5-1-1996

Investigation into the capturing, manipulating, calibrating and outputting of black and white images on a Xerox Docutech

Sebastian Schwarz

Investigation into the Capturing, Manipulating, Calibrating and Outputting of Black and White Images on a Xerox Docutech

by
Sebastian Schwarz

A thesis project submitted in partial fulfillment of the requirements for the degree of Master of Science in the School of Printing Management and Sciences in the College of Imaging Arts and Sciences of the Rochester Institute of Technology

May 1996

Thesis Advisor: Professor Frank Romano

ROCHESTER INSTITUTE OF TECHNOLOGY
rochester, new york

School of Printing Management and Sciences
Rochester Institute of Technology
Rochester, New York

Certificate of Approval

Master's Thesis

This is to certify that the Master's Thesis of

Sebastian Schwarz

With a Major in Graphic Arts Publishing
has been approved by the Master Coordinator as satisfactory
for the Thesis requirement for the Master of Science degree
at the convocation of
May 1996

Thesis Committee:

Frank Romano
Thesis Advisor

Marie Freckleton
Graduate Program Coordinator

C. Harold Goffin
Director

Permission to Reproduce

I, Sebastian Schwarz, hereby grant permission to the Wallace Memorial Library of the Rochester Institute of Technology to reproduce my Thesis, *Investigation into the Capturing, Manipulating, Calibrating and Outputting of Black and White Images on a Xerox Docutech,* in whole or in part. Any reproduction will not be for commercial use or profit.

May 1996

Dedication

. . . it is not a shame to fall down,
but it is a shame not to get up again!
(Stefan Schwarz)

This project is dedicated to my parents Brigitte and Stefan Schwarz, my brothers Andreas and Christian, to my Grandmother . . .

and to
Eva-Christina Hofmann

Thank you very much for your help, assistance and support!

Acknowledgments

I would like to address my special thanks to the Dr.-Ing. E. H. Hubert H. A. Sternberg Stiftung whose generous scholarship enabled me to attend the Graduate Program at R.I.T..

Furthermore, I am greatful for the help and assistance of Mrs. Nancy Marrer and her students of the NTID. Without their support and the given access to the NTID's Docutech this thesis project would not have been finished in time.

Moreover, I would like to thank the friends I found in the United States for the great time we spend together and who made the last months to an unique and unforgettable part of my life, especially

Eric Miner

Chris Hahn

Jérôme Jallu

Cindy McCombe

&

The Family "who was always good to me"

Thanks guys!

TABLE OF CONTENT

Table of Content

List of Figures

Figure

List of Tables

Table

ABSTRACT

It is the purpose of this investigation to determine whether or not the output quality of black and white images on a Xerox Docutech can be enhanced. The Docutech is a black and white digital printing device. In times of a growing demand for on-demand printing and publishing, the Docutech not only has to reproduce text and graphics properly but also has to cope with the increasing task of rendering images.

Although there are multiple options to improve the output quality, this project focuses on the impact of image capturing on the output. As a result of this investigation, a user's manual should help to achieve satisfying reproductions on the Docutech.

The project goals are reached by extensive testing and a careful evaluation of the experiments by visual, densitometric and statistical means. Prior to any testing and as a prerequisite for the project, the print characteristic of the Docutech is determined. With stable printing conditions as a starting point, the impact of the scanning process is investigated. For this purpose, four different scanners — ranging from flatbed, desktop devices to high-end scanning systems — are used to capture two test images. Those images are manipulated within this process step to improve the rendering quality of the printed output.

The printed output is analyzed finally by statistical means to base the perceived quality differences on the objective judgement of a larger audience of observers.

Focusing on the results of this evaluation process, one will find that the output quality can be enhanced. Not only are adjustments found which increase the perceived quality of the printed result but also is insight gained into the printing process and its limitations.

There is no doubt that the Docutech has its restrictions but its low cost and low quality image is not justified. It is possible to improve the output quality of black and white reproductions by applying the basic rules of image reproduction. Thus, utilizing the capabilities of this digital printing device efficiently, one can achieve satisfying output quality.

Chapter 1. Introduction

At first glance, it may seem exaggerated to worry about the reproduction of images. But careful investigations, sophisticated technology and personal skills have improved the printed results. Moreover, in today's publishing world everyone is concerned about color. Placing so much emphasis on color image processing, separation techniques, color management and color measurement, the graphic arts industry obviously considers the successful reproduction of black-and-white images as an easy feat. But reality paints a completely different image. As black-and-white images become more and more popular in advertising due to their ability to achieve a high level of contrast, these images are still difficult to reproduce. Decent black-and white reproductions are hard to find and are often underestimated during the reproduction process.

Considering these facts, one will agree that investigations in the field of black-and-white reproductions are neither a waste of time nor energy. Especially if a new, emerging technology is involved. Digital printing in general and digital printing presses in particular were the hot topics during DRUPA 1995, the world's largest printing and paper exhibition held in Düsseldorf, Germany. One of these printing devices, which is standing in the spotlight of interest, is Xerox's Docutech. Although the Docutech is a one-color printing device — with an option for multiple units, it is a competitive new technology as compared to the traditional printing processes. The Heidelberg GTO, for example, is also a one-color printing press and will face the competition of Xerox's release. However, the major difference between both pieces of technology is that the reproduction qualities of the GTO are already known and widely accepted, while the capabilities of a Docutech have not been fully examined. Therefore, it is the purpose of this project to investigate the output capabilities of a Docutech as far as black-and-white images are concerned.

The requirements for printed products also apply to digital printing concepts, so it is not surprising that the means of evaluation are similar to those of established printing processes. If one wants to investigate the output qualities of a Docutech, one needs to evaluate the whole process including scanning and processing of images. Every processing step that is involved in the reproduction of the original has its impact on the final output. Although

emphasis must be placed on the quality of the printed product — whether or not it matches the original — the final outcome is the result adherent to a chain of single steps, all relating to another.

Internet publishing, database concepts and CD-ROM publishing have changed the character of the printing industry. Today, information can be delivered around the world in digital format and output wherever and whenever — with a digital printing device. Digital printing opens the door for the graphic arts industry to information management. Printing is no longer an isolated process but one piece of an overall concept that enables people to share information with several media.

The challenge of this project is that digital printing is a new and unexplored technology. Furthermore, it is an evolving technology, still under construction and development. By examining the capabilities of these technologies, one can gain an insight into the concepts that lead into the future of printing.

CHAPTER 2. BACKGROUND THEORY/THEORETICAL BASIS OF THE PROJECT

The successful reproduction of originals requires the knowledge of two factors — how should the final reproductions look like and how the given printing device renders the images. When plotted into a Jones diagram, this information describes the required reproduction curve for a given original.[1] Though it may sound simple on the surface, this process is very involved. Focusing first on the original, one should consider its density range. Most likely, the original's density range is wider than the density range reproducible by the printing process. Consequently, tone compression becomes unavoidable. Tone compression, however, must be adjusted to the original and to the perception of the eye. The human eye does not detect density differences in the shadow areas of an image immediately, but it records the slightest density difference in the highlight area.[2] Additionally, the right tone reproduction is of high importance. By placing the mid tone, one not only compensates for dot gain of the printing process, but also changes the perceived contrast of the image. A low key image, for instance, which carries most of its detail in the shadow areas, requires different treatment than a high key picture carrying most of its detail in the highlights. If a low key original has to be reproduced, the shadow contrast should be emphasized by placing the midtone properly. In other words, there are as many possible tone reproduction curves as there are different originals.[3] As one can easily see, "the" standard reproduction curve is nonexistent. Each original requires individual treatment, otherwise the output will not be satisfying.

The print characteristics of a given ink/substrate/printing process combination, on the other hand, can be evaluated and recorded as a constant parameter within the reproduction process — as long as the reproduction takes place in a calibrated environment. Once the characteristics of a reproduction system such as the Xerox Docutech are defined, standard settings can be established that will lead to the same output. The prerequisite is, however, that the necessary information is gathered by careful testing and measurement.

If both the print characteristic and the reproduction curve of the original are determined, it is possible to describe the requirements of the reproduction process. Knowing that the printing device can render a 5% dot stably, one should assign the highlight of the original to this particular value. Furthermore, one can account for the dot gain of the printing system during the reproduction process. This knowledge leads to the proper scanning and manipu-

lating of images with appropriate hard- and software tools. After plotting the aforementioned information into a Jones diagram, the necessary information for an image's reproduction curve is derived.

Therefore it is part of this investigation to determine the mentioned prerequisites prior to analyzing the output. Like any other printing process the Docutech has limits in terms of rendering images. Unfortunately, one cannot refer to extensive studies about the print performance of this machine. Consequently, the evaluation of the printing process becomes part of this project prior to focusing on scanning and image output. The points of interest — and of importance to draw the print characteristic — are:

Amount of dot gain
Achievable resolution
Levels of gray
Density range
Lightest printable dot
Highest possible screen ruling

Knowing the capabilities of the printing process and considering the unique qualities of varying originals such as high, low and normal key, one can focus on the image capturing process. Part of the Docutech is an attached scanner which is controlled by Xerox's proprietary scan software. Unfortunately, this software does not provide the user of the Docutech the delicate options required to reach the demanded reproduction curve. One of the many questions to ask is whether or not the attached image capturing tools are sufficient to fulfill the task. Furthermore, how well does the scanning station work? Is it an easy and straightforward process, or are time consuming adjustments necessary? Does the system react flexibly? Are there a lot of restrictions as to what and especially to how originals can be rendered? Have probable adjustments actually made any significant impact on the output? Those questions and more build the background and the need for this investigation.

But this project will not only focus on an analysis of the state-of-the-art. By using the capability of the Docutech to process digital files, one can compare other scanning devices with the attached scanning station. Can better results be obtained by processing, for example, an image which was captured at an external scanning device and then sent to the Docutech in

an appropriate file format? In addition, how well are images handled that were scanned by a customer and provided on a floppy disk? By investigating and answering these questions, one might be able to compile reproduction recommendations for processing images with a Docutech.

The theoretical background of this project is whether or not varying scanners will improve the final image output if the printing process is properly evaluated and remains constant.

ENDNOTES FOR CHAPTER 2

1. Gary G. Field, *Color and its Reproduction* (Pittsburgh: GATF, 1988), 228
2. Professor Joseph Noga, *Color Image Processing Systems* (Rochester: Rochester Institute of Technology, 1995)
3. Donna & Miles Southworth, *Color Separations on the Desktop* (Livonia: Graphics Art Publishing, 1993), 33

Chapter 3. Literature Review

The thrust of this project is the impact of image capturing on the final output. Besides this point, evaluating the printing process and considering the tone reproduction of the original are mentioned because they are prerequisites for the main part of the investigation.

With regard to the given task, the literature review within this section will place emphasis on the process of image capturing. The process of scanning, however, is divided into two separate sections. One discussion will take the different scanning devices into consideration, while the other section provides insight into the importance of scanning variables such as sampling rate, reproduction size, density range bit depth or file size.

3.1 Specification of the Xerox Docutech

As mentioned in Chapter 2 of this thesis project, all process steps within the reproduction workflow are close related. It is essential, however, to analyze the Docutech prior to any further investigations in order to gain insight into the significance of certain process steps during image capturing. Neither the output nor the input side can be evaluated without referring to each other because the quality of the printed image is restricted to the capabilities of the weakest part in the process chain. The core of Xerox's digital printing device is the printing unit which is based on Xerox-copier technology. Prior to its exposure to a Helium-Neon laser, the revolving electrophotographic belt is uniformly charged. During the exposure, the laser eliminates the charge on the drum in the non-image areas. An electrical charge remains in the image area that attracts the applied toner which has an opposite charge. The toner is heated to 200° F to fuse the toner elements and to form a laminate on the belt. The belt is now carrying the complete image which is to be printed. The laminate is finally transferred to the paper. After the transfer process the belt is cleaned and recharged.[1] Xerox's specifications define the output capabilities of the Docutech with an addressability of 600 dots per inch(dpi) or a 150 lines per inch screen (lpi) ruling. The further specifications are:

Printable area:	*11 x 17*
Paper:	*sheet*
Ink/toner:	*dry toner*

Finishing option: *optional*

Scanning device: *optional*

3.2 Scanning devices

The literature in the world of scanning devices is divided into two parts — charged coupled devices (CCDs) and photomultiplier tubes (PMTs).

