on the part of the packaging industry to embrace digital printing methods. The advantages of the method, however, are so convincing that completely changed conditions must certainly be expected if the obstacles posed by the print substrate are to be overcome.

The research project that arose from these observations focused on providing optimum board surfaces (optimised board coatings) for digital package printing on folding boxboard which made it possible to produce high-quality prints preferably independently of the type of digital printing process employed. The measure of quality also included factors pertaining to the usability of printed boards to manufacture folding boxes.

2. Experimental work and results

2.1 Examination of paperboard properties and implementation of printing test runs

In order to be able to study the effect of paperboard properties on print quality in digital package printing, a total of five paperboard samples of the most frequently used board grades GC and GD (see Table I) were obtained from different, well-known paperboard manufacturers.

Table I: Selected industrial paperboards

Board sample	Type of board	Grammage [g/m²]	Thickness [µm]
1 (base board, precoated)	GC1	278	472
2	GC1	301	461
3	GC1	270	358
4	GD2	305	404
5	GD2	299	407

P.S.: Sample 1 is produced in large quantities by a well-known board manufacturer as a base board with one precoat. This was used for the coating trials that were conducted within the scope of the research project. Sample 2 was a board similar to sample 1 except that it had a standard board coating (precoat + top coat).

These board samples were used to determine the following essential board parameters:
- Surface roughness (DIN ISO 8791 Part 4: Parker Print Surf method (PPS));
- Surface energy (PTS Method PTS-PP: 103/85);
- Moisture content (DIN EN 20 287);
- Electrical volume resistance (DIN 53 482);
- Electrical surface resistance (PTS Method PTS-PP:101/84);
- Electrostatic recharging and discharging behaviour (static charge analyzer (Model 276 A));
- Coating layer analysis (scanning electron microscopy (SEM), Type JEOL 5600 LV).

The board samples were subsequently printed with a suitable test subject (see Figure 2) using the Xeikon DCP/500-SP, HP-Indigo Press s2000 and NexPress 2100 printing presses.

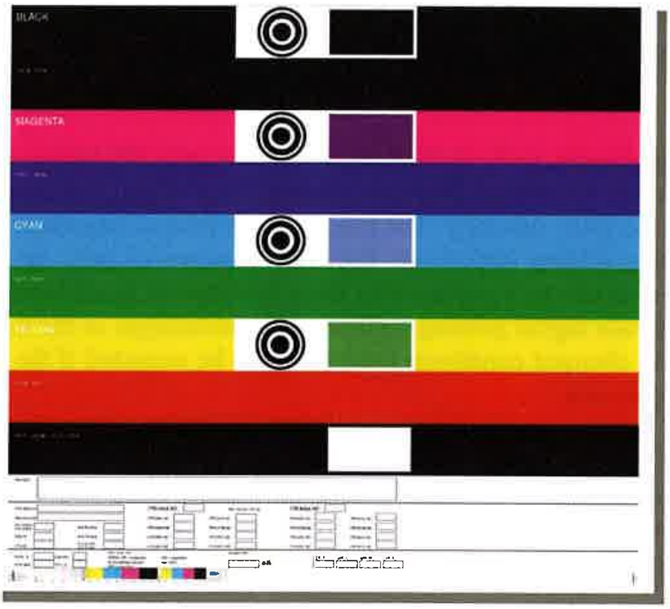

Figure 2: Test subject

The important features of the digital printing presses mentioned above are compiled in Table II below.

Table II: Features of the Xeikon DCP/500-SP, HP-Indigo Press s2000 and NexPress 2100 digital printing presses

	Xeikon DCP/500-SP	**HP-Indigo Press s2000**	**NexPress 2100**
Printing method	Electrophotography	Electrophotography	Electrophotography
Toner	Dry toner	Liquid toner	Dry toner
Colours	4 (CMYK)	6 (CMYK & special colours)	4 (CMYK)
Imaging technology	LED array	Laser	LED array
Toner transfer	direct (electostatically)	indirect (rubber blanket)	indirect (rubber blanket)
Fusing	pressure & heat	--------	pressure & heat

One essential criterion for evaluating print quality is the uniformity or unevenness of the printed image in full tone areas. Uniformity is evaluated by the operator during the printing process or later by experts as well using an appropriate ranking system. Despite the high expertise of the experts, such ranking strategies are always subjective. The use of digital image analysis systems can objectify and quantify a uniformity evaluation.

DOMAS (Digital Optical Measurement and Analysis System), an image analysis system developed by the PTS research institute, comprises a module entitled "Print Unevenness" in full tone areas. To acquire the image, the image source (full tone areas on the printed sheet) is scanned digitally using incident light. The result obtained is an unevenness index in the form of a non-dimensional numerical value, thus making an objective comparison of the printing quality of different printed samples possible. Figure 3 illustrates the results of the print quality evaluation of the printed board samples:

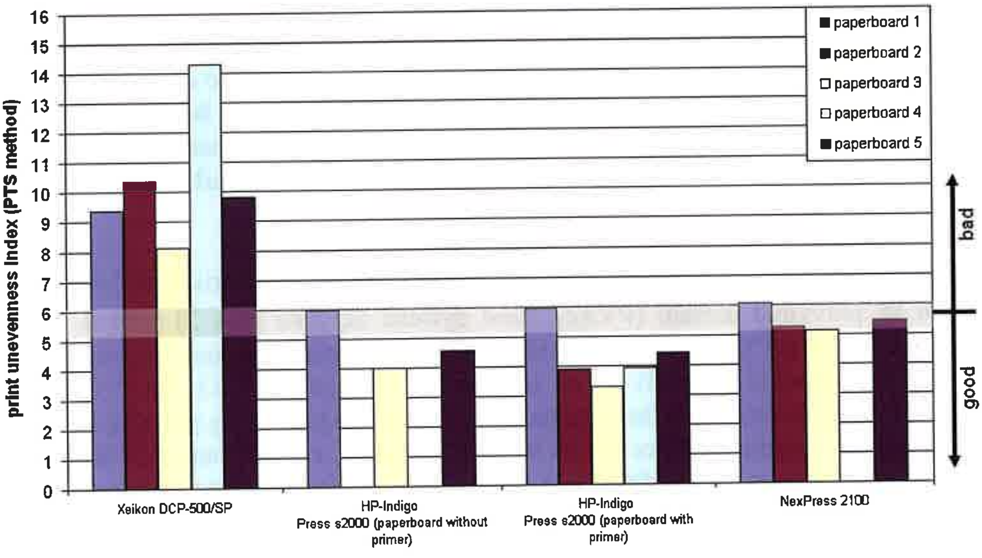

Figure 3: Diagram showing the unevenness index

In addition, the finishing suitablity criteria toner adhesion, abrasion resistance and the creasability of the printed boards were examined as well. Generally speaking, all printed sheets could be creased perfectly irrespective of the printing press that had been used. The abrasion resistance, however, was insufficient throughout and for this reason it became necessary to varnish all printed boards.

2.2 Correlation analysis

The following relationships between the influencing parameters (board properties) and the target parameters (print quality and finishing suitablity) were able to be deduced from a comprehensive correlation analysis:

With respect to the Xeikon DCP-500/SP digital printing press:

Print quality of the printed board samples improved with:

- increasing surface energy ($\approx > 40$mN/m);
- increasing electrical surface resistance ($\approx > 1*10^9$ Ohm);
- decreasing electrical volume resistance ($\approx < 1*10^9$ Ohm).

With respect to the HP-Indigo Press s2000 digital printing press:

The print quality of the printed board samples (without a precoat) improved with:

- increasing surface energy ($\approx > 40$mN/m);
- decreasing surface roughness (PPS $\approx > 1.5$–2.5 µm).

The aim with respect to the HP-Indigo Press s2000 print process was, among other things, to find a suitable coating colour that would completely eliminate the normally use of primer before printing.

With respect to the NexPress 2100 digital printing press:

The print quality of the printed board samples was very good in all cases and therefore no correlation analysis was made.

2.3 Optimisation of board coatings on a laboratory scale

Coating colours were developed on a laboratory scale that were intended to contribute to achieving the desired values that had been developed (see section 2.2). Sample 1 (base board with a GCC precoat) was used for the laboratory coating trials. The first trial series was developed to studying the influence of the binder on the required board surface properties. Natural calcium carbonate (GCC) was used as the pigment in all cases.

The most important findings from this particular trial series can be summarised as follows:

- In addition to polyvinal acetate (PVAc), hard sytrene acrylate (SA 2) with a glass transition temperature (Tg) of 27°C produced the highest surface energy values. It was also found that adding polyvinyl alcohol (PVOH) to the soft styrene acrylate (SA 1) (Tg=5°C) increased both surface energy and electrical surface resistance. However, since using polyvinyl acetate makes it difficult to prepare coating colours due to its low pH value, a combination of SA 2 (8 parts) and polyvinyl alcohol (3 parts) was defined as a standard binder for the next trial series.

The surface energies that were achieved on the board surface are shown in Figure 4 below.

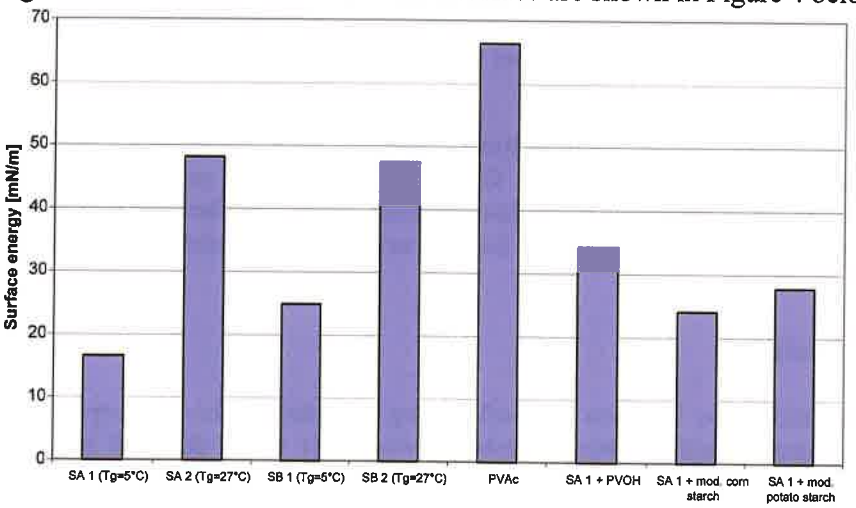

Figure 4: The influence of binder on surface energy

The second trial series was devoted to studying the influence of eight different pigments. The binder combination of the coating formulation remained constant with 8 parts of SA 2 and 3 parts of PVOH. The coating colours produced in the laboratory were then applied to the base board. The coat weight was 15 g/m² (o.d.) in all cases. NaOH was used to adjust the pH of the coating colours to approx. 8.8.

