COMPARATIVE ANALYSIS OF THE QUALITY OF DIGITALLY PRINTED BARCODES

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Abstract

Barcodes on packaging or labels are commonly used as part of the identification of goods at every stage of their flow in the logistics system. The efficiency and speed of the entire process related to the logistics of supply and the distribution of raw materials and finished products depends, among other things, on the proper marking of the loading units. This in turn relates to the correct reading by the automatic identification devices of the information, which is carried by the appropriate symbolism. Barcode is a set of quite simple graphic elements in the form of spaces and lines, arranged in an appropriate layout on a plane. However, the simplicity of these symbols is apparent, as they have precise linear dimensions with relatively narrow tolerances, crossing of which may make it difficult or sometimes impossible for readers to read the code. This is mainly due to the accuracy of the print. Unfortunately, despite the increasing technical and technological level, such situations still occur, as the printing techniques used pose certain problems resulting from the very principle of reproduction. The subject of the research were colour originals in the form of barcodes, printed using the ink-jet method and electrophotography on paper products being the outer layer of packaging on which the printing is applied and on papers used for labelling logistic units. The results of the research allowed to determine the differences in the quality of prints in the area of particular reading parameters.

Keywords: packaging, GS1 system, barcodes, supply chain, print quality

1. INTRODUCTION

Packaging is an important part of the logistics supply chain for most products on the market as it has a significant impact on the efficient flow of goods throughout the logistics system. Efficient supply chain management requires the integration of logistics processes through access to more and more data, the ability to process them and to share them with partners. In practice, this is among other things related to the use of automatic identification (ADC).

Automatic identification systems and technologies are used for the purposes of managing both the company and the entire logistics chain, as well as for optimising and automatising the processes taking place in them. The tasks performed by these systems include: immediate obtaining of the required data, transformation of the collected information into an appropriate format, enabling permanent access to information in real time. Thanks to efficient and effective work, modern technologies can ensure product safety, transparency of the supply chain and accuracy of the transmitted data, which in turn translates into cost reduction and success of the project (Yam K. et al. 2005). Many automatic identification techniques have been developed, but the most widely accepted technique is based on GS1 barcodes printed on the packaging. The Global GS1 system includes international standards for electronic commerce, including several basic types of codes that mark units according to the needs and individual requirements of companies. The advantage of using barcode-based solutions is faster customer service, better information circulation, improvement of inventory and warehouse processes, and this makes barcodes the most optimal way to identify products and packaging for a long time to come.

GS1, as an international organization based in the world, for the sake of functionality and efficiency of information flow throughout the supply chain, supervises compliance with GS1 specifications concerning the correctness of marking of goods with GS1 barcodes through barcode quality improvement programs in both retail and distribution. As part of this activity, the quality and correctness of barcode readings is tested in retail chains, but also in the laboratories of the organization, where a detailed analysis is carried out in order to verify the quality of symbols, which main purpose is to eliminate codes that are incorrect in terms of quality and therefore do not comply with ISO/IEC 15420:2007.

In addition to qualitative studies, time losses due to the need for cashiers to manually enter GTIN of the product when the barcode could not be read by the scanner were also analysed.

In 2012-2013, the French organisation GS1 conducted research in one of the retail chains into the problems caused by poor quality barcodes in the market. The tested sample consisted of 6405 shopping baskets and 81984 products.[1] The results showed that more than 6% of baskets included purchases with incorrectly marked products, 5% of customers using self-service checkouts gave up purchasing an incorrectly marked product, and the average time loss related to additional operations needed to identify an incorrectly marked product is more than 22 seconds.

Similar research has been carried out in Poland since 2005. On the basis of reports obtained in cooperation with 3 retail chains from 2011-2013, the Institute of

[1] http://www.iriworldwide.fr/ , Research carried out by IRI Worldwide for GS1 France

Logistics and Warehousing obtained output data, which, taking into account previous studies, show that the average time lost daily in the entire chain as a result of poor quality barcodes is about 13-27 hours, depending on the number of retail outlets. Any product with a wrong barcode causes a loss of time at the cash desk of approximately 2.4-2.6 minutes on average per day. Time losses are associated with specific financial losses. It is also necessary to take into account the situation of the market known as "shortage of labour in trade".

