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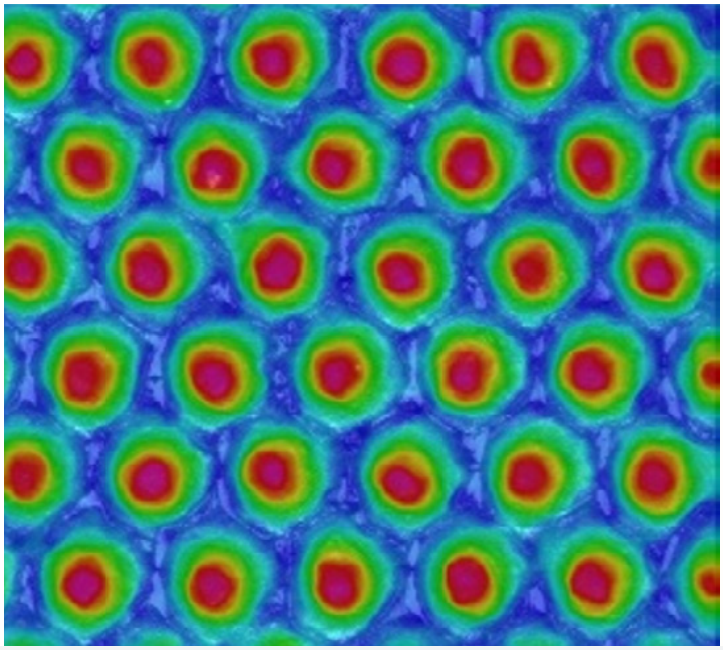

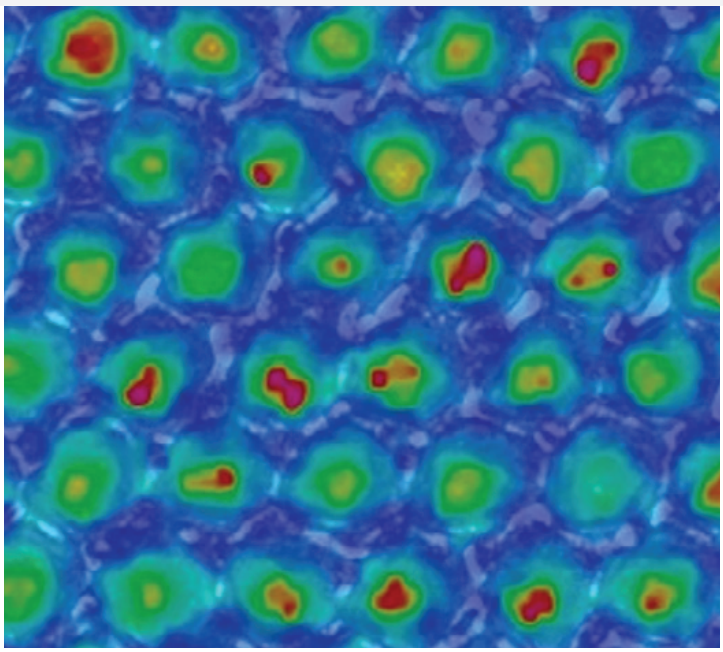

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Faculty of Technical Sciences,
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21000 Novi Sad, Serbia

Telephone numbers:
+381 21 485 26 20
+381 21 485 26 26
+381 21 485 26 21

Fax number:
+381 21 485 25 45

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Contents

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Analysis of quality factors for digitization process of old books

ABSTRACT

The digitization process of old books is one of the measures to preserve the cultural heritage of mankind and to make them accessible to a large audience. The task of creating a high quality digital copy of an old book is quite complex and it depends on many factors. Thus, the analysis of the factors that determines the quality of the digitization process has been done, the models of relationships between the factors have been constructed and their priority has been established with the help of the method of factors ranking using the hierarchical representation of relationships between them in the form of graphs, the calculation of the corresponding weight coefficients and the expert survey with its interpretation in a fuzzy form.

KEY WORDS
old book digitization, quality, multilevel model, fuzzy sets

Olena Tsimer
Vyacheslav Repeta
Ihor Myklushka

Ukrainian Academy of Printing,
Faculty of Publishing, Printing and Information Technologies,
Lviv, Ukraine

Corresponding author:
Vyacheslav Repeta
e-mail: vreneta@yandex.ua

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Introduction

In the process of obtaining a digital copy of an old book, there are difficulties that require the adjustment of its technological operations, in particular the general condition of pages, the opening degree of the book block, the heterogeneity of the page background and changes in the optical density of the text and illustrative information due to the aggressive influence of different environments in the process of the old book storing. They form the range of optical densities for each page and require adjusting the light distribution over the recorded area.

Specialized equipment is used for the old book digitization, the application of which does not involve the fastest possible process implementation but obtaining a high quality digital copy. It is known that such equipment is currently installed in many scientific libraries of Ukraine (Kotsyuba, 2012; Anon, 2019; Kotsyuba, 2019). The following companies present it on the market: Zeutschel GmbH, Image Access GmbH, Atiz Innovation Co., Ltd, TREVENTUS Mechatronics GmbH, SMA Electronic Document GmbH, ELAR, i2S SA. Each manufacturer offers several types of devices for old book scanning that differ in format, book placement principle, digital camera resolution, and different innovative approaches .

The operation of any recording system is characterized by digital noise. Digital noise is a defect in an image that results in statistically inevitable randomly scattered pixels of random colour and brightness over the area of the recorded image that does not match the original. It is clear that the value of digital noise varies depending on the condition of the original, the parameters of the scanning device, the principles of image processing software (Crowley, 2016). The result of optimal selection of the scanning process factors and its modes is the characteristic feature of a digital copy.

It is known that the software has been tested for performing technological operations with digital images and the expediency of using the following applications

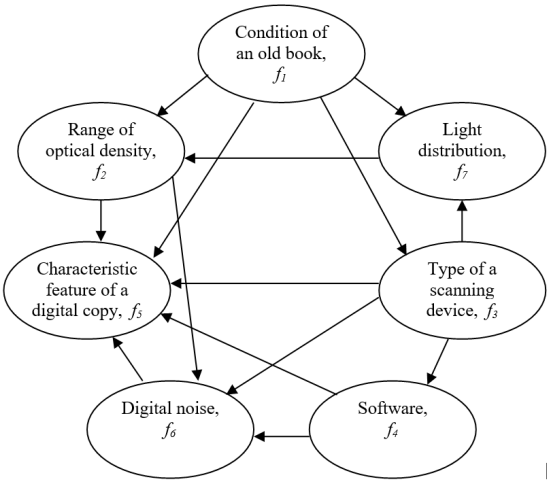
has been established: ACDSee, Book Restorer, Scan Kromsator Scan Tailor, Adobe Photoshop, Easy Scan Plus.

The objective of the work is to determine the priority of the factors that determine the quality of the digitization process of old books for their subsequent digital restoration. The following factors have been identified in the analysis of the digitization technology of old books:

- the condition of an old book (f_1);
- the range of optical density (f_2);
- a type of a scanning device (f_3);
- the software (f_4);
- the characteristic feature of a digital copy (f_5);
- the digital noise (f_6);
- the light distribution (f_7).

Methodology

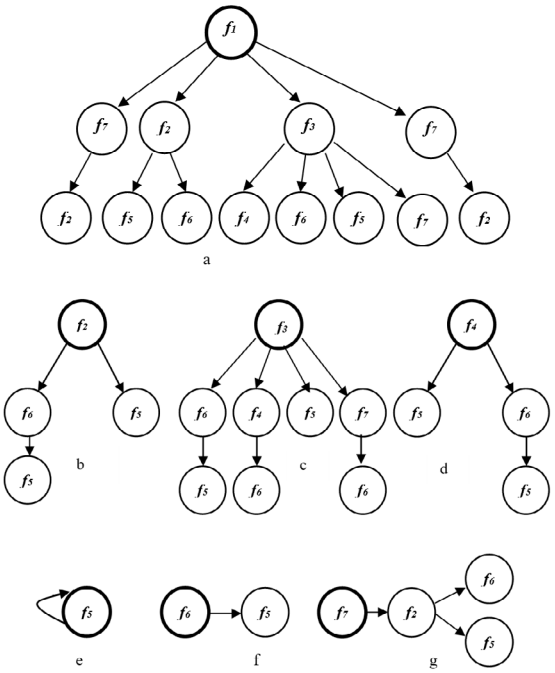
For the analysis of the process factors, the method has been used, which has shown its versatility to solve the problems of factors priority of different processes (Senkivskyy, Pich & Melnykov, 2013; Repeta, Senkivsky & Piknevych, 2014). This method, in contrast to the method of hierarchies analysis and solving the reachability matrix and pairwise comparison of factors (Pikh & Senkivskyy, 2013), takes into account both direct influences and dependencies between factors and indirect or mediate, that is, those that pass through another factor. The method of ranking distinguishes between the types of influences and the dependencies of factors by giving different weights to each of them, and the conducted analysis does not lead to the placement of two or more factors at the same level of the hierarchy.



» **Figure 1:** *An oriented graph of factors for the digitization process of old books*

Based on the graph (Figure 1), we construct for each of the factors hierarchical trees of their relationship with other factors, taking into account the influences of both types – direct and mediate, that is, indirect, passing through another factor.

After analysing the graphs (Figure 2), we calculate the total weight values of the direct and indirect influences of factors and their integral dependency on other factors. To do this, we introduce the following symbols. Let k_{ij} be the number of influences (i = 1 – direct, i = 2 – indirect) or dependencies (i = 3 – direct, i = 4 – indirect) for the j-th factor (j = 1,...,n); w_i is the weight of the i-th type. For calculations, we take the following conditional values for the weight coefficients in conditional units: w_1 = 10, w_2 = 5, w_3 = -10, w_4 = -5.



» **Figure 2:** *Graphs of multilevel hierarchical relationships for factors of the digitization process of old books (a – g)*

We denote the total weight values of all types of relationships of quality factors by P_{ij}.

We use the following formulas for calculations:

$$P_{ij} = k_{ij} w_i \ \ (i = 1,2,3,4; \ \ j = 1,...,n) \tag{1}$$

where n is a number of the factor.

For our oriented graph (Figure 1) taking into account (1), we get:

$$P_{Fj} = \sum_{i=1}^{4} \sum_{j=1}^{7} k_{ij} w_i \tag{2}$$

It is clear that, in the absence of one factor for one of the relationship types, its corresponding value k_{ij} in the expression (2) will be zero. The presented formula is the basis for getting weight values of factors ranking, taking into account different types of relationships between

them. For the formation of the number of influences and dependencies of factors (Table 1), we define direct influences for each of them, the number of which is fixed by the coefficients k_{1j}. "Ways of dependency" provide with obtaining the coefficients k_{3j} in a similar way. The combined consideration of indirect influences or dependencies of a factor (i.e. influence or dependency through other factors) determines the coefficients k_{2j} and k_{4j}.

Table 1

Directions of influence and ways of dependency of factors for the digitization process of an old book

Characteristics of the factor	Number of factor *j*						
	1	2	3	4	5	6	7
Impacts	4	2	4	2	0	1	1
Dependencies	0	2	1	1	5	3	2

It should be noted that $P_{3j} < 0$ and $P_{4j} < 0$ since according to the given initial conditions $w_3 < 0$ and $w_4 < 0$. So, to bring the total weight values of the factor with the lowest priority to zero and the rest to a positive value, we transform the formula (2) into:

$$P_{Fj} = \frac{1}{5}\left(\sum_{i=1}^{4}\sum_{j=1}^{7} k_{ij} w_i + S_j\right), \quad (3)$$

$$S_j = max|P_{3j}| + max|P_{4j}|. \quad (4)$$

The specified values are added in each row to the sum of the values in the columns P_{1j}, P_{2j}, P_{3j} and P_{4j}. Finally, we obtain the resultant weight of the factor, which is the basis for establishing the factor rank r_j, which is equivalent to the priority of its influence on the digitization process of old books.

At the next stage, a questionnaire has been formed according to these factors, in which experts (employees of Vasyl Stefanyk National Science Library, Ukrainian Academy of Printing, Lviv Printing College of Ukrainian Academy of Printing) have been asked to evaluate the importance of the factors influence on the digitization process of old books. And it is necessary to indicate how the digitization process will improve, according to the questions asked:

1. How does the condition of the old book affect the quality of the digitized copy?
2. Is the range of optical densities of the original essential during its digitization?
3. How will the selection of a scanning device affect the quality of the old book digitization?
4. How does the software affect the quality of the received digital copy?
5. Does the effect of digital noise have a significant impact on the quality of the digitization process?
6. How does the light distribution affect the quality of the digital copy?

The questionnaire form is filled in when answering six questions (Table 2).

Table 2

The form of the questionnaire, which is proposed to the experts

No.	Number of factor j				
	0	25	50	75	100*
1					
2					
...					
n					

*scale values 0-100% indicate the level of improvement of the process of digitizing the old print.

Each expert interprets these answers individually, that is, it takes a fuzzy form. Therefore, it is desirable not only to select an acceptable answer, but also to provide a quantitative assessment. To do this, the expert is suggested a so-called "soft" form of quantitative interpretation of answers when the expert has to give not one but several quantitative assessments. For the expert orientation, the set of possible quantitative assessments takes on values, for example, from 0 to 100% (Baranov & Ptushkin, 2004). In addition, the expert is asked to give a degree of certainty to each of such assessment that the selected quantitative assessment would be correct. The degree of certainty is quantitatively characterized by the verbal-numerical scale by Harrington (Saaty, 1980), which is presented below (Table 3).

Table 3

The verbal-numerical scale by Harrington

Confidence level	Value
very high	0.8 – 1.0
high	0.63 – 0.8
average	0.37 – 0.63
low	0.20 – 0.37
very low	0.0 – 0.20

Thus, the task of the expert is to select the answer in the form of Table 2, which is offered to the expert when answering the question, and to evaluate it on the verbal-numerical scale by Harrington. For example, this is one answer to the question: "Does the effect of digital noise have a significant impact on the quality of the digitization process?" in Table 4.

Table 4

The expert's answer to the given question

Possible values of the parameter changes, %				
0	25	50	75	100
0.8	1.0	0.5	0.3	0.1

In the presented questionnaire: 0 is the lowest degree of certainty, 1 is the highest degree of certainty.

According to the table, the membership function has the following form:

$$\mu(u) = [0.8; 1.0; 0.5; 0.3; 0.1]$$

The example in the table above points to the following:

- the influence of digital noise on the digitization process is 25% (the degree of certainty is 1.0);
- there is slightly less certainty (0.8) that such an influence will be absent at all.

The membership function of the generalized thought is determined by the formula:

$$M(U_i) = min\,[(\mu_1(u_i),(\mu_2(u_i),\ldots,\ (\mu_n(u_i)\ ] \quad (5)$$

The result of the expert survey is the maximum value of the function:

$$u^*_i = argmax\mu_i(u_i) \quad (6)$$

Results

The calculations (according to formula 3), we form Table 5 to establish the factors ranks. As it can be seen from the table, max $|P_{3j}|$ = 50; max $|P_{4j}|$ = 30. The factor with the highest value of P_{Fj} has highest rank.

Table 5

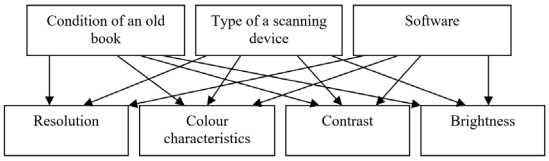
Calculated data of factors ranking for the digitization process of old books

Number of factors j	k_{1j}	k_{2j}	k_{3j}	k_{4j}	P_{1j}	P_{2j}	P_{3j}	P_{4j}	P_{Fj}	Factor rank r_j
1	4	4	0	0	40	20	0	0	28	1
2	2	1	2	2	20	5	-20	-10	15	4
3	4	1	1	0	40	5	-10	0	23	2
4	2	1	1	1	20	5	-10	-5	18	3
5	0	0	5	6	0	0	-50	-30	0	7
6	1	0	3	4	10	0	-30	-20	8	6
7	1	1	2	1	10	5	-20	-5	14	5

According to the received results, factors with the highest rank are (Figure 3): the condition of an old book, a type of a scanning device, the software. Accordingly, these factors have the greatest influence on such parameters of the resulting digital image as resolution, brightness, contrast and colour characteristics, which determine the prerequisites for the next digital copy processing.

At the second stage the subsequent answers to the *i*-th question is summarized in Table 6. If the expertise level of the experts is the same, then the overall fuzzy assessment will be obtained at the intersection of fuzzy sets belonging to the experts' answers.

The membership function quantifies this assessment according to the fuzzy set intersection rule.



» **Figure 3:** *Influence of priority factors for the digitization process of an old book on parameters of a digital copy*

Table 6

Experts' answer to the given question

Experts	Possible values, %				
	0	25	50	75	100
1	0.8	1.0	0.5	0.3	0.1
2	0	0.7	1.0	0.5	0.2
3	0	0.8	0.6	0.4	0.2
4	0	1.0	0.4	0.2	0.1
5	0	0.95	0.7	0.5	0.25
6	0	1.0	0.75	0.2	0
7	0.4	1.0	0.8	0.7	0.6
8	0	1.0	0.8	0.6	0.5
9	0	0.9	0.7	0.5	0.25
10	0	0.8	0.5	0	0

Ten representatives from the expert group have answered the above question (see Table 6) in the form of a fuzzy set M with the corresponding membership function μ:

M1=0,8/0+1,0/25+0,5/50+0,3/75+0,1/100	μ1(u) = [0.8; 1; 0.5; 0.3; 0.1];
M2=0/0+0,7/25+1,0/50+0,5/75+0,2/100	μ2(u) = [0; 0.7; 1; 0,5; 0.2];
M3=0/0+0,8/25+0,6/50+0,4/75+0,2/100	μ3(u) = [0; 0.8; 0.6; 0.4; 0.2];
M4=0/0+1,0/25+0,4/50+0,2/75+0,1/100	μ4(u) = [0; 1; 0.4; 0.2; 0.1];
M5=0/0+0,95/25+0,7/50+0,5/75+0,25/100	μ5(u) = [0; 0.95; 0.7; 0.5; 0.25];
M6=0/0+1,0/25+0,75/50+0,2/75+0/100	μ6(u) = [0; 1; 0.75; 0.2; 0];
M7=0/0+1,0/25+0,8/50+0,6/75+0,5/100	μ7(u) = [0; 1; 0.8; 0.6; 0.5];
M8=0/0+1,0/25+0,8/50+0,6/75+0,5/100	μ8(u) = [0; 1; 0.8; 0.6; 0.5];
M9=0/0+0,9/25+0,7/50+0,5/75+0,25/100	μ9(u) = [0; 0.9; 0.7; 0.5; 0.25];
M10=0/0+0,8/25+0,5/50+0/75+0/100	μ10(u) = [0; 0.8; 0.5; 0; 0]

The answer for the influence of digital noise is: [0; 0.7; 0.4; 0; 0].

Thus, u^* = 0.8 correspond to 25 % influence on the process quality. The answers to other questions are shown in Table 7.

This survey has revealed that the condition of an old book and the light distribution are of the highest importance, experts have shown for them with certainty u^* = 1 that these factors determine the digitization quality by 75 and 100%, respectively.

Table 7

Results of the survey according to the suggested questionnaire

Question	Maximum value of the function, u^*				
	0	25	50	75	100
1	0	0	0.5	0.7	1.0
2	0	0.2	0.6	0.8	0.6
3	0	0	0.5	0.9	0.7
4	0	0	0.9	0.8	0.5
5	0	0.7	0.4	0	0
6	0	0.4	0.5	1	0.8

Conclusions

According to the analysis by the method of ranking, the following factors have been found to have the highest priority in the digitization process of old books: the condition of the old book, a type of a scanning device, and the software. The survey conducted in the second stage has confirmed the priority of such factor as "the condition of the old book". In addition, the importance of the factor "light distribution" has been shown, for which experts have revealed with certainty $u^* = 0.8$-1 that this factor determines the quality of the digitization process of an old book by 75-100%, although this factor has occupied the fifth position during ranking. It should also be noted that the factor "light distribution" in the construction of the relationship model between the factors depends on the condition of the old book and the type of a scanning device, which reduces its importance. The third most important factor ($u^* = 0.9$) is the factor "a type of a scanning device", which is expected to achieve 75% of the process improvement. The factor "software" was next in priority and experts have indicated with certainty $u^* = 0.9$ that selecting it correctly could improve the digitization process by 50%. The two methods of the factor analysis used have allowed getting almost identical results that complement each other. The next stage of our study will be the research of the influence of priority factors by means of fuzzy logic.

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Environmental impact of printing inks and printing process

ABSTRACT

In the Printing Industry, printing inks, varnishes, lacquers, moistening solutions and washing solvents (ethanol, methyl acetate, ethyl acetate, isopropanol, n-propanol, hexane, benzene, toluene, xylene, isopropyl acetate, propyl acetate, dimethyl ketone, glycols and glycol ethers) contain volatile organic compounds (VOCs) and air pollutants (HAPs). Especially solvent based inks used for flexo, gravure and screen printing, offset printing dampening solutions and cleaning solvents contain high concentration of VOC. These organic compounds evaporate during the production process or contribute to the photochemical reaction. VOCs and HAPs, together with sunlight and nitrogen oxides, cause photochemical smoke, air particles and ground level ozone emission in the atmosphere. The VOCs and heavy metals can lead to soil and even water pollution when left in landfill. The amount of solvent retained by flexo, gravure and screen-printed products is 3-4% of total ink solvent used. The solvent in the printed ink content, except for the one held by the printed material evaporates in its own environment after the printing process. Most of these solvents and organic compounds used in printing environment contain at least one carbon and hydrogen atom and have negative effects on health and environment.In this study, the environmental impacts and risks of inks and solvents used in the printing industry have been evaluated. Measures to be taken to reduce and manage these environmental effects and risks have been addressed and recommendations have been made.

Cem Aydemir [1]
Samed Ayhan Özsoy [2]

[1] *Marmara University, School of Applied Science, Department of Printing Technologies, Istanbul, Turkey*

[2] *Istanbul University Cerrahpasa, Vocational School of Technical Sciences, Printing and Publication Technologies Program, Istanbul, Turkey*

Corresponding author:
Cem Aydemir
e-mail:
cemaydemir@marmara.edu.tr

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Introduction

Solvents may be defined as complicated chemical mixtures containing several different types of hydrocarbon such as small aerosolisable aromatic molecules and vaporizing as VOCs and as alkanes, alcohols, ketones, aldehydes, esters, ethers (Viegas, 2011). In almost every production industry the solvent is used in the processes such as degreasing, cleaning and etc. There are two different types of solvents as halogenated and halogen-free. They may have the characteristic of a 'hazardous chemical' according to the feature of the chemical materials they contain and may also have the feature of hazardous waste at the end of its use. Halogen-free solvents are aliphatic and aromatic hydrocarbon compounds. Methyl-chloride, ethyl chloride, trichloroethanol, chloroform, chloroethane compounds, chlorinated benzines and chlorinated phenol compounds could be

given as examples of halogenated solvents. The chemical compounds containing at least one carbon and a hydrogen atom are called “organic compounds”. Organic compounds are examined under three main groups (Table 1) as very volatile organic compounds (VVOCs) volatile organic compounds (VOCs) and semi-volatile inorganic compounds (SVOCs). These compounds cause soil pollution, underground water pollution, environment pollution and air pollution (US EPA, 2018).

Table 1

Classification of Organic Pollutants (Okubo & Kuwahara, 2020)

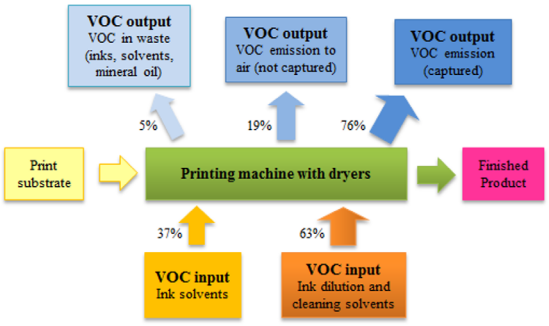
Chemicals group	Boiling point (°C)	Organic chemicals
VVOCs	<0 to 50-100	Propane, methane, formaldehyde, acetaldehyde, dichloromethane, butane, methyl chloride, etc.
VOCs	50-100 to 240-260	Ethyl alcohol, acetone, benzene, toluene, xylene, isopropyl alcohol, hexanal, etc.
SVOCs	240-260 to 380-400	Chlorpyrifos, dibutyl phthalate, bis (2-ethylhexyl) phthalate, pesticides (DDT, chlordane, plasticizers), etc.