The most important findings obtained from this trial series were as follows:

- The various pigments had no effect on surface energy.
- The smoothness values (PPS), however, showed significant differences between the different coating colour formulations. As had been expected, it was possible to achieve the required smoothness of 1.5 to 2.5 µm with the platelet-shaped kaolin and talc pigments (see Figure 5).
- It was possible to achieve the desired electrical surface resistance of approx. >$1*10^9$ Ohm by using all pigments.
- The board glueing trials with a commercial dispersion adhesive exhibited adhesion ruptures between the adhesive and the coat as well as between the coat and the board surface. A decision was therefore made to increase the proportion of binder in the coating colour formulations for the next trial series (10 parts of SA 2 and 3 parts of PVOH).

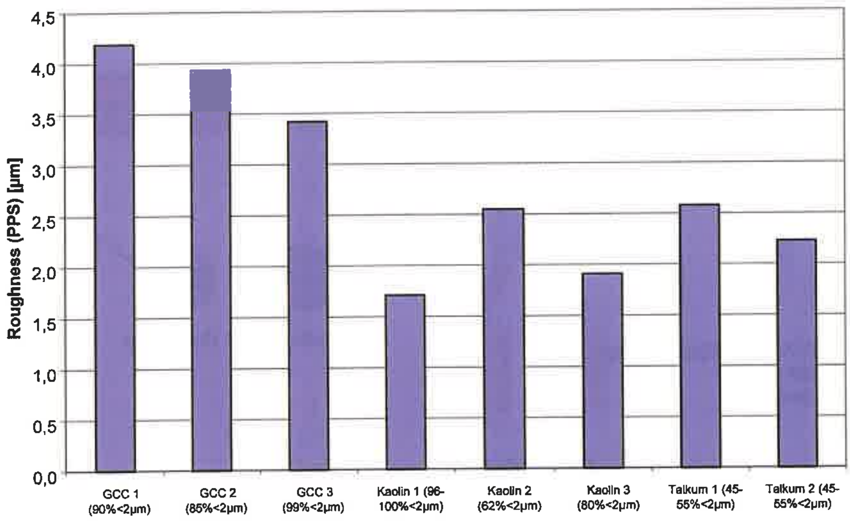

Figure 5: The influence of pigments on surface roughness

The final series of trials involved developing formulations (see Table III) for coating trials that were to be conducted under practical conditions on the VESTRA pilot coater in Munich. All coating colour formulations surpassed the minimum surface energy of 40 mN/m by far. The surface roughness values (PPS) that were achieved were within the required range of 1.5 to 2.5 µm for all formulations. The electrical surface resistance of approx. > $1*10^9$ Ohm was able to be achieved with all formulations.

Table III: Formulations for the pilot coater

No.	Pigment	Parts	Binder	Parts	Opt. brightener	pH
1	Kaolin 1	100	SA 2 / PVOH	10 / 3	tetrasulfo type	8.8
2	Kaolin 1 / GCC 3	50 / 50	SA 2 / PVOH	9 / 3	tetrasulfo type	8.8
3	Kaolin 1 / Talc 2	70 / 30	SA 2 / PVOH	10 / 3	tetrasulfo type	8.8
4	Kaolin 1 / GCC 1	30 / 70	SA 2 / PVOH	9 / 3	tetrasulfo type	8.8

P.S.: The pigments comply with the information supplied in Figure 5.

2.4 Coating trials on the pilot coater and evaluation of the results

The four coating colour formulations (see Table III) were applied to the base board (sample 1) by the pilot coater (see Figure 6). The speed of the pilot coater was 400 m/min in all coating trials corresponding to the conditions that prevail in practice during board coating. A F-NIP2 combi-blade with a bent blade was used as the coating unit for applying the top coat.

As already mentioned in section 2.1, the coated board samples were subsequently reprinted on the printing presses (**Xeikon 5000, HP-Indigo Press s2000** und **NexPress 2100**).

It must be mentioned in this context that these print runs were carried out on the newly developed **Xeikon 5000** digital printing press instead of the Xeikon DCP/500-SP printer that was used for the print runs with the industrially manufactured board samples, since the latter machine has been taken out of the Xeikon sales programme. The most important differences between the Xeikon 5000 and the older Xeikon DCP/500-SP are that the newer model has the following capabilities [2]:

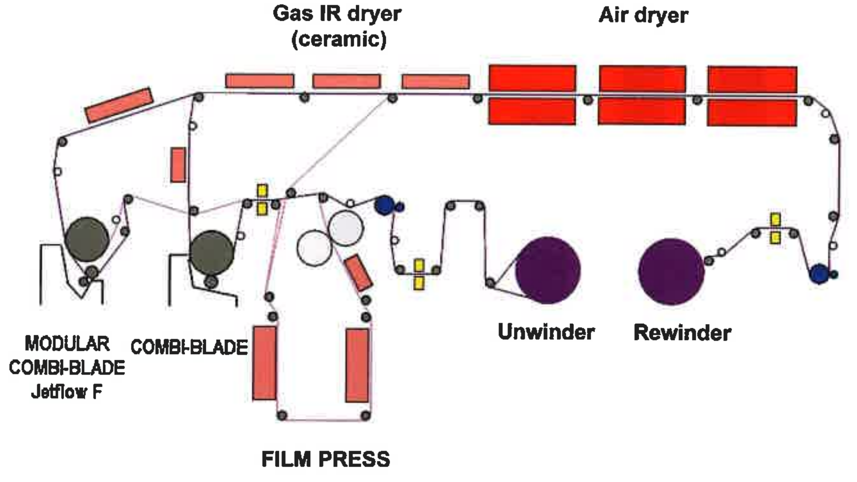

Figure 6: Schematic setup of the pilot coater

- Duplex printing (4/4 standard single-pass duplex printing)
- Print substrates: paper, paperboard, cardboard, plastics, label material with grammages of 40 to 350 g/m²
- Printing speed (duplex, full tone DIN A4 sheets):
  - for paper with 40–170 g/m²: 130 pages/min
  - for paper/board with 170–250 g/m²: 100 pages/min
  - for paper/board with 250–350 g/m²: 70 pages/min
- Inline densitometer for achieving optimum colour image quality
- Non-contact toner fusing by IR.

Another remark must be made concerning the print runs carried out with the HP-Indigo Press s2000. The board samples were **not** pretreated with a primer before the print runs. It was an objective of the research project, among other things, to develop suitable coating colour formulations to eliminate the use of primer, thus achieving a savings of time and costs.

The print quality and finishing suitability of the printed board samples were subsequently examined. The results of print quality are shown in Figure 7.

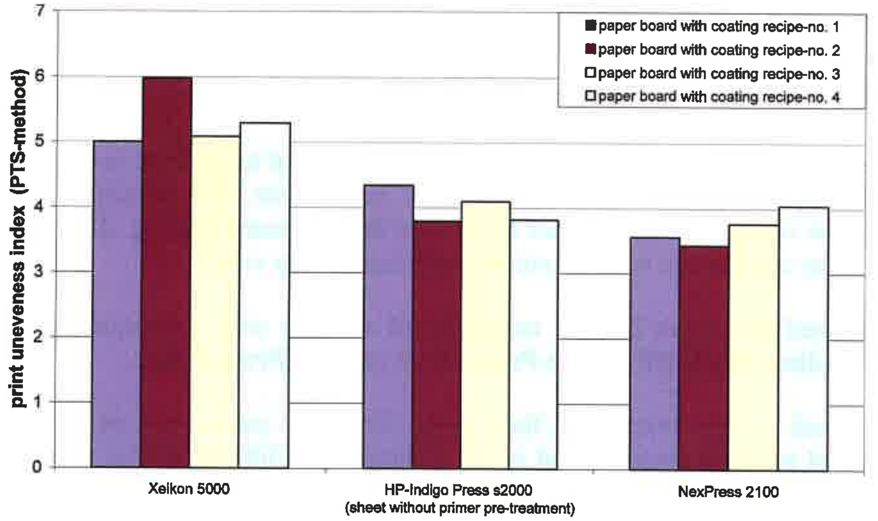

Figure 7: Diagram showing the print unevenness index

In addition, the finishing suitability criteria toner adhesion, abrasion resistance and the creasability of the printed boards were examined as well. Toner adhesion and the creasability of the printed board samples were perfect, irrespective of the printing press that had been used. The abrasion resistance of the printed board samples, on the other hand, was insufficient, especially in the case of board samples that had been printed with dry toner systems. This made it necessary to apply a coat of varnish.

Table IV compiles an overview of the results of the industrially produced boards, the boards coated in the laboratory and the boards coated using the pilot coater.

Table IV: Total results

	Industrial paper boards					Developed coating formula at lab				VESTRA pilot coater trials			
	1	2	3	4	5	1	2	3	4*	1	2	3	4*
Surface engergy [mN/m]	36,0	26,5	38,6	24,5	28,9	58,4	59,5	59,8	---	43,1	42,0	43,1	39,4
Roughness (PPS) [µm]	3,10	0,92	0,78	1,17	1,58	1,87	2,07	1,86	---	1,26	1,37	1,63	1,65
Electric surface resistance [*10^{9}Ohm]	3,13	2,30	1,23	1,18	1,13	4,40	6,70	4,50	---	2,20	3,40	2,30	3,60
Print unevenness index (Xeikon)	9,39	10,37	8,12	14,30	9,81	---	---	---	---	5,00	5,98	5,08	5,29
Print unevenness index (HP-Indigo)	5,96	---**	3,98	---**	4,57	---	---	---	---	4,34	3,80	4,10	3,82
Print unevenness index (NexPress)	6,05	5,24	5,11	---***	5,47	---	---	---	---	3,57	3,44	3,77	4,04

*: as standard formulation (including the same binder as no. 1-3) not tested at lab
**: paper board which could not printed due to toner transfer problems
***: paper board which could not printed due to sheet transport problems

3. Conclusions

The objective of the research project was to provide optimum board surfaces or coatings for digital package printing on folding boxboard that make it possible to achieve high-quality prints preferably independently of the type of digital printing method used. This objective was accomplished by the successive, step-by-step development of coating colour formulations first on a laboratory scale and later by practical trials on a pilot coater. The board coatings permitted both good print quality and finishing suitablity as a measure of the suitability of the printed board for the manufacture of folding boxes.