CCD scanners use an array of cells which record the image information. The amount of cells on this array is limited to the construction of the scanner. Consequently, a CCD array cannot be extended, thus impacting the resolution. The achievable resolution depends upon the amount of recording cells. Due to the fact that the resolution is restricted, the scanner operator should choose the "right" resolution carefully with regard to the intended output. Basic parameters for the calculation of the required resolution are screen ruling and output size. The number of reading cells not only limits the resolution, but also the scannable size of the original. Image information that lies beyond the recording CCD array is not covered. Possibly the most inconvenient limitation is that a scanner of this type is not capable of separating tones in images with densities exceeding 2.8. Transparencies, on the contrary, can reach densities of 3.2 or higher which means that all tones exceeding 2.8 can not be differentiated by the CCD scanner and are recorded as black with no detail.[2] As a result, variations in higher densities cannot be reproduced during the printing process — the image lacks detail in the shadow area. However, the opposite is stated in recent publications. CCD scanner such as the Scitex SmartScanner and AGFA's SelectScan are said to cover a density range of 3.6.[3] Functions such as unsharp masking and color correction are not performed on the fly and will have to be applied separately on an image manipulation workstation with the appropriate software. The described disadvantages of CCD scanner can be summed up to:

Limitations in terms of original's size

Limitations in terms of resolution

Limitations in terms of enlargements (due to resolution problems)

On the other side of the balance, one can see the CCD scanner are easy to use, fast and inexpensive. Usually, they do not require either specific knowledge about the reproduction process in general or knowledge about sophisticated scanner technology.

The second group of interest are scanners that use PMTs to sample the original. Enclosed one can see the scheme of a PMT.:

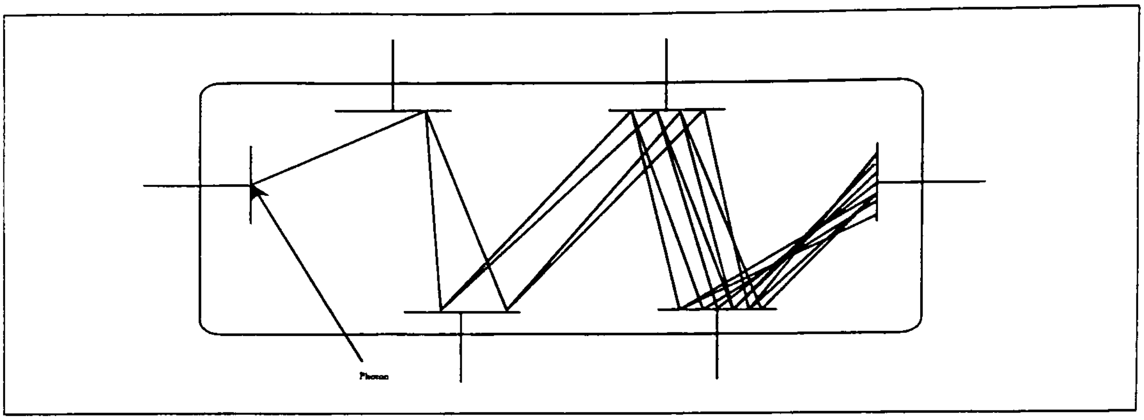


Figure 1: Scheme of a Photomultiplier

PMTs are based on the premise that light is capable of setting photons free by hitting a surface. Photons, however, are electronically charged and therefore attracted by the pole with the opposite electrical charge. While the photon is traveling through the tube, it sets more photons free which leads to a chain reaction or a massive amplification. The resulting electrical charge has two major advantages. Due to its amplification, it is easy to measure. Furthermore, the resulting charge is proportional to the incoming light. This sophisticated concept is responsible for a PMT's high sensitivity that results in its ability to record more detail of the original.[4] Although PMTs are found in high-end scanning systems in most cases, they are not exclusively used in high-end scanner. PMTs are also incorporated into desktop drum scanners which might serve as an input source for the Docutech.

However, the combination of PMTs and drum technology features some remarkable advantages. Having a higher sensitivity than CCD arrays, PMTs are not only able to record more detail, but also to detect densities of the original which are higher than 2.8. In addition, the limitation of resolution is not a topic for a drum scanner. By moving the scanning unit over the rotating original, a drum scanner can vary the steps forward and as a consequence gain resolution. Adjusting the sampling rate to the original is both an advantage in terms of achievable resolution and in terms of enlargements. Enlargements are one aspect of the issue "scaling the original." As pointed out, a CCD scanner has its limitations with regard

to the scannable size of the original due to the width of the CCD array. But by using a drum scanner, the operator can both adjust the sampling rate to the requirements as well as the drum to the size of the original. If, for example, a small and a very large image have to be scanned, the scanner operator will use drums with different diameters to compensate for the difference in the original's size. It is not a surprise that this accumulation of advantages has its price. Usually, drum scanners which use PMT technology are more expensive than CCD scanners.

3.3 Scanning images

The quality of a scan does not only depend upon the capability of the scanner. Moreover, the scanning software and especially the adjustments that are made by the operator with this software have a major impact on the appearance of the image. Prior to the discussion of these issues, it is essential to agree on some definitions to ensure that no misunderstandings arise from the terminology.[5]

resolution:	*ability of an output device to render detail*
addressability:	*a measure of how many marks an output device can make within a liner inch*
dpi:	*dots per inch; addressability of an output device*
spi:	*samples per inch; a term also referred to as optical resolution because it determines the capability of the scanner to record detail*
ppi:	*pixels per inch; a term also referred to as image resolution because it determines how good a screen can render the image details*
lpi:	*lines per inch, screen ruling of the finally printed output*

Table 1: Terminology

The topics of interest for the purpose of this project are:

reproducible levels of gray
screen frequency and levels of gray
resolution (choosing the right resolution)
bit depth and levels of gray
file size

Reproducible levels of gray:

The reproducible levels of grays are of major importance for the reproduction process of black-and-white images. If, for example, not enough levels of gray are available, the output will show an effect know as posterization.[6] Posterization is a term used to describe an obvious stairstepping from one level of gray to another quite different gray level — as opposed to a smooth transition. Another unwanted effect, known as banding, is also caused by a limited number of gray levels. Banding usually appears if one wants to output a smooth gray scale that contains more levels of gray than the number that can be reproduced. As a result, the blend will have obvious steps and segments.[7] When scanning images, the operator normally has to consider the gray levels that can be captured in conjunction with the scanning device. Consequently, the reproducible levels of gray are determined by the scanning device and by the output device.

Bit depth and levels of gray:

One measure that influences the number of gray levels is the bit depth or dynamic range. The bit depth is the number of bits the scanner uses to represent each sample. Therefore, the higher the bit depth, the more levels of gray the scanner can discern.[8] If a scanner uses one bit per sample, only two levels of gray can be represented — either black or white. With the number of used bits, the possible number of gray levels increase.

1 bit	*2*	2^1
4 bit	*16*	2^4
8 bit	*256*	2^8
24 bit	*16 Million*	2^{24}

Table 2: Possible number of gray levels

Screen frequency and levels of gray:

In addition to the limitations in terms of bit depth, another essential trade off exists between screen frequency and gray levels.[9] The higher the screen frequency, the fewer levels of gray one will get with a given output addressability. Consequently, the two possibilities to work around this obstacle are to either increase the output addressability or decrease the screen fre-

quency. Recalling the fact that the number of gray levels is determined by the number of dots in a halftone cell, one can see the relation between screen frequency and levels of gray. The finer the halftone screen, the fewer number of dots reside in each halftone cell. Resulting from this ratio, fewer levels of gray can be rendered. Referring to the literature, the relationship is described by the following formula:[10]

$$levels\ of\ gray = (output\ addressability/screen\ frequency)^2 + 1$$

Example:

$$gray\ levels = (300\ dpi/100\ lpi)^2 + 1 = 10$$

With this equation, the operator can figure out whether the levels of gray are sufficient to output an image with certain screen ruling and a given output addressability. However, the equation can also be used to calculate the limits of a reproduction system. If a output device can handle 256 levels of gray and 600 dpi addressability, the screen ruling is limited to 38 lpi. One might be surprised by the low screen ruling but the key is that all 256 levels of gray are not always necessary. Often, less levels of gray are absolutely enough to render an image in a sufficient manner. Even more important is a limitation given by PostScript. PostScript can only create 256 levels of gray and ignores everything that extends this number. Even with an output addressability of 2400 dpi, a PostScript device will only render 256 levels of gray.[11] The same is valid in terms of screen frequency. If the screen frequency is reduced to a coarse pattern, the number of achievable gray levels is limited to 256. As a result of this PostScript limitation, the given formula for calculating the relationship between screen frequency and levels of gray can be modified to:[12]

$$256 = 16^2$$

With 256 = maximum number of levels of gray which can be represented by PostScript

and 16 = maximum value of the ratio of addressability/screen ruling

Resolution:

When scanning images, one should take a thorough look at both optical and image resolution. Optical resolution, which is the number of samples per inch that the scanner can discern, is restricted to the capabilities of the image capturing device and its CCD array. On the other hand, image resolution which can be modified by scaling and resampling of the

scanned image, can be manipulated once the image is scanned.[13] One possibility is to scale the image. If an image with the size of 2" x 2" is sampled with 100 spi and afterwards reduced by 50%, the image resolution will equal 200 spi because the same amount of samples is packed into half the space. By enlarging an image, one can achieve the opposite effect.

The other possibility is resampling the image by applying special algorithms to the image. Again, one can modify the resolution in both directions. The quality of the downsampling or interpolation process depends on the the algorithm (for example, "nearest neighbor" function, "bilinear" or "bicubic" algorithms). Regardless of the chosen method, the important question is how one achieves the "right resolution". Because the chosen resolution has an influence on the file size, it is recommended to avoid unnecessary high resolutions. As a rule of thumb one should know that the image resolution should not be more than two times the output frequency. Any higher resolution would be a waste of information. This rule of thumb, based on the "Nyquist Criterion" states that a scanning ratio of 2:1 would provide the best results. Research has shown — contrary to the Nyquist Criterion — that scanning ratios depend upon the original and the screen ruling used. Therefore, other scanning ratios might be sufficient.[14]

File size:

As already pointed out, the chosen image resolution has a large impact on the file size. But so has the bit depth. In general, the more information used to represent the original, the larger the file becomes. In regards to process stability and speed, file size becomes a significant value. Large files are not only difficult to store and transfer, but also difficult to manipulate and to output. That leads to recommendations such as one should always use the most powerful computer with the largest random access memory (RAM) and hard drive if one wants to work with images. Using the following equation, one can estimate the expected file size: File size = ((resolution * width * height * bits per sample)/8192) with 8192 is the number of bits in a kilobyte.

Considering file size, one should also notice that different file formats result in varying file sizes. For example, a tagged image file format (TIFF) of an image will carry a different size as compared to encapsulated PostScript (EPS) file of the same image. In addition to the pre-

vious topics, it is essential for achieving proper reproduction to focus on functions such as unsharp masking and tone reproduction. Various concepts for both functions exist. Either unsharp masking is applied on the fly while the original is scanned or it is applied later to the already scanned image with a specific image manipulation software. Some scanning software offers a sharpness option that allows adjustments prior to the scanning process. In terms of tone reproduction, one can rely upon similar possibilities. Some applications offer adjustments for highlight, midtone and shadow placement due to given specifications, whereas other concepts are based on corrections within image manipulation programs such as *Adobe's Photoshop*.

However, from an economical point of view, it is most desirable to reduce any image manipulation between image capture and output to a minimum. A high degree of automation at this process step speeds up the reproduction process and prevents subjective adjustments by the operator in addition to saving costs.

Endnotes for Chapter 3

1. Caren Eliezer, *Indigos E-Print: New Generation of Offset Color Printing* (Media, Pennsylvania: Seybold Publications Division, 1993)
2. Frank Cost, *Using Photo CD for Desktop Prepress* (Rochester: R. I. T. Research Corporation, 1993)
3. Christopher Hahn, *The wide Range of Flatbeds* (Rochester: Rochester Institute of Technology, 1995), 2
4. Professor Lothar Pauckner, *Reproduktionstechnik Teil I & II* (Munich: Fachhochschule München, 1991)
5. David Blatner and Steve Roth, *Real World Scanning and Halftones – the definitive guide to scanning and halftones from the Desktop*, (Berkley: Peachpit Press, 1993), 106
6. Ibid., 16
7. Ibid., 65
8. Ibid., 121
9. Peter and Anton Kammermeier, *Scanning and Printing* (Oxford: Butterworth-Heinemann, 1992), 71
10. Ibid., 72
11. David Blatner and Steve Roth, *Real World Scanning and Halftones – the definitive guide to scanning and halftones from the Desktop*, (Berkley: Peachpit Press, 1993), 19
12. Ibid., 20
13. Ibid., 142
14. J. Michael Beaulieu, *Scanning Ratios for Desktop Images*, (Rochester: Rochester Institute of Technology, 1993

CHAPTER 4. STATEMENT OF THE PROJECT GOAL

This thesis project is based on three steps. First, the involved digital printing process is evaluated as a prerequisite to any further investigation. For that purpose, the print characteristic of the Docutech will be determined. Secondly, following the evaluation of the printing process, the output qualities of the Docutech are determined during an experimental test phase. Within this test stage, the required raw data is gathered for the final process step. Based on the material gained during the experiments, a statistical analysis and a conclusion will sum up the project's results.