VOCs released to the environment from solids and liquids in gas form (Khan & Ghoshal, 2000). Vapour-phase organic compounds are very important for the control in air pollution due to the direct and secondary environmental effects. VOCs are of concern as both indoor air pollutants and as outdoor air pollutants. However, the emphasis of that concern outdoors is different from indoors. The main concern indoors is the potential for VOCs to adversely impact the health of people that are exposed (US EPA, 2018). Some of these compounds contain several chemicals which may have short-term and long-term negative health effects, and their impact on human health becomes much more severe in indoor spaces (Rösch et al., 2014). The existence of these indoor air pollutants increases the risk of people with breathing problems, such as asthma sufferers, and with compromised or underdeveloped immune systems (Leung, 2015).

Ink always comes to mind as the latest when the health of living things and the environment are considered. In fact, printed products surround people in every stage of life. We come across with printed products everywhere as daily newspapers, books and packaged products. The printing of the materials such as newspapers, magazines, books, catalogues, packages, prospectus, leaflets, advertising supplements, flyers, calendars, company directives, posters and publicity posters has been increasing every passing day. There is a need for energy, paper and ink in order to produce these materials (Blue Angel, 2020).

Printing inks, overprint varnishes and lacquers, additives, diluting solvents, cleaning solutions and wash-up materials, dampening solvents, glues and adhesives used in packaging systems may have a potential effect on the environment at certain points during their own usage cycle (Khan & Ghoshal, 2000; Svendsen & Rognes, 2000) have stated that most important factor of solvent material exposure in offset printing is the humidifier used in printing machines. VOCs should be addressed at this point. VOCs cause greenhouse effect and ozone in the sub-atmosphere (US EPA, 2018). For this reason, it is associated with global warming (Aydemir, Yenidoğan & Özsoy, 2020).

Organic solvent-based flexo including organic solutions, gravure, digital and screen-printing inks, oil-based heat-set web offset inks and solvent compounds used in printing surface coating and solvents added for dilution are the sources of VOC emissions. VOC emissions can occur in any processes of ink mixing, printing, surface coating and storing (IFC, 2007). In other words, it means the organic solvents and diluents are released to the atmosphere during printing process (Figure 1). Moreover, printing inks, solvent based cleansers used in machine cleansing process also cause the release of ozone and volatile organic compounds contributing to the air pollution (Blue Angel, 2020).



» **Figure 1:** *VOC input and output during the printing process*

As the environmental awareness increased globally, the demand for the ink made of renewable resources with low carbon footprint has also been increasing (Aydemir et al., 2018). In the ink systems, water began to replace the solvent and vegetable began to replace mineral oil (Robert, 2015). Using water and vegetable oil instead of evaporative chemical solvents in the ink systems, enables the VOCs to be reduced during printing process (Sensorex, 2017). Replacing water with the solvent in the ink, seems environmentally beneficial. However, four times more power is required in order to evaporate the same amount of water in the ink (Aydemir & Özakhun, 2014). This situation may cause high carbon footprint (EuPIA,

2013). Thus, substrates with high absorbing capacity requiring low drying energy should be preferred for the prints performed with water-based ink. The absorption, wettability and surface energy of the substrate should be well-known (Aydemir et al., 2019). During the industrial printing processes, optimization of energy use is extremely important in terms of environment. In order to evaluate the environmental impact of each ink and printing technique, it is necessary to make a Life Cycle Assessment that considers the raw material, manufacturing, distribution, use, and final disposal (Hermann, 2014).

In recent years, the number of studies focusing on the reduction of VOCs content produced by inks has boosted due to increased environmental awareness (Aydemir, Yenidoğan & Özsoy, 2020). In this study, the effects of inks and solvents on the environment have been evaluated and recommendations for the elimination of such effects have been given.

Solvent Emissions Directive and the Control of VOC Emissions

The emissions result from evaporation of VOC and HAP contained in the inks during the printing process. The fact that vaporized solvents damages the ozone layer seriously according to the studies, leads the countries to take measures. Thus, it is inevitable for printing industry to carry out regulations about VOC and HAP having negative effects on the environment (Khan & Ghoshal, 2000). The Environmental Protection Agencies in US, Europe, Canada, and many other countries have restricted the amount of solvent that can be released into the air to reduce the pollutants released to the environment by the printing industry (Saad, 2007).

The emissions of VOCs should be controlled within the limits under the EU Solvent Emissions Directive (EuPIA, 2013). The purpose of this directive is to limit the total content of VOC in certain dyes, inks and varnishes in order to reduce and prevent the air and environment pollution (US EPA, 2018). Emission is controlled by recovery such as adsorption (scrubbing), desorption, condensation and traditional systems of abatement such as catalytic thermal oxidation, thermal oxidation and biological scrubbing (Inglezakis & Poulopoulos, 2006). In large-scale flexographic and gravure printing processes, thermal oxidation is the most common (EuPIA, 2013).

The Environmental Impacts of Pre-Press Processes

Although no significant VOC emissions are generated from the prepress / imaging process, developers and fixers may generate emissions of sulphur compounds, acetic acid, and ammonia from blueprint, as well as odours, particularly in older processes (IFC, 2007).

Computer-to-plate technology (CTP) increased the efficiency of pre-press processes in all printing systems and reduced the use of water significantly. Moreover, other chemicals such as photographic film and photographic developer containing silver and print developer were not used. Thus, the factors having negative effect on the environment due to the waste film, waste developer and water consumption and causing waste formation were eliminated. Using metal by engraving instead of using acid in preparation print developer for gravure printing, is one of the important measures minimizing the environmental impact of pre-press processes.

Solvent Impacts in Printing Environment

Printing environment is usually the major source of emission due to the storage, usage and final disposal of chemicals and liquid waste. Most common emissions caused by printing process are gases and emissions of VOC caused by process chemicals and cleaning solvents. VOCs such as xylenes, ketones, alcohols and aliphatic are available in printing inks, dampening water solutions and cleaning solvents. The solvents used in cleansing of printing plates, blankets, rubber rollers and metal cylinders are traditionally petroleum-based products including naphtha, mineral content alcohols, methanol and toluene, xylene, methanol, MEK (methyl ethyl ketone), glycol ether, TCA (trichloroethane), etc. (NSW, 2006).

VOC and HAP Emissions in Printing Performed with Water and Solvent Based Inks

Pigments and binders are non-volatile solid components of the ink mixture. However, solvent-based inks include alcohols and esters as volatile organic components that have the concentration ranging from 50% and 70% (US EPA, 1980; Saad, 2007). The amount of solvent retained by flexo, gravure and screen-printed products is 3-4% of total ink solvent used. The solvent in the printed ink content, except for the one held by the printed material evaporates in its own environment after the printing process (Hettige, Mahanama, & Dissanyake, 2001). While the majority of this solvent is released to the air, the remaining part continues to blend into the environment for a long time right after the application albeit at a diminishing pace (Özçelik, 2006). VOCs contribute to atmospheric photochemical reactions. VOCs mean organic solvents and diluters releasing to the atmosphere during the

printing process in practice. Around 75-90% of the emissions of volatile organic compounds releasing from ink dryers exhaust into the nature, depend upon the printing speed, frequency of printing hesitation, ink solvent compound, printed product, design and efficiency of drying systems. Most of the emissions in the production environments are caused by solvent evaporation in the ink tank and the solvent evaporation on printed product in the drying systems between uncontrolled printing units. The amount of leakage evaporation depends on volatility of the solvent, temperature in ink tank and in the environment, design and efficiency of dryer, the time and frequency of printing machine's pause and restart (Jones, 2004). The amounts of potential VOC or the air-pollutant emissions are equal to the amount of solvent used during the printing process (US EPA, 1982).

The solvents widely used in printing industry are ethanol, toluene, ethyl acetate, isopropanol, n-propanol, hexane, toluene-xylene-naphtha mixture, methyl ethyl ketone, isopropyl acetate, n-propyl acetate, glycols, glycol ethers and water (Özçelik, 2006; Rösch et al., 2014). Organic solvent-contain heat-set web offset, flexographic, gravure, non-impact (digital) and screen printing inks are all possible sources of VOCs. While solvent based inks are widely used in flexo, gravure and screen-printing systems, the use of water-based inks is limited (Özçelik, 2006). Liquid inks used in flexo and gravure printing have pretty volatile solvents. (e.g. aliphatic and aromatic hydrocarbons, alcohols, ketones and esters) and they can dry rapidly due to their volatility; these inks put VOCs into the air during the printing process (Saad, 2007). The use of water-based inks as emission reduction alternative is limited, because some non-absorbent substrate surfaces with high surface energy are not printable due to the difficulty of adhesion and evaporation (Jones, 2004; Sensorex, 2017). Nevertheless, use of water-based inks is encouraged due to some environmental concerns (Aydemir, 2016).

During the flexo and gravure printing process, the raw ink is diluted with solvent. In these systems, the ink mixture is transferred constantly to the printing material surface through the plate cylinders. After the first colour is printed, the printing material moves across the heat-set air dryer to evaporate the volatile solvent in the ink. Thus, it is provided that the first printed colour be dried by vaporizing the volatile organic compounds in the ink. This process is repeated for all other colour printing units (US EPA, 1980). As a result of the drying process, VOCs recirculating in dryer are released into the air without any processing (filter or afterburner) and they become an important source of environmental pollution (Saad, 2007).

VOC and HAP Emissions in Printing Performed with Oil-Based Ink

Production of printing ink releases pigment extenders and potential VOC emissions into the atmosphere. The materials containing VOC and HAP used in sheet-fed offset printing method are isopropyl alcohol or dampening solutions, ink, upper varnish, lacquer and cleaners of other printing compounds, blanket and roller washers, ink oils and coatings.

Isopropyl alcohol (IPA) is traditionally used to control the physical features of dampening solution. The use of flammable and toxic isopropyl alcohol in offset printing dampening solution at the rate of 8-10 percent is the primary cause of VOC emissions polluting the working environment (Rossitza, 2015; Government of Canada, 2016).

No retention or release factor for VOC and HAP in other materials used in dampening solutions, blanket washers, coatings or sheet-fed offset printing processes has been introduced. Thus, emissions of these materials are considered to be released into the atmosphere (US EPA, 1982). Changing to waterless offset (dry offset) eliminates the VOC emissions caused by IPA. However, this requires a large initial investment.

The inks used in heat-set web offset printing contain high boiling mineral oils. During the process where these inks are dried in coated paper surface, solvent oils are evaporated at the temperature of 120-150°C. However, the gases formed during the process of evaporating the mineral oils are released into the nature and increases air pollution.

In UV curing, printing stability and printing quality are at a good level. The reason is that the chemical reaction does not start until the energy is applied during the drying process. Therefore, there is no VOC problem (Argent, 2008). The lack of solvent in UV ink, turns the UV curing into an attractive option in cases where the solvent emissions should be reduced (Brilliant Universal Limited, 2020).

VOC and HAP Emissions in Post-Press Processes

Materials containing VOC and HAP used in post-press processes are adhesives, binding and finishing equipment and glues. Using water-based adhesives for binding and self-adhesive labels will reduce the negative impact on the environment.

The Use and Storage of the Solvents

National and international legislations impose obligations on both producers and the users of a solvent.

Solvents should be labelled in accordance with the provisions of the regulations. The adhesive should include producer information, name and formula of the chemical, trade name of the product, intended usage area and hazard symbols.

Solvents should be sealed-packaged where there will not be any leakage, spreading, etc. during normal storage and transportation processes. The shape and label of the package should not look like the packages of foodstuffs in terms of general view and scope.

Solvents should be stored in a manner that they will not damage the environment and human health. Necessary measures should be taken so that these materials will not be misused by irresponsible individuals.

Issues to be Considered During the Use of Solvent and Material Containing Solvent

Solvents may have the feature of *'hazardous chemical'* according to the feature of chemical materials they contain, and they may also have the feature of hazardous waste as a result of its usage. While a specific part of the solvents expired in printing is released to the atmosphere as air emissions through ventilation and process pipes, other specific part evaporates and vanishes into the air. As in other industrial facilities, precautions that will ensure an ideal working environment in accordance with Occupational Health and Safety Legislation should be taken by measuring the degree of solvent in the environment. The employees having health problems due to the working in the printing companies with solvents should be prevented. For this purpose, the following risk control measures should be taken in printing facilities:

- Personal protective equipment should be used in accordance with Occupational Health and Safety Legislation.
- Unnecessary use of halogenated solvent should be avoided.
- Water based product without solvent should be preferred.
- Multipurpose solvent use should be preferred rather than using separate solvent for each process.
- Solvents or products containing solvent should be used in well-ventilated zones.
- Attention should be paid to warning information and safety recommendation on the labels.
- Solvents or products containing solvent should not be thrown away into the sewer.
- Contact of solvents or any product containing solvent with the skin should be avoided and protective equipment should be used when necessary.
- Solvent should never be used to remove the materials such as paint, oil, etc. on the skin.
- Solvents should be preserved in closed areas and the leak-proof containers should be used for the wastes of solvent.
- Unless necessary and suitable ventilation is available in closed areas, materials containing solvents should not be used and appropriate masks should be used in these areas when necessary.

Conclusion

Printing ink manufacture results in the potential emissions of VOCs and pigment/extender dusts to atmosphere. Therefore, it is a technical imperative to reduce VOCs in petroleum-based printing inks to meet environmental regulations without sacrificing functional properties. Reducing VOC's is a technical obligation. In this context, mineral oils and hydrocarbon solvents used in production of cold-set, heat-set and sheet-fed ink should be minimized or they should be replaced with the solvents with low aromatic content (linseed–soybean oil-based, etc), if possible. The emissions of volatile solvents used in production of flexo and gravure printing inks, should be kept at minimum by using fully enclosed systems. Emissions of volatile solvents used in the manufacture of flexographic and gravure inks are kept to a minimum by use of fully enclosed or covered systems. Non-recyclable liquid wastes produced by ink manufacturers and printing companies should not be discharged to the drainage, they should be moved away from the environment by accredited waste management companies. Process water should be purified and recycled, and the precious chemicals and compounds should be regained.

Since not any ink technology or printing process offer a universal environmental solution, most appropriate production and ink option should be identified by taking the factors such as substrate absorptivity, source of energy, energy consumption and carbon footprint into consideration. Excessive ink consumption will certainly have adverse effects on the environment, because of higher consumption of energy resources. Therefore, environmental sustainability of printing can be achieved by keeping ink consumption at an optimum level in the printing production process.

There are many ways to prevent the VOC emissions. Usually, these require changes in raw material types or production process. When selecting the raw material, the requirements of special environmental protection legislation such as Packaging and Packaging Waste Directive and Restrictions on Hazardous Substances Directive for the printed materials and products should be taken into consideration. Disposal/Replacement and process modification is a control step that should be considered in each workflow if there is a solvent risk. Closed loops that does not produce any waste and preserves precious raw materials should be designed. VOC containing chemicals can in many cases be substituted with other agents that have lower environmentally and health effects. The option of not using solvent or replacing it with harmless or less harmful solvent should be considered. Water and plant-based systems should be preferred to a certain extent if possible. Thus, the amount of VOC released into the atmosphere and hazardous waste will be less.

Various emission control equipment and techniques can be used to control VOC vapours. For a modern printing facility, air pollution control system consists of two categories: recovery of evaporative solvent or disposal of the solvent. The solvents should be disposed according to the waste management hierarchy. Solvent recovery is the only available method controlling VOC emissions coming from printing machines. Solvent recovered with the recycling system should be directly reused in printing process. For instance, in gravure inks, solvents can be subjected to recovery phase above 98 percent and recovered solvent can be reused in ink production.

European REACH Regulation (EC) regarding the use of certain chemicals and volatile organic solvents should be taken into consideration in terms of human health and environmental effects. Certain activities that may damage the environment and human health in printing companies, should be controlled. The employees of printing house should be trained about keeping the use of solvents at minimum and producing without causing pollution or problems in the environment.

In production line, the equipment reducing ink, dampening water solvents, cleansing solvents and other contaminant emissions or applicable regulations should be taken into consideration.

There are two ways of reducing VOC emissions from the dampening systems: IPA can be replaced with alcohol substitutes, or the degree of evaporation can be reduced. Changing IPA to glycol- or glycol-ether based alternatives can reduce VOC emissions. In addition, the evaporation of IPA can be reduced by refrigerating the dampening solution. Similarly, solvent evaporation can be slowed down by using cooling systems in flexo and gravure printing ink tanks.

Planning should be carried out in order to keep washing needs at minimum and efficient blanket washing systems that use the least amount of blanket washing solvent should be preferred. An important retention factor in determination of VOC and HAP emissions are low vapour pressure cleaning solutions used with swabs. Swabs should be preserved in a closed container when not in use. They should be disposed by a licensed effluent treatment plant after they are used.

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Innovative and sustainable toothpaste packaging design

ABSTRACT

Oral care products and especially toothpastes, are vital for the human daily hygiene. Nowadays tooth brushing is, without a doubt, an integral part of preventative dentistry, but on the other hand the extensive use of toothpastes has a great impact on the environment. Traditional toothpaste tubes have many negative aspects, in terms of usage and recycling. Their modest size, mixed and merged materials, remnant toothpaste inside toothpaste tubes and other tube based containers, make them difficult to disassemble and recycling almost impossible. The main objective of this study, is to investigate the disadvantages of the toothpaste packaging and the proposal of new innovative packaging solutions, which will not only reduce the environmental impact that traditional toothpaste tubes cause, but will also be user-friendly. In this paper, a combination of literature survey and market research is being presented. Finally, based on the findings and well-established techniques, a number of innovative, user and environmental friendly toothpaste packaging is proposed.

KEY WORDS
Packaging design, toothpaste, eco-design, sustainability

Anastasia Malea [1]
Anastasios Tzotzis [2]
Athanasios Manavis [2]
Panagiotis Kyratsis [2]

[1] International Hellenic University, School of Science and Technology, Thermi, Greece
[2] University of Western Macedonia, Department of Product and Systems Design Engineering, Kila Kozani, Greece

Corresponding author:
Panagiotis Kyratsis
e-mail:
pkyratsis@uowm.gr

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Introduction

Nowadays, more and more consumer product industries lean towards sustainability and green manufacturing. Thus, areas such as eco-friendly packaging design attract many researchers. Svanes et al. (2010) described a holistic methodology for sustainable packaging design. With the proposed methodology authors studied the combined systems of packaging and the packaged products across the whole distribution chain, from manufacturer to end consumer and the life cycle from raw material extraction to the waste phase. Alexopoulos, Kyratsis & Efkolidis (2011) used the principles of industrial design engineering and the use of advanced CAD/CAM systems to propose a number of different innovative packaging designs for traditional products. These designs can be used for both the everyday consumption as well as the feta cheese touristic promotion. Ulrich & Eppinger (2012) analyzed techniques of concept generation and selection in order to reach the stage of testing and manufacturing. Efkolidis & Kyratsis (2012) focused on the development of a novel methodology called Ecology Push that aims to help designers to educate customers through their work and motivate them towards a more sustainable way of life. This methodology takes into consideration the economic and environmental aspects of product design. Kyratsis et al. (2015) used a different approach in nature-based methodology which uses similarities based on the geometrical form or/and the functionality. The proposed conceptual product design framework supports and highlights the necessity of a nature-based design to all product industries. Dimou et al. (2017)

presented a case study that refers to the design of an intelligent, programmable shoe for pregnant women made of synthetic biological material. Authors implemented a research methodology based on a literature review and a series of interviews with some of the experts in the field of physiotherapy. Manavis et al. (2019) proposed a nature-based conceptual product design methodology and included in their work a number of case studies of in-store displays. The work by Carli Lorenzini & Olsson (2019) aimed to increase knowledge about medication and health care products packaging. In addition, authors presented the constraints that occur during the design process of such packaging concepts. Kovačević, Brozović & Itrić Ivanda (2019) investigated the influence of the eco-mark on the product packaging to the perception of the product and the attractiveness of its packaging by carrying out two different experiments.

The main objective of this study, is to investigate the disadvantages of the toothpaste packaging and the proposal of a new packaging solution, which will not only eliminate the environmental impact that traditional toothpaste tubes cause, but is also user-friendly. After a brief marketing research of toothpaste market and the presentation of the new packaging designs, an environmental analysis was performed with the SolidWorks™ Sustainability module, in order to select the most sustainable materials and the most sustainable manufacturing method suitable for the specific design.

Research and Analysis of the Design

Market research

The growing awareness of oral hygiene, product innovation in new market segments and the frequency of launching in existing segments, have led to a large increase of sales in major markets worldwide. As a result, the toothpaste market is regarded as one of the most dynamic parts in the oral hygiene market.

According to data from Global Industry Analysts, in 2012, Europe is considered to be the largest toothpaste market in the world and its value is estimated to be US$5 billion, with UK having precedence, while Asia Pacific is considered to be the fastest growing market of toothpaste globally, with annual growth rate of over 4% (Sriram & Pugalanthi, 2013). In particular for the United Kingdom, the share of the toothpaste market is £330 million from the total amount of £840 million. As a result, there is a large increase in competition in order to differentiate the toothpaste on the shelves of supermarkets, and manufacturers, have made efforts to turn the toothpaste into high quality product, according to specific dental needs and age groups. Thus packaging options for consumers are countless and clearly upgraded. They range from pump dispensers to aerosols, and brands in order to attract the attention of consumers, they have turned into bright metallic prints with outer cartons to be decorated with foil blocking, high color printing and other more special techniques such as embossing and holographic printing that provide more intricate textures.

In general, there is the perception that the use of metallic and foiling in a packaging supports the value of the brand and gives a more luxurious feel to the product. On the other hand, a visit to the supermarket, proves that the industry is still dominated by the tube, a packing device which first appeared in 1892, and despite the efforts for innovation in packaging, consumers do not dare to change their habits, while the competition game is held between the main OEMs that have the five leading brands in sales.

Another demonstration of how slowly this sector evolves, is the adoption of laminate tubes globally. Although today, metal tubes have been eliminated and replaced by polyethylene (PE) or aluminum laminates, it took several decades from their initial launch in 1972 to be established. Australia had the exclusive sale of plastic in 1983 and began to penetrate into the Chinese market in 1997, when an Indian manufacturer of Essel Propack, started operating there (Elliot, 2010).

Today the introduction of laminate packaging has increased significantly in many types of packaging apart from the toothpaste, such as coffee packs and pet food pouches, as the benefits that offers, compared to the established packages, are numerous. Nevertheless, the presence of residual product in combination with the difficult separation of the laminate, makes the recycling process particularly difficult or impossible. An assessment of the size of the UK market, which is estimated at 193000 tons of packaging annually, containing an average of 97% aluminum foil by weight and the growth rate of laminated packaging in about 10% per year, are sufficient to consider the damage being done to the environment (Slater & Chrichton, 2011).

Below is a list of all types of toothpaste packaging that are commercially available until now:

- Metal tubes
- Plastic tubes
- Laminate tubes
- Stand-up tubes
- Pumps

Environmental approach for design

As simple toothpaste tubes become more complex, the more they harm the environment. Old style aluminum tubes, made from a single slug of metal, were much

more recyclable than laminated ones, who replaced them. On the other hand, the extraction of bauxite, from which aluminum is made, is also detrimental to the environment, as the melting process is much more energy intensive. In addition, tubes that are still made of aluminum, may carry a label stating that they are recyclable, but in fact a disposable tube of toothpaste, which has product residues, a plastic cap and a thread, is not welcomed in an aluminum can. Switching from the use of aluminum to the use of plastic for the tubes, it could be a positive action in environmental terms, but dentifrice residues can give rise to the same problem. A plastic tube, may contain high contamination to be introduced into a recycling system, while it takes about 4000 empty plastic tubes to convert into a ton of plastic (Stypka et al., 2005). The benefits of laminates, from performance aspect are numerous and therefore its use is growing rapidly. In contrast to these advantages, laminated packaging systems have a serious drawback. The combination of plastic and aluminum in the waste, presents a technical challenge to recycle them, so these materials are discarded by conventional means (Slater & Chrichton, 2011). Environmentally this is undesirable, since aluminum and plastic resources used for production, are wasted and should be extracted from the nature, in order to renew them. This has consequences on economic level too, as this method is very costly and the significant value of both the aluminum and the plastic could be exploited, if there was a sustainable way to recycle (Slater & Chrichton, 2011). Despite their lightweight nature and the relatively low price, so far they are strictly non-recyclable, since the collection and recovery of recyclates is driven by weight-based targets. It could be applied, if replaced by heavier packaging options, but again their viability is controversial. There is currently no sufficient and proven technology, capable of separating the plastic from aluminum, and to fully recycle these materials in an efficient and cost effective manner (Slater & Chrichton, 2011). The only sophisticated plastic / aluminum laminate recycling operation created by Enval Company, which was formed after research at Cambridge University's Chemical Engineering Department, where they managed to separate the aluminum from laminate by heating it in low oxygen environment to evaporate the plastic. After 12 months of operation of a pilot project conducted at Cambridge, the company has now opened a large-scale plant in Luton. Although Enval collaborates with major toothpaste brand owners to develop a recycling certification system, this expertise is not yet widespread around the world (Elliot, 2010).