The print unevenness index, a measure of the evaluation of print quality, was lower than the critical value of 6 ± 0,5 (an empirical value established by PTS) for all board samples which were coated on the pilot coater with the coating colours prepared in the laboratory and were then printed on the digital printing presses. This meant that the print quality could be reduced to a considerable extent compared to the initial print runs that involved industrially manufactured boards.

The following comments are made concerning the individual printers:

- The sheet with the optimised coating formulations was able to be printed flawlessly without primer pre-treatment during the print runs with the HP-Indigo Press printer. This means that an important goal of this project, i.e. substituting optimised board coatings for primary pre-treatment, was achieved in full scope.
- The improvement in print quality achieved using sheets printed with the Xeikon 5000 were probably due to the coating optimisation as well as to the new printer design (Xeikon 5000).
- By far the best print qualities were achieved using the NexPress 2100.

Another important finding was the enormous influence of the binder (with as much as 12-13 parts in the coating formulation in this case) on the surface energy of the paperboards. The use of a hard styrene acrylate binder (with a glass transition temperature of 27°C in this case) in combination with polyvinyl alcohol proved to be a success.

The immense importance of conducting trials under practical conditions was also confirmed in this project, since the surface properties of the coated board samples tended to coincide both in the laboratory and pilot coater trials, although there were differences in the absolute values that were achieved (pilot coater samples had lower values than the laboratory samples, see Table IV).

The printed board surfaces were not found to be abrasion-resistant irrespective of the toner that was used (dry or liquid toner). Subsequent (inline or offline) varnishing is advisable for this reason in order to thus guarantee the quality of the final product (folding boxes). Unlike abrasion resistance, toner adhesion and the creasability of the printed board surface were perfect in all cases.

Because formulation No. 4 (Table III), which consisted of 70 parts GCC and 30 parts kaolin, was found to be much more economical than the other formulations and still achieve comparatively good print quality, a decision was made to further optimise the coating colour based on this formulation. It was decided in this context to retain binder SA 2 and the GCC/kaolin pigment combination and to study the effect of other additives (cobinders with cationic groups, modified starch types, cross-linked modified microcellulose) on the surface properties, i.e. on the print quality, of the paperboard.

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Influence of different factors on unit cost of digitally printed packaging

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Abstract

This study focused on product costing and cost structure of digital package printing. The objective of the research was to analyse factors affecting the product cost and economic viability of packaging. After feasibility study some of the most significant cost drivers were selected and their values were changed in a relevant scale to assess the impact on total cost. Special attention was paid to the batch-level costs because in the case of on-demand package production the order sizes are relatively small and product diversity is high. Hence the primary focus was on the printing activity and small order sizes.

Costing model was done applying the principles of activity-based costing and practical capacity approach. When capacity costs are based on practical capacity more equal and stable benchmarking can be done when assessing the impact of structural changes in current production process. That way the cost of resources actually needed will be included in product costs and the cost of unused capacity can be disclosed separately.

To assess the viability and impact of on-demand production a case-specific evaluation and model has to be done. In every case the total economic viability depends on the total volume and market distribution. If one significant customer can fulfil the capacity of a digital printing machine a satellite production unit near the customer is an option. If the volume is spread across different market areas, it might be better to print short runs next to the conventional press in a centralised location where the necessary infrastructure already exists and deliver them with other orders.

1. Introduction

Production of items and packaging is slowly changing due to shortening delivery times and order sizes. This causes a need to develop packaging production and packaging logistics. Also increasing product diversity and test marketing affects production plans. When test marketing products, special orders and small order sizes are needed digital printing offers a viable solution.

It is estimated that it will take several years for digital printing to significantly penetrate packaging sector. Although different forecasts show that of the various digital printing technologies, inkjet is most suited to package printing it has not yet gained significant market share at the expense of the others. Some estimates propose that inkjet in all its forms will account for more than 80% of digital package printing by 2008 (Romano, 2004). According to patents and patent applications piezo inkjet is the technology where most of the R&D money is put. Most of the applications will also use UV curable inks.

In order to make right decisions and fair comparisons between different technologies it is essential to look at all the factors affecting the economical production. When current costs exceed the allowable costs cost reductions are necessary if the value (price) of the product can not be increased. Otherwise the product might be recalled. Usually it is reasonable to focus on the most expensive activities and resources as well as high cost driver rates.

By gaining accurate costing information from the current production processes and supply chain, one could estimate if the cost level, the potential for creating value and the profitability of an alternative method of producing packages are satisfactory. However, if one wants to make strategic and economically more accurate and better decisions, the information coming from internal accounting practices and used for the financial statements and profitability comparisons has to be reliable, relevant and informative.

2. Methods

The study is based on quantitative research through case studies. Three different fibre-based products were selected for case products and they belonged to the following product categories:

- office supplies,
- media packaging,
- disposable goods.

The analysis of the case products began with mapping out the current processes and activities. That was supported by interviews with production personnel and other people responsible for the production. Interviews were essential for understanding the current production processes and business logic. In different cases the demand chain was defined so that it would be possible to gain enough information from activities that were included and that would be of interest. In general the modelling was done for the production chain starting from the raw material supply and ending to the delivery of printed or packed product to the customer. That was followed by the definition of resources and basic data. Next the main factors affecting resource consumption and behaviour were defined and resource costs were divided according to four-stage activity hierarchy (Cooper, 1990).

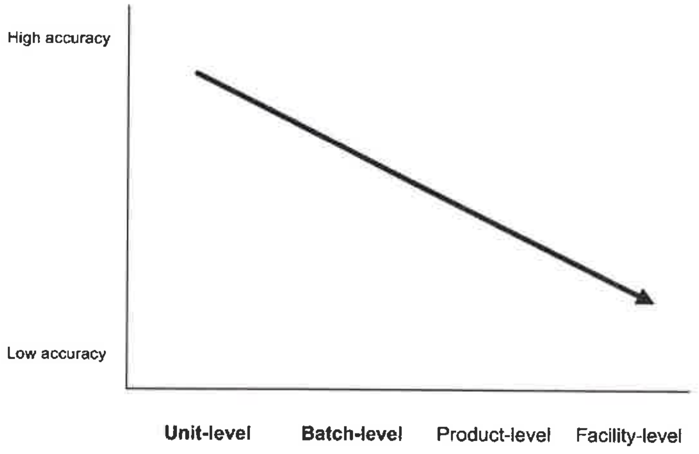


Figure 1: Different levels of activities and their corresponding influence on costing accuracy in activity-based system

In this study focus was on the unit-level and batch-level activities and their resource consumption. These levels are the most important because they contain costs that can be allocated directly to individual products and orders. This means that these resource groups can be determined and their behaviour can be forecasted with a high degree of accuracy. Also the real variation between different products can be characterised better when product-specific cost drivers are used instead of averages. In this study resource costs were grouped and assigned to products on a time-driven basis (Kaplan & Anderson, 2004). Activity-based costing was combined with practical capacity approach and only the costs of resources actually consumed were included in product costs (Kaplan & Cooper, 1998). This way the time unit cost of supplying resource capacity, unit times of resource consumption and unused capacity could be defined and compared. The cost of unused capacity was disclosed separately.

Compared to traditional cost accounting practices where low-variety models are utilised cost models have been developed from a traditional accounting point of view. That is why it is very common to notice that indirect costs are allocated according to some standard percentage, which can be avoided when ABC is applied. Paying attention to the batch-level costs is particularly important in the case of demand driven production because the order sizes are relatively small and products are diverse.

The models were built on commercially available activity-based costing software and data processing and pre-calculation were done using standard spreadsheet application. Three different methods were used to support modelling: educated guess, systematic appraisal and collection of real process data. To gain information for the costing and simulation print trials were carried out for selected case products. After technical studies and discussions with production personnel and machine suppliers a framework for package production was created. As a result cost models were built to characterise package production. Cost models for the current production chain and the alternative supply chain structure were established and analysed.

If digital printing is used for package production different techniques have distinct cost behaviour. In this study following techniques were used:

- inkjet,
- dry toner electrophotography,
- liquid toner electrophotography,
- flexo (as a reference).

Both distributed and centralised production was modelled and both inbound and outbound logistics were evaluated. However, it was assumed that order size does not generally affect the inventory levels of raw material stock. Deliveries of these materials depend more on the overall capacity utilisation.

3. Results and discussion

The results of this research show how different factors affect the total cost of packaging. The cost structure of packaging and its ratio to the total cost of packed item can vary significantly depending on the situation. When order sizes decrease batch-level cost become more significant. According to the evaluation some of the most significant factors affecting costing results are:

- batch size in different activities,
- cost driver rate especially at the batch level,
- packaging design and structure (format, printed area, material),
- stock turnover and levels.

In the case of package production two significant cost factors are raw material price and printing activity. Current demand and supply mainly determine raw material price, but printing costs depend greatly on the technique used. Other significant factor affecting production cost is location, which typically determines 15-25% of the cost variability (Teir, 1998). In the case of on-demand production logistics costs can increase significantly if small order sizes are being deliver separately. Also if raw material for the near-line package printer has to be delivered from a distance compared to printer next to raw material supplier some of the cost benefits are lost. The solution for avoiding this is sharing activities. Although sharing is not always possible it will lead to a significant cost advantage if it involves an activity that account for significant portion of operating costs and lowers the cost of activity (e.g. transportation cost).

In the case of digital package printing, the most significant product cost factors are ink or toner price, consumables and printing throughput, which are classified as unit-level costs. Whereas significant factors affecting the total costs of conventional printing methods include the number of colours, the number of printing plates and set-up time, which assign batch-level costs to products.

Those digital printing presses covered in this study have noticeable differences in their operating costs, which can be shown in figures below. Figures 2-5 present the cost structure of case products when different order sizes are produced. These results are indicative of the cost structure related to the technology in question.