Although the project goal can be defined in a single sentence, it has several aspects which shows the complexity of the given task. It is the purpose of this master's thesis project to determine guidelines for achieving optimal black and white reproductions by using a digital printing device. These guidelines sum up the results of various tests and should include recommendations in terms of:

screen ruling
scanning resolution
tone reproduction
file format
image capturing units

With regard to these issues, the project investigates the following theories:

THEORY 1:

There will be an optimum combination of screen ruling, pleasing reproduction and image resolution.

Referring to the literature review, one should keep in mind that there exists a trade off among screen ruling, image resolution and possible levels of gray. Due to its technology, the Docutech has limitations in terms of possible gray levels and achievable screen ruling. One might be able to reproduce images with 150 lpi screen ruling, but will have to sacrifice the amount of gray levels. Opposite to that, one might be able to reproduce images with the complete range of possible gray levels but will have to choose a coarse screen ruling. Therefore, it can be expected that an optimum combination might lay in between both extremes.

THEORY 2:

There may be better output results achievable with an external scanner than with the attached Xerox scanner.

A large section of the literature review was devoted to scanning and scanning devices. One of the conclusions was that there are differences in quality among several desktop scanners. One scanner might enhance the reproduction because of its capability to cover a wider density range. Another reason for an improved output might be an advanced scanning software. Considering the easy-to-use and straightforward scanning technology of the Docutech's attached scanning unit, one can assume that the output will be improved by using an external image capturing system. In other words, the process of capturing images with a sophisticated desktop scanner, saving these images in PostScript format, and then processing the files on the Docutech will lead to better output than scanning and processing the images with the attached scanning device. Although not a criteria for quality but for profitability, time plays an important role in choosing the process.

THEORY 3:

The quality of the reproduction depends upon the original's tone distribution and tonal range.

As a result of the rendering capabilities of the Docutech, it can be assumed that normal key images with a limited, evenly distributed tonal range lead to the most pleasing reproductions. Considering the restrictions of the reproduction process, one will agree that it is most likely that images with strong contrast will not be reproduced properly. Examples can be found in Frank Romano's book *On-Demand Printing* which was printed on a Docutech. The problems one will face are either blown out highlights or a lack of shadow detail.

Whether or not and — equally important — to what extent these assumptions can be proven will be discussed in the analysis of the experimental section of this project.

Chapter 5. Methodology

It is the purpose of this section to describe how the project goals, as described in the previous section, can be achieved. The detailed description of the involved procedures is based on the three major sections that carry the project.

Evaluating the printing process

Testing the output quality due to varying scanning devices

Statistical analysis of the samples

5.1 Evaluation of the printing process

As to the prerequisite of evaluation, the characterization of the process requires stable printing conditions. That means first, when using inks for printing only standardized inks should be used. With regard to the Docutech's printing concept, this task can be fulfilled. The Docutech uses a specific toner and the printing toner can be kept stable. In addition to standard inks, only one sort of substrate should be used to fingerprint the printing process. By limiting the available substrates to one or two kinds of paper, one is able to exclude variations due to changing substrates. Usually, characterizing a printing process also requires a standardized prepress process. Materials and the chemicals, especially, have to be maintained within their given tolerances. If these prerequisites are not taken care of, one cannot define whether a certain amount of dot gain, for example, is caused by the printing process or by variations of the development process. However, due to its unique workflow, the Docutech does not face those problems. Xerox's digital printing technology does not use film or plate material and therefore does not have to consider issues such as exposure, developing time, temperature of the development chemicals or plate material. Summing it up, one must remember that the evaluation of the printing process is based on stable printing conditions.

Stabilizing the printing process is as important as defining the key points within the evaluation. The Docutech is a black-and-white digital output device with an output addressability of 600 dpi. Consequently, variables such as screen angles, printing sequence, misregistration, process colors, exposure time and the platemaking process have no impact on the final output. The major issues are compiled in the following matrix:

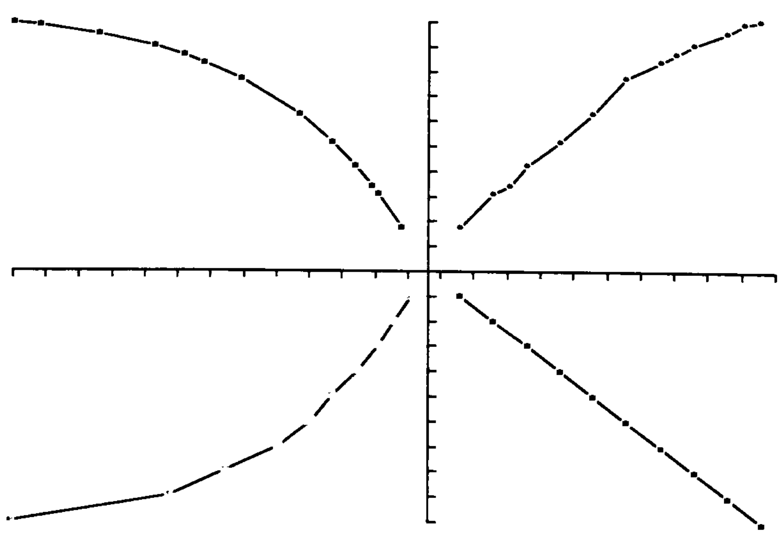
Variables :	Reason for interest:
Solid ink densities	Important for determining the amount of dot gain and the print contrast
Resolution	Essential for rendering details
Screen ruling	Important because of its impact on the resolution and the output quality
Tonal range	Essential for tonal range and tone compression

Table 3: Evaluating the Printing Process

The final goal of the evaluation is to define requirements for the reproduction process. Considering the plot of a Jones diagram, one will understand the importance of a press curve.

If the tone reproduction of an original is defined, the print characteristic will define how the reproduction curve has to look in order to achieve the required tone reproduction. However, the system is based on two assumptions. The required tone reproduction curve is given by the original. If one does not know whether or not the shadow contrast should be emphasized, one cannot compensate for it during the reproduction process. Therefore, the desired output should first be defined. Secondly, the print characteristic requires stabilization of the whole printing process. This includes a calibrated environment, stable printing inks and standard paper. After these two parts of the diagram are stabilized, it is possible to evaluate the missing reproduction curve by connecting the appropriate lines on the Cartesian coordinates to generate the necessary information for the desired output.[1]

Figure 2: Jones Diagram, Preview



The first part of the evaluation process is to establish a starting point with a set of adjustments that is kept constant for the following tests. However, it is imperative that the chosen output parameter represent reproducible, standard printing conditions. If the printing process has already been pushed to its limits to achieve the final product, one cannot assume stable, standard conditions. Those requirements were achieved by adjusting the Docutech to settings that are used to process the vast majority of jobs on the Docutech with satisfying results.

The second step of the evaluation process is to reproduce a piece of artwork with known values by using the determined standard settings. For this purpose, the Graphic Arts Technical Foundation (GATF) test form was used (Appendix A). Utilizing this test form combines several advantages. One of the major advantages is that the GATF test form provides numerous kinds of patches, test targets and images with known values. Therefore, the output can easily be compared to the original values. Another advantage is that the GATF test form is available in digital form. Thus, it can be processed directly by the Docutech without any intermediate process steps. As a result, one does not have to consider any influences due to image capturing. Because the test form does not have to be scanned, it is not exposed to the various parameters that determine the quality of the captured image.

For the evaluation of the Docutech's print characteristic within this project the GATF digital test form was extended by a second page (Appendix B). The second page of the test form consists of three test targets which were specially designed to evaluate digital output devices. The purpose of their use is to confirm the results that were gained with the GATF digital test form and to enhance the understanding of the process with additional data. After creating the digital test form in its final two page version, the file was stored in PostScript format, transferred to the Docutech's Media server processed by the Docutech's RIP and printed. The test form was printed on the most commonly used paper stock (Hammermill,Tidal DP 75 g/m^2 , 8,5 x 11 inches) with three inking levels: light, standard and dark. By varying the amount of toner, one should be able to analyze the impact of toner film thickness on the tonal range and dot gain. The gathered press sheets were evaluated by applying densitometry and visually. For all densitometric measurements a X-Rite, Status T, reflection densitometer was used.

The amount of dot gain was determined by measuring the densities of solid ink/toner and tint patches. Due to the fact that dot gain is not a linear function but varies over the range of tonal values, the dot gain was calculated for 10%, 25%, 50% and 75% tone value. By applying the Murray Davies equation, one is able to calculate the printed tonal value.

$$\text{Dot gain} = \text{tone value of the original} - (1 - 10^{-D_{tint}} / 1 - 10^{-D_{solid}})$$

Murray Davies, however, does not compensate for optical dot gain. Consequently, the dot gain calculated by Murray Davies includes optical and mechanical dot gain.[2] Although other formula such as the Yule-Nielsen equation compensate for the effects of optical dot gain, the Murray Davies equation was used with regard to the non-impact character of the printing process. It is a matter of fact that mechanical dot gain which is caused by pressure and surface contact, cannot be considered as a major cause for dot gain within a non-impact printing process. Compared to the "film dot area" of the GATF test form, the computed tone values lead to the amount of dot gain. The relationship between tonal value of the GATF test form and the printed values is plotted into a graph. Moreover, this dot gain evaluation was performed for varying screen rulings. Referring to the fact that the amount of dot gain increases with an increase in screen ruling the tint-patch/screen ruling matrix of the GATF test form was measured to describe this relation for the Docutech. The relation between screen ruling and dot gain was visualized in another graph.[3]

To ensure a reasonable analysis not only one sample sheet was measured but moreover a whole series of ten sheets. The average of the gathered values was used for further investigations. As mentioned before, the press run was performed with three toner levels. Therefore, the densitometric measurements, the dot gain calculations and the plot of the related graphs were performed for all three toner levels.

Furthermore, the test targets of the GATF test form and especially the test targets on the second page can be used to evaluate the resolution capabilities of the process. The ability of the Docutech to render fine detail can be analyzed with the microline and checkerboard patches of one of the test targets. Comparable to dot gain, resolution also depends upon the screen ruling used. As a rule of thumb, one can expect that fine screen rulings support the rendering of fine detail, thus enhance the resolution.

However, the evaluation of the microline and checkerboard patches was performed visually. The same applies to the analysis of the smallest possible point size that can be printed as a positive or negative text. Another very important value that was determined visually was the lightest tone value that was printed without drop outs and the darkest tone value that was reproduced without filling in.

All visual evaluations took place under the same viewing conditions and were carried out with a standard magnifier. Similar to the densitometric measurements, the visual analysis were done for the three toner levels separately and compiled in a table. By using multiple targets with similar patches, it was possible to confirm and cross check the findings to each other.

Summary: A step by step description of the evaluation of the printing process

- *Creating the necessary test form and saving it as a PostScript file.*
- *Printing the test form on the Docutech with the three toner level: light, standard and dark.*
- *Measuring the 10%, 25%, 50% and 75% tint patches for 85 - 175 lines per inch screen ruling together with the solid ink patch (also for the three toner level).*
- *Visual analysis of the microline patches, the checkerboard patches, the text/point size box, the lightest and darkest tone value.*

5.2 Testing the output quality

Part of the GATF test form is a grayscale which gives insight into the tonal range that can be reproduced by with a Docutech. Important values for highlight and shadow placement are the lightest and darkest printable tone values. Repeatable means not the absolute achievable limits but the values that can be achieved under standardized conditions and maintained throughout the press run. It might be possible, for instance, to print a 1% dot, but one might not be able to keep the 1% dot stable over the whole run length. The GATF test form provides patches with small highlight and shadow dots. These patches were visually evaluated to figure out which tone value is reproduced consistently by the printing process. As to the results of this evaluation, one can refer to section 6.1 which gives an in-depth description of the print parameters.

Last, but not least, the placement of the midtone should be determined. Reproducing images with varying keyness, one should adjust the midtone placement to the image to achieve the most pleasing output. Whether or not this assumption proves to be true was determined by choosing two images: a normal key image that provided an even distribution of gray levels over the whole tonal range and a dark, low key image that carries huge parts of the image information in the shadows. According to the reproduction theory, both images should require unique reproduction settings which differ from each other.

The information gathered during the previous section are the prerequisites to successfully evaluating the performance of several image capturing devices. By setting a standard, one has a scale to refer to and can separate the influences that are due to the image manipulation software from the influences that are caused by the scanning device. It is the intension of this project to cover a representative overview of image capturing devices. Within this investigation, one normal key image will be scanned at at least four scanning devices. All scanners mentioned are available at the School of Printing Management and Sciences.