Another issue that burdens the environment, and should be reviewed if its use is necessary, is the cardboard outer box. Cartons and tubes cooperate as a system for the protection of the product during distribution and provide stability to the retail shelf, while their use ends there. Typically they weigh 14.5gr for a tube of 100ml. Whilst through the years, it has been observed that the energy and the material used for the tube, has been reduced significantly with the aid of the carton box, as wastage would be greater if destroyed (INCPEN, 2011). This of course, could change if there were attempts to redesign the packaging of the toothpaste. In dental care products containing medicinal application, an instruction leaflet may be necessary, so it still remains essential a packing box. Nevertheless, the tendency for packages such as plastic stand-up tubes, which do not require an external box, is constantly concerning toothpaste brands. Another view prevails, which claims that consumers should extend the end-use of products manufactured after the collection and processing of recycled materials. Of course, a toothpaste carton may consist at 80% of recycled paper, but this does not imply that it is good to use packages that are no longer necessary. For that reason, it is important to take seriously into account contagion effects that lead to certain changes made in the name of improving the environment (Stypka et al., 2005). Finally, toothpaste residues caused by each type of tube, where the toothpaste is packed, definitely worth mentioning, since they not only hinder the recycling process, but also have an overall negative impact on both users and the environment.

Packaging design requirements

The simultaneous satisfaction of all the design guidelines is a major challenge in the design process as there may be conflicting features which are not feasible to be compatible. In Table 1, these requirements have been recorded, and divided into four basic categories, based on functionality, ergonomics, sustainability and aesthetics, so that it becomes easier to understand user needs, and they are presented in a hierarchical order so that later can become an essential criterion in the concept selection stage.

Table 1

Design requirements

Functionality	Ergonomics
Maintain the product fresh	Minimizing required force
Ability to stand up	Ergonomic grip – stable holding
Possibility of Controlled Dosage	Ability to use with one hand
Reduce UPR levels (facilitate empting)	Ease of opening – closing
Re-closability	Facilitate left – right hand use
Avoid accidental losing the lid	Prevent slipperiness
Safety lock	Intuitive use
Range of sizes based on needs	Narrative Instructions
Travel size – Portability	Indicate residual quantity
Modularity – space saving (enhance stacking, warehousing, shelf display and transportation)	Differentiation of product range
Sustainability	**Aesthetics**
Avoid over-packaging	Harmonization with bathroom environment
Use of sustainable materials	Differentiation from competitive products
Recyclability	Follow packaging trends
Reusability	Make fashion statement
Reduced waste bulk	Natural – Eco Aesthetic
Possibility of cleaning residues of container	Provide a sense of purity and freshness
Facilitate disassembly for material separation	

Ideation

For the creation of the initial concepts, some tools were used, in order to enhance the creative process and trigger the generation of new ideas. In this phase, the brainstorming technique was employed which is a proven tool for such cases (Vasileiadis et al., 2019), while an attempt for mapping these ideas, as shown in Figure 1, with central axis the design requirements mentioned above. At this point, it is important to mention that the decomposition of the main problem and the treatment of each sub problem separately, were particularly helpful to propose solutions, which lead to the creation of initial ideas.

Subsequently, a visual representation of the proposed solutions presented in the mind map above, was carried out with the ultimate aim to be further interpreted and to study the possibility of their achievement. Inspiration was drawn from either various existing mechanisms, either by nature and created a fertile ground for the study of more specific characteristics that can contribute to the creation of an integrated concept as structure, form, color, texture, materials, as well as aesthetic qualities.

Concept Generation

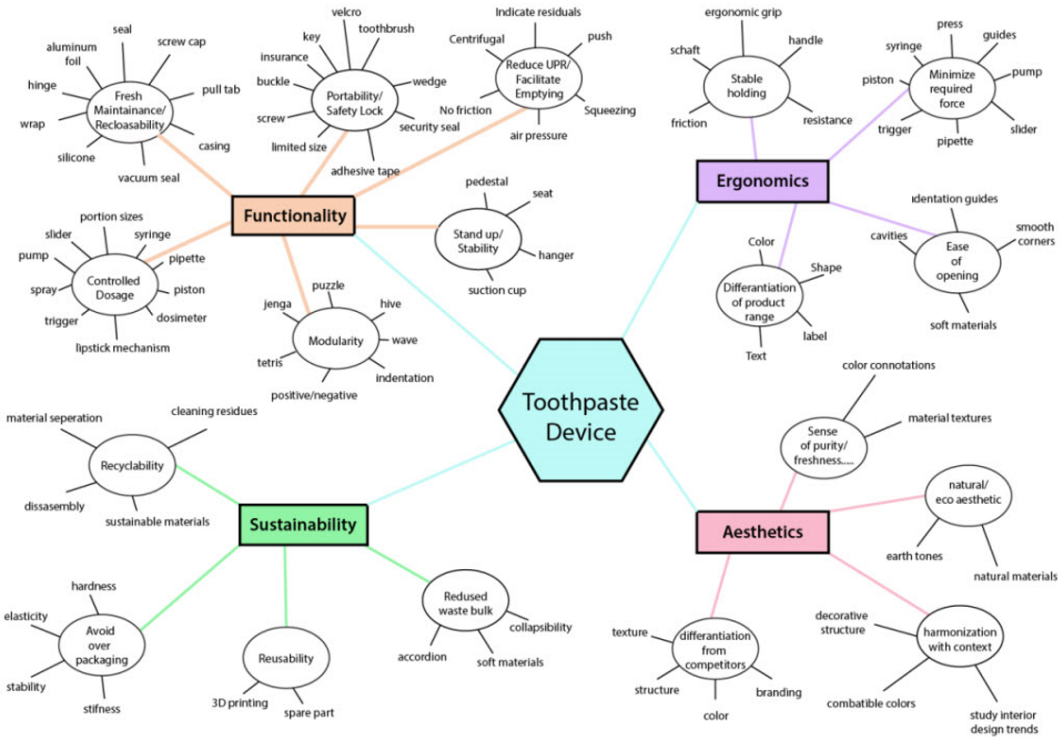
Conceptual structures

The next step of this study was the investigation of the morphological features of the object under design. Based on the design requirements that are included in Table 1, it is concluded that the criteria that primarily affect the structural elements of the packaging are mainly ergonomic. Some of them are steadiness of holding, left- right hand usage, minimization of slipperiness and intuitive use. From the perspective of sustainability, the recyclability also played an important role. As a key condition a number of issues were identified i.e. the cleaning capability of residues, disassembling for separating materials and the possibility of reusing the outer case by replacing the spare part. Finally, a key factor that affects the aesthetics, when designing a package, is the brand identity, which is not taken to consideration in the current design brief (the redesign of a commercial brand). Together with the conceptual structure investigated the prospect of creating a virtual brand that could incorporate aesthetical criteria was considered.

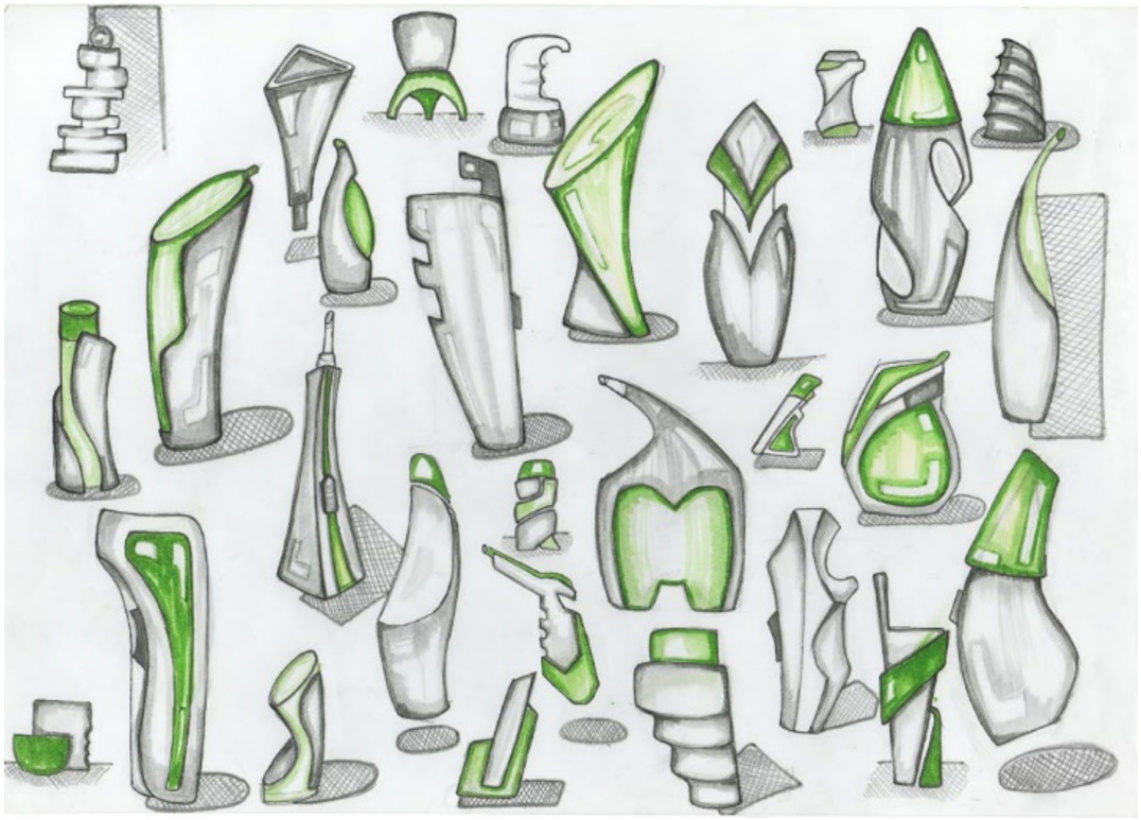
Figure 2 illustrates the exploration of different structural concepts and the inspiration drawn either by nature or from objects of art or the aesthetics communicated from perfume bottles. At the same time, upgrading of toothpaste aesthetics could be accomplished by achieving harmonization with the bathroom environment.

Presentation of the selected concept

The main objective and concern, on which the idea of the proposed design concept was based is to improve the operating mechanism of the toothpaste. In order to accomplish this, several tests were conducted and many combinations of the proposed solutions were created, some of which were rejected by the



» **Figure 1:** *Mind map based on the design requirements*



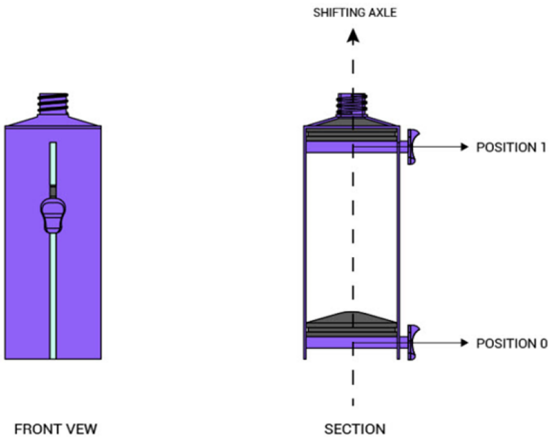
» **Figure 2:** *Conceptual structures sketches*

hierarchy of the design requirements or because some solutions of these contradicted some other design guidelines, such as the ability to use with one hand, which is particularly important for the smooth operation of the tooth brushing process. Hence the selected concept, which meets the majority of design requirements, is based on the piston mechanism.

Some of the advantages offered by this mechanism are the following:

- the required strength of the piston stays constant throughout the following path
- the flow velocity can be maintained constant
- the path length is easily and accurately adjusted
- the sliding speed of the movable head is relatively low
- smooth and linear movement
- silent operation

Figure 3 illustrates the operation of the basic idea of the main mechanism on which the development of the final concepts is based. This mechanism consists of the main vessel, which is open at the bottom and is filled with toothpaste. The providing of the dentifrice is extracted from the vessel with the aid of a piston, following the movement on the shifting axis, from position 0 to position 1, as shown in Figure 3. The piston has bonded to its surface, a rubber component, which assists by friction with the walls of the container, the extrusion of the dentifrice abroad and simultaneously provides the airtight seal of the container.



» **Figure 3:** *Operation Mechanism of the proposed concept*

In this manner, the design enables the user to exploit the entire product, by reducing the wastage, without requiring much human effort. The piston in turn, has a button extruded from the side surface, which slides between the slit, which is formed at the side of the container. At the same time, the sliding button could function as an indication of the amount of toothpaste remaining in the container. Finally, to protect the product from contact with the ambient air, the slot could be airtight with an aluminium foil, which will tear gradually during the upward

movement of the sliding handle. Eventually, the user should use both hands to properly handle the packaging as long as the content is below 50%. Later, it is possible to use only one hand. Figure 4 depicts the manner of use of that mechanism and its interaction with the user.

» **Figure 4:** *Conceptual sketch of the proposed mechanism use*

Concept development

The brand name chosen for the design of the first concept is “Say Cheese!”, and is an alternate way, especially popular among photographers, to ask someone to smile. The objective of the specific brand is to transmit a playful experience for younger audience and this is achieved by providing a modern look, which is relevant to comic aesthetics. The message which is communicated through the design of graphic elements is the uniqueness that each individual human smile has. This uniqueness of the human denture as illustrated graphically, also serves to diversify the range of products of the same brand. This differentiation is also achieved by the use of strong and saturated colors, while further enhances the funny and relaxed mood that the brand tries to promote, while contributing to a more eye-catching result (Reimann et al., 2010; Vladić et al., 2016), in comparison with competitors, as selected colors vary considerably from those used so far in the toothpaste market.

In figure 5, the implementation of brand is presented visually on the packaging and some structural elements of the package can also be observed. The selected form is characterized by simplicity and contrasts with the loud aesthetic of the brand, in order to achieve a balance.

The name of the second brand under investigation is “Dental Fresh” and the visual communication could be considered more conventional, because design is closer to the style and aesthetics of classical toothpaste packages, as most people have in their minds, whilst the graphic references clearly refer to the content of the package. The specific aesthetic was intentionally chosen in order to place more emphasis on morphological elements of the package. The selected colors also follow the color palette of the content, and the communication of the aesthetical requirements is achieved in this manner. These are the sensation of freshness, purity, cleanliness and environmental friendliness.

Regarding the structural elements of the package, an attempt was made to further improve the ergonomic factor, compared to the previous idea so as to mainly foster their stability to hold during use. The visualization of the result is shown in figure 6. For the outer casing transparent materials were selected in order to attract the interest of the public, and addi-

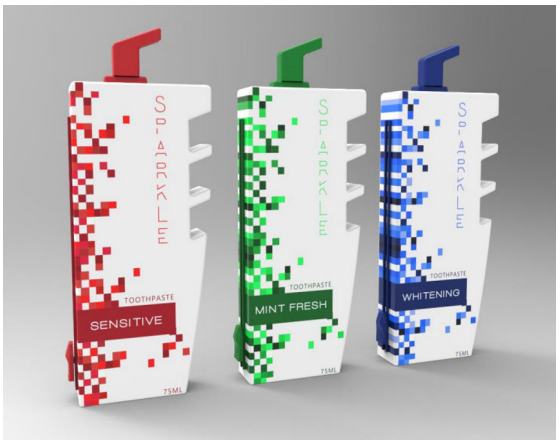
» **Figure 5:** *Rendered image of the “Say Cheese!” concept and product range differentiation*

tionally for the label to be evident, which has been applied to the surface of the container interior part.

» **Figure 6:** *Rendered image of the "Dental Fresh" concept*

The name chosen for the third brand is "Sparkle" and refers symbolically to the shiny effects, which might have the use of this specific toothpaste. The brand image of this idea is further strengthened by means of graphic elements, which sought to create the sensation created by light reflection, when incident on shiny surfaces (i.e. water), through the use of geometric abstraction and different hues of the same color. Inspiration is drawn from pixel art in order to be ascribed effectively with abstract way the glowing effect.

As shown in Figure 7 product differentiation is accomplished chromatically and more vivid, RGB colors are selected, which make high contrast with the white background. Morphologically, the aerodynamic shape of the package follows the design language of the brand and the notches on the right side of the package serve as a handle for better grip during use and avoid slipperiness.



» **Figure 7:** *Rendered image of the "Sparkle" concept and product range differentiation*

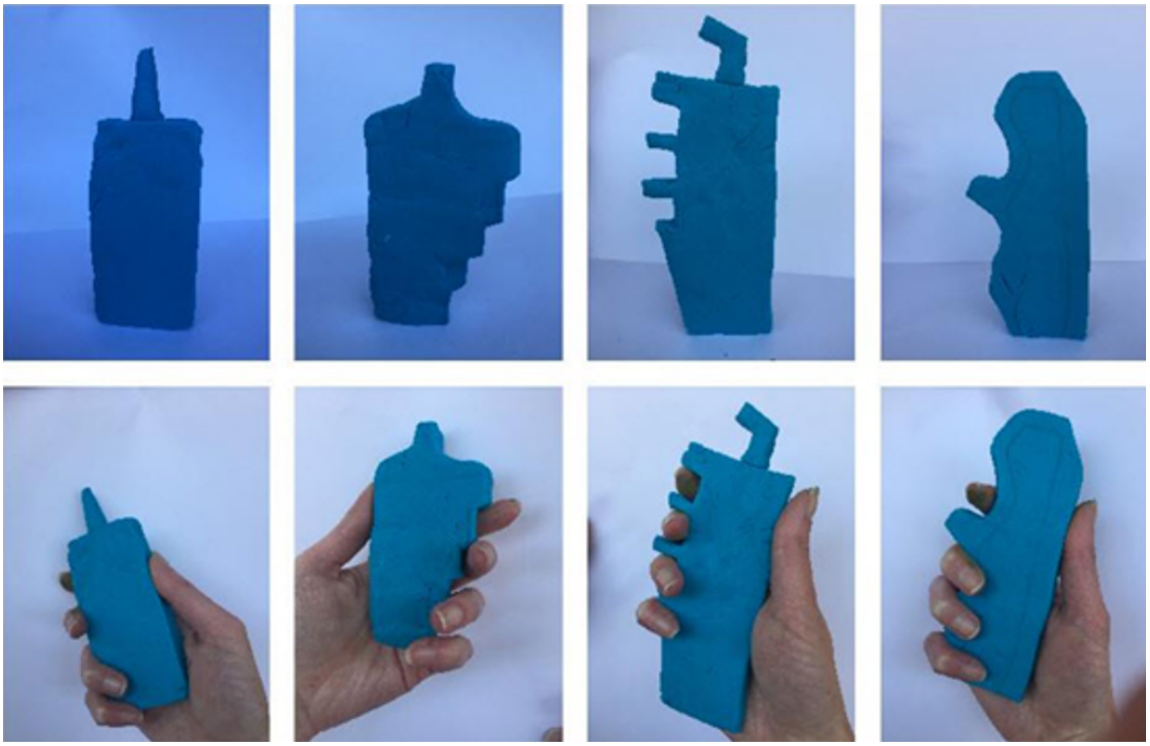
The last proposed brand is named "Crystalline" and is intended to convey a sense of crystal coolness. The unusual design of the outer case, as the name implies, is inspired by the structure of crystals, while the minimalist design of the logo attempts to promote a superior quality of the product. For the design of the label, a pattern consisting of divided triangular geometric forms was created. The same applies for the formation of the logo as well. Chromatically, an attempt was made to reflect the iridescent glow of crystals with different caps used for product range differentiation.

Morphologically, as shown in Figure 8, the asymmetry of the structure of the crystals was utilized except from aesthetical reasons, for the further improvement of the ergonomic gripping of the package. During the final phase of the packaging design for "Say Cheese", "Sparkle" and "Crystalline" concepts, it is anticipated to reduce the sliding button travel by adding a simple internal "piston-spring" mechanism for aiding user with the toothpaste extraction. In addition, the slider will probably be repositioned to the middle of the shell. The mechanism (piston-spring) will be positioned just below the sliding groove since the more orthogonal-oriented shell has more room for this addition compared to the cylindrical one.

» **Figure 8:** *Rendered image of the "Crystalline" concept and product differentiation*

For the better understanding of the form of each packaging case and in order to test their operating method and ergonomic usability, physical models were created made of clay (Figure 9).

This process was particularly fruitful to study the scale and dimensions of the proposed objects, make the appropriate refinements, begin the development process and the detailed design of the concept, as well as their realistic imagery that were previously presented.

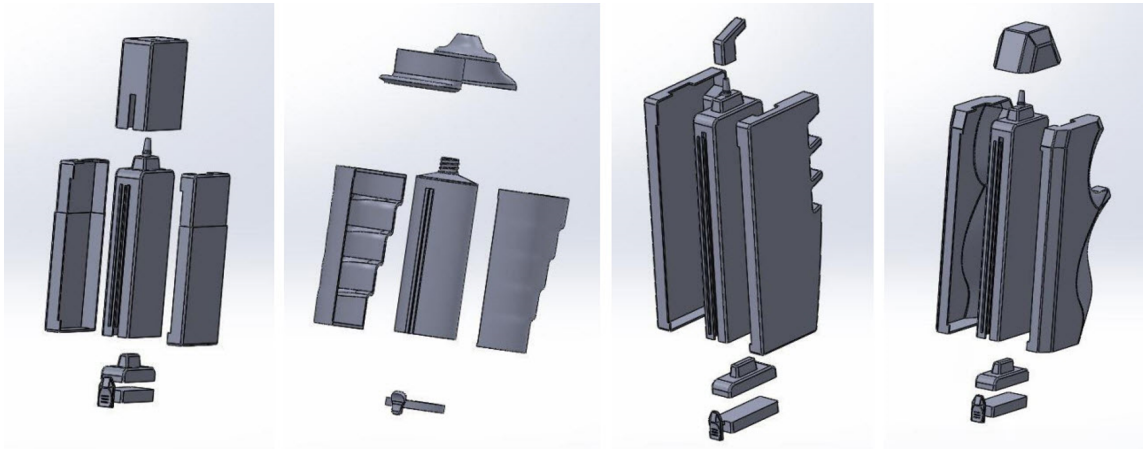


» **Figure 9:** *Physical mockups and concept testing*

Detailed description of the concept parts

Figure 10 illustrates an exploded view of the assembly and all the proposed concepts consist of four basic features. The lid, the inner vessel that contains the toothpaste, the outer casing which protects the product, and the sliding button that forces the toothpaste to extrude from the inner vessel. These parts are detachable in order to facilitate the recycling process.

In order to enable the user to exploit the entire product (by reducing the wastage without requiring much human effort), the design is based on the concept of the syringe. It consists of the main vessel, which is open at the bottom and is filled with toothpaste. The providing of the dentifrice is extracted from the vessel with the aid of a piston. The piston provides the airtight seal of the container. At the same time, a sliding button functions as remaining toothpaste indicator. To protect the product from contact with the ambient air, the slot could be airtight with an aluminum foil, which will tear gradually during the upward movement. The opening of the container has the necessary threads to screw the cap. In addition to this, the lid is either hinged or screwed cap so that during its use to be reclosable. The outer casing, has the specific structures not only for aesthetical reasons, but is designed in a way to ergonomically fit the hand of the user. Eventually, at the outer casing two thin strips of silicon are attached.



» **Figure 10:** *Exploded views of the proposed concepts*

Sustainability evaluation

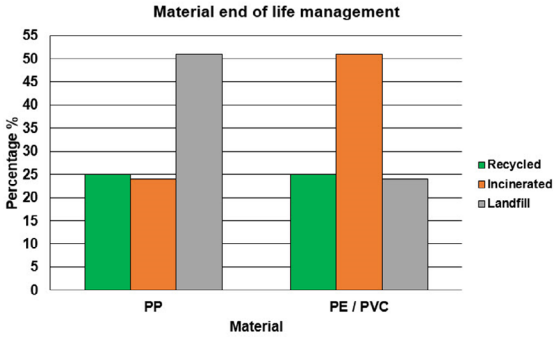
All the individual parts of the proposed concepts are designed to be from plastic materials but in order to evaluate the sustainability the fourth concept was selected due to the fact that it has the most complicated geometry. In order to select the most eco-friendly materials, a sustainability analysis has been performed in SolidWorks™ and the results are summarized in Table 2. Additionally, the end of life management for each of the materials evaluated in this study is depicted in Figure 11.