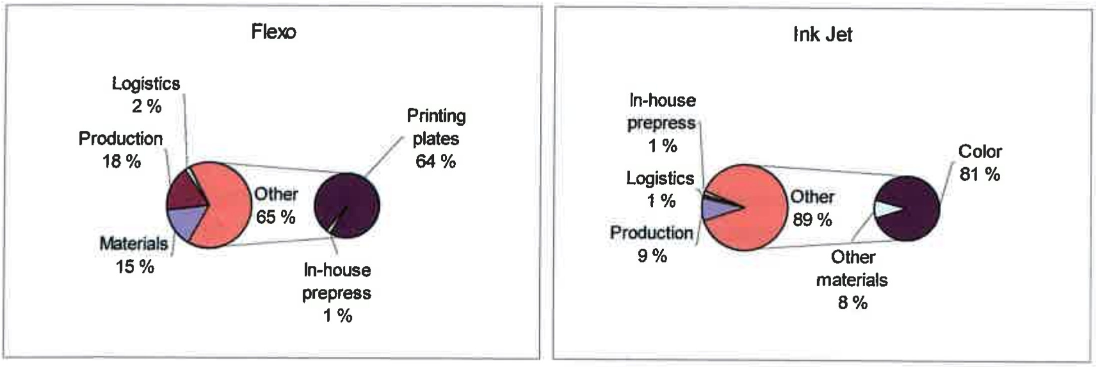


Figure 2: The cost structure example of a case product 1 when printed with inkjet and flexo presses. Order size approximately 3100 m², which equals 14 000 packages

According to the results one dominating cost factor can be recognised in most cases when production batches are small. In the case of inkjet the influence of ink price was dominant whereas flexo printing was dominated by printing plate cost. It has to be noted that in this example most of the prepress work is included in the plate cost. Because the number of colours also has a strong effect on set-up activity in flexo printing it can be stated that activities and resources related to print design define the total cost level. These results mean that inkjet printing is dominated by unit-level costs and flexo printing is more dependent on batch-level costs. The total cost level in Figure 2 is equal in both cases.

In this case flexo printing was performed in a centralised production facility and printed packaging was delivered from Finland to Germany. It was assumed that digital printing was performed next to the packaging line.

The situation was almost the same when liquid toner electrophotography was used. The total cost of packaging is dominated by digital press consumables, which accounted around 40% or more of the total cost in this case. Because consumable costs are assigned to a product on the unit-level basis, their influence on the unit cost of digitally printed packaging will even increase when batch sizes increase and if consumable prices do not decrease. However, in liquid toner electrophotography printing throughput is strongly dependent on the number of colours used. That is because every colour needs a separate rotation of the impression cylinder. Because of that feature the operating costs of liquid toner electrophotography behave the same manner as for conventional printing methods.

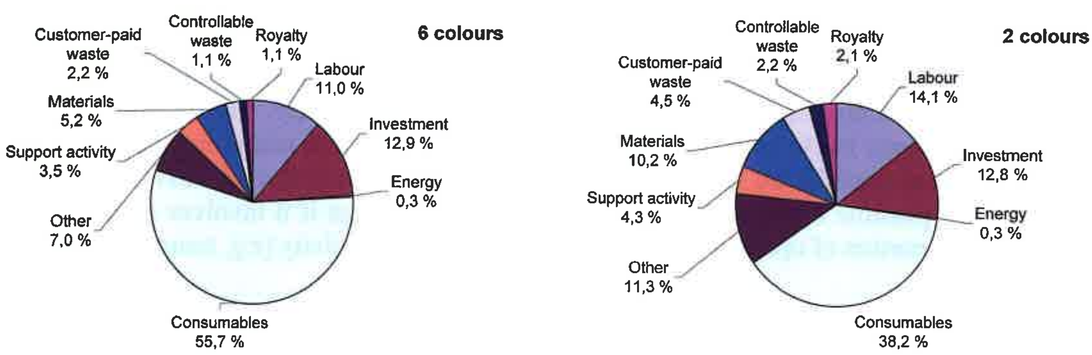


Figure 3: Cost structure examples of a case product 2 when printed with liquid toner electrophotography with two and six colours. Order size 5000

When dry toner electrophotography is used the situation is somehow similar to inkjet. One of the most significant factors affecting the total cost of packaging is the toner price, but compared to inkjet ink its share is usually not that high. Other significant factors affecting the total cost in this case were human and machine resource costs. This is partly because of relatively slow throughput of dry toner technology.

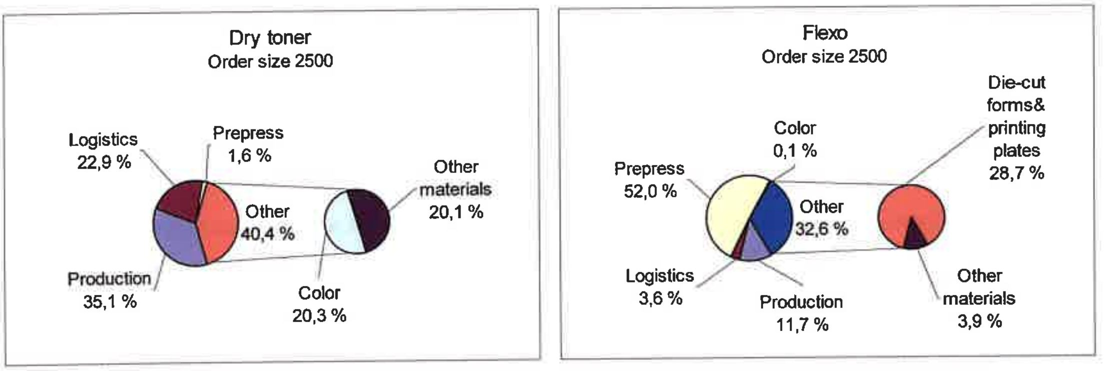


Figure 4: The cost structure examples of a case product 3 when printed with dry toner electrophotography and flexo. Order size 2500

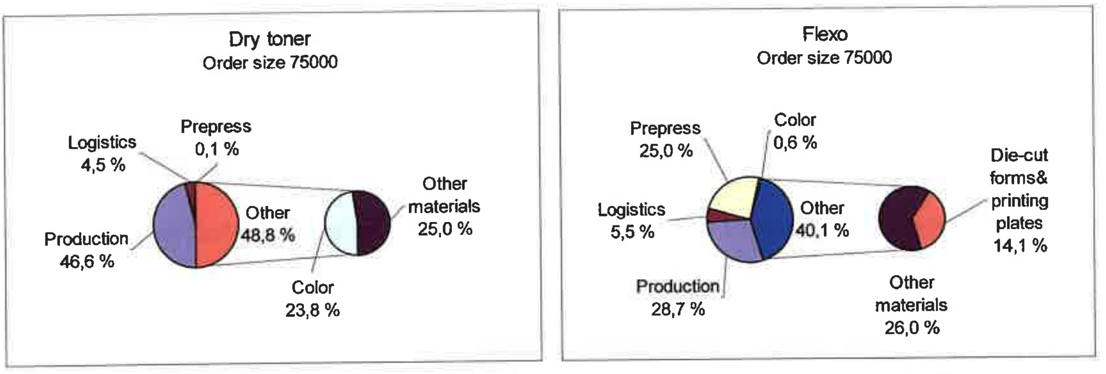
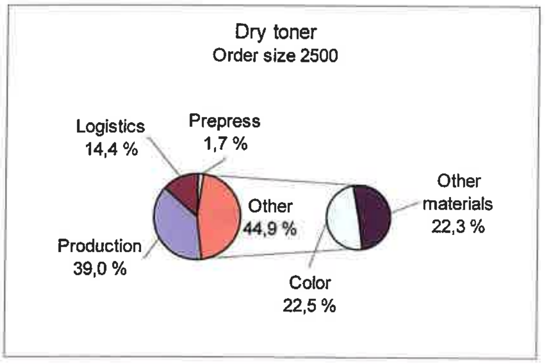


Figure 5: The cost structure examples of a case product 3 when printed with dry toner electrophotography and flexo. Order size 75 000

In both cases printing was performed in a centralised production facility and printed products were delivered from package converter to customer. In this case distance from converter to customer was 250km and these orders were individual deliveries. It can been seen that the share of logistics cost can be relatively high when order size is small (Figure 4). If printing were performed next to customer the share of logistics would decrease approximately from 23% to 14% when the order size is 2500 and from 5% to 1% when the order size is 75000. This is a good example of the influence of batch size on cost structure. Batch size is also a significant factor when breakeven point is calculated. According to this study a typical breakeven point of conventional and digital printing was around 20000-30000, which is pretty close to the findings in other studies (Cahill, 2004).

When the economic viability is analysed the value of the packed item and total volume and market distribution should be taken into consideration. Also if digital printing technology is considered as complementary capacity to current production line, in this case flexo, the situation might look different. New investment means additional capacity and it will affect the current production line. This gives the possibility to move small order sizes from flexo to digital press, which could lead to increased run time on flexo press and decrease lost profit contribution related to set-ups. This is on condition that demand exceeds current supply on the market. For one case product it was calculated that incremental ROI could be between 3-20% if digital press made zero profit, but increased run time of flexo press 0,3-2,3%.



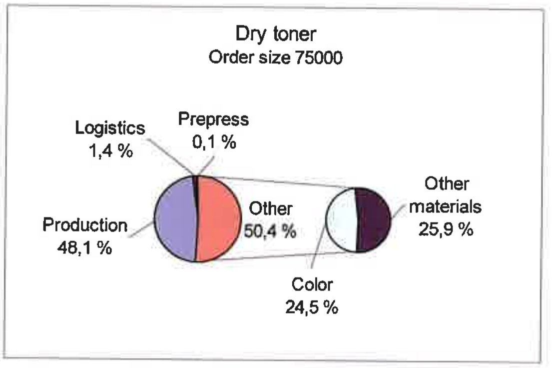


Figure 6: The cost structure example of a case product 3 when printed with dry toner electrophotography next to customer

4. Discussion

The application of activity-based costing can improve costing accuracy compared to traditional costing models if the input data is of good quality and proper technical expertise in applying ABC exists. Some studies have been published dealing with the percentage changes in product costs between activity-based costing and standard costing, which allocate all the overheads as a percentage of direct costs. This kind of public information has not been widely available in the packaging industry, but results obtained from different case studies show that in general the percentage change has been between -1-25% (Fogelholm, 2000).

When more accurate costing models are needed activity drivers for each product or customer should be quantified separately. Average driver rates should be avoided because the accuracy and usefulness of the results diminishes. However, an accurate cost model requires more work and it is also more complex. If the tools used for calculation and analysis are not familiar, it might be better to look for expert help in this field.

Because current business practices focus on tighter cost control and many companies are facing tough competition it is reasonable to evaluate costing models at regular intervals with the objective of determining the need for updating the model. This is crucial especially when company is adopting new technology, has a large number of customers, who have their special demands and thus need for customising their orders.