Crosfield Magnascan	*highend drum scanner*	*PMT technology*
Optronics ColorGetter	*midrange drum scanner*	*PMT technology*
AGFA Horizon	*flatbed Scanner*	*CCD technology*
AGFA Studio Scan	*flatbed Scanner*	*CCD technology*

The list of tested scanners can be extended. Regardless of the kind of scanner and the number of tested devices, the test procedures stay unaltered.

As already stated, a test image with normal keyness and a low key image were chosen: "people", normal key image and "drops", low key image. The image was either mounted on a drum or placed on the flatbed scanner. Following the specifications for the printing process, the correct settings were entered either directly or via an attached scanning software. This process step involves placing the highlight and shadows, adjusting the highlight to midtone range and entering the appropriate screen ruling.

Other adjustments such as unsharp masking and setting the reproduction size were not performed at this stage of the experiment. The reproduction size was kept at 100% throughout this experiment. Scanning the same image with the same reproduction guidelines on various scanners and finally outputting the images at the Docutech under stable printing con-

ditions, it was possible to assign differences in the image quality due to the scanning devices and the software used. It cannot be overemphasized that at this point of the project all process components remained stable for all tested scanners. Therefore, all images were stored in the identical file format (TIFF).

As pointed out, it is the purpose of this project to improve the output quality of a Docutech. With regard to the output quality, the process of scanning images offers a variety of adjustments. To reach the given objective, three scanning parameters were selected and manipulated, while the impact of those modifications was closely monitored. Referring to chapter three of this project, one has seen that file format, screen ruling, sampling rate and image resolution have a major impact on the output quality. Hereby the relationship between output process and scanning becomes evident. If an image requires the full amount of gray levels, the screen ruling should be decreased. Assuming one would like to output an image with 64 levels of gray using the Docutech's 600 dpi output addressability, one will need a 75 lpi screen ruling. Consequently, following a rule of thumb a sampling rate of 150 spi should be absolutely sufficient.[4] Higher sampling rates would be a waste of information.

The parameters of choice were the sampling rate of the scanner, the applied amount of sharpness and the tone reproduction by varying the midtone placement.

Although there are various other scanning parameters, the three mentioned above are considered as the most influential ones. The sampling rate of the scanner is often described in output screen ruling such as 85 lpi or 133 lpi. It is a matter of convenience. By characterizing the sample rate of the scanner with the output screen ruling, the operator does not have to calculate whether or not the sampling rate is sufficient for the output. However, the scanning ratio should be set in the preference settings with regard to the demands of the user. The importance of the sampling rate is based on the amount of image information that is gathered by the scanner. To reproduce a high resolution image with a fine screen ruling, one needs more image information of the original compared to the requirements of lower resolutions and coarser screen patterns. Consequently, the distinguishing factor among scans with varying sample rates is the amount of image information that is recorded by the scanner. By manipulating the sample rate of the scan, one can evaluate whether a higher sample rate leads to improved image quality or just to a waste of information which does not result in a perceived quality difference.

In addition to the sampling rate, the sharpness of the image is an important quality aspect. Applying more or less sharpness, one is able to enhance specific parts of an image. Contrasts can be emphasized, image details are rendered more precise and the overall output quality can be increased significantly. However, images have to be sharpened carefully because to much sharpness can turn the results into the opposite.

The third scanning parameter accounts for the different kinds of originals. While highlight and shadow placement have an impact on the image's lightness or tone compression in general, the midtone placement increases or decreases the highlight or shadow contrast. A low key image which carries its image information in the shadows should be reproduced by emphasizing the shadow contrast. The resulting decrease in highlight contrast can be tolerated due to the distribution of the image information content. By narrowing down or widen the highlight to midtone range the effects described above can be achieved. It is understandable that the midtone placement compensates most effectively for the unique qualities of various originals. With regard to the flexibility that the control of this scanning parameter provides, it becomes evident why this parameter was chosen.

At this stage of the experiment, the mentioned parameters were selected one by one and modified while the others stayed unaltered. Thus, the effects on the output quality can be evaluated. It is self explanatory that the rendering parameters of the Docutech were not changed.

After choosing the scanning parameters both originals were scanned with the four different scanning devices and — as a reference — with the scanner that is attached to the Docutech. However, the Docutech scanner does not provide the operator with the possibility to perform various adjustments which can be made with the other scanning devices or by utilizing the image manipulation software. Starting point were the scanner's default settings, to ensure comparability.

Agfa Horizon	Scanner settings	
Mode	Gray Scale	
Original	Reflective	
Output	100 lpi	
Scale	100%	
Range	Automatic	
Tone Curve	None	
Descreen	None	
Sharpness	None	
Preferences	Gray Scale	min = 10%, max = 90%

Crosfield	Scanner settings		Magnascan & Maganlink 600 V2.1
Mode	Reflection		
Scale	100%		
Sample Rate	304 dpi	ratio 1.5	
Gray Scale	Default settings		
Saved as	Tiff		
Scanning	to 304 dpi	downsampling in Photoshop for 85 - 133 lpi	

Optronics	Scanner settings	
Mode	Gray Scale	
Original	Reflective	
Highlight	0.1	
Shadow	1.28	
Scale	100%	ratio 1.5
Aperture	200 µm, # 2	
Papertype	unknown	
Sharpen	off	

Studio Scan	Scanner settings	
Mode	Gray Scale	
Original	Reflective	
Output	100 lpi	
Scale	100%	
Range	automatic	
Tone curve	none	
Descreen	none	
Sharpness	none	
Preferences	Gray Scale	min = 10%, max = 90%

Table 4: Scanner Settings

Once the images were scanned with default settings, the process was repeated by varying the sampling rate from 85 lpi output, over 100 lpi and 133 lpi to 150 lpi output. The results of the press evaluation the images with an output screen ruling of 100 lpi were used to apply three levels of sharpness with the sharpness tools of the image manipulation software *Adobe Photoshop.* Within Photoshop the three functions "Sharpen", "Sharpen More" and "Unsharp Masking" were utilized to manipulate the scanned images. As to the function "Unsharp Masking", the user can customize another set of three values. For all images that were modified with the "Unsharp Masking" function, those settings were kept stable with:

amount	*180%*
radius	*1*
Pixel	*5*

Table 5: Settings for Unsharp Masking

Functioning as a common denominator, the same images that were used to apply varying levels of sharpness were the source for the midtone adjustments. The changes of the tone reproduction curve were also conducted utilizing *Adobe Photoshop.* Considering the effect of midtone placement on the appearance of the final output, the midtone range was narrowed to increase the highlight contrast as well as widened to enhance the shadow contrast.

Image testing matrix (the matrix is valid for both images, people and drops)

	Agfa Horizon	Crosfield	Optronics	Studio Scan
85 lpi	A 1	B 1	C 1	D 1
100 lpi	A 2	B 2	C 2	D 2
133 lpi	A 3	B 3	C 3	D 3
150 lpi	A 4	B 4	C 4	D 4
Sharp	A 5	B 5	C 5	D 5
More Sharp	A 6	B 6	C 6	D 6
Unsharp	A 7	B 7	C 7	D 7
low midtone	A 8	B 8	C 8	D 8
high midtone	A 9	B 9	C 9	D 9

Table 6: Image Test Matrix

The altered images were assembled in the page layout program QuarkXpress and saved as Level 1 compatible PostScript files with all fonts included. Those pure PostScript test forms were transferred to the Docutech's Media server. Originating from the Media server the files were prepared for output on the Docutech by the RIP that not only translates the PostScript

code but also converts it into Xerox's proprietary Interpress page description language. The last process step was the output of the test forms with regard to the defined, standard printing conditions. Although it is not an issue for the given objective of this project, it should be mentioned that the described workflow is very time consuming. While the actual printing process only takes a couple of minutes, the network transfer and the process of ripping can take up to 40 - 45 minutes. The source of these problems are the large PostScript files. With all images and fonts embedded a single test form can grow to 10 MB. However, only PostScript can be transferred from a Macintosh based page layout program via a DOS based Media server to the Docutech which is operated by Xerox's Interpress page description language. Due to those limitations and the problems related to data storage, the press run was divided into two sections. Overall twelve test forms had been printed:

Number	Image	Scanner
1	people	Horizon/Crosfield sampling rate ranging from 85 - 150 lpi
2	people	Horizon/Crosfield sharpness variation
3	people	Horizon/Crosfield midtone adjustments
4	drops	Horizon/Crosfield sampling rate ranging from 85 - 150 lpi
5	drops	Horizon/Crosfield sharpness variation
6	drops	Horizon/Crosfield midtone adjustments
7	people	Optronics/Studio Scan sampling rate ranging from 85 - 150 lpi
8	people	Optronics/Studio Scan sharpness variation
9	people	Optronics/Studio Scan midtone adjustments
10	drops	Optronics/Studio Scan sampling rate ranging from 85 - 150 lpi
11	drops	Optronics/Studio Scan sharpness variation
12	drops	Optronics/Studio Scan midtone adjustments

Table 7: Table of Test forms

5.3 Evaluation of the samples

The evaluation of the printed images was one of the most important steps during the testing. All tests were be accompanied by permanent visual and densitometric analysis of the results. While the densitometric measurements were made to ensure process stability and to guarantee that the images were output within the specifications, the visual evaluation determines the quality of the output. The method that is applied to achieve an objective evaluation is known as "pair comparison". This method shows the relationship between images which have similar characteristics, but not exactly the same.[5]

Prior to the description of this method, two important points should be mentioned. All image comparisons were made under standard viewing conditions. Standard viewing conditions include a stable light source, an unaltered viewing environment and a defined and maintained viewing distance. As a reference for standard viewing conditions, one can refer to the specifications given by the SWOP specifications. SWOP defines ANSI PH 2.30 - 1989 as the standard for viewing conditions.[6] The viewing booth which is available at R.I.T fullfils the requirements of 5000 Kelvins and stable viewing conditions. Therefore, all visual evaluations were conducted by utilizing the R.I.T. viewing booth.

Secondly, the observers were students of the printing department. Not only is this audience available for the evaluation, but those observers are critical, well trained printing experts who have the necessary background knowledge for the evaluation of printed products. Moreover, it is assumed that an untrained observer would not be able to detect a difference between two images if a printing expert does not see any quality difference.

Bartelson states that the number of comparisons needs to be defined by the formula:[7]

$$N = n*(n-1)$$

with N = total number of comparisons

n = number of samples to be compared

To keep the number of comparisons N as small as possible, one should eliminate redundant pairs and thus the time for testing is decreased.

$$N = n*(n-1)/2$$

However, the number of comparisons should not be decreased too much, otherwise one will lack the necessary information to make a clear statement about the image quality. Sometimes, the number of comparisons can be decreased by excluding pairs of images which will be judged unanimously in one way or the other.[8]

To perform a reasonable pair comparison those prerequisites were taken under consideration. Given the number of tested devices, the number of performed adjustments and the fact that two images were processed, one ends up with an image matrix such as the one outlined in the previous section. This image matrix leads to 36 different versions of one image. Even with eliminating redundant pairs, the pair comparison would consist of 630 pairs (Following the formula $N = n(n - 1)/2$). It is obvious that a pair comparison for two images with 1260 pairs is not conductible for 10 to 15 observers. Another approach would have been a simplified version which would have resulted in 154 pairs for each of the two images. This attempt uses 36 pairs to determine the best possible reproduction for each scanning device used and is therefore multiplied by four. The final four images are compared to each other and to the reference Docutech scan, causing an additional 10 comparisons. Although the number of comparisons can be reduced significantly, it is not practical to confront an observer with 308 comparisons (154 pairs for each of the two images). Furthermore, the point of interest is the quality difference caused by various scanning devices. Therefore, emphasis was placed on the comparison among the image capturing devices.

As a consequence, a preselection was made to focus on the key issue. For each scanning device, the best possible reproduction was chosen and the pair comparison was conducted with 10 pairs for each image. The following table shows the chosen images and their encryption for the visual evaluation by the observers.

Code	Image	Scanner
A1	people	Docutech
A2	drops	Docutech
B1	people	Horizon 100 lpi, midtone adjustment (dot gain compensation)
B2	drops	Horizon 100 lpi, sharpness
C1	people	Crosfield 100 lpi, midtone adjustment (dot gain compensation)
C2	drops	Crosfield 100 lpi, sharpness

D1	people	Optronics 100 lpi, midtone adjustment (dot gain compensation)
D2	drops	Optronics 100 lpi, sharpness
E1	people	Studio Scan 100 lpi, midtone adjustment (dot gain compensation)
E2	drops	Studio Scan 100 lpi, sharpness

Table 8: Encryption Table for Pair Comparison

Within the comparison, it is essential that the observer has no in-sight into the performed image manipulations, their encryption and the randomization of the way the pairs are presented. To achieve these requirements all images were cut to the same format and were presented without any tags, visible codes or descriptions. Prior to the pair comparison, the comparison matrix was created and the order of the presentation of the pairs was randomized. Once randomized, each observer was exposed to the same order of pairs. During the evaluation of the images, the observer decisions as to which image of a given pair shows a better reproduction. The answers were recorded in a table which will be analyzed by statistical means at the end of the testing .