For the design of the lid, after a brief research, there are two candidate materials, polypropylene (PP) and low density polyethylene (LDPE), which have the most appropriate mechanical properties. LDPE is flexible and tough enough, whereas PP has high stiffness, good impact balance, high gloss appearance and good hinge properties since it is fatigue resistance, making it more suitable for the hinged lid. After the life cycle assessment study of the two materials it is concluded that PP is more sustainable, although it has greater financial impact. If we compare the results found in Table 2 we can observe that PP has sufficiently improved the design. The total measurements of carbon dioxide and other greenhouse gas emissions are estimated to be 0.011kg. In addition, the non-renewable energy sources used during the parts lifecycle and it is estimated to 0.271MJ. The air acidification is related with the emissions of sulfur dioxide and nitrous oxides that are responsible for the acidity of rain water, and is calculated to be $3.4e^{-5}$kg. On the other hand, water eutrophication, which concerns the overabundance of nutrients like nitrogen and phosphorous from waste water to the ecosystem, is measured to be $4.0e^{-6}$kg

For the design of the outer case, the same materials with the lid were selected, PP and LDPE, since the requirements for the mechanical properties are the same and the factor of non-breakability is very crucial in order to achieve the reusability and durability for longer lifespan. If we compare the results of the charts below, we can observe that PP has sufficiently improved the design. The total measurements of carbon-dioxide and other greenhouse gas emissions are estimated to be 0.032kg. Moreover, the non-renewable energy sources used during the parts lifecycle and it is estimated to 0.0824MJ. The air acidification is related with the emissions of sulfur dioxide and nitrous oxides that are responsible for the acidity of rain water, and is calculated to be $1.0e^{-4}$kg. On the other hand, water eutrophication which concerns the overabundance of nutrients like nitrogen and phosphorous from waste water to the ecosystem, is measured to be $1.2e^{-5}$kg.

For the inner vessel, the initial material for the test was PVC. After several tests with materials that have similar properties, we can conclude that high density polyethylene (HDPE), has improved the environmental impact of the design. It is worth mentioning that the total energy consumption for the both materials is approximately the same, since the energy required for the material procurement is slightly worse.

The plunger with the sliding button, requires a material that is rigid enough in order not to break easily due to the forces that are being applied to the slider. The baseline material was set to HDPE, whereas PP slightly improved the environmental impact.



» **Figure 11:** *Chart for the end of life management of proposed each material*

Table 2

Sustainability report results

Part	Material	Carbon footprint (kg of CO_2)	Total energy consumption (MJ)	Air acidification (kg of SO_2)	Water eutrophication (kg of PO_4)
Lid	PP LDPE	0.011 0.014	0.271 0.289	$3.4e^{-5}$ $3.6e^{-5}$	$4.0e^{-6}$ $5.8e^{-6}$
Outer case	PP LDPE	0.032 0.041	0.824 0.828	$1.0e^{-4}$ $1.1e^{-4}$	$1.2e^{-5}$ $1.8e^{-5}$
Inner vessel	HDPE PVC	0.046 0.069	1.2 1.2	$1.5e^{-4}$ $2.3e^{-4}$	$1.7e^{-5}$ $3.6e^{-5}$
Plunger with slider button	PP HDPE	0.010 0.013	0.273 0.281	$3.4e^{-5}$ $3.6e^{-5}$	$4.0e^{-6}$ $5.9e^{-6}$

Conclusions

Despite the fact that toothpaste market is one of the most dynamic segments of the oral care market, little innovation has been occurred on the packaging of toothpaste, considering the fact that the market is still dominated by the tube, a packaging device that was initially launched in 1892. Since traditional toothpaste tubes cause many functional and environmental problems, in the specific project has been made an effort to propose a new packaging design that is not only environmental friendly, since all the parts are detachable and from recyclable materials, that facilitate the process of separation and recycling and allows full export of the product from the package, but is also user-friendly. To enhance the environmental awareness, the device could also be reusable and the inside vessel containing the toothpaste, could be purchased separately in the market, as a replacement part. As far as the methodology of design process is concerned, it is concluded that every project has needs, that are unique and factors such as the objective of the project, the available information, the provided accessibility and timing constraints, which may affect the order and flow of the designing phases, while the need for evaluation, with the ultimate aim to filter information deemed necessary at each step, like the continuous feedback with the requirements.

The design proposals derived from this process, seems to achieve the objectives set on the design brief. However it is worth noting that the simultaneous satisfaction of all requirements is usually not feasible and constitutes a major challenge in the design process. For the selection of the material, it is concluded that is a huge chapter in product design application, and despite the fact that there are materials that are more sustainable than others, more considerations should be taken into account, in terms of financial impact, mechanical properties, optical properties, in order the design to give the best feeling to the product and find a better balance. At the same time, further research could be done with materials which allow full slipperiness of viscous liquids, in order to solve the problem of residues. Nevertheless, for the needs of this study, the used materials were more than one. PP was chosen as the best suit for the lid, the outer case and the plunger, whereas HDPE was chosen for the inner vessel.

Furthermore, the observation that more and more people have become conscientious about the environment and the products that chooses to use is very encouraging. The social responsibility that the designer has must be stressed and often the need for innovation and originality, in terms of improving the comfort of everyday life, can lead to waste of materials and destructive solutions for environment. The simplicity of the past might be an innovation of the future, since less is more.

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An investigation on printability of different solvent based inks by gravure printing onto various substrates

ABSTRACT

Gravure printing is an intaglio printing process, the image to be printed is engraved on the surface of the gravure cylinder, so that the image to be printed is embedded into the surface. The places engraved in the cylinder during printing are filled with ink, surplus of ink is stripped by a blade and separated for reuse. Print quality consistency and efficiency is high in gravure printing. It is also possible to print on different substrates. Ink systems, viscosity, surface properties of substrate material and dot structures on the gravure cylinder are the main factors that determine the print quality. Appropriate inks can be chosen depending on the material to be printed and finished product used area. Mostly solvent based inks are used. The aim of this study is to determine the solvent that can enable higher quality printing on different substrates, which are frequently used in the gravure printing system, and to investigate the conditions under which the ink-substrates interface relationship can be the best in terms of printability. In this study, IGT F1 laboratory type gravure testing machine was used. Polyethylene and polypropylene printable films are used as the substrate materials. Three different solvent-based inks are used, prepared with ethyl alcohol, ethyl acetate and isopropyl alcohol. Density, contact angle, surface energy and gloss properties of the printed materials were examined. The printability properties of selected substrates and inks have been determined.

Arif Ozcan [1]
Rasim Zulfigaroglu [2]

[1] Marmara University, School of Applied Sciences, Department of Printing Technologies, Istanbul – Turkey
[2] Marmara University, Institute of Pure and Applied Sciences, Department of Printing Technologies, Istanbul – Turkey

Corresponding author:
Arif Ozcan
e-mail: arifozcan@marmara.edu.tr

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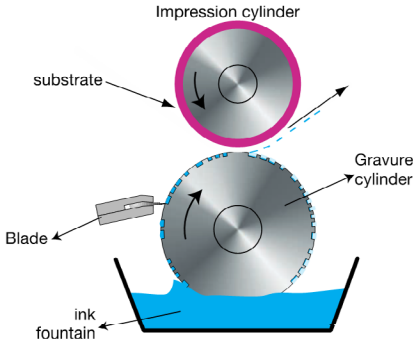
Gravure printing, printability, solvent based inks, surface energy

Introduction

Gravure printing is an intaglio printing process, the image to be printed is engraved on the surface of the gravure cylinder, so that the image to be printed is embedded into the surface. The places engraved in the cylinder during printing are filled with ink, surplus of ink is stripped by a blade and separated for reuse (Figure 1).

The image areas to be printed consist of honeycomb shaped cells or wells that are engraved into a copper cylinder. When the substrate material touches the gravure cylinder, the ink on the roller is transferred to the material and printing takes place (Gillett, 2003). The next step is the drying of the ink. Shortly, printing takes place this way.

As seen in the figure, the components of the printing system are the tank where the liquid ink is held, the engraving roller as a printing plate, the blade that is used to scrape the surplus ink, and the impression cylinder that enables the substrate material to take the ink from engraving roller. The primary function of the impression cylinder is to ensure that the substrate material is in adequate contact with the ink in the cells, ensuring the correct ink transfer from the engraving cylinder. The cylinder is typically steel coated with rubber or similar compatible material (Simseker, Kurt & Arman, 2012).



» **Figure 1:** *Schematic diagram of gravure printing (Kipphan, 2001)*

As the pressure in the impression cylinder increases, the contact area in the gravure cylinder and the pressure between the substrate material and the impression cylinder also increase. This contact area is referred to as the printing nip (Gillett, 2003). The purpose of doctor blade is to remove surplus ink from the engraving roller (Elsayad et al, 2002). The blade is generally a thin, flexible material made of steel or, in some cases, plastic. In general, the doctor blade moves in and out along the length of the gravure cylinder as it rotates. In this way, undesired particles or surplus inks are prevented from remaining under the doctor blade. The pressure adjustment should be done well with the gravure cylinder so that the doctor blade can scrape the ink properly (Neff, 2009).

Today, its use as rotogravure printing is common. It is basically the same as its working principle. Gravure printing is at the forefront with its high quality prints and high circulation prints in conventional printing systems (Lee, Mun & Yoo,2009). Print quality consistency and efficiency is high in gravure printing. It is also possible to print on different substrates. Ink systems, viscosity, surface properties of substrate material and dot structures on the gravure cylinder are the main factors that determine the print quality (Tora & Sharma, 2016).

Gravure printing is a sophisticated system. It is possible to print on numerous materials with gravure printing, however, widely prints on metallized films and plastic films (PE, PP, OPP, BOPP, PVC) (Goyat, Singh & Sharma, 2018). In general, the three main products and product groups printed with gravure printing are as follows;

- Publication
- Magazines, retail inserts, and catalogs
- Packaging
- Folding cartons, flexible packaging, and labels
- Product
- End-use items: Floor coverings, gift wrap, and wallpaper

Gravure printing in all these products and product groups guarantees consistently high print quality, even on low-quality paper and other substrates. However, due to the preparation cost of the engraving cylinder, it is preferred for high circulation prints rather than low circulation prints to lower the average unit cost. The most important feature that limits gravure printing is the cylinder preparation cost (Gamota et al, 2013).

It is only possible to print on different materials with gravure printing processes by choosing the appropriate ink for the material. Appropriate inks can be chosen depending on the material to be printed, finished product used area, and even environmental awareness or human health (Nguyen et al, 2015). Gravure inks are low viscosity liquid inks that can easily hold onto the engraved cells in the cylinder and allow them to be transferred to the substrate later. Mostly toluene based, alcohol based, water based and UV based ink options are common. Due to the increasing environmental and human health sensitivity in recent years, the use of water based ink is expected to increase (Park et al, 2015).

The image is created on the surface of the gravure cylinder by processing the gravure printing system. After the cylinder is supplied as a steel raw material, copper coating is made in several grades in order to process the surface. For image formation; the image to be printed with the digital engraving system (engraving) method is sent from the computer to the engraving machine (Joshi & Bandyopadhyay, 2014). The laser processing head moves in and out on the cylinder and renders the image to form dots (Figure 2).

In the processing head of the machine, there are the diamond tip for processing the image and the auxiliary cleaning tip, cutter tip, absorbent tip. According to the image data received from that machine, diamond tip opens dots on the surface of the copper on the cylinder. After the image is processed on the cylinder surface, its surface is covered with chrome so that it can print. After the cylinder surface processes are completed, proof is taken, and any errors are detected (Figure 3). The depths and width of the cells vary based on the amount of ink required to obtain the desired ink density and color in the printed image.

» **Figure 2:** *Gravure cylinder engraving*

» **Figure 3:** *Gravure printing proofing process*

In this study, prints were made with inks prepared with three different solvents on two different printing materials and the effects of variables on printability were examined.

Materials and Methods

Material

The raw materials (binders, dyestuff additives) for the inks to be prepared in the study were obtained from Siegwerg (Turkey). The polyethylene and polypropylene printing substrate used were obtained from a local manufacturer. All solvents used in ink dilution are of analytical purity and were purchased from Sigma Aldrich (Turkey).

Method

The cyan inks used in the study were prepared according to Table 1 under laboratory conditions.

In ink preparation, dyestuff, resin, different additives are weighed and mixed in a mechanical mixer at 1000 rpm. The viscosities of the inks obtained were adjusted with their own solvent for 20 seconds with a ford cup. The solvent type of the inks obtained is shown in Table 2.

Depending on the properties of the solvent, the amount of solvent in each ink varies, which changes the pigment concentration. The properties of the solvents are given in Table 3.

With the produced inks, gravure test prints were made on the surface of Polypropylene and Polyethylene films with IGT F1. The film specifications are given Table 4. The gravure printing plate is IGT F1 gravure plate (402:153:432). Printing parameters; 250 N printing pressure and 0.1 m/s printing speed.

Table 1

Ink formulation

Component	Percentage (%)
Resin	40
Cyan dye stuff	20
Additive	5
Solvent	35

Table 2

Solvent type ink name relationship

Ink Type	Solvent Type
F1	Ethyl Alcohol
F2	Ethyl Acetate
F3	Isopropyl Alcohol

Table 3

Used solvents and properties

Solvent Type	Boiling Point (°C)	Evaporation rate (Bu Ac = 10)	Flash point (°C)	Density at 4 (°C)
Ethyl Alcohol	81	33	13.9	0.79
Ethyl Acetate	77	62	-5	0.9
Isopropyl Alcohol	82.3	29	11.7	0.78

Table 4

Polymeric films specifications

	Moisture permeability $g/m^2/day$	The O2 permeability $cm^3/m^2/day$	Operating temperature range °C	Enthalpy J/g	Glass transition temperature °C	Thermal decomposition °C	Specific gravity g/cm^3	Surface Energy mN/m
PE	20	6500	-50/80	70	-80	475	0,910	31
PP	6	2250	-18/135	90	-20	460	0,905	29

The wettability of polymeric films was determined using the contact angle with the sessile water droplet method. The characteristics of surfaces were determined with contact angle (TAPPI T 458). Distilled water was used as standard wetting fluid in a Pocket Goniometer Model PG-X, (FIBRO Systems AB, Sweden), which was measured as a function of time. The program is of version 3.4. Images of water droplets were then recorded by using a CCD video camera. Surface energies were calculated on the contact angle by ASTM D5946 standard test method.

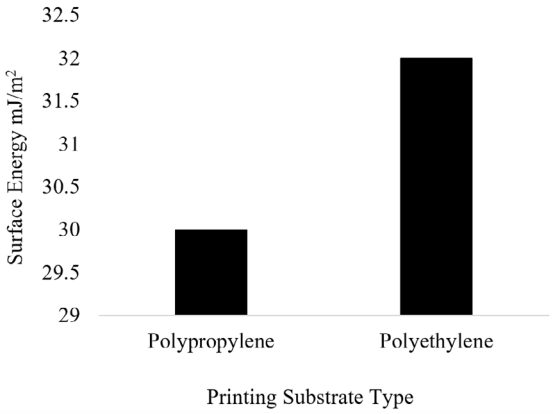
The color and density measurements of the prints on different substrates were made by CIE L*a*b* method using X-Rite eXact portable spectrophotometer according to ISO 12647-2:2013 standard (Tutak, Beytut & Ozcan, 2018). The measurement conditions of the spectrophotometer are determined as polarization filter with 0°/45° geometry with 2 observer angle with D50 light source in the range of 400-700 nm. The difference between the colors of the different prints was calculated according to formula 1 according to the CIE ΔE 2000 ISO 13655 standard.

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \frac{\Delta C'}{k_C S_C}\frac{\Delta H'}{k_H S_H}} \quad (1)$$

The gloss measurements of prints were carried out with BYK Gardner GmbH micro Tri-gloss 60° geometry in accordance with ISO 2813:2014.

Results

Contact angle and surface energies of polyethylene and polypropylene printable films are measured and given in Figure 4 in order to determine the printability properties of the substrates to be used.

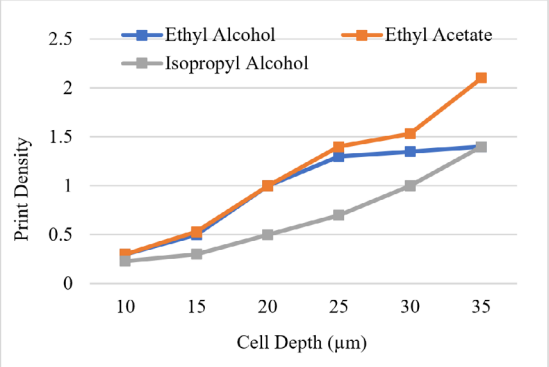


» **Figure 4:** *Surface energies of printing substrate*

When Figure 4 is examined, it is seen that the surface energy of polypropylene is smaller than polyethylene. The small surface energy indicates that it is easier to print on the paper with solvent based inks. In order to be able to print on a surface, there must be at least 10 mJ/m² difference between the surface energy of the substrate material and the surface energy of the ink. It has been concluded that the printing material with the lowest surface energy is the polypropylene and the printability is better than polyethylene. The results are compatible with the literature (Lindner et al, 2018). The contact angle and surface energy are inversely proportional. This is an expected result and is compatible with the literature (Ozcan et al, 2019).

Gravure test prints were successfully performed with inks prepared with 3 different solvents on two different printing materials.

Printing densities for different substrates were examined. Figure 5 shows the densities of the prints made with polyethylene film with different solvent inks. When Figure 5 is examined, it is found that the print density in both alcohols has lower density in all cell depth than the ink containing ethyl acetate. This is because ethyl acetate is more volatile than alcohol in room conditions. Thus, ink containing ethyl acetate dried faster and could not find time to spread so it could not find time to grow. In this case, the amount of colorant per unit area was excessive and the density increased onto printing. When the alcohols are compared with each other, it is equal in the high cell depth but as the cell depth shrinks, the print density of the isopropyl alcohol-based ink is lowest, but the values are very close to each other and are within the standard deviation range of ISO 12647-4.

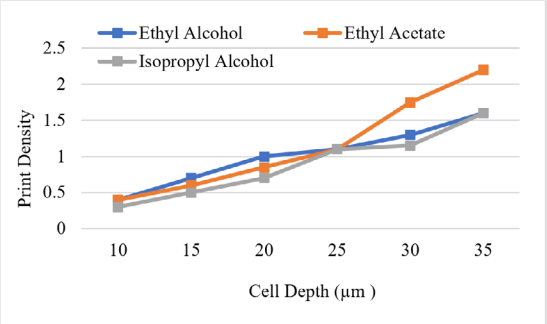


» **Figure 5:** *Print density of polyethylene film substrate*

In Figure 6, the densities of the prints made with polypropylene film with different solvent inks are shown. When Figure 6 is analyzed, it was found that the print density of both alcohols in the direction similar to polyethylene film has lower density than the ink containing ethyl acetate in all cell dept. When the alcohols are compared among themselves, the density values in all cell depth are very close to each other and in the standard deviation range of ISO 12647-4.

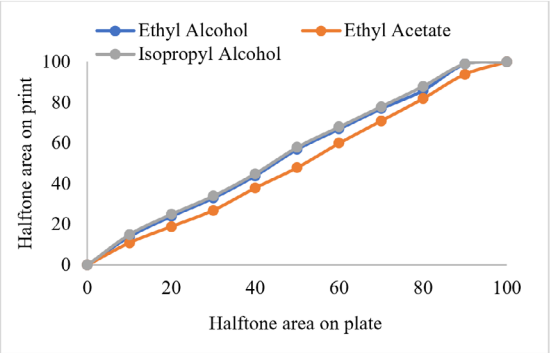
When two different films were compared for the same type inks, it was determined that higher print

density was obtained in polypropylene film than polyethylene film. This result is an expected result because when the surface energies were examined, the lower surface energy of the polypropylene film provided a better bonding surface for the inks and the density, one of the printability values, increased.



» **Figure 6:** *Print density of polypropylene film substrate*

The growth of the dot in prints varies depending on the drying time of the ink. The tone values of the prints on polyethylene and polypropylene films were measured and the values in Figure 7 were obtained. When Figure 7 is examined, it is determined that the change of the points of ethyl alcohol and isopropyl alcohol are similar. The evaporation of alcohols in close periods explains this result. However, the printed dot areas of the ethyl acetate in printing remained lower than the alcohols. Because while the ink dries, the dot did not grow large enough and the ink spread less than it should be.



» **Figure 7:** *Halftone values prints*

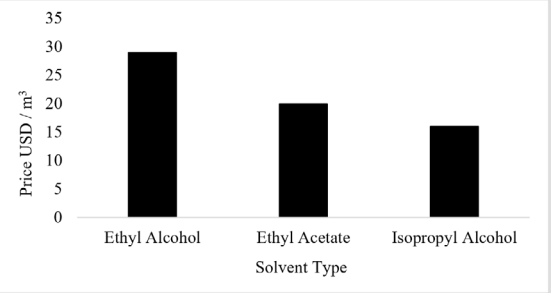
Color and gloss values of the prints are given in Table 5. When Table 5 is examined, it is determined that the darkest color in both printing materials is the ink prepared with ethyl acetate. Since the ink could not spread too much, the amount of pigment in the unit area was high, so the color became darker and the color difference of these inks was higher than ΔE of other ink prints. Ethyl alcohol and isopropyl alcohol for both films gave similar results in color. When the obtained ΔE values are examined, it has been determined that all color differences are below the range specified in ISO 12647-4 and below the range that can be perceived by the human eye (ΔE=3) (Frimova et al, 2005). All inks obtained according to this result can be used in both substrates. When the gloss values were examined, it was determined that the highest gloss was obtained with ethyl acetate inks.

Table 5

Printability parameters of test prints

	L*	a*	b*	ΔE	Gloss
F1 substrate PE	47.7	-25.7	-42.4	1.40	24
F2 substrate PE	45.4	-25.1	-44.9	2.30	28
F3 substrate PE	47.5	-25.6	-42.5	1.35	23
F1 substrate PP	47.6	-25.5	-42.3	1.39	25
F2 substrate PP	45.6	-24.9	-44.7	2.10	32
F3 substrate PP	47.6	-25.5	-42.7	1.26	24

Another selection parameter of the solvent to be used in ink is its prices. Figure 8 shows that the most expensive solvent is ethyl alcohol. For this reason, the use of isopropyl alcohol in real time printing is preferred to the use of ethyl alcohol because it gives very close results with isopropyl alcohol in all printability parameters. The use of ethyl acetate should be limited in gravure inks. Because the copper on the engraving cylinder, which is often exposed to ethyl acetate, corrodes after a while and the engraving cylinder is damaged.



» **Figure 8:** *Dated 28.06.2020 price values different solvents*

Conclusions

In this study, prints were made with inks prepared with three different solvents on two different printing materials and the effects of variables on printability were examined. As a result, it has been concluded that the printability is better than polyethylene, since the printing substrate with the lowest surface energy is polypropylene. As ethyl acetate dries faster than other alcohol-based inks, ink density and dot growth are better in terms of printability. Ethyl acetate gave the best results in terms of color and gloss. However, it is highly corrosive to the ethyl acetate engraving cylinder. For this reason, it is not recommended to use it for a long time and in large quantities. For this reason, it is more suitable to be mixed with either isopropyl or ethyl

alcohol. When examined in terms of price, the solvent with the lowest unit cost is isopropyl alcohol. For this reason, when it is necessary to choose among alcohols, isopropyl alcohol is a suitable solvent. As a result, it is recommended to use a mixture of ethyl acetate-isopropyl alcohol for both substrates in gravure printing.

Acknowledgements

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Preliminary report

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Competencies of the present-day Graphic Designer: A document analysis of online job ads in Ghana

ABSTRACT

This study sought to provide an overview of the competencies required by employers in advertising for graphic design position in relation to interactive design in Ghana. This was done in the context of the dynamism of graphic design profession with current technological advances. Both thematic and content analysis were used to analyse online job advertisements collected within eight months to determine the patterns and frequencies of occurrence of specific requirements for the job position relating to graphic design. This was to better understand employers' expectations from the graphic designer in terms of designing for interactivity and the implications for graphic design pedagogy. Findings from the study revealed that, traditional graphic designers in Ghana will now have to acquire skills in interactive design and competencies associated with them. These include among others, responsive design, problem-solving, coding skill, software skills, creativity, CMS tools, project management and personal characteristics. Beyond these, request for skills in coding, knowledge in responsive design, knowledge in content management system tools, software skills and teamwork are the most frequently expected skills from the present day graphic designer. We end the paper by suggesting how our study could trigger graphic design pedagogy development.

KEY WORDS

Graphic design, job ads, design competencies, design education, interactive design

Nicholas Opoku [1]
Edward Appiah [2]
Patrique deGraft-Yankson [1]

[1] University of Education, Department of Graphic Design, Winneba, Ghana
[2] Kwame Nkrumah University of Science and Technology, Department of Communication Design, Kumasi, Ghana

Corresponding author:
Nicholas Opoku
e-mail:
opoku.nickky@gmail.com

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Introduction

With advent of technologies, couple with dynamism in the graphic design industry, graphic design graduates and students face diverse demands by organizations in applying for job position. The requirements placed on graphic designers also form an essential discourse for design educators in ensuring the employability of their students when they graduate. As the scope and content for graphic designers evolve in the industry (Davis, 2005; Ashigbey, 2016; Dziobczenski & Person, 2017), the competencies required to practice as a designer is also changing.