5. Conclusions

Ink cost is a unit-level cost factor and therefore batch size does not affect the unit cost of packaging as much as with conventional printing especially when small batch sizes are produced. Because structural changes in the production chain do not lead to sufficient cost savings, they do not compensate for the higher production costs of digital printing. However, improvements in digital printing technology together with declining ink and equipment costs could change the situation in many ways.

In the case of conventionally printed packaging the number of colours used is more dominant and therefore affects the total cost and profit accumulation significantly. In the case of digitally printed packaging the colour amount or ink coverage is more dominant if inkjet or current dry toner electrophotography technology is used. In the case of liquid toner electrophotography the number of colours also has an effect on cost structure because every colour needs a separate rotation of the impression cylinder. This should be taken into consideration when setting the price for the product.

The potential of digital package printing exists in niche markets where more value added products, small run lengths and packaging formats with small ink coverage and various cut lengths are demanded. The total economic viability depends on the total volume and market distribution of these products. Because current supply and demand chains are very streamlined and capable of doing JIT production with low inventory levels the opportunity to implement digital printing technology will offer advantages in the areas where distinct advantages are more obvious. Special advantages of digital printing are design and production flexibility and customisation, ability to integrate into traditional equipment, low waste levels, fast response time when near-line with the packaging process and decreased warehousing costs for slow-moving consumer goods packaging. Also when the application of new functional features (e.g. printed electronics) will spread out they can make use of inkjet printing as part of the production line.

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Exploring cross-media concepts for future packaging - Challenges for the printing industry

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Abstract

Currently, packaging is one of the most significant application fields for the graphic arts industry. Recent studies and industry observations indicate that packaging is gaining even more importance for the graphic arts and print media industries since packaging, by its very nature, cannot be replaced by an electronic medium, but is a medium that requires printing.

However, packaging is currently the centre of an intensive research effort that is being carried out regarding new technologies that integrate digital data on a package. This has been fuelled by developments in electronics technology, materials and processes that have the potential to create packages that can carry digital - machine readable data, in particular new materials (such as printed polymers) and tagging applications (such as RFID and EAS systems) which are described as “intelligent”, “smart” or “active” packaging.

This situation has given rise to several challenges. The first is to examine whether the application of the above mentioned technologies can leverage the cross-media concept in terms of the processing and distribution of information for packaging. Another challenge is to determine the degree of awareness of graphic arts companies concerned with print and packaging with regard to these new technologies and concepts. Further, to understand whether these companies would be interested in implementing and integrating these technologies in their packaging printing production processes.

This paper is based on a literature study of cross-media concepts and of new technology applications for packaging as well as on a survey based questionnaire with companies from the packaging printing sector. The outcomes of the study showed that the coexistence of printed and digital data on a package does not constitute a cross-media concept (at least not considering its traditional interpretation in the media landscape). The concept can be described more accurately with the term “hybrid package”, where both printed and electronic data coexist on physical substrate. In addition the survey analysis revealed that the developments towards smart or intelligent packaging concepts are of great interest for packaging printing companies.

Keywords

Cross-media concepts, information flow, packaging production workflows, printing technologies, smart and active packaging

1. Introduction

Traditionally, packaging is a printed matter used for specific purposes, namely:

- to protect contents of the package, especially during transport packing and handling;
- to identify the contents of the package;
- to help sell the product, both by;
    - providing information about the contents and their use,
    - and making use of aesthetics in form, shape and colour.

These three purposes may use different types of packaging, an outer cardboard or plastic wrap binding, with printed information/data, and inner box with identification marks, and the individual product packaging that is aimed at the end user of the contents.

In its traditional form the information on the package relies upon a certain production workflow and certain types of information that need to be communicated between the producer, the retailer and the consumer. All the information required is produced and transferred to the packaging by means of traditional printing technologies.

However, recent developments and applications mean that not only human readable printed information, but also machine readable data needs to be incorporated in the packaging. Such data can be in the form of sounds, or smells, or other perceptions (for instance weight- some products such as fruit become lighter as they get older, and the juices inside them evaporate). These various perceptions and transformations or changes of conditions can be traced by sensors that compare the "printed" descriptions with the actual data from handling/scanning the package. A convergence of emerging technologies that rely on new materials (such as printed polymers) and tagging applications (such as RFID and EAS systems) are leading to new concepts of "intelligent", "smart" or "active" packaging.

The gradual application of these new technologies is leading to new norms for packaging where not only printed but also electronic (digital) data and information co-exist. The coexistence of printed and electronic data on a package, have led us to pose the question, of whether this development can be viewed as variation of the cross-media concept, and whether this is helpful.

Cross media is a concept found in the mass media landscape and most commonly refers to the idea of distributing the same message through different media channels. Many people understand cross-media publishing to be the ability to publish in both print and on the web without manual conversion effort. Because recipients behave differently and have different needs, the conversion cannot be automated with the electronic means available today. An increasing number of wireless devices with mutually incompatible data and screen formats make it even more difficult to achieve the objective "create once, publish everywhere" (COPE).

Having experienced the development of cross-media applications in the media sector, our interest was to see if this concept would be useful in regard to the information on packaging, particularly in the light of this information being digital. More specifically, we were interested in the flow of information in relation with the printing processes that are traditionally applied for packaging printing. Related questions were to explore whether the production of new technologies enabled packaging will be affected (or significantly changed) thus creating the necessity for application of new design and production processes.

2. Background: The importance of packaging for the graphic arts industry

Packaging is about 2% of the GNP in the developed countries. The volume of the packaging industry is about 345 million euros, and about one third of this is in Europe. As Juhola (Juhola, 2002) points out, packages will remain and their proportion will clearly increase in the Information Society. Increasing e-commerce will also serve to augment the number of packages. The packaging itself will carry more and more information, for consumer, for parcel tracking, becoming more and more an important communication media. Meanwhile, 50% of the packages are food packages, indicating the importance of this industry for packaging.

Packaging is one of the most significant application fields for the graphic arts industry at present. Recent studies and industry observations indicate that packaging is gaining even more importance for the graphic arts and print media industries since packaging, by its very nature, cannot be replaced by an electronic medium, but is a medium that requires printing (Politis, 2005). In addition, data from the last DRUPA exhibition reveal that the vast majority of graphic arts manufacturers of prepress systems, printing and finishing equipment as well as producers of printing substrates and inks (DRUPA, 2004) Packaging printing constitutes probably the most important interest for the printing industry. All the main printing methods are being continuously developed for serving the specific characteristics of packaging printing. Tables I and II show the increasing rates of packaging production and the share among the principal packaging methods.

Table I: Basic packaging categories: Percentage of annual increase 2001-2005 in the USA. Source: Graphic arts marketing information service, USA 2004

Basic Packaging Categories	Percentage of Annual Increase 2001-2005
Flexible Packaging	4,5%
Labels	4,5%
Corrugated - paperboard Packaging	3,5%
Paper - Board Boxes	2,5%

Table II: Percentage of total printing market and basic segments of basic printing methods. Source: ERA (European Rotogravure Association e.V.), www.era.eu.org, April 2004

Total printing market and basic segments of basic printing methods	Percentage (%)
Lithography Offset	40%
Flexography	30%
Rotogravure	22%
Other Printing Technologies	8%

Information on packaging today is almost exclusively from printing. Graphics, texts, images, instructions as well as advertising carried on packaging are nearly all made by traditional or digital printing technologies. Barcodes (EAN-code) serve the identification required for machine-readable data and various additional non-impact printing processes (such as ink-jet), create human-readable information on ready packages (e.g. the expiry date of a dairy product).

However, packaging is currently the centre of an intensive research effort that is being carried out regarding the types of information and flows of data that need to be used on a package. This has been fuelled by developments in electronics technology, materials and processes that have the potential to create packages that can carry machine readable data as well as information.

It is predicted that the application of the new technologies on packaging will affect not only printing but the whole design and production process. Those to be affected include designers, subcontractors, prepress, and printing departments of packaging producers.

At the same time, it is possible to see these new types of packaging within the context of pervasive computing, Packages (i.e. package and content) can be considered as smart objects that communicate with one another and with other smart objects around them. Thus software frameworks from research areas like pervasive computing can be used to talk about packaging and the creation of entire smart environments, where objects describe themselves, are context aware, and can exchange data between them, as well as communicate over networks. (Siegemund & Krauer, 2004). The next section explores some of the new technologies that are being used in packaging and that make this scenario feasible.

3. New technologies for packaging: RFID, EAS and Printed Electronics

In the main, the new technologies refer to the machine readable data on packaging, that is, Radio Frequency Identification (RFID), Electronic article surveillance (EAS), and printed electronics. A brief description of the uses and operation of each is given below.

There are two descriptions on RFID (Rychee, 2005):

- The technology that is considered to be the next generation of barcodes. The RFID tag contains an antenna and a microchip. This technology was prompted by the need of the consumer product industry and large retail chains to update outdated and inefficient barcode systems. RFID technology can be used for supply chain distribution logistics, asset tracking, and inventory management.
- The use of small devices that can be electronically identified (and sometimes their data changed) at a distance without line of sight. Although radio is typically defined as 300 Hz to 300 MHz, in RFID the term even encompasses tags interrogated at 100 Hz and others at microwave frequencies (GHz). These devices are called tags and they may be used alone - contactless smart cards and car clickers are examples - or fitted to something in order to monitor its identity remotely. Sometimes RFID will employ tags that perform extra functions as well such as sensing what is happening or recording updated data remotely, for future remote interrogation.

EAS (electronic article surveillance) is akin to an antenna. It is a conductive electronic component that radiates and/ or receives electromagnetic energy usually in the radio frequency spectrum or thereabouts, an aerial on an RFID tag or interrogator, for example. All RFID interrogators have antennas as do most RFID tags. They are increasingly printed, usually with silver ink, the resolution and conductance required for adequate performance being more onerous the lower the frequency. Antennas for other uses are also sometimes printed. Ink makers are developing better silver inks that can be printed at high speed yet achieve adequate conductance in one pass. (Glyn et al., 2005).

RFID tags come in a wide variety of physical forms dependent upon shapes sizes and protective housings. Animal tracking tags, inserted beneath the skin, can be as small as a pencil lead in diameter and ten millimetres in length. Tags can be screw-shaped to identify trees or wooden items, or credit-card shaped for use in access applications. The anti-theft hard plastic tags attached to merchandise in stores are also RFID tags, as are heavy-duty 120 by 100 by 50 millimetre rectangular transponders used to track inter-modal containers, or heavy machinery, trucks, and railroad cars for maintenance and tracking applications.