Summing up the previous paragraphs, the image evaluation took place in the following way:

1. *A preselection of the printed results was made.*
2. *The images were prepared for the comparison. That included cutting the images to the same format, determining the number of comparison, randomizing the order of the presentation and designing an evaluation sheet*
3. *The observers were instructed about the proceedings of the test and that they have to evaluate the overall image quality by choosing one of the shown images.*
4. *The pairs to compare were presented. Hereby, labels to identify the images were not visible. Moreover, the observer has no insight into the order in which the images are presented.*
5. *The choices of the observers were recorded on the evaluation sheet.*

After a number of observers (10 - 15) had analyzed the images, the data was collected in a table and a statistical analysis was carried out.

This statistical evaluation consisted of collecting the answers of the observers in a frequency matrix, transforming the frequency matrix into a proportion matrix and converting the proportion matrix into z- or interval scores. It is the purpose of the frequency matrix to provide information about how often a particular image was preferred over another one. In addition, the frequency matrix is used to determine whether or not the results follow a normal distribution. The frequency matrix results out the total number of responses for each combination. Derived from the frequency matrix by dividing the frequencies by the total number of observers, the proportion matrix assigns percentages to the values found in the frequency matrix. The z-scores are evaluated by utilizing the values of the proportion matrix. Providing the operator with an internal ranking based on the proportions, the averages of the z-scores are often referred to as interval scale values. To derive the appropriate z-score, one can use a look up table such as the one in Donald H. Sanders' *Statistics: a first course.* The z-scores as seen in this project were calculated:[9]

1. by subtracting 0.5 from the value of the proportion matrix

2. by looking for the closest value within the look up table that corresponds to the result of the subtraction

3. by evaluating the z-score as the sum of the two z-score coordinates which determine the location of the corresponding value within the look up table.

By calculating z-scores, one is able to determine whether or not the mathematical analysis confirms the visual perception of the observers. The initial ranking which is based on the frequency matrix might be inaccurate or might not represent the quality differences properly. To verify the results, one can apply statistical means in the form of z-scores.

Thus, an additional point has to be added to the step by step description of the pair comparison test:

> *6. The observer sheets were analyzed and the gathered data transformed into a frequency matrix, a proportion matrix and into z-scores. While the frequency matrix defines how often an image was preferred over another one, the proportion matrix assigns percentages to the values found in the frequency matrix. Furthermore, the z-scores provide an internal ranking scale.*

Endnotes for Chapter 5

1. Gary G. Field, *Color and its Reproduction* (Pittsburgh: GATF, 1988)
2. Professor Franz Sigg, *Tone and Color Analysis* (Rochester: Rochester Institute of Technology, 1995)
3. Ibid.
4. David Blatner and Steve Roth, *Real World Scanning and Halftones – the definitive guide to scanning and halftones from the Desktop*, (Berkley: Peachpit Press, 1993), 150
5. J. Michael Beaulieu, *Scanning Ratios for Desktop images* (Rochester: Rochester Institute of Technology, 1993)
6. SWOP, *Specifications Web Offset Publications* (New York: SWOP, 1993)
7. James C. Bartelson, *Optical Radiation Measurements,* vol. 5, *Visual Measurements* (Orlando: Academic Press, 1984)
8. Ibid.
9. Sanders Donald H., *Statistics: a first course* (New York: Mac Graw Hill, 1995) A-10

Chapter 6. Results and Findings

This section focuses on a critical analysis of the gathered information. It is equally important to evaluate the data which originates from an experiment as it is to design and to perform an experiment.

6.1 Evaluation of The Printing Process

As described in section 5.1. the press run on the Docutech was designed to provide all necessary information to characterize the printing process and to distill some core reproduction requirements.

The densitometric analysis of the press sheets leads to an interesting insight into the printing process. Among the three toner levels, one discovers no dramatic difference in solid toner density. While the lowest toner level results in a solid ink density of 1.23, the standard toner level creates a solid ink density of 1.27 and the highest toner level gives a solid ink density of 1.29.

In terms of dot gain, however the amount of toner as well as the chosen screen ruling have a major impact. While the lightest toner level resulted in an average dot gain of 10%, the standard toner level causes 20% dot gain. The darkest toner level leads to even higher values of approximately 30% dot gain.

Dot gain, standard toner level

% Original	Dot Gain 85 lpi	Dot Gain 133 lpi	Dot Gain 150 lpi	Dot Gain 175 lpi
10	9.78	7.78	7.78	1.49
25	15.52	17	18.45	9.23
50	20.68	22.26	23.76	23.76
75	12.73	16.74	16.74	18.82

Dot gain, light toner level

% Original	Dot Gain 85 lpi	Dot Gain 133 lpi	Dot Gain 150 lpi	Dot Gain 175 lpi
10	3.71	-5.22	-2.91	-7.58
25	7.75	-1.22	-1.22	-17.91
50	10.93	7.69	7.69	-3.5
75	9.06	9.06	9.56	7.47

Dot gain, dark toner level

% Original	Dot Gain 85 lpi	Dot Gain 133 lpi	Dot Gain 150 lpi	Dot Gain 175 lpi
10	19.05	22.48	22.48	22.48
25	26.35	35.44	35.44	37.47
50	27.68	34.85	34.37	38.77
75	16.51	21.43	20.79	22.77

Table 9: Dot Gain Evaluation

These results are not surprising. As known from the lithographic process, one can anticipate a higher dot gain with an increase in ink film thickness. Dot gain is a very complex value and depends upon numerous parameters. One of these parameters is the chosen screen ruling. Usually, higher screen ruling results in higher amounts of dot gain. Opposite to the expected results, the dot gain calculations and diagrams for the four screen rulings (85 lpi, 133 lpi, 150 lpi and 175 lpi) indicate an unusual process behavior. Instead of an increase in dot gain with higher screen rulings, one can observe a significant decrease in dot gain. For certain screen ruling/tone value combinations, one faces negative dot gain. Another surprising fact is that there are nearly no differences among the values for the screen ruling of 133 lpi and 150 lpi.

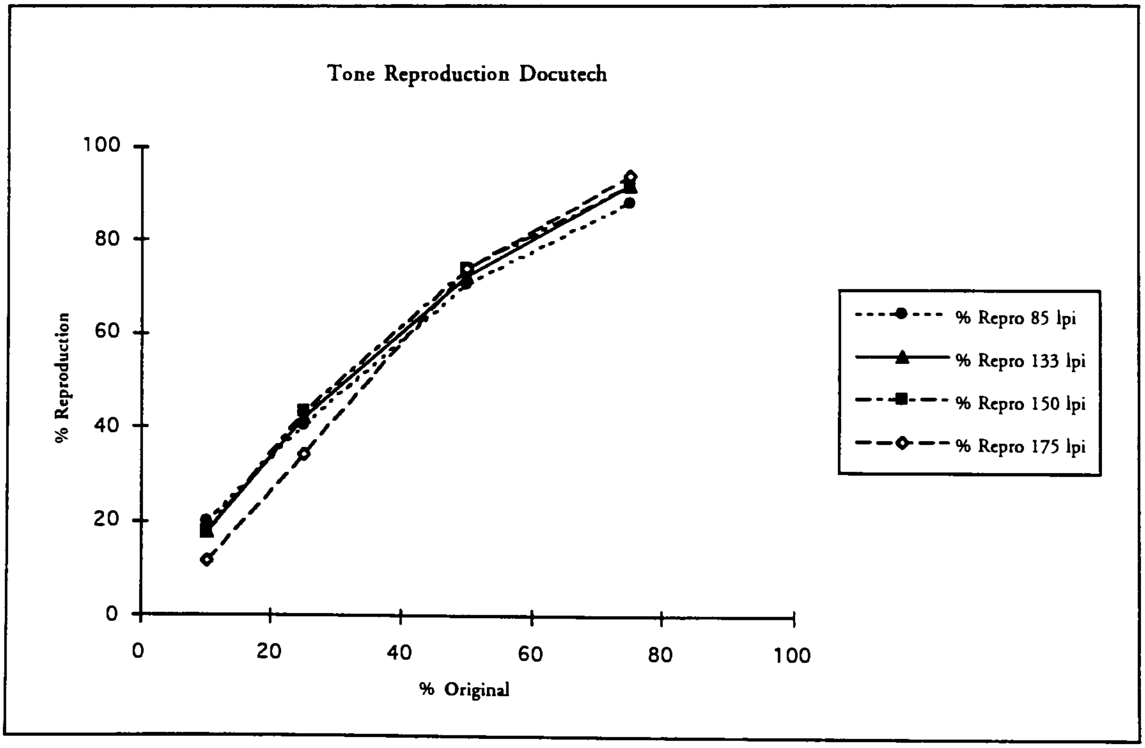


Figure 3: Tone Reproduction of the Xerox Docutech

The reason for those characteristics are the limitations of the printing process. At the lowest inking level the Docutech cannot reproduce tone values under 25%. Instead of a stable dot pattern, one will see randomly distributed toner particles with uncontrolled drop outs. Consequently, the densitometer readings and the related calculations are misleading. These effects can be observed in the graph below. The dot gain curve for 175 lines per inch screen ruling is wrong because of exactly the reasons mentioned before. Due to uncontrolled toner spread and the resulting drop outs the density readings are wrong and should be ignored within the further evaluation. Although a dot gain of 10% would be desirable, the limited range of reproducible tone values at the lowest toner level excludes this setting from any serious reproduction considerations.

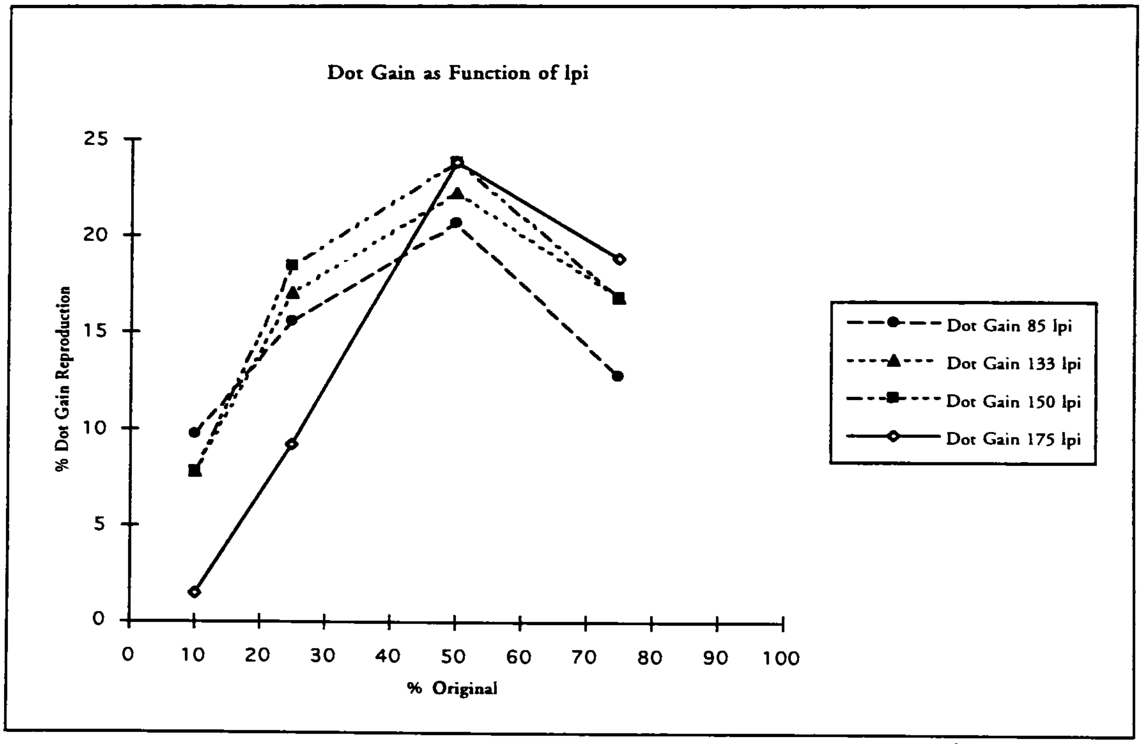


Figure 4: Dot Gain as a Function of Screen Ruling

On the other side of the spectrum, the darkest toner level provides the user with the expected correlation among the various process parameters. With an average dot gain of 30%, the darkest toner level is more affected by the impact of dot gain than the lower toner level. Besides, the amount of dot gain increases steadily with an increase in screen ruling. However, similar to the observations already made for the lowest toner level, one will dis-

cover that the findings for 133 lpi screen ruling are equal to the values of 150 lpi. With regard to the given goal of this project — to enhance the output quality of the Docutech — a dot gain of 30% cannot be tolerated. As a reference, one can refer to the SWOP specifications which recommend a 22% dot gain for a tone value of 50% at 133 lpi screen ruling. The same applies to the tonal range that can be reproduced with the highest toner level. Especially the fact that the darkest tone value that can reproduced is 80% limits the process capabilities to render shadow details adequately.