Graphic Design Practices in Ghana

The practice of graphic design is not a novel field. From the Guttenberg era, which was characterized with the transfer of text matter onto paper through to the production of graffiti's, which is not limited to the beautification of our landscape scenes, graphic design has evolved into a new phenomenon taking an interesting tangent.

In the case of Ghana, the practice of graphic design is known to have been characterized with the use of handy tools such as pencils, calligraphy pens, artists' brushes, etc. to communicate visually. In this phase of practice, the predominant substrates were paper, fabric and wall surfaces. The advent of the computer and subsequent

features of design software, such as CorelDraw, Page Maker, Photoshop, Illustrator, and InDesign introduced precision and accuracy in the final output of graphic designer's work. Though these computer generated graphic design applications did not totally annihilate the use of the traditional devices in the industry by those who saw themselves as avant-gardes, it is important to note that they limited production time. Reckoning that these software ensured precision, several graphic design firms have been established in almost every nook and cranny of the country typically, promoting a vibrant printing industry in Accra and Kumasi, the two major cities.

Technological advancement in graphic design practice has seen graphic design content moving to virtual, powered by sophisticated computer programming language. This phenomenon appears to be affecting the current stage of the graphic design community in Ghana. Designing for interactivity is gradually gaining popularity as most businesses in Ghana especially those in the financial sector have resorted to the use of mobile applications and websites with interesting graphic design content to communicate with their clients making contact hours at the banks relatively less. With globalization effects on graphic design industry and ubiquitous growth of the Internet, one can post design problem on the Internet and get someone elsewhere to design for them. This puts the traditional Ghanaian graphic designer in a fierce competing battle with other graphic designers globally for the same job. Ghana is considered one of the emerging vital players in digital economy and over 9 million jobs will require coding skills by 2030 as reported in International Finance Corporation (IFC) 2019 report (IFC, 2019). The use of mobile devices by Ghanaians is gradually making the practice of graphic design transit from the conventional print media to one, which is technologically driven. This brings a new dimension to how graphic design as an industry is evolving as a new designer titles such as UI designer, UX designer, web designer, etc. are being offered to the graphic designer in job listing. In this paper we provide an overview of the competencies required by employers in advertising graphic design positions in relation to interactive design through job advertisements. We asked the question, *"what are the expected competencies employers referenced in advertising for graphic design position in relation to interactive design?"*

Literature Review

Graphic Design Practice in the Digital Era

Graphic design, which traditionally is about communicating visually and presenting information to the targeted audience, has witnessed many changes in the digital media era. Earlier, the domain of graphic design practice was limited to print media. However, following advancement in industry, growth of interactive technologies, and increase in mobile device usage for visual communication, transforming ideas into visual solutions and communicating ideas via visual components such as colour, pictures and typography in digital media has also been regarded to be the duties of graphic designers (Bestley & Noble, 2016; Dziobczenski & Person, 2017). Today, graphic designers are found in various positions such as UI designer, UX designer, web designer, among others within industry, forcing designers to adapt and expand their competencies in relation to a scope of new activities and responsibilities. As indicated by Ashigbey (2016) 'design is currently migrating to digital platform, we are preparing to take our newspapers to multimedia platforms and there is the need for designers to acquaint themselves'. This assertion therefore calls for new skills and competencies to keep the designer in the job market. From mobile application user interface design to website design, the job prospects for graphic designer in Ghana are now taking a dynamic trend.

The Job Market Demands

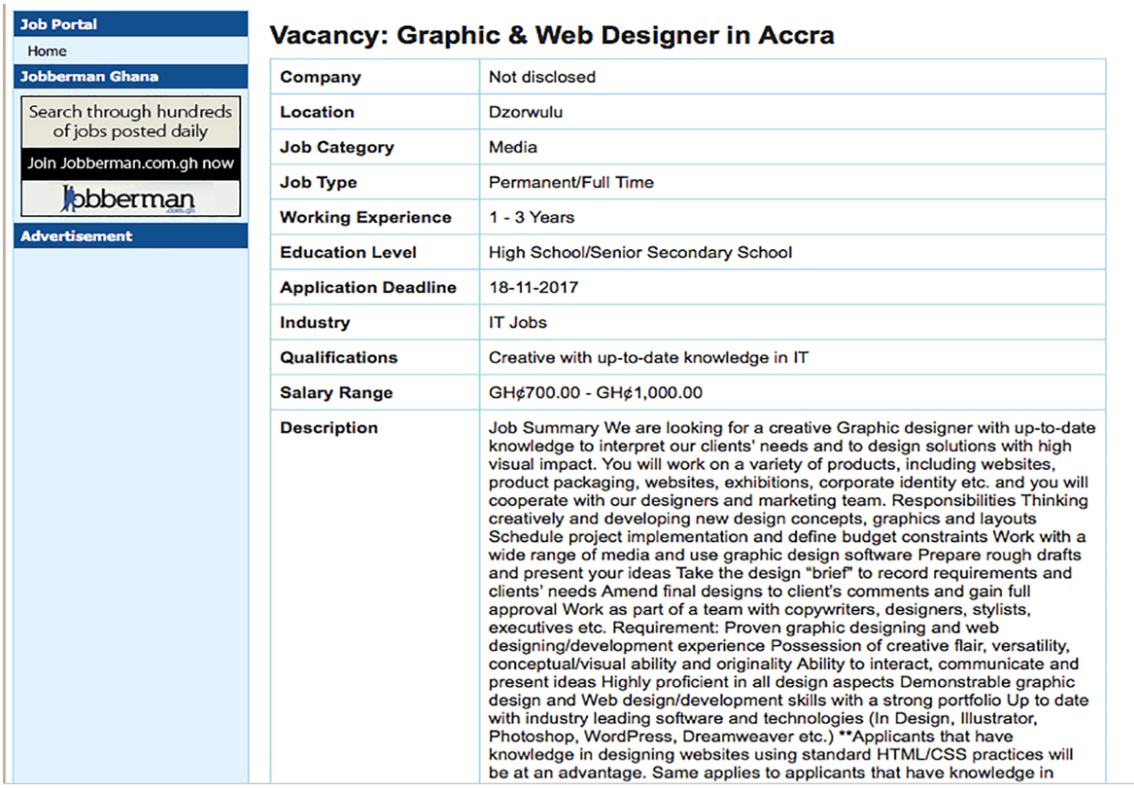
A good place to start when mapping the competencies designers should possess is to consider the kind of qualifications the industry looks for when hiring a designer. Studies have shown that designers with contextual understanding, proficient design skills, planning and integration capabilities, design knowledge, programming skills like PHP, HTML, CSS, knowledge in the use of prototyping tools such as Axure, Adobe XD, Sketch, etc. are more likely to be hired (Sørum & Pettersen, 2016; Dziobczenski & Person, 2017; Dziobczenski, Person & Meriläinen, 2018; Dziobczenski et al., 2018). The most successful designer will be those who can work with intangible materials – code, voice, and words (Maeda, 2017). Figure 1 indicates example of recent job listings that display how the role of graphic designer has expanded to include interactive design.

Methodology

In this study, we pursued document (thematic and content) analysis of job ads in which we combined thematic and content analysis as way of analysing both electronic and printed texts created without the researchers' intervention (Bowen, 2009). Ritchie et al. (2013) claim that job offers provide natural occurring data written to the interest of both applicant and employers.

Job Advertisement Analysis

We gathered job advertisements for graphic designers in relation to interactive design from online recruitment platforms over a period of six months (September, 2017 – May, 2018). Job advertisements have been used to study trends and requirements placed on other professionals (Wade & Parent, 2002; Choi & Rasmussen, 2009; Smith



» **Figure 1:** *Sample of job ads*

& Ali, 2014; Grigoriadis, 2014). In design, job ads have been used to study the competence on new design graduates, skills companies require from industry designers, and skills set of graphic designers (Yang, You & Chen, 2005; Ramirez, 2012; Dziobczenski & Person, 2017; Dziobczenski, Person & Meriläinen, 2018). Publicly available job listings is claimed to be a genuinely representative list of what is available with respect to the knowledge and skills in demand (Molinero & Xie, 2007; Kennan et al., 2009). The job search portals include Job House *(jobhouse.com.gh)*, VimJobs *(vimjobs.com)*, GhanaWeb *(ghanaweb.com/GhanaHomePage/jobs)*, Ghana Current Jobs *(ghanacurrentjobs.com)*, Joblist Ghana *(joblistghana.com)*, and Jobberman *(jobberman.com.gh)*. The search covered job offers with the term 'graphic designer' in the job title. It was discovered that graphic designers working for interactivity positions are advertised under a diverse titles (e.g. front-end designer, UX designer, UI designer, web designer). The second search covered ads with the term 'designer' in the job title, 'interactive designer, front-end designer, UX designer, UI designer, web designer' in the job description. Following this course of action, we managed to gather an initial set of 103 job advertisements.

Data Refinement

During data gathering, it became apparent that recruiters frequently publish the same job advertisements on multiple recruitment platforms. In printing the advertisements, jobs published by the same organization under the same job title on different recruitment platforms were captured as one. Finally, only job ads where the job title contained graphic designer, digital designer, web designer, UX designer, and UI designer were included in refining the data. In doing so, certain advertisements that did not require the competencies for the expertise of interactive design were excluded. As a result of data refinement, the initial sample of 103 advertisements was reduced to 57 unique job advertisements for the analysis.

Analysis

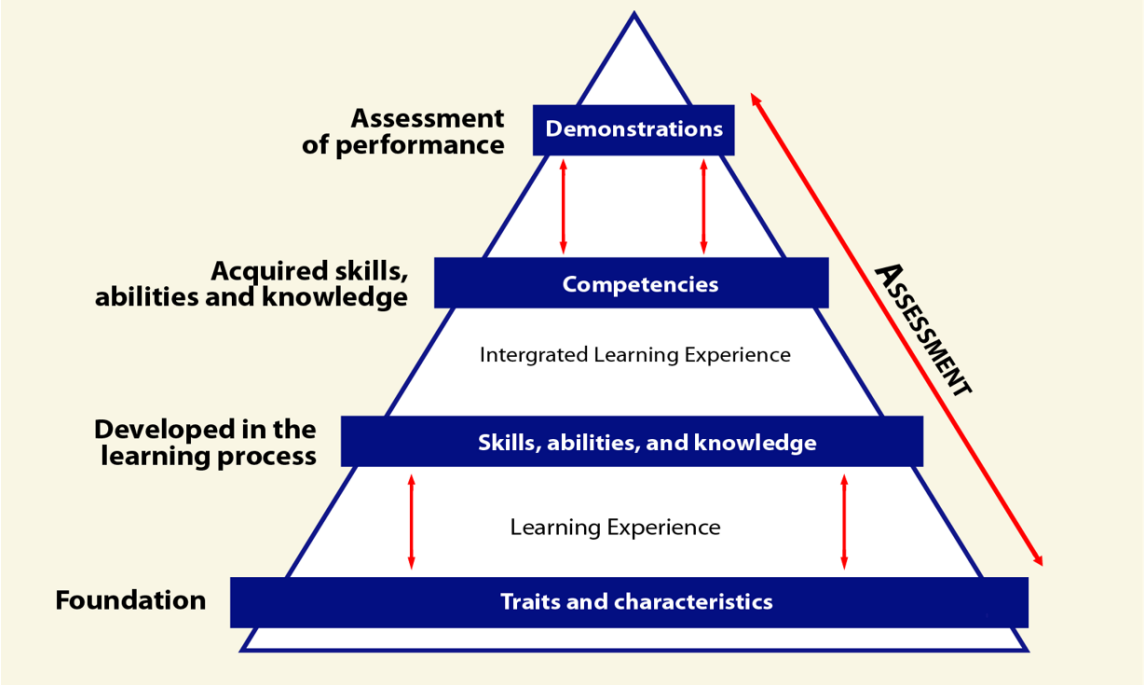
Similar to other studies (Yang, You & Chen, 2005; Ramirez, 2012; Sørum & Pettersen, 2016; Dziobczenski & Person, 2017), we approached the knowledge and skill sets of designers as a multifaceted. Thematic analysis was utilized to ascertain an initial set of patterns to recount what recruiters required from designers who engaged in interactive design in the job offers. As indicated by Lapadat (2010), thematic analysis is appropriate to work with a lot of written information without losing context. The initial coding plan was made by examining the job offers while inductively mapping what was required from designers, in connection to interactive design practice through manual coding. A set of patterns recounting what recruiters anticipated from designers in the job offers was ascertained through this technique and later re-examined, updated, and refined. In evaluating the quality and relevance of the outcomes, we expanded the analysis by performing a content analysis

of the data set. Specifically, we set out to evaluate the recurrence and noteworthiness of the themes that have emerged from the knowledge and skill set requirements in the job advertisements. This was done by mapping out the number of job offers captured in the advert (presence or absence). Less recurrence codes were combined to produce more holistic and descriptive patterns.

For the final coding plan, Richard Voorhees' conceptual learning model (a competence-based view of education) as captured in Figure 2, was utilized as a lens to sought the connection between requirements in the job advertisement and structured the results of the analysis in terms of competence areas, knowledge and skills, and personal traits.

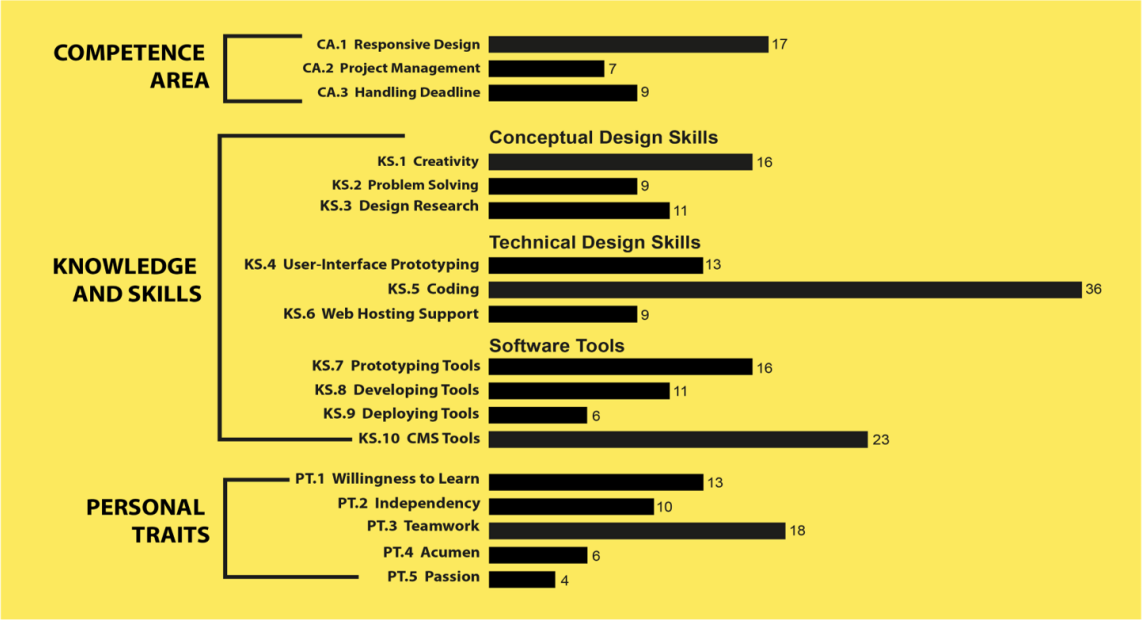
Results

The analysis revealed patterns in what employers anticipated from designers in the job offers (figure 3). Altogether, the final coding plan comprises five main themes and 18 sub-themes (CA.1, CA.2, KS.1, etc.). The job offers in the data set comprise a broad number of competence, knowledge and skills, and personal traits. Additionally, 48 (indicating 84.2%) job offers made mention of two or more "knowledge and skills" demonstrating that employers seek designers who can execute projects in multiple areas. Details of these qualities are presented in the appendix. Figure 3 gives an overview of different types of knowledge and skills required from a graphic designer as captured in the analysis.



» **Figure 2:** *Conceptual learning model pyramid: Voorhees (2001)*

» **Figure 3:** *Examples of knowledge and skills required from a graphic designer*



» **Figure 4:** *Distribution of each subtheme in terms of frequency*

The Competence Areas address what graphic designers should deliver through their work. Our analysis produced three kinds of these requests in the job ads: responsive design, project management and handling deadlines. Responsive design references the ability to design interactive content that focuses on a user's environment and behaviour based on the orientation and size of their interactive media screen as well as the platform. Project management includes reference to the ability of the designer to apply his knowledge, skills, tools, and techniques to manage multiple projects to meet the project requirements. Handling deadline comprises how designers should complete tasks within the time by which interactive design projects must be completed or submitted.

With regard to Knowledge and Skills, the study identified 10 subthemes across the job ads. Similar to Dziobczenski & Person (2017), we classified the subthemes across three main themes: *conceptual design skills, technical design skills and software tools* as indicated in Figure 4.

The *conceptual design skills* theme describes how designers should have the capacity to support hands-on design work. Specifically, the related subthemes cover how interactive designers should have skills in creativity, problem-solving and design research. The *technical design skills* theme mentions the abilities and knowledge needed to perform design duties in day-to-day practice. Specifically, the associated subthemes cover knowledge and skills in user-interface prototyping, coding and web hosting supports. The use of software tools is fundamental in interactive design. In relation to design *software tools* used by designers, prototyping software, developing software, deploying software and content management system software were mentioned in the job advertisements.

Going beyond the main competencies graphic designers needed to design for interactivity, the requirements in the job ads also include statements that qualified applicants should display certain *personality traits* that support learning and professional practice. The study identified five reoccurring statements in the job ads that suitable applicants should hold "Acumen, Teamwork, Passion, Independence and Willingness to learn trends in the industry.

Discussion

This study through document analysis of job ads, sought to highlight the expectations of Ghanaian organizations regarding the kind of skills and competencies that graphic designers should possess in relation to designing for interactivity. Compared to some years back, many graphic designers today are marking themselves as UI designer, UX designer, web designer, interactive designers, resulting in a frequently used work position with a variety of duties performed.

The analysis suggests that designers who designed for interactivity are expected to possess a diverse skill set ranging from conceptual design skills to technical and software skills and personal traits. The most frequently cited competence area is found in responsive design. This illustrate the pressure that design companies in Ghana face from the variety of technological devices being used to access information and communication. The analysis also found that current awareness and suitable technical and software skills in the interactive design environment, abilities in creation and management of interactive content, and collaboration were the most requisite qualifications for interactive design

position with high accentuation on coding abilities. Moreover, software tools such as Adobe Dreamweaver, Axure RP, Adobe Photoshop, InVision and FileZilla were sought frequently in the job advertisement.

These findings confirm the claims in previous studies about the high value employers place on these skills in other countries (Yang, You & Chen, 2005; Ramirez, 2012; Dziobczenski & Person, 2017) and are also in accordance with Grigoriadis (2014) study on job advertisements as indicators of the skills and competencies employers required from supply chain graduates. There is also a massive trend towards content management system (CMS) that helps clients to create, manage, and modify content on a website without the need for specialized technical knowledge and skills. In this regard, having knowledge in Wordpress, Joomla, Drupal, PHP, CSS, and HTML are fundamental for interactive designers to ensure interactive design projects adhere to standards and best practices for clients to be able to manage their own interactive content.

The findings also prove that the demand for project management skills, teamwork, problem-solving, and design research are emerging for interactive design practice. Ramirez (2012) announced that a successful case of internal collaboration and research help in completing industrial design projects. The demand for design research and leading industry software qualifications is an indication that there are new tools for designers in creating interactive content, and that software keeps changing within a slip of time due to technological advancement in interactive media for communication. To ensure the interactive designers consistently possess the evolving knowledge and skills for practice, they must have an accurate understanding of the processes within the interactive design environment. To do so, designers must possess the necessary core knowledge and skills of designing for interactivity as well as new technological knowledge and personal traits.

Conclusion

This study has explored the skills and competencies employers in the Ghanaian design industry are expecting from new graphic design graduates in terms of designing. Several key findings from this study make an essential contribution to understanding skills required by employers of graphic design graduates in the Ghanaian context. The most frequently require skills associated with coding consisting of knowledge and skills in HTML, CSS, JavaScript and PHP. This cluster of skills, which appeared in 63% of the job advertisements, raises questions about the nature of the graphic designer work in today's technological era. The knowledge and skills in coding indicate that graduates with Computer Science and Software Engineering degrees might be better suited than Graphic Design graduates. On the other hand, it is easy to understand that design employers might be looking for graphic design graduates but with more emphasis on coding skills.

Graphic design is a rapidly changing profession due to technological advancement and while researches conducted some time back are useful and informative, it is imperative to continuously gather data about graphic design education and employment. While our study focuses on one aspect, job advertisements, there are other data for analysis such as interviewing employers and design educators, which could contribute to providing a bigger picture. To make it easier to understand graphic design professional careers as a whole we need more studies on the knowledge and skills required to practice graphic design in today's technological era where interactive media is been used for visual communication.

This study is not without limitations. We only analysed job advertisements from online recruitment platforms. Further studies could include an analysis of the graphic design programme offered by educational institutions. Also, future studies could involve practitioners, educators and organizations offering such position, their individual needs and expectations in relation to the tasks graphic designers are expected to perform and design pedagogy to teach it.

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Appendix

Description of the codes in our coding Scheme		
Competence Areas	**Responsive Design (CA.1)**	Implement responsive web experiences and interactive prototypes; ability to create interactive assets for websites, digital media, social ads that accommodate all screen sizes; experience in building highly polished responsive user interface using HTML and CSS; knowledge in responsive web design; implement responsible web design principles to ensure that clients project renders well across multiple devices.
	Project Management (CA.2)	Manage all social media platforms and websites; setting up and managing websites with leading CMS application (WordPress, Drupal, Joomla): managing multiple creative projects simultaneously.
	Handling Deadline (CA.3)	Able to work to tight deadlines; work well under pressure and meet deadline; deadline-oriented; provide accurate timing estimates on work; must able to manage workload and meet critical project milestones and deadlines.
Knowledge and Skills	**Conceptual Design Skills**	
	Creativity (KS.1)	Ability to be creative in design; ability to translate other's concept into visual captivating graphics; thinking creatively to produce new ideas, concepts, and developing interactive design; ability to collaborate, ideate, and deliver UX concepts for new websites, apps, and customer touch points; transform wireframes and verbal concepts into working prototypes.
	Problem Solving Skills (KS.2)	Demonstrate problem solving skills; creative thinker and problem solver; must be conversant with solving other IT problems; understand user pain points in existing designs and provide user-friendly solutions to these roadblocks.
	Design Research (KS.3)	Investigate new resources to use which will improve functionality, usability, loading speed, and search engine (SEO); researching current design trends; must have a firm understanding of changing technologies, including software and tools for web design.
	Technical Design Skills	
	User-Interface Prototyping (KS.4)	Experience in any rapid prototyping tool - Axure RP, InVision, Balsamiq, Sketch; design a framework for creating user apps that grow with the needs of the client; capable of converting Photoshop/Fireworks mock-ups into CSS/XHTML; and "execute all visual design stages from low fidelity wireframes, interactive prototypes, to final high fidelity mock-ups required by technical team and stakeholders.
	Coding/Programming Skills (KS.5)	Top-notch programming skills and in-depth knowledge of modern HTML/CSS; working knowledge of HTML, CSS, JavaScript, and bootstrap or equivalent framework; solid understanding of HTML5, CSS3, JQuery, PHP, and responsive design; must have a fair knowledge in HTML, CSS, and JavaScript.
	Web Hosting Support (KS.6)	Upload the site onto a server and register it with different search engines; testing website to ensure it is working and identify any technical problem; setting and managing websites with leading CMS application (WordPress, Drupal, Joomla).

	Software Tools	
	Prototyping Tool (KS.7)	Experience in any rapid prototyping tool-Axure RP, InVision, Balsamiq, Sketch; proficiency in Photoshop for prototyping; experience in using prototyping software to build user interface from wireframes; and must know how to slice from Photoshop into a website.
	Developing Tools (KS.8)	In-depth knowledge on industry leading software (Adobe Dreamweaver); proficient in Dreamweaver and related web developing software.
	Deploying Tool (KS.9)	Knowledge on hosting cPanel; ability to use FileZilla to upload and download web content onto live server; asuccessful candidate should be able to put apps in Google Play.
	Content Management System (CMS) (KS.10)	Setting up and managing websites with leading CMS applications (WordPress, Drupal, Joomla).

Personal Traits	**Willingness to Learn (PT.1)**	continual professional development to keep up to date with software developments; willing and ready to learn and implement what is learnt; must be motivated to continue learning.
	Independency (PT.2)	ability to work independently under pressure without supervision.
	Teamwork (PT.3)	Must be a team player; work collaboratively with our marketing and content team to capture design requirements and translate them into innovative digital solutions; working as part of a multidisciplinary team.
	Acumen (PT.4)	Demonstrated ability to take leadership role in new and current projects.
	Passion (PT.5)	passion for creating experiences in online environments; passion for technology and learning; demonstrate a good aesthetic sense and passion for design.