The tags are data carriers, and the data they contain invariably requires some organisation and additions, such as data identifiers and error detection bits, to satisfy recovery needs. The amount of data carried depends on the application and requires an appropriate tag to meet the need. Basically, tags may be used to carry Identifiers, in which a numeric or alphanumeric string is stored for identification purposes or as an access key to data stored elsewhere in a computer or information management system, or portable data files, in which information can be organised, for communication or as a means of initiating actions without recourse to, or in combination with, data stored elsewhere. (Harrop & Raghu, 2004).

The data storage capacities of tags vary. Data storage capacities up to 128 bits are sufficient to hold a serial or identification number together, possibly, with parity check bits. Such devices may be manufacturer or user programmable. Tags with data storage capacities up to 512 bits, are invariably user programmable, and suitable for accommodating identification and other specific data such as serial numbers, package content, key process instructions or possibly results of earlier interrogation/response transactions.

Tags characterised by data storage capacities of around 64 kilobits may be regarded as carriers for portable data files. With increased capacity the facility can also be provided for organising data into fields or pages that may be selectively interrogated during the reading process.

The more the data, the greater the need to calculate the Data Read Rate. The data transfer rate is essentially linked to carrier frequency. Generally speaking the higher the frequency, the higher the transfer rates. Reading or transferring the data requires a finite period of time, even if rated in milliseconds, and can be an important consideration in applications where a tag is passing swiftly through an interrogation or read zone.

There are also various data programming options. Depending upon the type of memory a tag has, the data carried may be 'read-only', 'write once, read many' (WORM) or 'read/write'. Read-only tags are most often low capacity devices programmed at source, usually with an identification number. WORM devices are user programmable devices. Read/write devices are also user-programmable but allow the user to change data stored in a tag. Portable programmers may be recognised that also allow in-field programming of the tag while attached to the item being identified or accompanied.

As noted by ID TechEx, once such a tag is included in packaging, many benefits of brand protection, tamper-evidence and supply chain management applications are available to the brand owner (Gen-Daniel & Brown, 2002).

In order to create these tags, and the communications between them, as well as with other devices, much of the circuity can actually be directly printed onto flexible plastic substrates. Printed electronics have a lot of potential in various industrial fields. With regard to packaging, printed electronics can be applied on various substrates for packaging, and the printed elements include circuits, antennas, power indicators, sensors, sensor indicators, batteries etc. Baumann and Weiss (2005). Central to these is the increasing importance of printing, although they caution that there increasing complexity and new skills to be acquired.

The use of these technologies allow for visions of the future such as Active communicative Packaging Systems. Such smart and intelligent systems can offer cost-effective solutions for new product concepts for traditional machine industries. These are defined by Juhola & Lindqist (2000) as intelligent logistics systems with active, communicative packaging for sensitive products. Such systems would be able to:

- continuously monitor or perceive their status and environment (awareness)
- react and adapt to environmental and operational conditions
- maintain optimal performance in varying circumstances, also in unexpected cases
- actively communicate with the user, the environment or other products and systems.

Further, many of these properties can be seen as a result from long evolution in living organisms - in the future, machines are expected to imitate nature (biomimetics) and will be smart or intelligent, where a "smart" system is defined as one that adapts to expected situations in a predictable manner, and an "intelligent" system is able adapt to unexpected situations as well by reasoning and learning. (Juhola, 2002).

From the descriptions of the technologies and their capabilities, and the visions they afford, it is understandable that with these new technologies opening up so many new possibilities, there is a need for guidance in terms of concepts and models. Especially promising appear to be those from areas that have also been affected by new ways of doing things and by convergence between previously separate industries. One such concept is that of cross media, which is explained in the next section.

4. Cross media concepts for packaging

This paper set out to discover whether the integration of digital data and enabling technologies such as RFID and EAS along with printed electronics on packaging can make use of the concept of cross media. Cross-media refers to the ability to use the same content across multiple output media without having to reprocess the content at its origin. It may be considered as an integrated approach to managing documents for print and electronic versions of documents. Huusko (2001), defines publishing in multiple media or multimedia publishing as the process where the information is kept in one data source, for example a database, and published through different media, making use of database and metadata technologies, XML, (eXtended Markup Language), XSL (eXtended StylesheetLanguage), and DTD (Document Type Definition). Cross media as a concept works well in current atmosphere of convergence. According to a study published by the German Federation of

Printing and Media industries, print, publishing and Web run together and create new forms of communication, with media independent data handling, (BVDM, 1999).

So far, the cross-media concept is applied in particular to publishing, (GATF, 2000), (Comprint, 2002), (Politis, 2004) and its main characteristics are classified as follows:
- Application of new workflows based on the common processing of data for printed and electronic media.
- Development of asset and content management software.
- Increasing applications of new processing technologies for publishing based on XML
- Development of new standards and formats for production management and workflow in publishing such as Job ticket, CIP 4 initiative and JDF format, PPML (Politis 2004).

By extension, cross media concept are widely established in the media industry and account for numerous applications (Politis, 2002). Generally speaking, in terms of the graphic arts and media industry, cross-media applications are to be found in two main areas. Firstly in the area of publishing process, mainly applied as the guiding concepts for the management and workflow of data for various input and output media. A prominent output example is newspapers with their printed and electronic editions. Secondly, in the area of the application of specific technologies for multiple media (mainly the use of machinery and production systems and the application of software), compared to their traditional use oriented to only one media.

In a similar vein, cross-media publishing is an emerging concept in the production-process of print and electronic media, whose main features can be seen one or combinations of the descriptions below:
- As workflow production applications for the publishing process.
- As the common processing of data for publishing of print and electronic media.
- As the application of production tools and new software applications (such as XML editors).
- As the establishment of production workflow systems (such as JDF - the Job-definition format) applied from pre-press to finishing for the print media, combining production and management processes.
- As the reorientation of existing production systems, processes and tools (scanning, image processing, color management, proofing) into common production environments for print and electronic media.
- As content management of any sort, e.g. format and multimedia (any combination of text, images, graphics, sound and video) (Politis 2002).

With this in mind, the question now arises "Are the production workflows of publishing (as a cross-media concept) and the new packaging production workflow comparable?" According to Baumann and Weiss, (2005), the packaging production workflow, with the integration of printed electronics, tags or antennas is structured in the following way:
- Design and print antennas (with semiconductor ink).
- Print (texts, images, graphics, colour printing).
- Put a chip (at the necessary point).
- Lamination.
- Folding / transformation / transfer / distribution.

This workflow can be further specified as follows, with an example of the integration of an antenna on a package:
Antenna for interaction with computer system:
- short to high run length,
- image and text information [to be recognized by the eye] (in conventional printing),
- Pasting of Silicon Chips or Plastic Circuitry,
- Finishing.

Writing/Reading (Supply Chain Management System [PC]/(radio frequency) (Baumann and Weiss, 2005).

This packaging workflow can be compared to a cross media workflow, using the model suggested by Kipphan (2001), which combines print, electronic media and multimedia documents with workflow and transmission media for customer use, as illustrated in Figure 1:

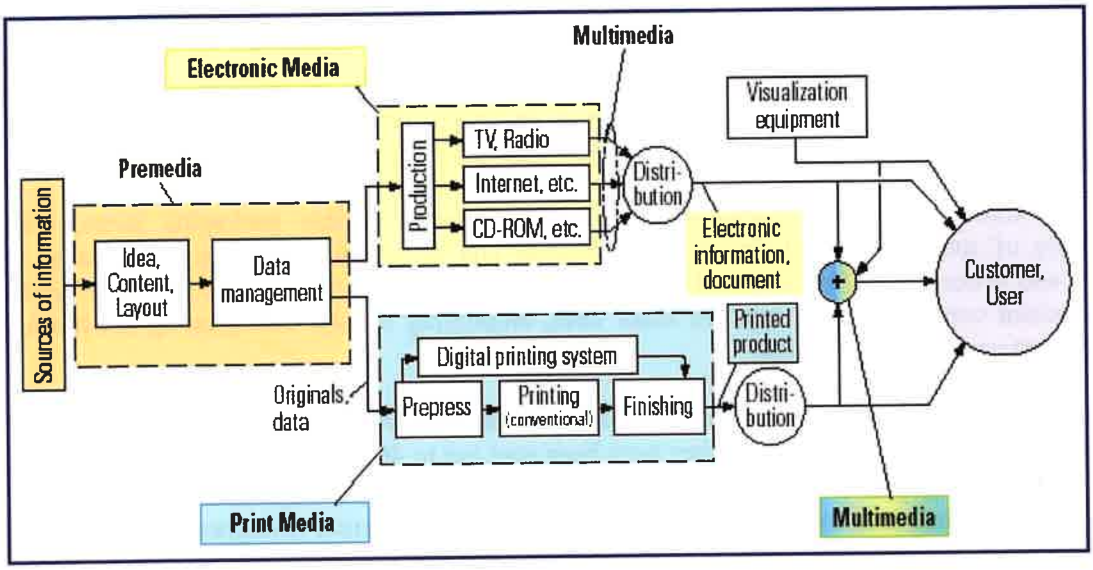

Figure 1: Cross Media Workflow (Kipphan 2001)

In its simplest form it consists of common processes of information which can be processed together and then it can be transferred to various media (print and electronic. Such a concept is applied for newspapers production both in electronic and printed form (Politis and Halonen, 2002).

By contrast however, the packaging production workflow however, still remains a print media production workflow. What is added, is the integration of electronic data via a wide range of new technologies and applications in the form of tags, antennas, and printed electronics (circuits, microchips) (Harrop & Raghu, 2004). By contrast cross media concepts constitute either the processing and management of content to be produced jointly before the definition of the output (print or electronic), or new technical developments in production workflow for media. However, packaging, even in its new form - with the integration of digital data one or the other way - is still a printed medium, carrying information on a substrate. With new technologies it becomes a digital data carrier, but is not akin to having one source of data, to be output to different media.

In order to understand better what the industry thought about these issues, we made a survey of printing packing industries in Greece. The next section describes the survey and its results.

5. Survey

In order to extract results regarding whether and how the previously mentioned technologies and developments on packaging affect the packaging printers, we decided to carry out questionnaire based interviews with Greek companies specialising in this field. A questionnaire was developed for this purpose, structured in order to receive answers to fundamental issues concerning the objectives of the study. The selection of the companies was based on the type of packaging printing according to the main printing substrate and the printing process applied, as follows:

- Packaging printing of paper and board - production of folding boxes (Offset sheet-fed printing and die-cutting of boxes)
- Packaging printing of rolls of flexible substrates production (Gravure and flexography printing)
- Label printing production - production self-adhesive labels (Narrow web printing with letterpress and flexography).