The standard toner level causes a dot gain of 20% and lays within the range of acceptability. Moreover, the tonal range spans from 10% as the lightest dot that can be printed constantly to 90%. Tone values under 10% or above 90% cannot be rendered properly. While drop outs endanger the representation of highlights at the low end of the range, filling and plugging is responsible for restricting the tonal range to 90%. However, the standard toner level confirms the trend that values for 133 lpi and 150 lpi screen ruling are almost identical.

As already indicated, those identical values are caused by limitations of the printing process. An analysis of the 133 lpi and the 150 lpi patches with a screen ruling indicator and a visual evaluation show that the Docutech reproduces both screen rulings with the same value of approximately 140 lpi. In other words, the Docutech does not distinguish between a screen ruling of 133 lpi and 150 lpi. The same can be observed for the differentiation between 175 lpi and 200 lpi. As a consequence, with de facto the same screen ruling and the same toner level, it is not surprising that the measured and calculated values for 133 lpi and 150 lpi are nearly identically.

But not only the limitations in terms of numbers of gray levels that can be reproduced at a high screen ruling (with a given output addressability) but also an obvious moire pattern forbid the use of fine screen rulings. As one of the results, it can be stated that 133 lines per inch is the highest screen ruling which can be printed reasonably at a Docutech. The optimum screen ruling can be set between 85 lpi and 106 lpi.

All these findings and the results of the visual evaluation of the microline and checkerboard patches are compiled in the following table which can be seen as a reference for the basic reproduction requirements which are valid for Hammermill,Tidal DP 75 g/m², 8,5 x 11 inches, paper stock.

screen ruling	*85 lpi - 106 lpi*
dot gain	*20%*
solid toner	*1.27*
Highlight dot	*10%*
Shadow dot	*90%*
smallest text	*4 point, positive*
smallest text	*4 - 6 point, negative*
microlines	*3µm, positive and negative*

Table 10: Summary of the Reproduction Requirements

Plotting the gathered information into a Jones-Diagram, one can draw a reproduction curve that compensates for the anticipated dot gain.

Densities, GATF Test form

Original %	Density GATF light	Density GATF stand.	Density GATF dark
5			0.08
10		0.08	0.14
20	0.1	0.15	0.23
25	0.11	0.17	0.34
30	0.15	0.22	0.37
40	0.21	0.29	0.42
50	0.3	0.39	0.54
60	0.44	0.57	0.7
70	0.57	0.68	0.84
75	0.63	0.74	0.88
80	0.72	0.83	0.96
90	0.86	1	1.13
95	1.02	1.18	1.26
100	1.21	1.26	1.3

Table 11: Densities measured at GATF Test form

Tone Reproduction, GATF Test form

% Original	% Repro light	% Repro standard	% Repro Dark
5			17.71
0		17.8	29.01
20	21.92	30.9	43.29
25	23.85	34.28	57.16
30	31.12	42.06	60.37
40	40.86	51.55	65.25
50	53.16	62.71	74.91
60	67.88	77.33	84.27
70	77.89	83.71	90.06
75	81.59	86.56	91.4
80	86.26	90.16	93.73
90	91.86	95.23	97.47
95	96.39	98.82	99.49
100	100	100	100

Table 12: Tone Reproducrion Values

Amount of Dot Gain, GATF Test form

% Original	% Dot Gain light	% Dot Gain Standard	% Dot Gain Dark
5			12.71
10		7.8	19.01
20	1.92	10.9	23.29
25	-1.15	9.28	32.16
30	1.12	12.06	30.37
40	0.86	11.55	25.25
50	3.16	12.71	24.91
60	7.88	17.33	24.27
70	7.89	13.71	20.06
75	6.59	11.56	16.4
80	6.26	10.16	13.73
90	1.86	5.23	7.47
95	1.39	3.82	4.49
100	0	0	0

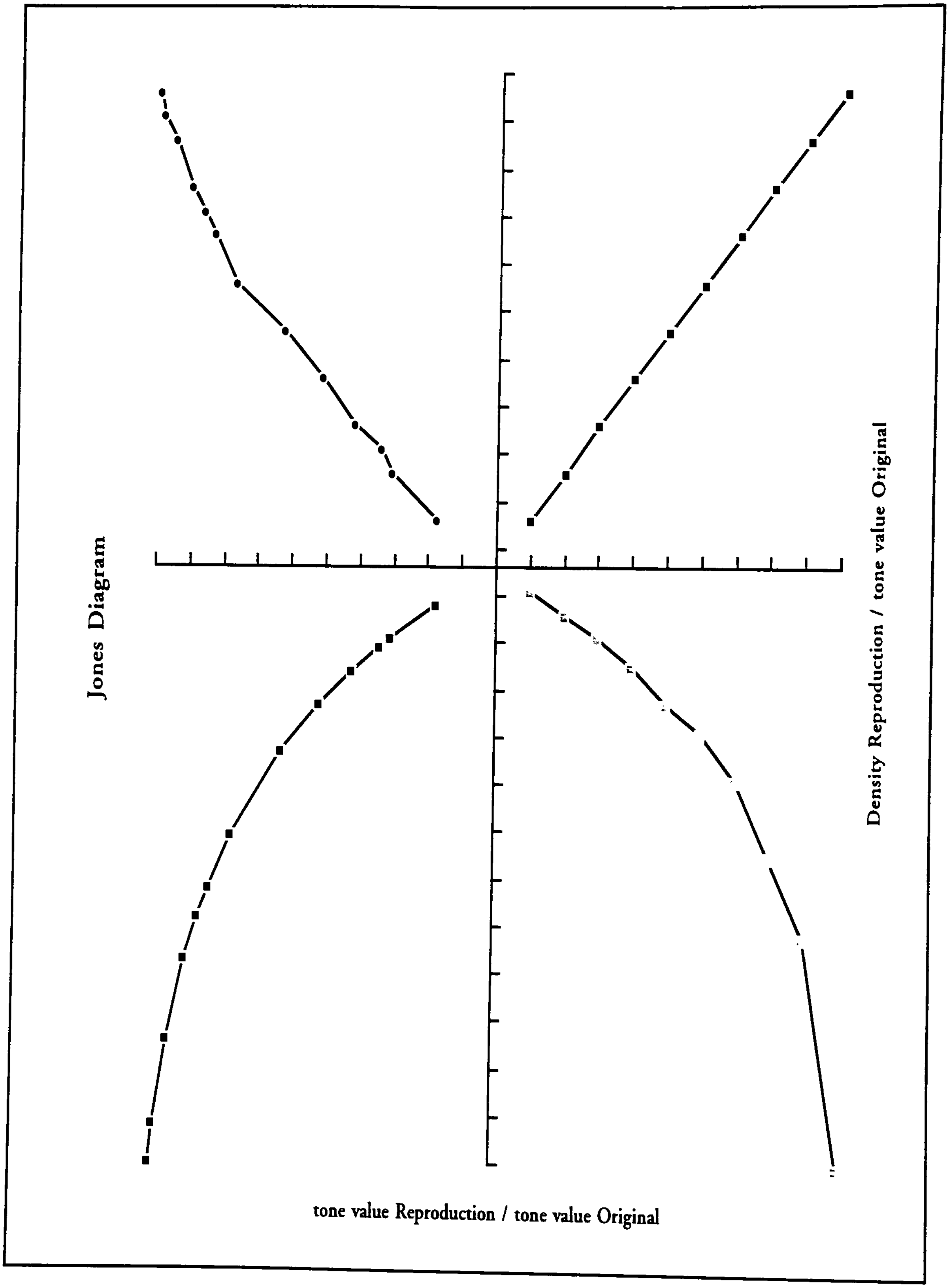
Table 13: Dot Gain Values

Values, evaluated from the Jones Diagram

% Original	Density Reproduction
10	0.05
20	0.1
30	0.15
40	0.21
50	0.29
60	0.35
70	0.45
80	0.61
90	0.78
100	1.26

Table 14: Corrected Tone Reproduction Values

Figure 5: Jones Diagram (next page)


Jones Diagram
Density Reproduction / tone value Original
tone value Reproduction / tone value Original

6.2 Evaluation of the Output Quality

Analyzing the output quality of the Docutech and — moreover — the impact the chosen scanning devices have, one is able to identify trends in the perceived image quality. Compiling the answers of the observer in the frequency matrix and plotting a histogram, one can see two important facts. First, the gathered information follows a normal distribution which is indicated by the bell shapes of the histogram. If the distribution were not normal, any further statistical analysis would be questionable because the applied theories are based on a normally distributed population. Apart from this basic requirement, for the statistical evaluation, it is essential that there is a clearly defined preference in terms of output quality. The graphical representation of the frequency matrix shows that the scans that originate from the Crosfield highend scanner lead without any doubt to the best perceived output. Furthermore, this statement is valid for both images.

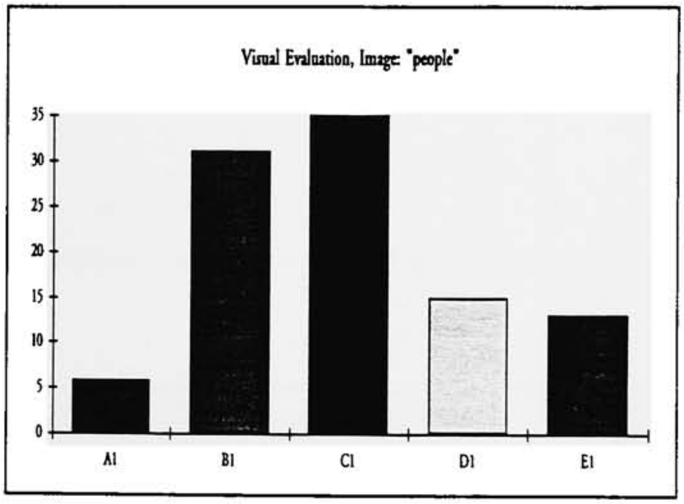


Figure 6: Histogram "people"

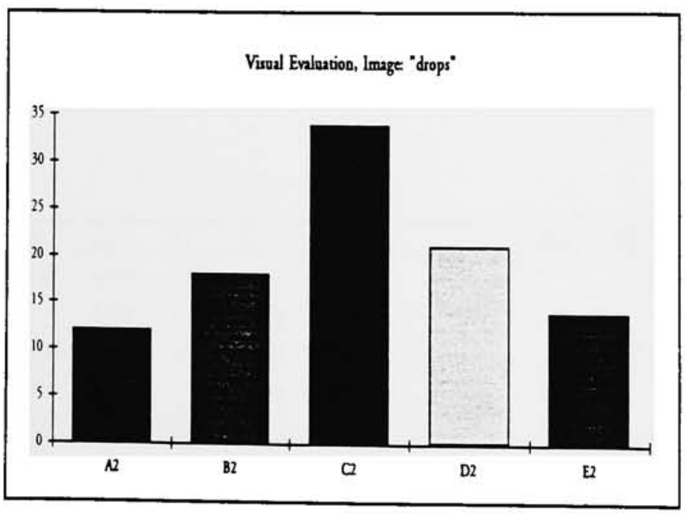


Figure 7: Histogram "drops"

On the other end of the scale, however, the findings are also unequivocal. Although Xerox might claim the opposite, the scanner that is attached to the Docutech delivers the least satisfying prints. Utilizing the histogram for a first rough ranking, one can see that the best image quality is achieved with a highend scanning system that is based on PMT technology. As far as the second rank is concerned, the two tested midrange scanner struggle for a significant quality advantage. While the CCD base AGFA Horizon provides a perceived improvement as it comes to the reproduction of normal key images, the PMT based Optronics shows better results in capturing and processing low key images. Focusing on the end of the scale, the Docutech scanner cannot compete with the advanced capabilities of the other image capturing devices. Those rankings were confirmed by the statistical analysis of the observer's answers. Calculating and plotting the z-scores for the given values, one can evaluate the internal ranking.