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Tone Reproduction Curve: rendering intents and their realization in halftone printing

ABSTRACT

Approaches to determining the Tone Reproduction Curve (TRC) which provides the reliable transfer of visual information in typical conditions of the halftone gray scale compression in relation to dynamic range of a graphic original or input image file are overviewed. The issues of such curve realization are also analyzed with taking into account the specifics of multiple stages of illustrative printing technology.

KEY WORDS
Tone Reproduction Curve, gray scale, rendering intent, transfer function

Yuri V. Kuznetsov [1]
Andrey A. Schadenko [2]
Vycheslav V. Vaganov [3]

[1] St. Petersburg State Institute of Cinema and Television, Saint Petersburg, Russia
[2] St. Petersburg State University of Industrial Technology and Design, Saint Petersburg, Russia
[3] St. Petersburg State Polytechnical University, Saint Petersburg, Russia

Corresponding author:
Yuri V. Kuznetsov
e-mail:
yurivk@mail.ru

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Introduction

The brightness range of a print image is many orders of magnitude lower than for the outdoor objects. It is also much smaller in relation of slides or digital camera files at their use as originals for print reproduction.

Problem of the shortened halftone scale is somewhat solved by digital High Dynamic Range (HDR) photography, where sections of the scene of very different average brightness after being captured at different exposures are seamlessly joined in the resulting image (Reinhard et al., 2010). However, these copies are not completely reliable and natural, because in the conditions of outdoor lighting, the observer isn't able to simultaneously perceive all the gradations of such areas. Unlike to such a copy viewing, he can do it just separately after temporal local adaptation to the brightness level of an each part of a scene.

Therefore, as with the origin of photography itself (Jones, 1920), the development of approaches to determining the form of TRC, which would provide the most reliable transfer of visual information in the conditions of inevitable compression of a dynamic range, remains the key problem in theory of print reproduction. At the same time, even after finding such a curve in the light of certain tone rendering intentions, the task of its practical implementation is no less urgent, taking into account the non-linearity of numerous stages of the printing process.

Tone reproduction curve

It's difficult to get physically identical reproduction all of whose pixels have the same reflection spectra as the original or imaged object. Due to restrictions, inherent in any means of display, is not always achieved the colorimetric, metameric identity based on the physiology of vision. Therefore, most of the practice is necessary deal with the so-called psycho-visual matching of the copy and original.

In these circumstances, special importance for the regulation of customer and printer relations has itself statement the goal of reproduction. Color Management Standard (CMS) partly accounts this (Has, 1995), suggesting four variants of the so-called rendering intents. However, it is for clarity useful to consider such intentions in the simplest case of a monochrome, b/w printing (Hunt, 1998), where they are completely determined by the curve which links the values of such copy optical parameters as the reflection coefficient, optical density, brightness... with the same of the original.

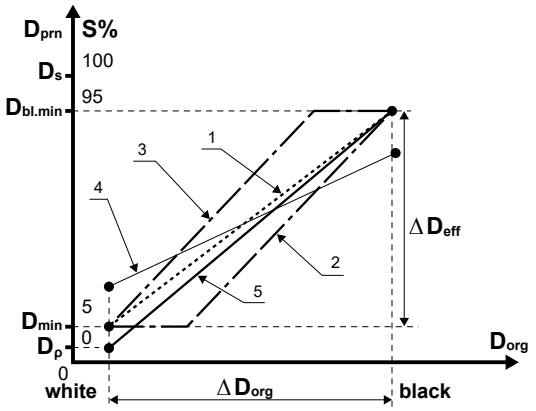
The first step in this characteristic generating is the finding of coordinates for its extreme points to match each other white and black levels of a copy and original. The next and no less important step is in finding the proper shape of the curve that will connect all the other values in effective, i.e. manageable interval of halftone printing. At last, there stay important the issues of a target TRC realization in multistage printing technology.

Range of the transferred gradations

Tonal content of CT originals is rather different. Reproduced objects may vary in contrast (ratio of ultimate reflectance values) or in density range (difference between the ultimate optical densities). The entire range may be also shifted left or right along the abscissa in figure1.

Paramount for the proper tones reproduction is possible precise alignment the interval $\mathbf{\Delta D_{org}}$ of an original with the effective print range $\mathbf{\Delta D_{eff}}$ (graph 1 in Figure 1). In the absence of such alignment, as can be seen from graphs 2 and 3, the tonal steps (details of brightness) are irreversibly lost in light (2) or dark (3) areas at the very beginning stage.

Assume that the original is a multi-step tone wedge and the reproduction task is the distinguished transfer of all its steps on the print. Then the line 3, passing at an angle of 45° from the origin will correspond the loss of some darker wedge patches, despite the absolutely accurate reproduction of the rest ones[1]. Much lighter, though with the same differences in density will be transferred just grey and dark patches of this wedge while following the graph 2. It is also obvious that the introduction of any nonlinearity in these graphs will not increase the number of distinguished patches and impact only on the lightness relationship between the ones, caught in the reproducible range.



» **Figure 1:** *Examples of combining optical density intervals (1, 5) and errors in setting the "white" and "black" levels: loss of brightness details in highlights (2) and shadows (3); decrease in overall contrast (4)*

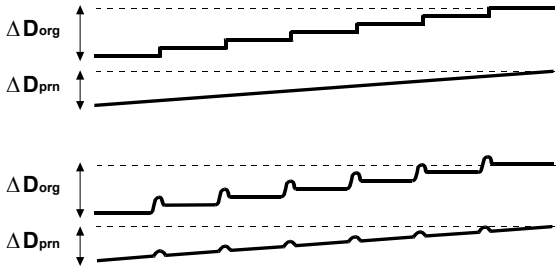
It is not always possible at least slightly extend this range, commonly reduced relative to that of the original, by assigning, as shown by graph 5, to minimal, "white" level of original the density $\mathbf{D_p}$ of substrate. In lithography, such assignment leads to loss of the brightest gradations. Halftone dots for the second, third and, may be for the fourth patch can occur smaller of the minimal printable one and the lightest reproduced patch will be the one whose density $\mathbf{D_{min}}$ corresponds to the size of "just printable"- reliably and consistently reproducible dot of, for example, 5%. The exception is, however, for originals containing the areas with specular reflection or self-illuminating objects for which, unlike given example, it is advisable assignment the Dp level of "whiter than white"- 0% value. Sun glare on the glasses can be transferred by clean paper because the rest of the image has no details of brightness or its differences with the values between the level of such glare and "white" of 5%. Otherwise, i.e. when assigning the latter to specular highlights, the contrast of the copy unjustifiably decreases.

The reproduction task is also not solved according to graph 4 with decreasing the image contrast when the differences between adjacent patches may become invisible. This case is additionally explained in Figure 2 (a, b), which shows such step wedge transform into degrade- continuous tone ramp on a print, which in essence distorts the meaning of the original data.

These general ideas underlie the assignment of print tone values to ultimate gradations of the reproduced original. Loading illustrations in DTP usually involves pre-scan of the original with rather low resolution just sufficient for its display on a monitor. If in areas with

[1] In terms of Color Management this option corresponds to the *Absolute Colorimetric* rendering intent and to Gamut Mapping strategy (Morovic, 2003) with *clipping* the out-of-gamut colors.

values close to extreme, the scanner does not distinguish gradations (graphs 2 and 3 in Figure 1), the operator repeats the scan with changing such parameters “brightness” and “contrast”. Management "brightness" corresponds to the vertical parallel shift of these graphs while the "contrast" control changes their slope. With sufficient experience the appropriate levels setting, i.e. the positioning of original range between the extreme points of graphs 1 or 5 is achieved in a few iterations.



» **Figure 2:** *The steps of the original wedge (a), which are close to the brightness sensitivity threshold or print noise level, are lost on a print (b) as a result of the density range compression; illusion of such steps (d) can be created just by retouching the original (c)*

There is also possible the automatic finding of original extreme densities for assigning them the prescribed tone values by analysis for histograms of the pixel meanings occurrence in the pre-scan image file. This analysis allows, for example, for finding out how representative is the particular value for the reproduced object, i.e. can it be taken as a basis for the range setting or is a random outlier caused by a particle of dust or damage of original.

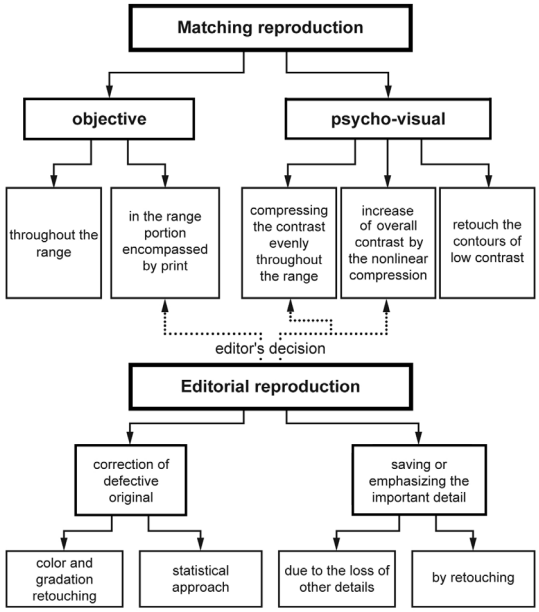
Form of tone curve

Next stage of creating a curve is the assigning to it a certain form within the above set range. Replacing camera by electronic scanner allowed for manipulating the TRC form highly flexibly and several scientific schools actively developed in the 70-ies the approaches to finding some optimal, universal curve suitable for "all cases" as the solution of cornerstone theoretical problem of print reproduction. For example, it was proposed (Namakura & Namakura, 1994) its analytical calculation accounting the substrate and ink film reflections, optical density of the reproduced detail, ratio of the density ranges on print and original.

However, such empirical equations can have only a limited application, since for the proper connection of the original and copy parameters is necessary, first of all, to determine the nature of reproduction goal. It may be rather different in such, for example, contradictory approaches as the matching original and editorial (with certain changes) one. However, the line between these, it would seem, fundamentally different approaches is blurred even when the original comprises not a natural scene or object but their intermediate representation as a hard copy or digital file.

For the most part, the observer judges the image reliability or quality in the absence of the original, i.e. from memory and according to personal experience, expectations or visual preferences. In addition, under the conditions of printing technology restrictions, the identical reproduction of certain property of an original makes impossible to match some its other parameter and vice versa. Therefore the mere decision about which of these properties should be saved on a print once again requires a certain editorial intervention.

The scheme in Figure 3 (Kuznetsov, 1998) differentiate approaches in the formulation of tone rendition intentions for only one of the attributes of color- its brightness.[2] Along with the figures 1 and 4 it points to interrelation of these options by the given below examples.



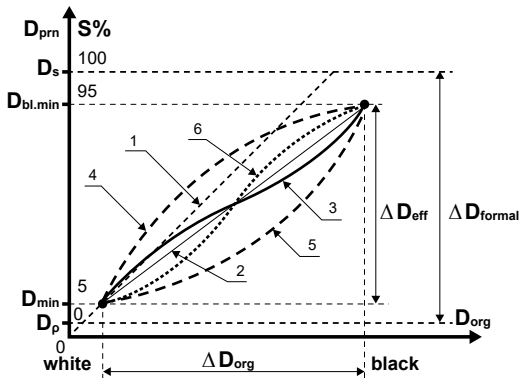
» **Figure 3:** *Variants of rendering intents within the original matching and editorial approaches to the tone reproduction goal*

Reproduction matching the original

Objective (physical, facsimile) matching takes place, when the brightness coming from original and print are the same for the viewer. Identity, in which the measured, for example, densitometer values of their corresponding areas are equal, is rarely met in practice and is possible just for the low-contrast, opaque originals, the range of which does not exceed the effective one of a printer. The graph under discussion here represents a straight line 1, coming at 45° in Figure 4, and correspond to reproduction variant 1 on scheme of Figure 3. In most cases, the interval of the original Δ_{Dorg} significantly exceeds the interval ΔD_{eff} of print and just the tone values that do not

[2] Applying to three attributes of color (brightness, hue, chroma), the ICC color management standard limits to cases of only four variants of such intentions (Morovic, 2003).

fall out of it can be transferred unchanged. At the same time all the brightness differences are clipped, according to curve 1, in deep shadows and matching the original as a whole is not achieved (case 2 in the Figure 3).



» **Figure 4:** *Tone transfer curves: 1 – objectively identical (facsimile) reproduction; 2 – linear, 3 - subjective-identical, (4, 5, 6) - editorial compressions of the density range of original*

In the conditions of range compression there is possible only the subjective identity, i.e. creation to certain extent possible the apparent similarity of two images, when all gradations acquire other meanings. Such cases are defined in options 3, 4 and 5 of figure 3. The aim is to ensure on a print the same relationship of lightness meanings which has place when looking at an object. If, for example, on an original step wedge the fourth and fifth patches differ from each other much more than seventh and eighth ones, in result of printing these differences should not be equal or in the opposite sense. Under this condition, the meaning of information is preserved, despite the change of patches values themselves and their between differences.

The most important is to preserve the image contours as reference data of image recognition. Priority of the correct contour strength and its geometry transmission over the brightness variation in stationary image area is confirmed through the whole experience of the visual arts, ranging from about the works of rock art and ending with the practice of retouching in photography and graphics. Therefore, following above example with a tonal step wedge the aim of reproduction can be interpreted as transmission of contours — brightness differences at the borders edges of adjacent each image areas.

In terms of optical density, finding the TRC form, which will better retain such differences, can be discussed with taking into account coarsening of the visual perception threshold at coming from lighter to grey and darker print areas from 0.02 up to 0,01 and 0,04 (Rabinovich, 1976).

It can be taken for example the aim of identical reproduction of a multiple, for example, 32 step greyscale with retention the visual differences between the all adjacent patches, i.e. when their tone values look equally meaningful. At assuming the 0.04 density differences between the neighboring patches, the entire original scale range comprises 1.28. Its linear compression at ¼ corresponds in figure 4 to curve 2 connecting the points ($\mathbf{D_{org.min}}$, $\mathbf{D_{min}}$) and ($\mathbf{D_{org.max}}$, $\mathbf{D_{bl.min}}$). Effective range on a print is of 0.96 units and all adjacent fields are different only 0.03 (instead of 0.04 on the original). As result, with the grey and lighter patches staying quite distinguishable the several darker ones will merge on a print copy.

Transfer of all 32 steps and, therefore, the informative matching of the print to the original can be achieved by increasing the curve gamma in shadows at the expense of the respective reduce it in the midtones, i.e. using the N-shape curve 3 related to case 3 in the diagram of Figure 3. This example shows that the linear (over optical densities) transfer is inaccurate and only adds to the loss of information, collateral to the tone range compression in printing.

If the number of fields or contours on the scale is large, more than for example, sixty-four, then the brightness differences that form these contours are extremely small already on the original and are close to the threshold contrast sensitivity of vision or level of the process own noise. So, even the use of mentioned N-shaped curve will result in this case, to the disappearance of all steps of the scale (Figure 2, a, b) and it will look on the print as a continuous tone ramp ("vignette"). The complete absence of steps within it says the linearity of the entire reproduction system. However, thus reached the linear lightness transfer retains only one part of the semantic image content but the information about the presence of steps or contours there between are lost.

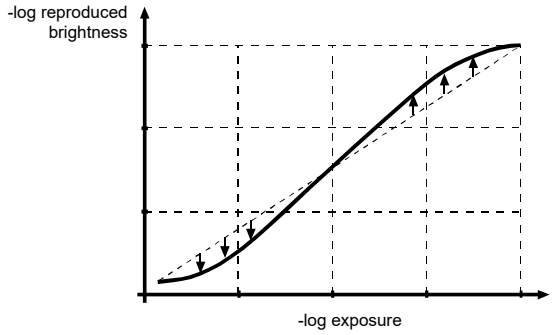
Save the situation in this, exaggerated example is possible, as already noted, just by retouching — introducing into the original or representing it signal of pre-emphasis to compensate for the reduced print range (option 5 in Figure 3). It can be, for example, the slight dividing lines drawing between the patches on an original (Figure 2, b, d). A similar result may give the unsharp masking, organized in such a manner as in the greater extent influence the weak tone steps than anyway saved the larger ones (Gast, 1981).

Tone rendition dilemma

Due to mechanism of brightness adaptation the flower stays looking white when taken indoors where its brightness decreased in the hundred or thousand times but there are no other, lighter reference objects. At the same time, the certain incompleteness of such adaptation creates the dilemma in subjectively identical tone rendering (Giorgianni & Madden, 1998). In spite of preserving lightness relationships along the whole input grey scale

on a print, the above concerned subjective matching is accompanied by reducing the overall, visually perceived contrast of an image. Despite the relative nature of brightness perception, the copy, preserving the greatest amount of a small local contrast details, looks faded and its colors unsaturated. Therefore in photographic, television and other systems the brightness, especially of natural scenes, is reproduced very non-linear.

As the exemplary curve in Figure 5 shows, under conditions of a range compression, the compensation of adaptation incompleteness is achieved by the redistribution brightness logarithms relationship with reducing the gradient in the lower and upper parts of a curve. Image contrast increases because its light areas become lighter and dark ones darker. However, the brightness differences are reduced or completely disappear there.



» **Figure 5:** *Because of the incomplete brightness adaptation, when looking at a natural scene reproduction, the appropriate overall contrast is achieved by the use of S-wise curve, thus losing tone steps in the light and dark areas*

Such a transformation and associated losses may have place in the manufacture of illustrative original in its material or electronic form due to the S-shaped sensitivity curves of the photo film or paper, scanner, TV and digital cameras. However, in the graphic arts reproduction may be necessary the additional compensatory control. This happens when the original is a slide with a density range two or more times greater than that in print and initially oriented, for example, on viewing its projection in a dark room. Insufficiently nonlinear, with respect to the overall contrast preservation, can be the lightness of a natural scene or in a file of computer graphics intended to be displayed not on a print but with the use of some other means, the brightness of which is considerably higher than in standard print viewing conditions.

In units of optical density, an example of such a complement compensation the lack of general brightness adaptation (case 4 in the diagram of Figure 3) can serve S-shaped curve 6 in figure 4 inverse to N- shaped curve 3. Wedding photo, taken in bright sunlight, might look quite contrast and saturated if made using an S-shaped characteristic. But it is unlikely to reproduce all the folds of the bride white dress and groom's black suit. Conversely, the use of N- shaped curve, which safes all the lightness differences within the tonal range, may make an impression that the event took place on a cloudy day. This is the dilemma of the very formulation of the tone rendition goal.

In the light of above, the choice of matching reproduction variant within the printing process limitations is ambiguous, stays beyond the technology bounds and requires creative intervention of an artist or editor.

Editorial tone rendering

Editorial approach to image tone rendering puts aside the demand of its matching an original. The TRC form is set in attempt to achieve the identity of a copy not to original itself but, for example, to the imagined by operator, technologist or editor visual object which the original copy is only trying to convey (variants 6, 7 in figure 3). This may be the case when the original is clearly inferior due to improper lighting of scene, errors in film processing, long term or poor storage conditions and other reasons. This may also happen to original in form of the digital photo file as a result of inadequate interpretation of its meanings values.

The exemplary characteristics 4 and 5 of such transmission are shown in Figure 4. The first of them allows for correcting the faded "underexposed" original and the second brightens "overexposed", too dark one.

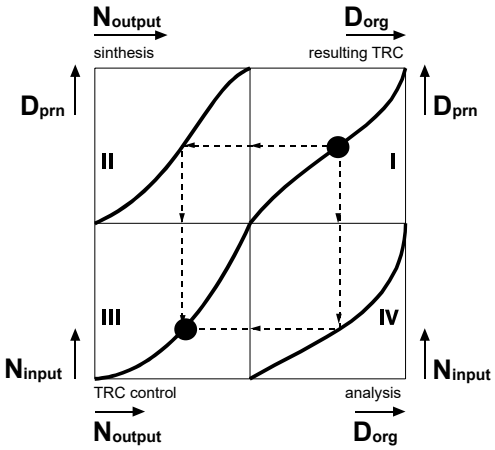
Such an approach to the optimal reproduction is sometimes construed more widely, on the assumption that the vast majority of originals are in essence a distorted, subjective replica of the visually perceived world, at least for the reason that to their production the man had a hand (Ovchinnikov, Fainberg & Litvan, 1971). Based on this premise, they consider the best gradation curve, which would lead to lightness distribution, in the so-called information component of an image, to the normal, Gaussian law inherent in this world. The distribution deviation from such law on the original is taken into account only as confirmation of the validity of this approach.

To another case of correcting the image tonal content can be related the deliberate distortion of lightness distribution of the original, even when its quality does not cause claims. The higher gradient is attached to the curve portion relating to brightness detail, which, according to the mind of customer, operator or art editor, is the most important for this scene. Local contrast of some detail can be strengthened disproportionately to contrasts of others, if, for example, in the illustrated text the author pays special attention to it. The tradeoff of such an accent again brought the contrasts of the details of other,

reducing their slope curve areas as far as to strengthen or at least save contrasts of important (informative) details is possible only by reducing the gradients for other ones.

As a case of such kind editorial rendition is the curve 2 of linear optical densities compression in Figure 4. The steps in midtones are disproportionately transferred due to the mentioned in above example their loss in shadows.

It should be also noted that the interrelation of such non similar quality parameters of an image as sharpness and overall contrast still stays out of the set of tone rendition variants in Figure 3 scheme. It's recommended to preserve the image naturalness by reducing contrast with lowering the TRC gamma up to 40% at the growth of the sharpness (Field, 2001).



» **Figure 6:** *Generalized scheme of tone transmission which shows that the managing conversion of an image signal (III) must consider the input (IV) and output (II) characteristics of a system.*

Tone value transfer

Interrelation of transfer curves

It has been shown above that the tone rendition problem is in its very statement ambiguous and the compromise editorial decision is necessary. However, for whatever reasons it was set the shape of resulting TRC, the following inevitable and purely technological stage is its practical implementation.

Illustrative original-to-print transformation is multistage. Each the step, whether it be electro-optical analysis, transparencies recording, plate making and printing itself, has its own transfer characteristic, linking the input and output values. Their product results in the whole process TRC and the issues of its realization should be discussed with accounting the characteristics of these multiple stages.

The generalized tone reproduction scheme is presented in Figure 6 by four interrelated curves with the target TRC- $\mathbf{D_{prn} = f_1(D_{org})}$ in its first quadrant.

In the third quadrant is located curve $\mathbf{N_{out} = f_3(N_{in})}$ of flexible control of gradation converter. Its dialog box gives it by default as a straight line running at 45 degrees and corresponding to the unchanged transfer of some of the 256 input and output tone scale quantization levels. However, the resulting graph of the first quadrant may be quite different without full compensation for the nonlinearity of the characteristics of other stages.[3]

Their performance is conventionally summarized in this diagram in two groups. The first of them includes a sequence of nonlinear transforms the optical density of original to the quantization level of the input signal entering the gradation converter: $\mathbf{N_{in} = f_4(D_{org})}$. It accounts the scanner characteristics and a number of other stages associated with the signal digital coding and perceptually uniform presentation.

The other group is represented in the second quadrant as the generalized characteristics of the synthesis-link of the converter output signal with the print density: $\mathbf{D_{prn} = f_2(N_{out})}$. It combines the results of nonlinear transformations accompanying the screening, transparency recording, platemaking, printing and continuous perception (descreening) of a halftone when viewing.

The diagram clearly shows that the control function of the third quadrant is a derivative of the other three ones which is indicated by the lines of one of its dots finding. So, accounting the characteristics of all other stages it subject to mandatory correction when changing any of them.

In more detail the process of tone transmission reflects the multi-quadrant scheme in Figure.7 the quadrants 1 and 7 of which are identical to 1 and 3 ones of Figure 6 but the rest ones reveal the generalized characteristics 2 and 4 of the latter. By analogy with the previous scheme, subscripts of the transformation functions **f** coincide here with the corresponding quadrant number. An image capturing step, where the optical densities of original are converted into voltages or currents proportional to the luminous flux, and, consequently, the reflection coefficient **ρ**, is given in the fourth quadrant by the link of the level number of a linearly quantized signal with density of an original $\mathbf{N_\rho = f_4(D_{org})}$. To go from the $\mathbf{N_\rho}$ signal proportional to reflections, to the signal $\mathbf{N_d}$ of more visually uniform optical densities, the logarithm transform is used schematically indicated by curve $\mathbf{N_d = f_9(N_\rho)}$. The sixth quadrant presents further the characteristic $\mathbf{N_{in} = f_6(N_d)}$ of signal pre-distortion to compensate for the dot gain.