According to data derived from industry analyses (ICAP, 2004), packaging printers in Greece are mainly small to medium companies employing 30 to 50 employees on average. There is a constant demand for packaging printing. Paper and carton packages, flexible polymeric and aluminum foil packages, carton boxes, labels, plastic and metal packages are constantly on the increase.

There are about 30 printing plants for printing exclusively flexible packaging items, with the application of rotogravure and flexographic printing and about 40 companies specializing in the printing and processing of cartons and boxes. With regard to label production, there are around 15 medium-sized companies and about 20 small ones, employing narrow-web printing machines (with flexo and letterpress printing units).

The aim of the survey was to gain information from the majority of medium-sized packaging and printing Greek companies. Questionnaires were been sent out to 40 companies, divided as follows:

- 15 questionnaires sent to of paper and board - packaging printing companies (offset printing).
- 15 questionnaires sent to Packaging printing of rolls of production (rotogravure and flexography packaging printing companies (printing of flexible substrates) and
- 10 questionnaires sent to label printing companies.

In Table III the questionnaires sent out and the answers received are presented:

Table III: Type of packaging printing companies interviewed, questionnaires sent out and answers received

	Paper-Board Printing -Production of folding boxes (Offset sheet-fed printing)	**Flexible packaging substrates production. (Gravure and flexography printing)**	**Label printing production (Narrow web printing with letterpress and flexography)**
Number of medium-sized Greek companies specialized in packaging printing (approx. number)	30	25	15
Companies where the questionnaire has been sent out	15	15	10
Questionnaires received	9	8	6

In total, 25 companies responded, a response rate of 62.5%, which was sufficient to enable us to make an analysis. It is worth noting that is that the number of 70 companies in the first row, represents over 95% of packaging printing production in Greece (excluding printers of corrugated board) (ICAP, 2004).

5.1. Objectives of the questionnaire

The questionnaire is designed to getting feedback on the degree of awareness of the graphic arts companies oriented in packaging printing, as to the new technologies to be applied in packaging

(RFID -EAS - printed electronic circuits, antennas and generally, smart and interactive packaging applications). It was also designed to obtain information about whether these companies are interested in implementing and integrating these technologies in their packaging printing production process.

The questionnaire has the following structure: The first section consisted of two questions to establish the main activity of the company and the printing method(s) incorporated in the company.

Question 3 deals with the degree of awareness of the companies regarding new technologies that are applicable on packaging Question 4 follows up on this querying the importance for receiving information and further knowledge about these technologies.

Question 5 briefly explains the characteristics of RFID and EAS- both employ special inks for printing of antennas, laminating technologies for the integration of microchips and according to manufacturers, they can be printed by all available main printing methods, and asks the respondents to judge which approach is best for fitting in with their production processes.

The aim of this question was to understand whether companies would prefer to receive antennas or microchips already-printed by a third party, or whether they would aim to proceed with investments for full integration of printing and production of antennas, microchips, etc. One of the responses to this question was also to wait and get further informed before making decisions.

Question 6 is aimed at those companies who want to invest in know-how, and asks them about the time frame for this. Question 7 addresses the issue of the implementation of the new technologies in the existing production workflow, whereas question 8 asks for feedback on the importance of these new technologies to be applied in the companies' production process, taking under consideration that these are capable of conveying data for the production process as well as quality control, stock regulation, etc.

Finally, question 9 is addressing the willingness of the companies (their owners and/or managers) to receive training, take part in seminars and generally develop their know-how on the new technologies to be applied on packaging, regardless of their intention on investing on such new applications.

The results of the survey are next discussed. The questionnaire itself and a summary of the results obtained are presented in Appendices 1 and 2.

5.2 Survey results - answers from the questionnaire

The findings from the interviews and the answers to the questionnaires received from the 25 Greek packaging printing companies, were as follows:

With reference to the range of the main business activity of the companies interviewed:

- 9 companies are involved in paper and board packaging printing,
- 8 companies are producing flexible packaging materials, employing rotogravure and flexographic printing machines
- 6 companies are printing and processing labels.
- 3 of the companies that use rotogravure and flexographic machines print also aluminum foils.

Concerning the degree of awareness of the companies as it regards the new technologies that are applicable on packaging (question 3), not a single company reported that is fully aware and informed on the new key technologies for packaging.

- 7 out of 25 companies reported that are sufficiently informed (28%),
- 12 that are relatively informed (48%),
- whereas 6 of the companies reported that are not well informed (24%).

With regards to the companies that are relatively or not properly informed (that is; 18 out of 25 companies), the majority responded that would like to be informed immediately about the new technologies for packaging (question 4).

The following question 5 explained briefly the characteristics of RFID and EAS Furthermore, the question asked which is the best approach they envisage with regard to the integration of the new technologies in their production process, namely whether they will receive the already-printed antennas or microchips from a third party, or whether they will proceed with investments for full integration of printing and producing antennas, microchips, etc.,

The answers to this question were quite diverse:

- 5 out of the 25 companies (20%) stated that they would prefer to cooperate with a subcontractor, to receive the already-printed antennas and integrate them in the surface of the packaging that they print.
- On the other hand, the majority of companies (11 out of 25 or 44%) reported that they intend to proceed with investments and development of know-how for full integration of printing and producing antennas, microchips, etc., in their own production process.
- A further significant number of companies (7 out of 25 or 28%), stated that they would prefer to wait to be informed more properly on the specifications, production characteristics, the processes of integration, etc. at this stage.
- Finally, 2 companies both oriented on flexible substrates printing, answered that they do not know - they have not yet decided how they will proceed on this subject.

With reference to the issue whether the companies should invest in the know-how and equipment of the new technologies and, when they foresee this happening, not a single company reported that this could happen within the next 6 or 12 months. Rather:

- 9 companies (36%) answered that they could proceed in 2 years time, whereas
- the majority (11 out of 25 or 44%) will be waiting to be informed further before they proceed in any investment;
- and 5 companies replied that they do not know yet whether they will go on with investments (question 6).

Regarding the importance of substitution of the linear barcode (EAN barcode) in packaging by new technologies (e.g. RFID), all 25 companies replied that this is a very interesting or interesting enough development (question 7).

Furthermore, with regards to the issue of the implementation of the new technologies in the existing production workflow and the importance of these new technologies to be applied in the production process of the companies and conveying data for the production process as well, quality control, stock regulation, etc. (question 8),

- 13 out of 25 companies (52%) replied that this is a "very important" issue for their production process and
- 7 companies (28%) that it is an "important enough" issue.
- For the remaining 5 companies (20%) this is a "rather important" issue.

Finally, replying to the final question addressing the willingness of the companies (their owners and/or managers) to receive training, take part in seminars and generally develop their know-how on the new technologies to be applied on packaging, regardless of their intention on investing on such new applications (question 9),

- 17 companies (68%) declared that they are ready for immediate participation and the rest
- 8 companies responded that they are rather ready for such activities (32%).

5.3 Survey analysis

Broadly speaking, the findings from the interviews and the answers to the questionnaires received from the 25 Greek packaging printing companies, show quite a strong degree of interest in new technologies and understanding of the importance they will have on future packaging production.

Offset printers (producing paper and board packaging) are slightly more aware on new technologies in comparison with the other two categories of packaging printing companies.

Companies are only relatively aware of the applicability of the new technologies to packaging. This means that they need to be more informed and this is expressed very clearly by the majority of the companies.

The remarkable differences reported on the subject of the approach that companies should follow regarding the integration of the new technologies in their production process and the steps they should follow, can be related with the degree of awareness and possibly on their different market orientation and production segmentation.

However, the willingness of the majority of the companies to proceed with investments and development of know-how for full integration of printing and producing antennas, microchips, etc. in their own production process shows that companies want to stay ahead in their business and production activities with everything that is new. In addition, a significant number of companies that stated that they prefer to wait to be informed more properly on the specifications, production characteristics, integration processes, etc. reveal that more information is required. This finding is further supported as not a single company intends to proceed in any investment in the next 2 years, with a significant number reporting that they might start investments after 2 years time and some companies (20%), to report that they do not know yet whether they will go on with investments.

As companies are familiar with the printing and processing of barcodes they all rate the ability of new technologies to replace or substitute this machine-readable element as very interesting and important development. The same exists for the implementation of the new technologies in the existing production workflow and the importance of these new technologies to be applied in the production process of the companies.

It is also considered important that owners and/or managers of the companies are willing to receive training, take part in seminars and generally develop their know-how on the new technologies to be applied on packaging, regardless of their intention on investing on such new applications.

A final conclusion regarding the survey with the 25 companies is that the "wait and see" behaviour together with the willingness of the majority of the companies to proceed with investments on these new technologies are the trends dominating the responses of the packaging printing sector in Greece. This holds for all types of companies. And companies have similar opinions regarding both their willingness to participate in training and to increase their degree of awareness about the new technologies.

6. Discussion - Cross-media for packaging?

The work undertaken here shows that the key technologies to be applied in packaging seem to affect considerably - or it is expected that they will affect considerably - the design, production and printing of packages. This is expected to happen with various interventions in the traditional production workflow. This means that packaging printing companies (including designers, pre-press and finishing) as well as graphic arts equipment manufacturers need to o consider the changes in the design and production process.

However, comparing the analysis of the characteristics of cross-media applications and the production workflow in packaging, we come to the conclusion that cross-media is not a concept that can be applied directly yet on packaging. This is firstly because cross-media in one of its interpretations is considered as a process for production of print and electronic media. Secondly, as regards the production workflow, cross-media constitutes a concept where common data are processed together until the output media is defined, whereas what we are looking at here is packaging production combined with the integration of print and digital information.

This is not to say, that in a future view, information will be authored and then processed separately as print and web, so that someone can read the package, as well as see the same information on a web page that may be displayed on a screen incorporated into white appliances, or part of the supermarket shelving. This is a form of cross media regarding information flow. Already scanners that read product information from packaging and display it elsewhere (or speak it aloud for those who cannot read) are at the end of their research phase ready to go into production.

For the present, we can say that electronic information will be integrated, designed and printed, following in many cases the same process as for printed data. What will be new are the systems to be established to produce tags, antennas etc. and that will be integrated in the existing workflow of packaging. As a conclusion, the future packaging will be a <hybrid information carrier> with both printed and electronic data.