Frequency matrix

	A1	B1	C1	D1	E1		A2	B2	C2	D2	E2
A1		9	10	7	8	A2		5	9	8	5
B1	1		6	1	1	B2	4		10	4	3
C1	0	4		0	1	C2	1	0		3	2
D1	3	9	10		3	D2	2	6	7		4
E1	2	9	9	7		E2	5	7	8	6	

Table 15: Frequency Matrix

Proportion matrix

	A1	B1	C1	D1	E1		A2	B2	C2	D2	E2
A1		0.90	1.00	0.70	0.80	A2		0.50	0.90	0.80	0.50
B1	0.10		0.60	0.10	0.10	B2	0.40		1.00	0.40	0.30
C1	0.00	0.40		0.00	0.10	C2	0.10	0.00		0.30	0.20
D1	0.30	0.90	1.00		0.30	D2	0.20	0.60	0.70		0.40
E1	0.20	0.90	0.90	0.70		E2	0.50	0.70	0.80	0.60	

Table 16: Proportion Matrix

Z - Score

	A1	B1	C1	D1	E1		A2	B2	C2	D2	E2
A1		1.29	4.00	0.53	0.84	A2		0.00	1.29	0.84	0.00
B1	-1.29		0.25	-1.29	-1.29	B2	-0.25		4.00	-0.25	-0.53
C1	-4.00	-0.25		-4.00	-1.29	C2	-1.29	-4.00		-0.53	-0.84
D1	-0.53	1.29	4.00		-0.53	D2	-0.84	0.25	0.53		-0.25
E1	-0.84	1.29	1.29	0.53		E2	0.00	0.53	0.84	0.25	
Ave	-6.66	3.62	9.54	-4.23	-2.27	Ave	-2.38	-3.22	6.66	0.31	-1.62

Table 17: Z-Score

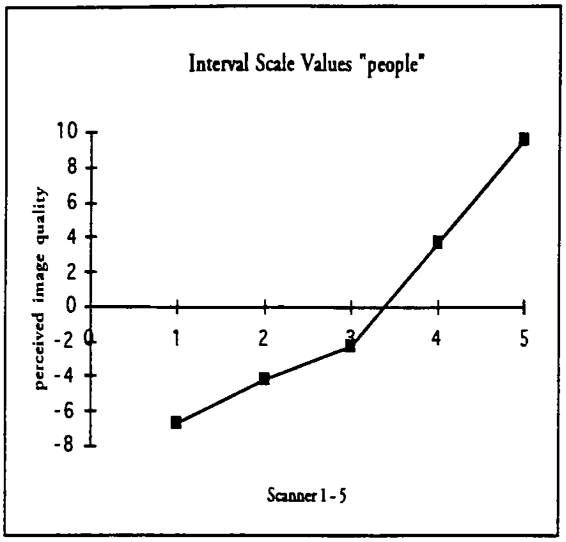


Figure 8: Interval Scale Values "people"

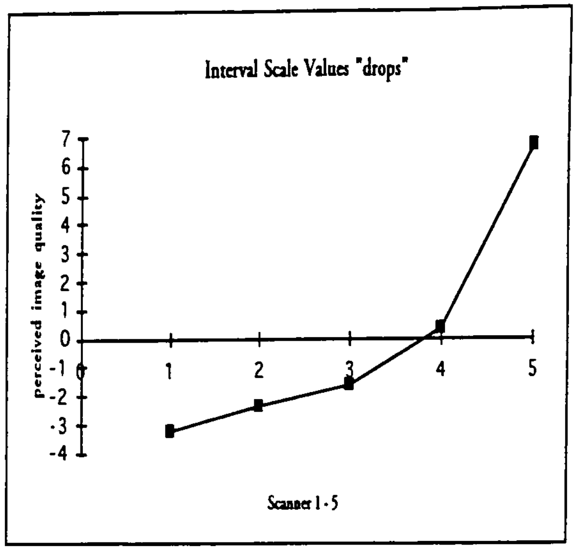


Figure 9: Interval Scale Values "drops"

The two graphs above visualize the results of the z-score calculations. Low z-scores represent a low perceived image quality. An increase in z-score can be seen as an increase in image quality. Within the plotted graphs, "scanner 1 - 5" stands for the tested scanning devices. The numbers indicate the ranking from 1 = "low quality" to 5 = "best output". As far as the image "people" is concerned, the internal ranking results in the following order:

Scanner 1	*Docutech Scanner*
Scanner 2	*Optronics*
Scanner 3	*Studio Scan*
Scanner 4	*Horizon*
Scanner 5	*Crosfield*

However, it is interesting to see and to understand what reasons have caused the final results. Analyzing the test images, the observer's choice becomes immediately obvious. While the Docutech scan features blown out highlights, the Crosfield scan gives a sharp and, in terms of tone reproduction, balanced output. Contrary to the Crosfield scans, the low end CCD scanner is not able to dissolve all the image detail, lacks contrast and looks flat. As far as the Optronics scan is concerned, sharpness and contrast are overemphasized which is not perceived positively by the observer (please see Appendix).

One of the reasons for those results is the used scanning technology. As already mentioned, the Crosfield is a highend image capturing device with a highly sensitive Photomultiplyer

tube technology. Consequently, the Crosfield scanner can discern and record much more image information which results in the optimum reproduction. Cheaper image capturing devices lack this capability. Therefore, the printed output does not reach the the same quality level.

Although the highend scanner provided superior image quality, one should note that different images require individual treatment. It is not possible to rely only on the scanning device. As seen at the test images, while midtone adjustments were performed to enhance the quality of the normal key image, the output of the low key image could be improved by applying more sharpness. The midtone adjustments for the normal key image compensate for the inherent dot gain and lead to a pleasing reproduction. Contrary to that, a midtone adjustment does not have the same impact on the low key image — because there are not many midtones that are affected by the adjustment. Due to the fact that the image information is divided into highlights and shadow detail, the enhancement of the image's sharpness has more influence on the perceived image quality.

Chapter 7. Conclusion

Considering the limitations of a 600 dpi black and white output device, the overall image quality that can be achieved with a Docutech is surprisingly good. Throughout the visual evaluation of the press samples, the observers were surprised by the fair quality of the reproductions. However, there is no doubt about the fact that the same output quality as offset lithography cannot be achieved — but this is neither the purpose nor the market the Docutech addresses.

Within Chapter 4 of this project, three major assumptions were made. Extensive testing and thorough evaluation provided the necessary information to find an answer to those questions.

Theory #1 stated that the limitations of the printing process will dictate a combination of screen ruling, resolution and number of gray levels which can be reproduced. Derived from the evaluation of the printing process, these settings can be defined for an output screen ruling of 100 lines per inch. A 100 lpi screen ruling provides the operator with an acceptable number of gray levels which can be reproduced as well as a fair reproduction of image detail. Although the screen pattern is still recognizable for the human eye, sufficient detail is rendered. Besides, finer screen rulings do not enhance the image quality due to the fact that the Docutech cannot reproduce higher screen rulings properly.

Theory #2 assumed that the use use of external scanning devices will significantly improve the possible output quality. In accordance to the statistical analysis, the experiments have shown that sophisticated and properly used scanning equipment will enhance the quality of the printed output. However, in this regard it is imperative to point out, that midrange desktop scanner that are based on CCD technology also lead to satisfying reproductions. As proven during the visual evaluation of the samples, a midrange scanner can result in nearly the same quality level for a normal key image as a highend scanning device — as long as the midrange scanner is adjusted to the image characteristic. This fact becomes even more interesting if one considers the difference in price between a midrange desktop scanner and a highend scanner. Despite all the mentioned advantages there remains one setback. As soon as time becomes a decisive factor and publications with plenty of images have to be printed

the use of external scanning devices can slow down the reproduction workflow. With regard to the time consuming process of printing externally created PostScript files, the image quality might be sacrificed to meet an important deadline.

Theory #3 anticipated a distinct difference in reproduction quality due to an image's unique characteristic such as tone distribution. If an essential prerequisite is met, this assumption is not valid. If one utilizes the capabilities of today's scanning technology, one is able to compensate for image defficencies. Thus, even images with strong contrast can be reproduced to an acceptable quality level. However, images with background blends will remain critical because of the trade off among resolution, screen ruling and gray levels.

Maybe the most important result of this project is the fact that digital printing will not overcome the established technologies of the Graphic Arts Industry within the next year but digital printing is not only a fashion. Digital printing will stay and further establish its position in the printing industry. Devices such as the Docutech will satisfy the customer's demands and find their niche. Even more encouraging, the output quality of digital printing devices can be enhanced by relatively simple means. As far as the Docutech is concerned, one can improve the output quality by using an external flatbed scanner and — at least — the following adjustments:

screen ruling	*100 lpi*
tone reproduction	*Compensate for 20% dot gain in the midtones*
file format	*TIFF*
highlights	*10%*
shadows	*90%*
D_{max}	*1.3*

If the manufacturers of digital printing devices are able to stabilize the printing process so that toner film thickness and densities can be kept within given tolerances and if future technological developments increase the output addressability of the print engine, the printed output will convince even critical judges. Digital printing is part of the printing industry's future. It would be foolish to live in the past and not utilize the technological possibilities. The key to success is not an either or but the use of the best of both worlds.

Suggestions for further Investigations

It was the purpose of this project to prepare the field for further investigations within the field of digital printing. While this project solely focus on the impact of image capturing devices, one possible topic would be an investigation into the limits of the printing engine.

Furthermore, the multiple scanning parameters and their variety of combinations offer another wide field of additional research.

Finally, with the announcement of the "Docucolor", Xerox enters the market of color reproductions. Thus this investigation into the capabilities of the black and white process can be carried to the reproduction of color

Bibliography

Bartelson James C., *Optical Radiation Measurements,* vol. 5, *Visual Measurements* (Orlando: Academic Press, 1984)

Beaulieu J. Michael, *Scanning Ratios for Desktop Images,* (Rochester: Rochester Institute of Technology, 1993)

Blatner David and Steve Roth, *Real World Scanning and Halftones – the definitive guide to scanning and halftones from the desktop,* (Berkley: Peachpit Press, 1993)

Bristow J. & Johansson P. A., *Subjective Evaluation by pair comparison: pitfalls to avoid and suggestions for the presentation of results*

Bruno Michael H., *Pocket Pal – A Graphic Arts Production Handbook* (Memphis: International Paper Company, 1995)

Cost Frank, *Using Photo CD for Desktop Prepress* (Rochester: R. I. T. Research Corporation, 1993)

Eliezer Caren, *Indigos E-Print: New Generation of Offset Color Printing* (Media, Pennsylvania: Seybold Publications Division, 1993)

Field Gary G., *Color and its Reproduction* (Pittsburgh: GATF, 1988)

Hahn Christopher, *The wide Range of Flatbeds* (Rochester: Rochester Institute of Technology, 1995)

Helgerson Linda W., *Introduction to Scanning Technology* (Silver Spring: Association for Information and Image Management, 1987)

Jorgensen George W., *Improved Black-and-White Halftones* (Pittsburgh: GATF, 1976)

Kammermeier Peter and Anton, *Scanning and Printing* (Oxford: Butterworth-Heinemann, 1992)

McIlroy Thad and Graham Gordon, *Desktop Publishing in Black-and White* (San Francisco: The Color Resource, 1992)

Romano Frank & Fenton Howard S., *On-Demand Printing — The Revolution in Digital and Customized Printing* (Pittsburgh: Graphic Arts Technical Foundation, 1995)

Sanders Donald H., *Statistics: a first course* (New York: Mac Graw Hill, 1995) A-10

Southworth Donna & Miles, *Color Separations on the Desktop* (Livonia: Graphics Art Publishing, 1993)