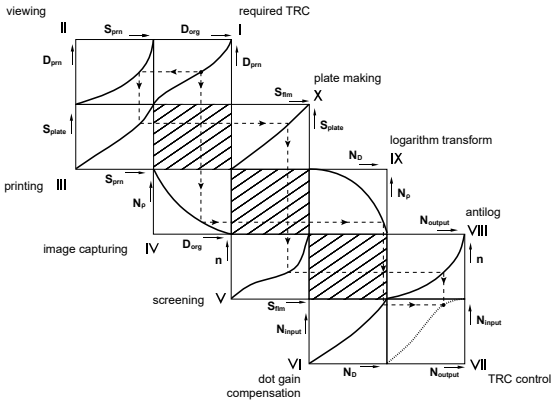
At following from the ordinate axis of the first quadrant to the left and further along the scheme, it should be reminded that the print density is related to the

[3] Some of the prepress programs include, for example, the Dot Gain Compensation for such compensation. In the context of the Color Management System discussed below, a similar task is assigned to the so-called Color Profiles.

area **S** of its halftone dots (tone value) in quadrant 2 ($\mathbf{D_{prn} = f_2(S_{prn})}$) logarithmically, namely, according to the Yule-Nielsen equation or other model of halftoning.

Curve $\mathbf{S_{prn} = f_3(S_{pl})}$ of the third quadrant is the print characteristics connecting the dot areas on a print and plate. Next, also nonlinear one is the function $\mathbf{S_{pl} = f_{10}(S_{flm})}$ of the dot area transfer from transparency onto a plate.

Neglecting the non-absolute nature of the ink film absorption and paper reflection, it can be assumed that the relative areas on a print are essentially its absorption coefficients connected, by definition, with uniform (proportional to density) output signal $\mathbf{N_{out}}$ by antilogarithm law. Because in most modern software and hardware screening the halftone dots are formed by even smaller elements (microdots), this is accounted at the halftoning stage. Therefore in this scheme the antilogarithm procedure is presented in quadrant 8 by the nonlinear connection of amount **n** microdots forming the dot with the level number of signal $\mathbf{N_{out}}$ controlling the halftone dot generator: $\mathbf{n = f_8(N_{out})}$.



» **Figure 7:** *Interrelation of tone transfer curves in printing.*

Essentially nonlinear in practice, the relationship $\mathbf{S_{flm} = f_5(n)}$ between the microdots amount n and therefrom formed halftone dot area Sflm in mechanicals recording displays the fifth quadrant.[4] Curve $\mathbf{N_{out} = f_7(N_{in})}$ of the converter, solving the gradation crucial task in quadrant 7 accounts the characteristics of all the other stages which is once again demonstrated by one of its points finding.

Step-by-step examined above the relationship of nonlinear image signal transformations allows to clarify their in-principle distinction. So, if the curve of quadrant 1 defines the goal of reproduction, then, being a derivative of all the others, the characteristic of a flexible, control function of gradation converter in quadrant 7 acts as a means of its destination.

A completely different role is played by all the other nonlinear transforms that make up the third, their most extensive category. For the most part, they reflect the relationship of output and input values inherent in specific physical nature of the various technological stages. Their modes are set and optimized according to their own criteria, and not in order to obtain some predetermined shape of the whole process TRC. For example, the printing of a halftone is adjusted by the criterion of ensuring an effective tone range. When recording a halftone dots on film the most important is achievement of high copying properties of the resulting transparency for platemaking, etc. Being associated with the properties of materials and equipment and are not changed at the will of the operator, i.e. not performing TRC control function, these characteristics nevertheless, have a direct impact on the final result and are therefore subject to strict checking. In a continuous or lengthy cycle, they are monitored periodically, but each time when changing the consumables or equipment. Such technology stages should be stable. Only if their parameters are maintained within the specified tolerances, the prepress is effective in controlling the final result. For example, at the last stage, the required stability and repeatability is provided on a press by the visual, instrumental or automatic evaluating the prints and their control scales.

It is also seen from this scheme that each step, having an individual nature, contributes to the resulting transfer. The nonlinearity of one stage, having the same or opposite shape (convex, concave, N-shaped, S-shaped, etc.) may enhance or compensate for the nonlinearity of the other.

In CMYK printing the achromatic scale is also greatly influenced by the applied strategy of the fourth, black ink use within such prepress options as Under Color Removal- UCR, Gray Component Replacement- GCR, Under Color Addition – UCA (Kuznetsov & Ermoshina, 2016).

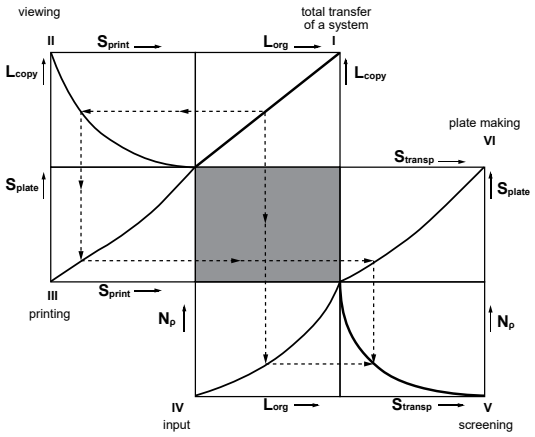
Transfer characteristic of the system

Of particular interest is the end-to-end characterization of the system itself as a cumulative result of all stages. With taking it linear in units, for example, of the Lab lightness L, the other stages effect on this linearity can be estimated according to the scheme in Figure 8. It differs from the previous one in that it includes only the characteristics of the materials using stages while those associated with the signal conversions are omitted.

According to this scheme, it can be seen that with fixed parameters of other operations, the overall linearity of the system can be provided only by an appropriate selection of the screening characteristics placed in the fifth quadrant- the connection of halftone dot area with the image signal value. Modern tools allow for flexible specifying it analytically, by the alphabet of halftone dots and other methods in the RIP, digital halftone generator or in the corresponding module of a computer program.

[4] Such function stays as well nonlinear in the CTP and various kinds of direct digital printing.

If the initial, at least approximate, overall linearity is achieved by the process stages agreement, then such corrections as, for example, shown in quadrant 6 of Figure 7 for Tone Value Increase (TVI) compensation, will be trimming, accounting only the transfer nuances of other steps. Otherwise, deeper nonlinear transformations of the discrete (quantized) image signal may be necessary, which are fraught with interference and loss of information.



» **Figure 8:** *Screening stage characteristic (quadrant **V**), linking reflection **Np** of the original with tone value **S**, is responsible for the TRC linearity (quadrant **I**) of a system. (In the CtP technology the quadrant **VI** is excluded of this scheme, while in digital printing - **VI** and **III**)*

Contouring capacity

In addition to the overall linearity is also important the number of responses- distinguishable steps of the Human visual System (HVS) contrast sensitivity thresholds or amount of just noticeable differences (JND) in the reflection copy viewing conditions. It, according to various estimates, is from 80 to 100. However, printing, as a rule, does not provide such a number of steps because of its own noise caused by the substrate roughness and fluctuations in the ink transfer. In the letterpress newsprint it is, for example, difficult to get a step wedge of more than 16 patches. However, it is obvious that the configuration of any printing system should provide the maximum possible their number.

Another obstacle to the tone steps transfer may comprise the second, after analog-to-digital conversion, tone scale quantization at the screening stage caused by the halftone dot discrete formation from microdots. The number of these quantization levels depends on the screen cell dimensions and is directly related to the output resolution of a film/plate recorder or digital printer.

It was reminded (Kuznetsov, 2019) that the basic criterion for substrate-ink-plate system optimizing is in providing of minimal possible, stable printing element.

Taking into account its size and effective tone range, the screen ruling value is set (Kouznetsov, 1999). The tone rendering within this interval is affected by the TVI, which depends not only on the ruling, but also on the screen geometry and is determined by the degree of dot area distortion when transferring its image, idealized by a computer program or a bitmap, to a print.

The most universal optimization criterion of the entire system behavior in illustrative printing can be, in this respect, the so-called contouring capacity $\mathbf{K_c}$ - the number of combinations of two in **N** steps of the *ultimate step wedge*, possible for a certain printing: $\mathbf{K_c = N\,(N - 1)/2}$ (Rabinovich 1976, Kuznetsov 1998).

The number **N** is limited by the noise level of printing. Theoretically, the *ultimate* can be considered a wedge of **N** patches, if an attempt to supplement it with one else distinguishable patch by reducing the differences between each pair of the others by **1/N**, converts it into a *vignette* throughout whole tone range.

In contrast to previous years, the creation of such wedges with freely adjacent patches and with an arbitrary step in up to 256 values of the uniform signal has become possible today thanks to the prepress computerization. Printing of such scales is not only the effective means of controlling the optimal adjustment of the screen-plate-paper-ink-press system, but also an operational visual indicator of the degree of its linearity, normalization and stability. Any setting deviation leads to the merging of more or less patches on a particular scale area. So, if the system noise increases as, for example, a result of using less smooth paper, some patches are perceived conjoint, but the other separate, this indicates the need for use of corrective "profile" at renewed print settings. If all the patches merge in the new conditions in a vignette, then there is reason to assume that the system remains linear.

The evaluation of small tone steps in the brightness logarithms, optical densities or the CIE Lab lightness is rather approximate and may not match the visual perception in the specific viewing conditions, since these metrics, in themselves, are not known to be absolutely uniform. It may happen that the Lab lightness distribution measured for the "ultimate", and, consequently, linear and visually uniform scale is nonlinear. However, this will just indicate the inadequacy of the used metric to the task. In such a case the calculation formula for L or other attribute of color can be replaced with a new one which will account the printing specific and such particular viewing conditions as the type of light source, illumination intensity, image background, the overall level of brightness adaptation ...

Uniform representation of the image signal

A signal, formally proportional on the sensor output to the light flux, and thus the reflectance or brightness, is used to be transformed at input into the perceptually uniform one either by logarithms, or by CIE non-linear empirical transforms. Naturally, this takes also into account a certain nonlinearity of the light characteristics of an input device. Because ultimately, at the system output, there is used the signal of ink amount (dot area), so again associated with reflections (this time of a print), the need for such a transform may seem, at first glance, not obvious.

The representation of an image signal with equal contrast, i.e. by the values most closely related to visual perception, makes it more resistant to interference that inevitably accompanies any functional transformations of such a signal. In analog part of imaging channel the noise is generated by the dark current of a sensor, fluctuations of the electronic circuitry p-n transitions, and in digital – due to the quantization errors in analog-to-digital and digital-to-analog transforms. Such errors also accompany the screening with halftone dots discrete formation by microdots.

It is known from signals theory that the concentrating noise or errors of communication channel effects most damaging the data. For an image, this means that at the same resultant power, they may be most noticeable if they are concentrated in some its part, in one of the areas of tonal range or band of spatial frequency spectrum.

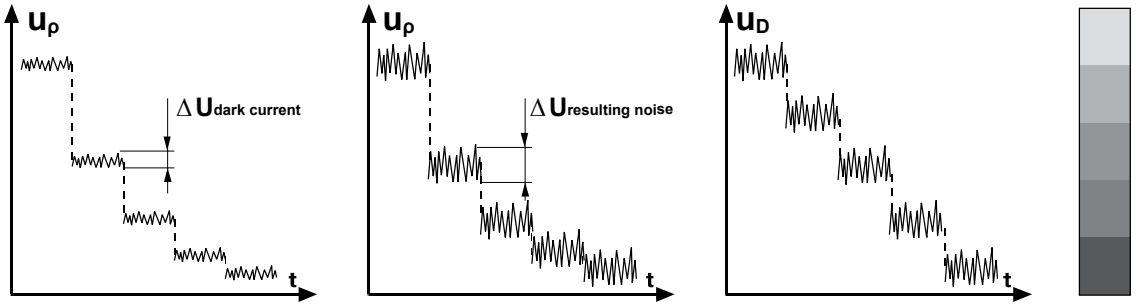
Noises affect the image additive, summing up those previously accumulated into each of the subsequent stages. Therefore, the signal is lead to uniform values at the very beginning of the channel, where the noise level is still relatively small being determined just by the dark current of a sensor. Effect of total process noise on the image, represented by such a signal, is uniform in the reproducible range and less affect the quality of resulting copy. Otherwise, it is accumulated in the shadows and leads to a noticeable loss of gradations as illustrated in Figure 9 by the logarithm processing the analog signal of a scanner. Figure 9 (a) shows a form of the voltage at the sensor output for a visually uniform step-wise tone scale (the adjacent patches of which the same differ in optical density in Figure 9 (d). Steps of this curve are in contrast very uneven, since this voltage is directly related to the patches reflection and not with their densities. Part of gradations, as conditionally shown in Figure 9 (b), will be "drown" in noise, the level of which can significantly increase as a result of the accumulation of noise accompanying subsequent functional transformations of a signal. And vice versa, from Figure 9 (c) it's seen that for the same resulting noise all the scale patches are equally discernible, if the signal is initially subject to logarithm conversion. Noise is uniformly distributed in this case over the tone range and, despite the same rate, its effect less negative.

Actuality of the brightness values conversion into optical density or lightness grows with the tone range increase of an original. Therefore, the input signal entering the analogue-to-digital converter (ADC) is usually of 10 and more digits. Reserve of bits (quantization scale steps) in the nonlinear conversion is needed to keep informative all the 256 levels of standard eight-bit output signal. In the scanner, equipped, for example, with 30 bit ADC, each of the captured RGB signals is quantized on a scale of the 2^{10} = 1024 levels. On the part of tone curve transform with a gradient of 4/1 each of output eight-bit values is, thanks to this reserve, corresponded to at least one level of an input signal. Professional scanners can use the 16-bit ADC in each color channel to process the originals of up to 4 density units.

Characteristic of the screening stage

In Figure 7 it's presented by quadrants 5 and 8 comprising together the function $\mathbf{S_{flm} = f_{5,8}(N_{OUT})}$ which connects the dot area $\mathbf{S_{flm}}$ and signal $\mathbf{N_{OUT}}$ recording the halftone transparency.

The halftone dot in most cases is formed from discrete microdots exposed by the output device. If to assume that its area is directly determined by the number **n** of



» **Figure 9:** *Forms of **Uρ** and **U$_D$** signals for visually uniform tone scale (d): at the sensor output (a) and at the end of a channel without (b) and with the use (c) of logarithm transform*

such sub-elements, it appears that it linearly expresses the print absorbance/reflection and not optical density or lightness values of a uniform output signal $\mathbf{N_{OUT}}$. Therefore, the screen mesh of, for example, of 4x4 microdots can formally transmit 16 plus one, corresponding clean paper, gradations. However, with its use of the sixteen visually uniform steps with considerable distortions of contrasts will be printed just 10-12. The rest, little differing from each other, will merge in shadows. So, the relationship between dot area and uniform signal needs to formally submit antilogarithm law what is indicated in quadrant 8 of Figure 7 as function $\mathbf{n = f_8\,(N_{OUT})}$.

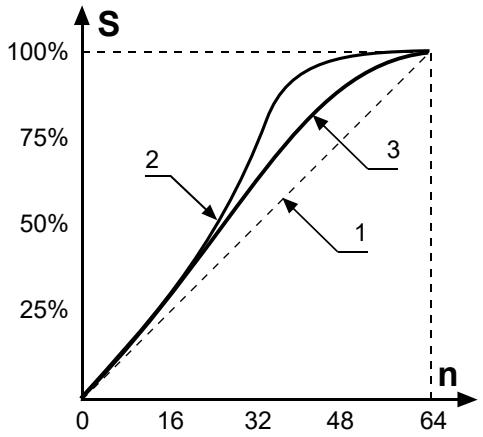
For this reason, it is not correct to calculate the number of reproduced tone levels according to the size of matrix or screen cell. Such widely recommended calculation (Kipphan, 2001) as the square of the output device resolution (**Dpi**) and screen ruling (**Lpi**) ratio: $\mathbf{(Dpi/Lpi)^2 + 1}$, lacking the logarithm or the cube root extraction, looks rather confusing.

And nevertheless, the question may arise: why is the dimension of matrices used in practice, although it exceeds the number of reproducible reflection coefficients, but still not as much as it suggests the reverse, for example, antilogarithmic, transition from the signal of optical density to halftone dot area on the print? After all, if direct conversion has assumed at the input, for example, 256 times the margin by the number of levels (to 2^{16} levels in ADC compared with 2^8 in the image file), then the output would be logical to use a screen cell size 256 x 256 = 65536 = 2^{16} microdots?

Several factors contribute to the practical limitation of the output record resolution and thereby the number of dot fonts of the halftoning alphabet.

First, the number of brightness levels, distinguished in print viewing conditions does not over of 100 and gray scale of a print rarely exceeds 1.8 density units (against to 3-4 units on slides). Second, even on very smooth papers because of the process noise are not achieved even 64 distinguishable steps. Therefore the uniform eight-bit signal, with its 256 meanings, enables in this relation the almost a fourfold margin.

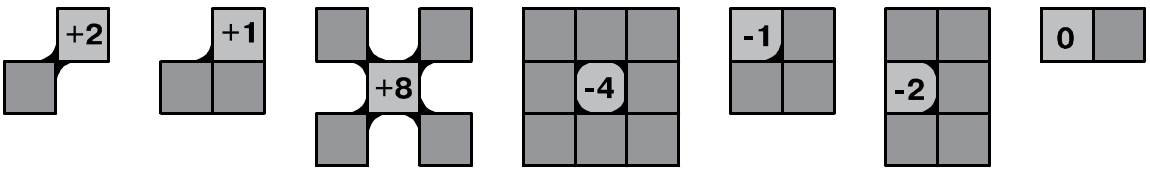
Another to be taken into account objective dependence is in the nonlinear connection of resulting tone value (dot area) with the number **n** of microdots forming the print elements in a regular screen or their conglomerates in its FM, stochastic version. This proportionality failure of $\mathbf{S_{flm} = f_5(n)}$ function was first mentioned at the very initial steps of electronic halftoning (Hallows & Klensch, 1968). It takes place at the stages of a latent image formation in the electrophotography as well as in halftone transparency recording amplified thereafter at the plate making and especially in printing. It's explained in Figure 10 by the example of randomly filling the 8x8 matrix with 64 assumedly square microdots.



» **Figure 10:** *Proportionality failure between the resulting ink coverage **S** and the number **n** of its constituent microdots (1 – formal; with the random 2 and in cluster 3 microdots placement)*

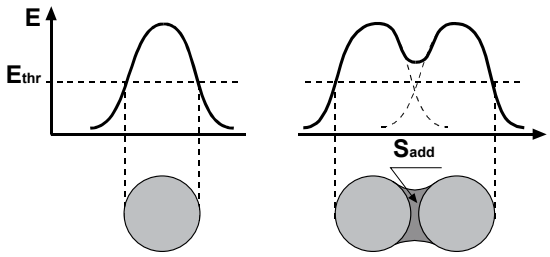
While the amount of microdots is relatively small, they are located mostly in isolation of each other and at first the curve is linear, because each added sub-element brings an equal value to the resulting coverage. But even with an ordered fill, this happens up to a tone value not exceeding 25%. The rate of coverage sharply growths as soon as the microdots begin to touch each other. In their contact zones, as shown in figure 11 (a, b, c), there are formed the additional, not geometrically provided areas. Their number depends on the amount of simultaneous contacts of introduced microdot (shown lighter in Figure 11) with neighboring, previously set ones and is accompanied by the formation of one (Figure 11 b) and sometimes of eight (Figure 11 c) such areas.

Formation of such extra area has the different physical nature. When recording onto a film or on sensitive layer of a plate, it is due to the summation of light scattered



» **Figure 11:** *Ink fill-in with the formation of unsolicited positive (a-c) and negative (d-f) coverage (marked dark) in different variants of mutual positioning the ideal, assumedly square microdots*

at the edges of neighboring exposed elements (Figure 12, b) while for isolated, taken separately elements this light stays insufficient for blackening (Figure 12, a).



» **Figure 12:** *Summation of exposure in the halos of neighboring elements leads to the formation of an additional area in the film or plate recording*

Additional areas occur further in the press due to the action of surface tension forces in the ink layer, pressure and other reasons.

In the electrophotography, for example, in a copier, laser or LED printer, the formation of these areas, in addition to the marked summation of exposures, is due to the spreading of the charge within the optical photoconductor (OPC). Sharp fractures of the electrostatic field equipotential lines in the zones of microdots contact are accompanied by an excessive increase in electric field strength, which is offset by the charge leakage through the OPC finite resistance.

For darker gradations, the rate of coverage growth is reduced because, as Figure 11 (d, f, g) shows and the shape of curves 2 and 3 in Figure 10 reflects, still blank areas already include the filled-in portions occurred when touching the elements earlier, for lighter tone values. So, the introduction of each new microdot gives here an increase smaller of its own area. As result the extra area with a single microdot adding depends on position of the latter in relation to others and ranges from +8 to-4 such unit areas. Each of them is absolute, i.e. not related to the size of a microdot, and therefore its share becomes greater at higher resolution thus strengthen the proportionality failure of curves 2 and 3 in Figure 10, i.e. their difference from the theoretical graph 1. The latter is true only when using such large microdots, compared to which the surplus areas are negligible.

The shape of curves is somewhat opposite to the logarithm characteristic. This partly explains the possibility of uniform transfer of the original values with a fewer number of microdots in the screen cell than it follows from purely geometric considerations.

Effect of the surplus inked areas is especially pronounced in stochastic screening (curve 2 in Figure 10) making the tone value close to that of ink solid (100%) at filling the matrix just by 70 – 80 % of its microdots. This explains the relatively low printability and tone responses ($\mathbf{K_c}$) of non-periodic halftoning as compared to its regular counterpart and, as result, rejection of the former by wide printing practice in spite of the great number of scientific publications and promotion efforts of last decades.

Forming additional areas was discussed above as applied to a simplified variant of filling the orthogonal matrices by conditional, square microdots with a uniform distribution of ink or radiation. In practice, their shape is closer to rounded and in addition to touching, they somehow overlap each other when positioned the orthogonal lattice idealized in an image output bitmap. Such resulting coverage dependence from of the neighboring microdots location is accounted in the analytical modeling of halftoning (Carrara, Analoui & Allebach, 1992; Allebach, 1994).

The non-linear transformation of uniform eight-bit signal to proportional the brightness or reflectance is not used in prepress software options. During the transition to tone values (a relative ink coverage areas — CMYK) the 256 levels of this signal are usually linearly converted to percent. Antilogarithm transformation is provide by the threshold function connecting the number of **n** microdots in bitmap dot font with the level of $\mathbf{N_{OUT}}$ signal in a RIP or printer driver (quadrant 8 in Figure 7). To achieve the maximum possible contour printing capacity, this function should also account other nonlinearities discussed above, for example, related to the shape, order of microdots positioning in a screen cell…

Optical and physical dot gain

Even more complexly the geometry of elements mutual positioning effects on the optical dot gain (Gustavson, 1997). In the Figure 7 it's formally taken into account in the second quadrant.

Unlike this apparent dot gain the physical Tone Value Increase (TVI) means the extension of size of a halftone dot at transfer it from transparency onto a plate and further to substrate.[5] For regular screens, the maximum of both optical and physical TVI occurs when adjacent dots are touched, i.e. in medium and darker tones. In non-periodic halftones such a touch is more or less common throughout the gray scale and the maximum is shifted to a lighter area. In the most general case, the TVI is considered as an ink coverage change in the entire technology chain: bitmap-film-plate-paper. It is obvious that in the CtP and digital printing from this chain fall respectively the second and third links. Curve $\mathbf{N_{IN} = f_6(N_D)}$ in the sixth quadrant of scheme 7 collectively compensates for these nonlinear distortions, denoted for platemaking and printing stages in quadrants 10 and 3.

Causes of physical dot gain are in the light scattering in transparency recording, its transfer onto a

[5] In the second edition (ISO, 2004) of ISO 12647 it's recommended to replace the term *dot gain* by *Tone Value Increase -TVI*.

plate, pressure in the printing contact, filling-in... These "natural" factors may be supplemented by the avoidable causes such as slur and doubling associated with improper press adjustments.

Specifying the TVI (ΔS) by a single number indicates the difference between the tone value on print from the 50% on a plate, film or in digital file. In sheet fed offset printing, the TVI reaches 15% (at 150 Lpi) and 20% (at 135 Lpi), respectively, for coated and uncoated papers. In web offset at 135 Lpi it is 22% while for newspapers at 100 Lpi achieves 30% (Southworth, McIlray & Southworth, 1992). If it is written in two numbers, they correspond to the similar differences for the margins of 40% and 80% of standard print control wedges. However, the most complete picture gives a TVI curve $\mathbf{S_{PRN} = f (S_{PL})}$ in the third quadrant of the scheme 7. The position of its maximum depends on both the dot shape and screen geometry. If the square elements are staggered, the greatest TVI occurs at about 50%. If they are round, the maximum is shifted to 79%. With irregular placement of fixed size dots, the same maximum is shifted to the light (25%- 35%) region.