7. Conclusions and further research

The research reported in this paper is based both on the study of literature as well as on a survey with graphic arts companies. The literature used for this study concerned research and analyses from the fields of cross-media concepts and applications within the media landscape as well as literature study on smart, intelligent and active packaging concepts. Various recourses have been investigated, including key technologies for application to packaging.

The final conclusion is that such developments in packaging are not helped presently by the cross-media concept. Packaging will continue to be printed on a substrate (paper, board, polymer aluminum or on a multilayer substrate), with new types of information carriers to be embedded in and/or on packaging, especially printed electronics, antennas, circuits, etc.

As a result, packaging - the substrate- which will continue to be printed and processed as usual, is changing, with regard to the types and structure of information to be presented. It becomes a physical carrier of both printed and electronic information and as such it could be termed a "hybrid information carrier".

The survey with companies revealed that packaging printing companies in Greece are willing to proceed with investments. However, they first want to be more informed and be in a better position to understand the potential of future packaging.

Further research is required in order to define further the information types and flow within packaging production as well as the range of information defined as electronic data. It is perhaps here that the cross media concept will prove more useful. In any case, it would be useful to explore the development of a model for gaining a better understanding of the complex processing and output of information from the package producer to the end-consumer that can be used by the packaging sector.

From a practical point of view, studies of the transformation required from the traditional design and production processes of packaging to the new production workflows are needed to help the packaging printing sector to better cope with new applications to be implemented in packaging production, including printed electronics.

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Appendix 1.

SMART PACKAGING - INTEGRATION OF DIGITAL DATA ON PACKAGING THROUGH PRINTING TECHNOLOGIES

Questionnaire for the integration of printed electronics and digital data in the existing production process of packaging printing.

Dear colleagues,

To the extend of our activity in the scientific research of innovative advancements that are expected to influence the industry of graphic arts, we are currently working on the field of new developments in packaging and in particular on the integration of printed electronics and digital data on packages through the packaging printing production process.

Within our study, we will present a paper in the international conference of the IARIGAI (International Association of Research Organisations for the Printing, Information and Communication Industries), that will be held in Finland during September 2005. The theme of our scientific paper is: "Exploring cross-media concepts for future packaging - Challenges for the printing industry"

Our study is dedicated on new possibilities that new technologies, such as Printed Electronics, RFID (Radio Frequency Identification) and EAS (Electronic article surveillance) offer to packaging. More specifically, we have processed a questionnaire containing questions aiming in exploring the degree of awareness of the graphic arts companies oriented in packaging printing, with these technologies. In addition, we would like to examine weather the companies are interested in implementing and integrating these technologies in their production process of packaging printing. Therefore, we would like to request your kind contribution, by spending a while of your time, to answer the questions that follow.

You can send the questionnaire to the fax number 210 4904500 or the e-mail address:
politisresearch@techlink.gr or nomic@aegean.gr, up to the 6th of July 2005.

On behalf of the research team,

Dr. Anastasios E. Politis and Spyridon Nomicos, M.Sc.

P.S. The data that you will be filling in will be kept confidential. These will be processed in total to derive scientific results that will be presented in the scientific conference.

Questionnaire for the integration of printed electronics and digital data in the existing production process of packaging printing.

Question 1:
Which is your main business activity?
(You can check more than one answers)
Paper and board packaging packaging printing
Production of self-adhesive labels (narrow web flexo and letterpress printing)
Production of flexible packaging materials
Corrugated board packaging production
Printing production of aluminum foils for packaging
Other, please specify

Question 2:
Which of the following printing methods does your business incorporate?
(You can check more than one answers)
Gravure
Flexography
Offset-lithography
Silk screen printing
Digital printing
Narrow web flexo and letterpress printing
Other, please specify

Question 3:
To what extent you are informed on the new technologies that are applicable on packaging (e.g. RFID - Radio Frequency Identification, EAS - Electronic article surveillance applications, printed electronic circuits, antennas and generally smart and interactive packaging applications)?

I am fully informed
I have sufficient information
I am relatively informed
I am not well informed
I am not informed at all

Question 4:
In case you are not properly informed, do you think that it is necessary to be informed:
Yes, immediately, Rather yes, Rather not, No

Question 5:
EAS and RFID technologies have a lot in common - both employ special inks for printing of antennas, laminating technologies for the integration of microchips and (as manufacturers claim) they can be printed by all available main printing methods. Which do you think is the best approach for your production process:

A. To receive the already-printed antennas or microchips from a third manufacturer - subcontractor and integrate them in the surface of the packaging that you print.
B. To proceed with investments and development of know-how for full integration of printing and producing antennas, microchips, etc. in your own production process.
C. You will be waiting to be informed more properly on the specifications, production characteristics, the processes of integration, etc. at this stage
D. You are not interested in this activity
E. Do not know
F. Other, please specify

Question 6:
In case you believe that you should invest in the know-how and equipment of the new technologies in your own production, do you foresee this happening:
Immediately (within 6 months)
In 12 months
In 2 years
I will be expecting to be informed further before I proceed in any investment
I do not intend to
I do not know
Other, please specify…..

Question 7:
The implementation of the new technologies (e.g. RFID), is possible to derive in substitution of the lineate barcode (EAN barcode) in packaging. How interesting do you think this application is in your business to the degree that it will amend your current workflow production?
Very interesting
Interesting enough
Rather interesting
Not interesting at all

Question 8:
The new technologies are capable of conveying data for the production process as well, quality control, stock regulation, etc. How important do you think is such an application on your production process?
Very Important
Important enough
Rather important
Not at all important

Question 9:
Regardless of your intention on investing on the new applications of smart packaging, do you think you should receive training, take part in seminars and generally develop your know-how on these subjects?
Yes, immediately, Rather yes, Rather not, No

Thank you for your valuable contribution in our research.

Appendix 2.

Questionnaire for the integration of printed electronics and digital data in the existing production process of packaging printing.

Answers to the questions

Question 1:
Which is your main business activity?
(You can check more than one answers)
Paper and board packaging packaging printing 9
Production of self-adhesive labels (narrow web flexo and letterpress printing) 6
Production of flexible packaging materials 7
Corrugated board packaging production -
Printing production of aluminum foils for packaging 3
Other, please specify

Question 2:
Which of the following printing methods does your business incorporate?
(You can check more than one answers)
Gravure..............5
Flexography..........8
Offset-lithography......10
Silk screen printing -
Digital printing......2
Other, please specify.....
Narrow web flexo and letterpress printing 6

Question 3:
To what extent you are informed on the new technologies that are applicable on packaging (e.g. RFID - Radio Frequency Identification, EAS - Electronic article surveillance applications, printed electronic circuits, antennas and generally smart and interactive packaging applications)?

Classification of companies questioned and interviewed	Paper-Board Printing - Production of folding boxes (Offset sheet-fed printing)	Flexible packaging substrates production (Gravure and flexography printing)	Label printing production (Narrow web printing with letterpress and flexography)
I am fully informed			
I have sufficient information	4	3	
I am relatively informed	6	3	3
I am not well informed		6	
I am not informed at all			

Question 4:
In case you are not properly informed, do you think that it is necessary to be informed:

Classification of companies questioned and interviewed	Paper-Board Printing - Production of folding boxes (Offset sheet-fed printing)	Flexible packaging substrates production (Gravure and flexography printing)	Label printing production (Narrow web printing with letterpress and flexography)
Yes immediately	4	6	2
Rather yes	3	3	
Rather not			
No			

Question 5:
EAS and RFID technologies have a lot in common - both employ special inks for printing of antennas, laminating technologies for the integration of microchips and (as manufacturers claim) they can be printed by all available main printing methods. Which do you think is the best approach for your production process?

Classification of companies questioned and interviewed	Paper-Board Printing - Production of folding boxes (Offset sheet-fed printing)	Flexible packaging substrates production (Gravure and flexography printing)	Label printing production (Narrow web printing with letterpress and flexography)
A. To receive the already-printed antennas or microchips from a third manufacture - subcontractor and integrate them in the surface of the packaging that you print.	3		2
B. To proceed with investments and development of know-how for full integration of printing and producing antennas, microchips, etc. in your own production process.	5	5	1
C. You will be waiting to be informed more properly on the specifications, production characteristics, the processes of integration, etc. at this stage	2	5	
D. You will be waiting to be informed more properly on the specifications, production characteristics, the processes of integration, etc. at this stage			
E. Do not know		2	
F. Other, please specify			

Question 6:
In case you believe that you should invest in the know-how and equipment of the new technologies in your own production, do you foresee this happening:

Classification of companies questioned and interviewed	Paper-Board Printing - Production of folding boxes (Offset sheet-fed printing)	Flexible packaging substrates production (Gravure and flexography printing)	Label printing production (Narrow web printing with letterpress and flexography)
Within 6 months			
In one year			
In two years	4	5	
I will be waiting to be informed further before I proceed in any investment	4	4	3
I do not intend to make any investment			
I do not know	2	3	

Question 7:
The implementation of the new technologies (e.g. RFID), is possible to derive in substitution of the linear barcode (EAN barcode) in packaging. How interesting do you think this application is in your business to the degree that it will amend your current workflow production?

Classification of companies questioned and interviewed	Paper-Board Printing - Production of folding boxes (Offset sheet-fed printing)	Flexible packaging substrates production (Gravure and flexography printing)	Label printing production (Narrow web printing with letterpress and flexography)
Very interesting	4	6	
Interesting enough	6	6	3
Rather interesting			
Not interesting at all			

Question 8:
The new technologies are capable of conveying data for the production process as well, quality control, stock regulation, etc. How important do you think is such an application on your production process?

Classification of companies questioned and interviewed	Paper-Board Printing - Production of folding boxes (Offset sheet-fed printing)	Flexible packaging substrates production (Gravure and flexography printing)	Label printing production (Narrow web printing with letterpress and flexography)
Very Important	4	6	3
Important enough	4	3	
Rather important	2	3	
Not important at all			

Question 9:
Regardless of your intention on investing on the new applications of smart packaging, do you think you should receive training, take part in seminars and generally develop your know-how on these subjects?

Classification of companies questioned and interviewed	Paper-Board Printing - Production of folding boxes (Offset sheet-fed printing)	Flexible packaging substrates production (Gravure and flexography printing)	Label printing production (Narrow web printing with letterpress and flexography)
Yes, immediately	6	9	2
Rather yes	4	3	1
Rather not			
No, not at all			

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