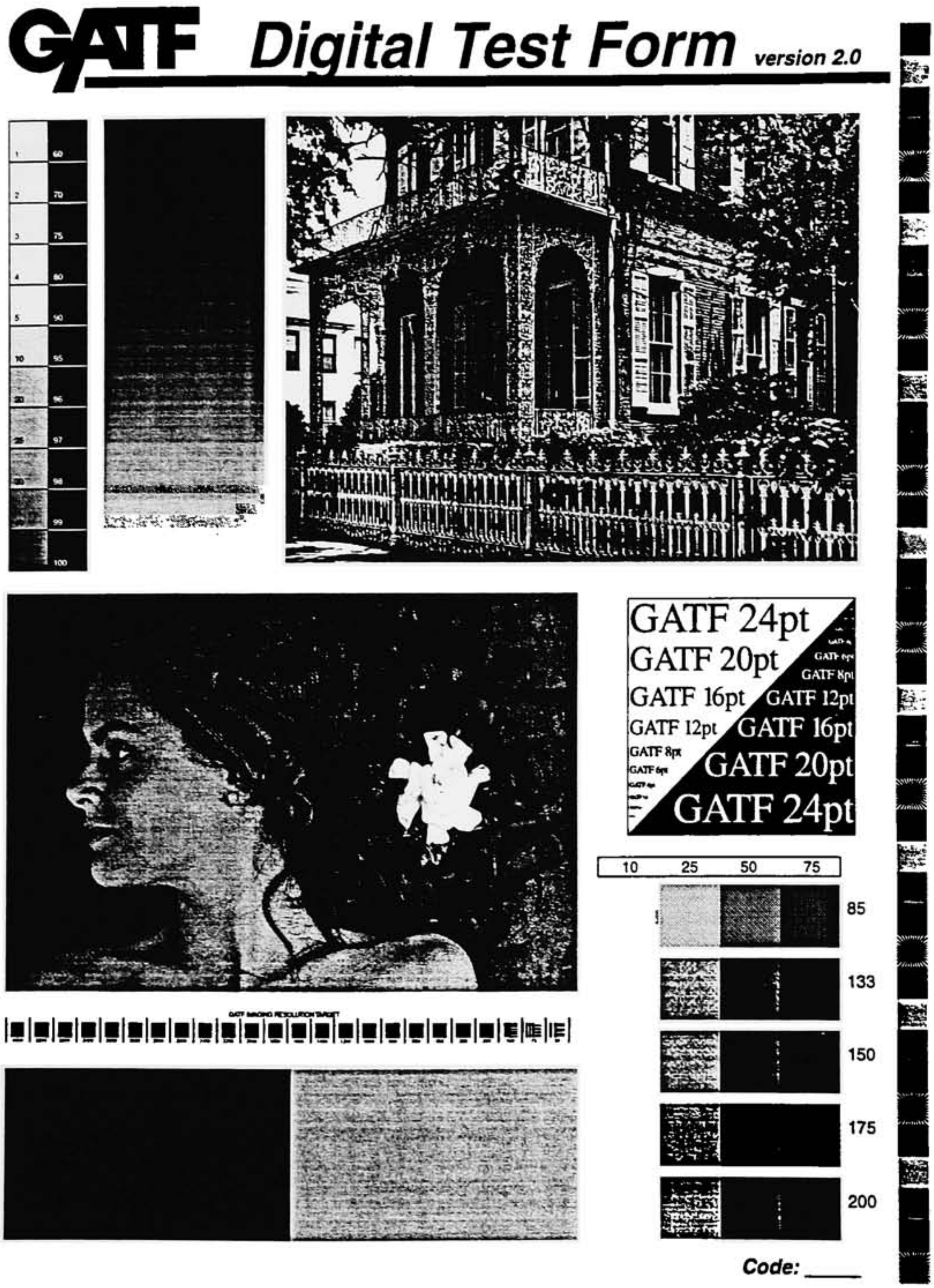
SWOP, *Specifications Web Offset Publications* (New York: SWOP, 1993)

Steiger Dipl. Ing. W. F., *Scanner 1995* (Heusenstamm: Der Druckspiegel – Publishing Special, 1995)

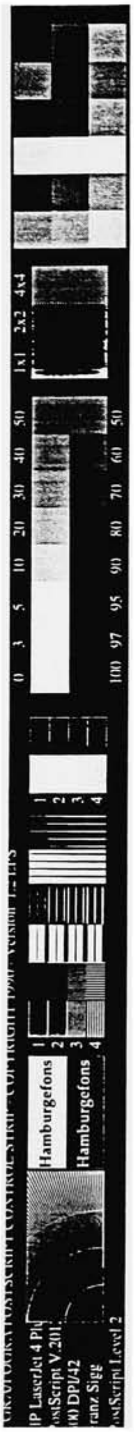
Thurstone L. L., *A law of comparative Judgement* (Chicago: Psychological Review Vol. 34, 1927)

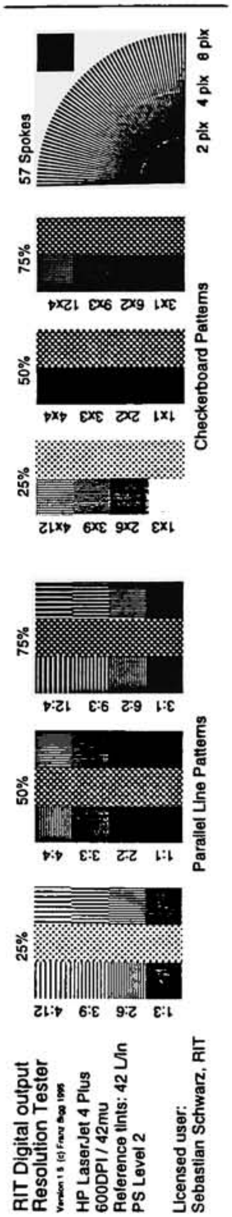
Wetzler Fred U., *Desktop Image Scanners and Scanning* (Silver Spring: Association for Information and Image Management, 1989)

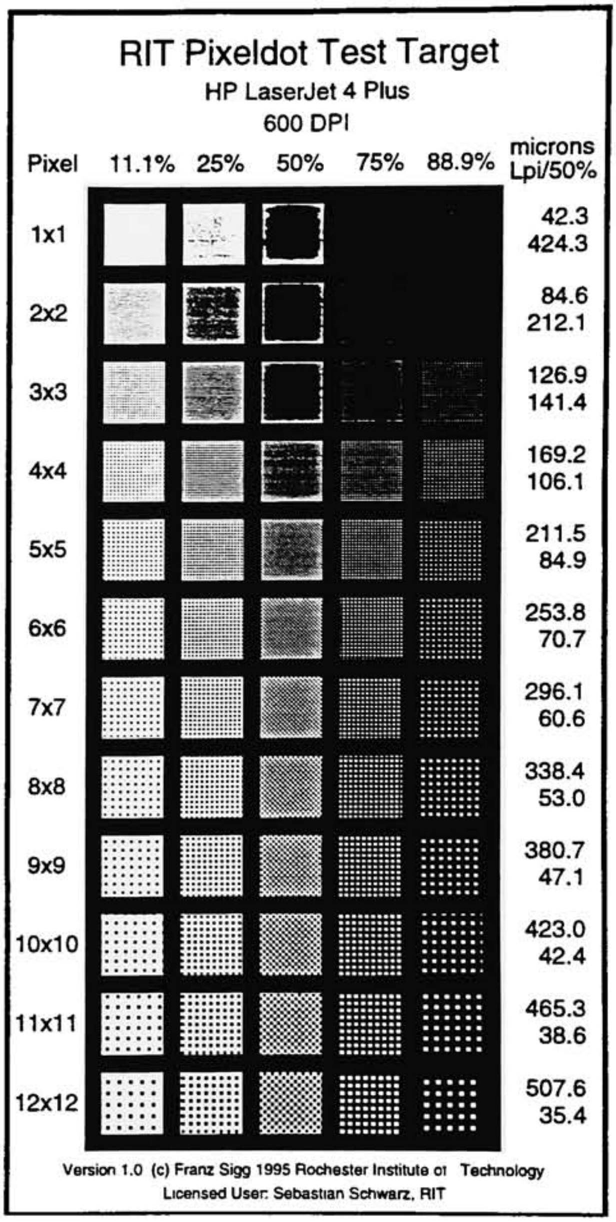
Zaucha Randy, *Scanner Book – How to make sellable Color Separations on any Scanner* (San Francisco: Blue Monday, 1991)


GATF Digital Test Form version 2.0
1
2
3
4
5
10
60
70
75
80
90
95
96
97
98
99
100
GATF 24pt
GATF 20pt
GATF 16pt
GATF 12pt
GATF 8pt
GATF 12pt
GATF 16pt
GATF 20pt
GATF 24pt
10
25
50
75
85
133
150
175
200
Code:

APPENDIX B: TEST TARGETS







Appendix C: Evaluation Sheet

Evaluation Sheet

Test person: Date:
Image: Time:

Pair	Sample preferred
A1 - E1	
B1 - C1	
A1 - D1	
B1 - E1	
C1 - D1	
D1 - E1	
A1 - C1	
B1 D1	
C1 - E1	
A2 - E2	
B2 - C2	
A2 - D2	
B2 - E2	
C2 - D2	
A2 - B2	
D2 - E2	
A2 - C2	
B2 - D2	
C2 - E2	

Appendix D: Observer Raw Data

Peter

	A1	B1	C1	D1	E1
A1		0	1	1	1
B1	1		1	0	0
C1	0	0		0	0
D1	0	1	1		0
E1	0	1	1	1	
=	1	2	4	2	1

	A2	B2	C2	D2	E2
A2		1	1	1	1
B2	0		1	1	1
C2	0	0		0	0
D2	0	0	1		0
E2	0	0	1	1	
=	0	1	4	3	2

Per

	A1	B1	C1	D1	E1
A1		1	1	0	0
B1	0		1	0	0
C1	0	0		0	0
D1	1	1	1		0
E1	1	1	1	1	
=	2	3	4	1	0

	A2	B2	C2	D2	E2
A2		0	1	1	0
B2	1		1	1	0
C2	0	0		1	0
D2	0	0	0		0
E2	1	1	1	1	
=	2	1	3	4	0

Phil

	A1	B1	C1	D1	E1
A1		1	1	1	1
B1	0		0	0	0
C1	0	1		0	0
D1	0	1	1		0
E1	0	1	1	1	
=	0	4	3	2	1

	A2	B2	C2	D2	E2
A2		1	1	1	1
B2	0		1	0	0
C2	0	0		0	0
D2	0	1	1		1
E2	0	1	1	0	
=	0	3	4	1	2

Bill

	A1	B1	C1	D1	E1
A1		1	1	0	1
B1	0		0	0	0
C1	0	1		0	0
D1	1	1	1		0
E1	0	1	1	1	
=	1	4	3	1	1

	A2	B2	C2	D2	E2
A2		1	1	1	1
B2	0		1	1	0
C2	0	0		1	0
D2	0	0	0		0
E2	0	1	1	1	
=	0	2	3	4	1

Ralf

	A1	B1	C1	D1	E1
A1		1	1	1	1
B1	0		1	0	0
C1	0	0		0	0
D1	0	1	1		0
E1	0	1	1	1	
=	0	3	4	2	1

	A2	B2	C2	D2	E2
A2		1	1	1	1
B2	0		1	0	0
C2	0	0		0	1
D2	0	1	1		1
E2	0	1	0	0	
=	0	3	3	1	3

Karen

	A1	B1	C1	D1	E1
A1		1	1	1	1
B1	0		1	1	1
C1	0	0		0	1
D1	0	0	1		1
E1	0	0	0	0	
=	0	1	3	2	4

	A2	B2	C2	D2	E2
A2		0	1	1	0
B2	1		1	0	0
C2	0	0		0	0
D2	0	1	1		1
E2	1	1	1	0	
=	2	2	4	1	1

Yaco

	A1	B1	C1	D1	E1
A1		1	1	1	1
B1	0		0	0	0
C1	0	1		0	0
D1	0	1	1		0
E1	0	1	1	1	
=	0	4	3	2	1

	A2	B2	C2	D2	E2
A2		1	1	1	1
B2	0		1	0	0
C2	0	0		0	0
D2	0	1	1		0
E2	0	1	1	1	
=	0	3	4	2	1

Chris

	A1	B1	C1	D1	E1
A1		1	1	0	0
B1	0		1	0	0
C1	0	0		0	0
D1	1	1	1		0
E1	1	1	1	1	
=	2	3	4	1	0

	A2	B2	C2	D2	E2
A2		0	0	1	0
B2	1		1	1	0
C2	1	0		1	0
D2	0	0	0		0
E2	1	1	1	1	
=	3	1	2	4	0

Ted

	A1	B1	C1	D1	E1
A1		1	1	1	1
B1	0		1	0	0
C1	0	0		0	0
D1	0	1	1		1
E1	0	1	1	0	
=	0	3	4	1	2

	A2	B2	C2	D2	E2
A2		0	1	0	0
B2	0		1	0	1
C2	0	0		0	1
D2	1	1	1		1
E2	1	0	0	0	
=	2	1	3	0	3

Jamie

	A1	B1	C1	D1	E1
A1		1	1	1	1
B1	0		0	0	0
C1	0	1		0	0
D1	0	1	1		1
E1	0	1	1	0	
=	0	4	3	1	2

	A2	B2	C2	D2	E2
A2		0	1	0	0
B2	1		1	0	1
C2	0	0		0	0
D2	1	1	1		0
E2	1	0	1	1	
=	3	1	4	1	1

APPENDIX E: TEST IMAGES

Image 1: Agfa Horizon, 100 lpi, with midtone adjustment

Image 2: Crosfield, 100 lpi, with midtone adjustment

Image 3: Optronics, 100 lpi, with midtone adjustment

Image 4: Agfa Studio Scan, 100 lpi, with midtone adjustment


Image 5: Agfa Horizon, 100 lpi, with more sharpness

Image 6: Crosfield, 100 lpi, with more sharpness

Image 7: Optronics, 100 lpi, with more sharpness

Image 8: Studio Scan, 100 lpi, with more sharpness