One of the operational parameters of densitometry monitoring this phenomenon is the *print contrast* **K** measured on the control scale for solid ink layer ($\mathbf{D_S}$) and patch of 80% ($\mathbf{D_{80}}$): $\mathbf{K} = 100\% \cdot (\mathbf{D_S} - \mathbf{D_{80}}) / \mathbf{D_S}$. Its zero value indicates the complete absence of a gap between the dots of 80%. If in such case the ink solid density greater of norm the cause may be in the excess of ink supply. Otherwise, the reason for this control parameter decrease should be found in the excessive pressure, appearance of slur or doubling, etc.

Above were considered the characteristics of the "material" stages associated with the production of mechanicals, plates, proofs and prints themselves, as well as the principles of accounting for their specifics in the prepress software when creating the output image file. However, the parameters of each of these stages are maintained only within certain specified technological tolerances. Their margins depend on the quality of materials used, equipment and degree of its wear, level of regimes normalization and stabilization, which, in turn, depends on both the economic opportunities and the overall technological culture of the production site. Deviation occurrences within these tolerances can be unpredictable and contribute to the corresponding uncertainty in the values obtained in printing.

Conclusions

The TRC defining is comprised of aligning the tone ranges of original and print copy and finding the shape of the curve connecting tone values of original and print within the range with the priority of a first stage as far as the ranges mismatch can result in irreparable loss of an image data.

There are two principally different approaches in setting the tone curve shape as a reproduction goal: matching an original and editorial. Physically (objectively) matching is possible for only those details of original whose values are within the printable range. In typical conditions of the latter compression relative to an original just the psycho-visual matching is possible.

Trade off in visually identical transfer of the overall contrast of an image in conditions of gray scale compression is the loss of brightness differences in the darkest and/or lightest image areas. Connection between the original and resulting print gray levels is greatly influenced by the transfer functions of all technology stages optimized according their own criteria.

In “closed” reproduction systems there is possible the end-to-end calibration compensating for the tone transfer nonlinearity of all stages while in the open reproduction environment the tone rendition programming involves individual records of separate stages characteristics. Image signal related to the visually uniform metrics is less susceptible to interference being evenly distributed over the reproduced scale. At the prepress stage, the maximal contour capacity of halftone printing is ensured by sufficiency of the dots alphabet and shape of the threshold function.

Balance provision for transfer characteristics of numerous reproduction stages in relation to the real conditions is a prerogative of technology. The accuracy of these stages parameters coordination directly depends on the degree of their normalization, general technological culture of the print site and, ultimately, determines the level and stability of print quality parameters.

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Investigation of anilox roller cell clogging

ABSTRACT

One vital component in the flexo inking system of high-line screen engraving technologies is anilox rollers. These deliver a precise and consistent amount of ink during the process of flexography, making it possible to produce high-resolution prints of exceptional quality. However, as print quality continues to improve, printing houses are experiencing more frequent problems with anilox rollers, such that ink transfer during printing operations is being unpredictably reduced. Due to the lack of research into anilox rollers there is insufficient objective information on how to maintain them at peak performance and condition. This study investigates the clogging of anilox roller cells (without assessing cell wear) in a number of printing houses in the Baltic States. Cell clogging of anilox rollers was determined depending on cell size, ink type and washing method.

KEY WORDS
Anilox roller, flexography, cells engraving, ink transfer, clogging

Arnas Savickas
Rimantas Stonkus
Eugenijus Jurkonis

Vilnius Gediminas Technical University, Faculty of Mechanics, Department of Mechatronics, Robotics and Digital Manufacturing, Vilnius, Lithuania

Corresponding author:
Eugenijus Jurkonis
e-mail:
eug.jurkonis@gmail.com

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Introduction

Flexographic printing is one of the growing printing technologies, ideal for printing on very different substrates such as paper, cardboard, foils, and film, and is mainly used in the packaging industry (FTA, 2014). Numerous studies have been conducted in this area analyzing the quality of prints and their effect on ink composition, contact pressure between the printing form and the substrate (Johnson, 2008), and deformation of the printing form (Bould, Claypole & Bohan, 2004). Slightly less research is related to the most important component of the inking system of flexographic machines, the anilox roller. Notwithstanding, there are studies evaluating the effect of pressure changes on print quality depending on the parameters of the anilox rollers (Bould et al., 2011), the rate of clogging of anilox rollers (Khmiliarchuk & Shubko, 2016), and differences in the volume measurement of anilox rollers (Provident Group Ltd & Troika Group Ltd, 2008).

Among other factors, print quality is greatly affected by the condition of the anilox rollers, and this depends on their operating conditions. Where maintenance of the rollers is deficient, there is an increased probability that the cells will become clogged more quickly. This results in wear in the cell walls and reduced transfer of ink, resulting in lower optical density of the prints and poor quality of output.

The aim of this study was to investigate the condition of anilox rollers used in flexographic printing in printing houses in the Baltic States, and to evaluate factors influencing their condition.

Hypotheses:

- Higher line screen anilox rollers tend to become dirtier than in the case of lower screen rollers.
- Cells with a higher cell depth to opening ratio tend to become more clogged than cells with a lower depth to opening ratio.

Any change in the condition of anilox rollers is directly related to a reduction in the amount of ink transferred, hence the amount of transferred ink decreases due to cell clogging or wear of cell walls.

Cell clogging is affected by a number of factors, including: the type of ink (faster drying ink can dry faster in cells); washing frequency (infrequent washing allows the ink to dry in the cells more often); washing method (inefficient washing does not completely clean the ink from the cells); the service life of the anilox roller (more frequent use leads to more frequent ink changes and clogging); and line screen (higher line screen anilox roller cells are smaller, making it more difficult to wash).

However, manufacturers alone cannot be held responsible for the amount of ink transferred by anilox rollers (Claypole & Cox, 2010). Until there is an established international standard for how such measurement should be performed, and what instruments should be used, the ink transfer parameters of each manufacturer will remain very different (Provident Group Ltd & Troika Group Ltd, 2008).

Previous studies confirm that in order to maintain optimal print quality, ink transfer inspection procedures need to be followed by the printing house. This would check not only the condition of the rollers after use, but also compare newly manufactured anilox rollers.

Methods

The study presented herein used AniCAM (Troika Systems Limited, UK) three-dimensional optical microscope with AniloxQC software to measure anilox rollers.

The parameters of anilox rollers that are investigated: changes in ink transferring from nominal value; line screen value; level of clogging; cell to wall widths and cell depth to opening ratios; the conditions of use of anilox rollers.

Anilox roller condition evaluation parameters

Level of cell clogging

The objective assessment of the clogging of anilox rollers provided data by which we could statistically estimate the clogging, and identify dependencies on other parameters. For this purpose, a methodology for assessing the level of clogging was developed, in which the degree of clogging was assessed at five levels, where 1 was completely clean cells and 5 were completely clogged cells (Table 1).

Change in ink transfer

Each anilox roller is measured at three locations, near the ends and in the middle. From the three measurements, the average is derived, which is considered to be the real average transfer of anilox roller ink. This measured parameter can be compared to the nominal transmission. Because a large number of anilox rollers with different ink transfer values are analyzed, the relative change calculated by the formula is more suitable for purposes of comparison:

$$change\ in\ ink\ transfer = \left(\frac{measured\ ink\ transfer}{nominal\ ink\ transfer} - 1\right) \cdot 100\% \qquad (1)$$

The calculated relative change shows how much the measured average ink transfer value differs from the nominal parameter (manufacturer's information). A negative value means that the measured ink transfer value is less than the nominal parameter, and a positive value means that it is higher.

Cell depth to opening ratio

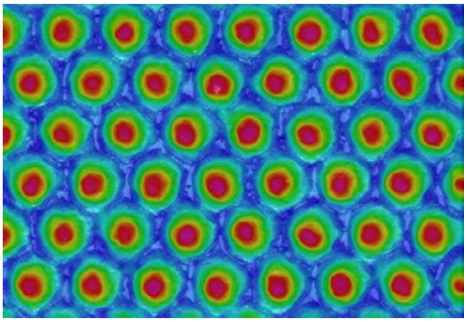
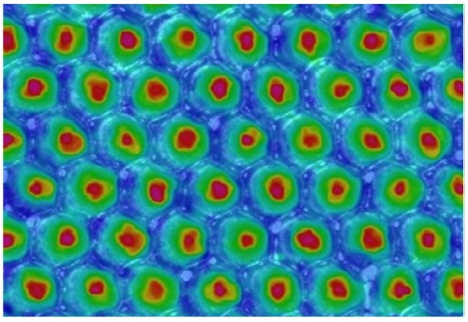
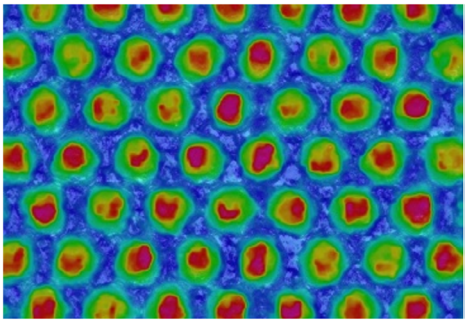
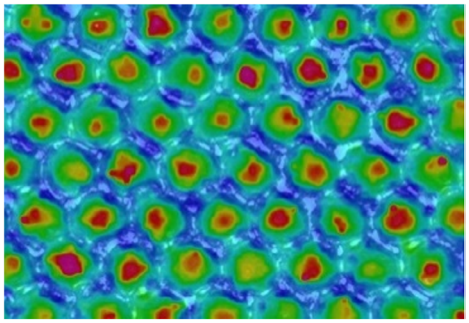
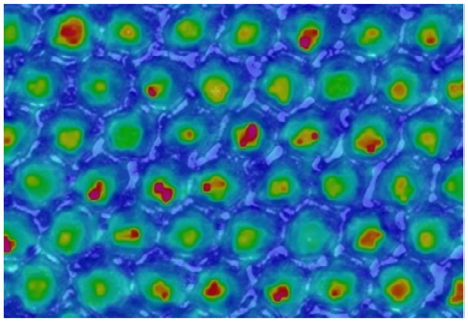
The ink transfer parameter of the anilox roller directly depends on the depth and opening of the cells engraved on it. To increase ink transfer, at least one of the cell's sizes must be increased.

If the opening (width) of the cells is increased, then fewer cells occupy the surface of the roller, thus reducing the line screen. Since the printing house often needs to print with printing forms with very fine raster dots, there is a limit to how much the line screen of the anilox roller can be reduced. While there are various theories about combining the line screen of the printing form and the anilox roller, the general rule is that the anilox roller line screen should be four times larger than the line screen of the printing form. Once the maximum cell width is set, only the cell depth can be increased. In theory, cell depth is limited only by the layer of ceramic on the anilox roller, however the depth to opening ratio recommended by the manufacturers should be followed- usually about 0.3 (Poppen, 2020; Harper, 2020). Problems can result in the case of too high a cell depth to opening ratio, such as 0.7, or even 1.1. These are:

- The capillary phenomena which results in a transfer of a smaller amount of ink.
- Cells become more difficult to clean and untreated ink eventually dries out.
- It is difficult to engrave cells with uniform parameters.

Table 1

Types of clogging levels with comments

Picture	Characteristics
	**1. First level clogging** • Bottom of all cells are almost uniform in shape and depth. • No signs of clogging.
	**2. Second level clogging** • Bottom of less than half of cells are narrowed. • Depths of less than half of cells are reduced - slightly red, widening yellow outline. • Average ink transfer must not be reduced.
	**3. Third level clogging** • Shape of the bottom of about half of cells is changed. • About half of cell depths have decreased- red is almost invisible, yellow predominates. • Average ink transfer is reduced.
	**4. Fourth level clogging** • More than half of cell bottoms are narrowed or no longer visible. • More than half of the cell depths have decreased- red is no longer visible. • Average ink transfer is reduced.
	**5. Fifth level clogging** • Bottom of almost all cells is narrowed or no longer visible. • Depths of almost all cells are reduced - yellow and green predominate. • Average ink transfer is reduced.

When a depth to opening ratio is less than recommended, such as 0.23 cells, it can cause other problems:

- The surface of the cells become uneven and rough.
- Ink may start to dry in the cells during printing.

The given cell depth to opening ratio recommendations are generally valid for hexagonal 60° engraving. To use a higher ratio, the manufacturers of anilox rollers offer engraving of elongated hexagonal cells at an angle of 75°. In the direction of rotation of the roller, the opening of the cells can be 1.5 to 3 times longer and due to the reduced capillary force, a larger amount of ink is transferred in the cell.

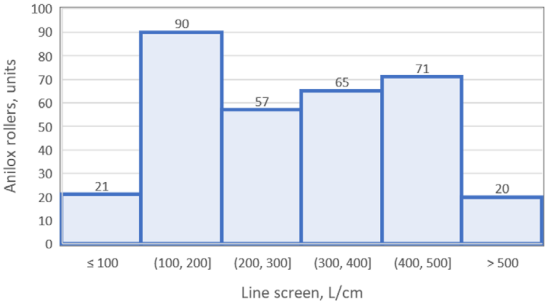
Results and discussion

Measurement statistics

The study measured 326 anilox rollers which were obtained from 16 printing houses in the three Baltic countries of Lithuania, Latvia and Estonia. Rollers produced by 9 different manufacturers from the USA, Italy, Germany, the United Kingdom, Poland and the Netherlands were measured. Measured anilox rollers are used in 28 different printing machines from 14 manufacturers.

Of the anilox rollers selected for the study, the largest measurements were made from Sandon (UK) (70 rollers), followed by Zecher GmbH (Germany) (64 rollers). The least measured was Tewex (Poland) with 14 rollers, although this manufacturer no longer supplies the European market, followed by Praxair (USA) with 18 rollers. Out of a total of 326 measurements, 12 roller manufacturers could not be identified due to worn identification marks.

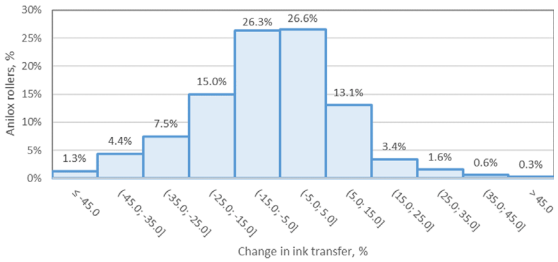
Most of the anilox rollers were engraved with a standard 60° angle (255 rollers out of 326). The second largest category, the 75° engraving angle, consisted of 55 rollers. About 30% of printing houses in the Baltic States are included in the research data. Figure 1 shows the anilox line screen distribution of all anilox rollers (dividing all rollers into ranges of 100 L/cm).



» **Figure 1:** *Line screen distribution of anilox rollers*

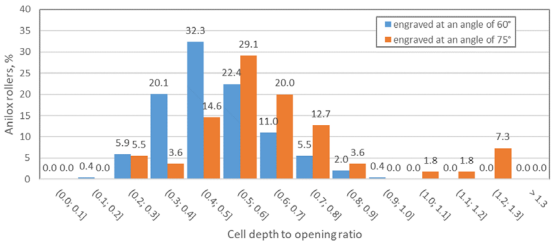
Figure 2 shows the distribution of anilox rollers according to the change in their measured ink transfer from the declared one. 26.6% of all measured rollers fall in the range (-5.0; 5.0]. Since the manufacturers of anilox rollers also apply a range of ± 5% ink transfer when engraving the surface and such results are considered to be the best. 26.3% of rollers fall within the range (-15.0;-5.0], which is a satisfactory result.

Surprisingly, printing houses still use anilox rollers with a reduction in ink transfer of more than 35%, which represents 5.7% of all rollers measured. Also, as many as 2.5% of rollers have a measured ink transfer increase of more than 25%, and one of these rollers exceeds 45%. A difference of this size from the declared value can cause difficulties in properly selecting the anilox roller for the printing process, as the print can produce much higher color intensities than expected.



» **Figure 2:** *Distribution of anilox rollers according to the change in ink transfer*

The described distribution of the cell depth to opening ratio according to the engraving angle is also confirmed by the data of anilox rollers measured during the study, which is shown in Figure 3. As can be seen, the largest part of the anilox rollers engraved at an angle of 60°, 32.3% of the rollers, falls within the range of (0.4; 0.5] cell depth to opening ratio, while the largest part of the anilox rollers engraved at an angle of 75°- 29.1 % fall into a slightly larger range of (0.5; 0.6] cell depth to opening ratio. It is also worth noting that the cell depth to opening ratio of anilox rollers engraved at an angle of 60° is located from (0.1; 1.0] and 75° to the longer range (0.2; 1.3], which shows the versatility of the extended cells- the same line screen can be given at both very low and very high ink transfer.



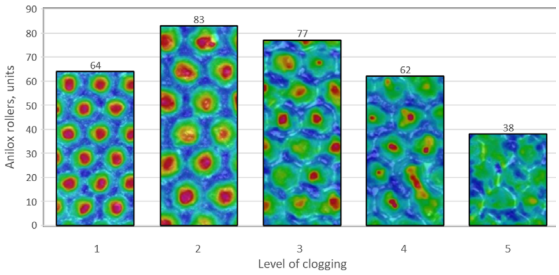
» **Figure 3:** *Distribution of anilox rollers by cell depth to opening ratio*

Although the condition of anilox rollers was found to be affected by both service life and washing frequency, the study failed to collect enough accurate data to make some comparisons. It is not possible to determine the exact service life of each roller; such information was not collected at any printing house. Also, each anilox roller is used for different jobs and even custom-made rollers ultimately maintain quality for a different amount of time. It is also difficult to calculate the frequency of washing of anilox rollers- due to the limited number of rollers that can be washed at one time, some rollers are washed immediately after being removed from the printing machine, and others only after one or two washing cycles, each lasting about 30 minutes.

Clogging of anilox rollers

Clogging distribution of anilox rollers

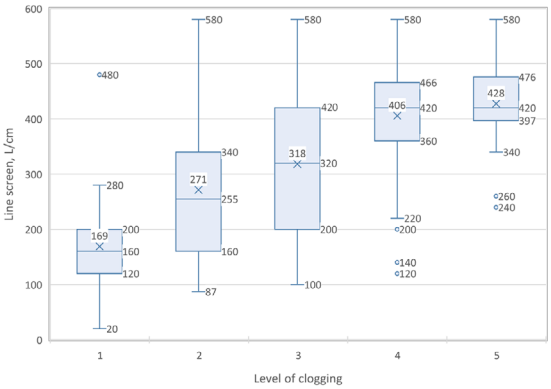
All anilox rollers were visually assessed and assigned a level of clogging from 1 to 5. As can be seen in Figure 4, most of the measured rollers are of the second level of clogging- 83 units, and at least of the fifth level- 38 units. It can be seen that there are more than half of the rollers with a clogging level of 3 and higher. This means that most rollers are either cleaned infrequently or poorly cleaned.



» **Figure 4:** *Distribution of anilox rollers according to the level of clogging*

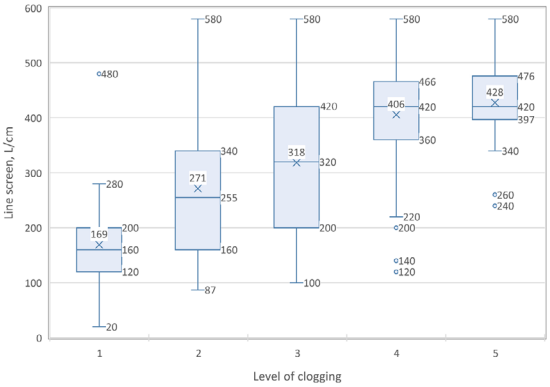
Dependence of clogging on cell size

In practice, larger line screen anilox rollers are generally considered to be more difficult to clean. Figure 5 shows the line screen distribution of anilox rollers according to the level of clogging. The graph shows that the higher the line screen of the rollers, the higher the level of clogging- the averages increase from 169 L/cm at the first level of clogging to 428 L/cm at the fifth level. It can also be observed that the higher the level of clogging, the higher the minimum line screen of the anilox rollers entering it. This may mean that the rollers of the lowest liners are more difficult to clog- for example, 21 anilox rollers with a liner not exceeding 100 L/cm were measured (see Figure 1) and none of the clogging levels were higher than 3. Meanwhile, the maximum line screen at each level of clogging is 580 L/cm, except at the first level 480 L/cm. Thus, it can be seen that even very high line screen rollers can be maintained in conditions where there is a state of unclogging or a state of nearly unclogging.



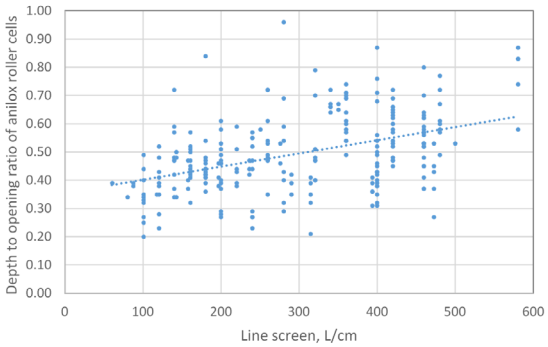
» **Figure 5:** *Line screen distribution of anilox rollers according to the level of clogging*

As mentioned earlier, one of the causes of cell clogging is too high a ratio of cell depth to opening, making it more difficult to clean the ink, which then dries more easily if it is not cleaned. In order to compare graphs of line screen and cell depth to opening ratios, it is necessary to analyze uniform engraving rollers. Figure 6 shows the line screen distribution of anilox rollers engraved at an angle of only 60° according to the level of clogging. The same trend is observed here as in Figure 5- as the level of pollution increases, the average line screen also increases. Thus, the hypothesis that the larger the line screen, the more clogged anilox rollers tend to become is confirmed.



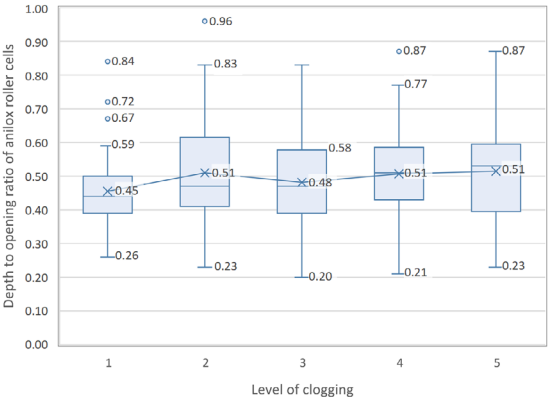
» **Figure 6:** *Line screen distribution of anilox rollers according to the level of clogging (Rollers with 60° angle engraving only)*

Also, with the exception of anilox rollers engraved at an angle of only 60°, Figure 7 shows a graph of the dependence of the cell depth to opening ratio on the line screen of roller. As can be seen, as the engraving line screen increases, the average cell depth to opening ratio also increases. This increase can be explained by the need to maintain high ink transfer when a high line screen anilox roller is used for printing, which is also used for a high-line screen printing form.



» **Figure 7:** *Dependence of the depth to opening ratio of anilox roller cells on the line screen (Rollers with 60° angle engraving only)*

The previously established high-line screen and clogging correlation suggests that the cell depth to opening ratio can be directly related to the level of clogging. However, as shown in Figure 8, no marked increase in the depth to opening ratio is observed as the level of clogging increases. This may be due to the fact that the measurements do not contain data on the parameters of the cells when the anilox roller was just manufactured and not yet clogged. When the roller is dirty, its average cell depth decreases and the ratio of cell depth to opening decreases directly. From a relatively horizontal line through the averages of the clogging levels (Figure 8), it can be assumed that the anilox rollers become, on average, clogged to a level where their cell depth to opening ratio decreases to 0.48–0.51. At the same time, the cell becomes easier to wash out and there is a slowing down in clogging.



» **Figure 8:** *Arrangement of depth to opening ratio of anilox roller cells according to the level of clogging (Rollers with 60° angle engraving only)*

Conclusions

Investigations of the state of clogging of anilox rollers used in flexography in printing houses in the Baltic States lead to conclusions:

1. 26.6% of analyzed anilox rollers ink transfer changes are within ± 5% (recommended by anilox roller manufacturers). 13.2% of the anilox roller ink transfer change was less than-35%, and 2.5% of the roller ink transfer change was more than + 25%. Large discrepancies in ink transfer from the ratings indicate potential difficulties for the print house in selecting the right anilox roller for each print job.
2. 177 of 324 anilox rollers had a clogging level of 3 or higher. This means that more than half of the anilox rollers in printing houses are not properly washed.
3. The hypothesis that larger line screen anilox rollers tend to become more clogged is confirmed. The average linearity in the first level pollution segment is 169 L/cm and increases with an increasing pollution level until it reaches an average linearity of 428 L/cm in the fifth level pollution segment.
4. The hypothesis that cells with a higher cell depth to opening ratio tend to become more clogged than a lower cell ratio cannot be tested due to the lack of data. Since both clean and already clogged anilox rollers were studied, after adjusting the data for the level of clogging, an increase in the average cell depth to opening ratio was observed with increasing clogging level of 0.45 at the first clogging level and 0.62 at the fifth clogging level.

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