Most retail chains are aware of the importance of barcode quality problems and cooperate with GS1 Poland as part of the Barcode Quality Improvement Program. Many chains verify barcodes as soon as they enter their distribution centers, where they request the product supplier to correct the barcode in the event of a negative code evaluation. If the supplier or the producer does not react, he or she may be in danger of being denied cooperation, thereby losing customers for his or her products. Retail chains can easily find new suppliers who produce similar goods with correct barcodes. There are retail chains that go even further in supervising the correctness of barcodes: not only do they intervene in the case of illegible codes, they also check the time of reading the codes by readers. When it is longer than the average time of barcode reading, they require the supplier to correct the barcodes, and above all to correct them in accordance with the requirements of standards and "General GS1 specifications" because this is the primary reason for the increase in reading time, i.e. basically making many attempts to read the code through the readers. This is related to the trend towards the maximum reduction of the space taken by the barcode, which is considered by many graphic designers of packaging to be a perishable element of the label or the appearance of the packaging. People who place the barcode on the packaging very often do not know the specificity of its construction and the requirements related to its printing, despite the fact that information on this subject is generally available.

Based on the above mentioned research, the most common mistakes in barcodes and the reasons for them are also analyzed. Among the important features determining the quality and legibility of a barcode, which should be defined already at the stage of designing and preparing a barcode template, are:

- barcode size
- the height of the barcode's dashes - because if the dashes are too short, the feature of multidirectional reading is lost
- dash width reduction - this is a value by which the width of the dash should be reduced when designing a symbolic template, taking into account ink spillage while printing code's dashes
- adaptation of the barcode size to the resolution of the image setting / printing equipment - the width of the modular dash should be an absolute multiple of the smallest basic image forming component when exposed to a matrix or a printing component
- width of bright margins on the left and right side of the barcode - too narrow margin may cause the barcode not to be read by the scanner due to too narrow space necessary to calibrate the barcode.
- code dash orientation - according to print direction or perpendicular to print direction

- colour of the dashes and the background of the code - the dashes should be dark and the background of the code should be bright to maintain adequate contrast necessary for reading
- the location of the barcode on the packaging - the barcode should be placed in a place where it is easy to find it on the packaging, on as flat surface as possible, without distorting it.

Therefore the prerequisite for correct barcode readings and proper data interpretation is not only the information presented in a specific barcode symbolism, but also the observance of basic requirements as to the printing quality and technical parameters that barcodes must meet. These requirements concern, among other things, the size of margins, colours and even the location on a specific object which is marked with it. (Anna Kosmacz-Chodorowska, 2016)

The problem of technical progress and the use of modern technical solutions gives rise in practice to difficulties limiting their use and is the result of discrepancies between the expected and achieved results. Often, such problems require a lot of laborious and detailed adaptation research. This was the case with the implementation of modern computer techniques. Digital printing has opened up new market opportunities in the form of small-volume print-outs, low-cost, colour-coded brochures and frequently updated information (labels, solid and corrugated board for foldable cardboard boxes production), which would take too long to implement using traditional methods. This technique is relatively young and not all of its technical possibilities have been used so far. It is hardly used for the production of packaging on an industrial scale, due to the high costs and limitations it brings. Nevertheless, intensive work is being carried out to improve the existing solutions and to introduce new ones, based primarily on the use of various physicochemical phenomena and the development of computer techniques, which in the future will allow the use of this technique to a wider extent. The development of advertising, printing technologies, the increase in the use of computer printers and high competition among companies manufacturing computer equipment result in the fact that (interest in the quality of prints is very high) the recipients are constantly increasing their requirements concerning the quality of prints they receive, thus forcing them to increase their quality requirements.

Digital printing is increasingly used in the printing industry and it is therefore necessary to assess the quality of the prints produced under these new conditions against those produced using traditional technologies. Colour and its perception play an important role in attracting buyers, and in barcode printing they also influence the automation of merchandise trade processes. Hence, an attempt was made to examine the impact of digital printing techniques on the quality of particular parameters of barcode printing and their verification. The aim of the presented research was to determine which of the selected digital printing techniques and substrates, on which barcodes were printed, would obtain the most effective results of reading the symbols important for the proper functioning of the logistics supply chain. At the same time, looking for an answer to the question, what influence does the size and colour of spaces and dashes have on particular quality parameters of the studied symbols? Presented research includes analysis of dash width measurement and determination of deviations, as well as evaluation of optical and dimensional parameters of barcodes with the use of a verifier.

The collected results allowed to determine the differences in quality of particular barcode variants in the scope of barcode printing elements.

2. RESEARCH SUBCJET AND METHODOLOGY

2.1 Preparation of the Research Material

The first stage of the work was to prepare the experimental material. For this purpose, three different substrates were selected for the EAN-13 barcode application. They were selected from among the paper products used for the production of unit, bulk and transport packaging:

- Alaska multi-layer cardboard - double-coated with creamy backing; characterized by high rigidity, whiteness, density 230 g/m2, thickness 325 µm, whiteness 92% and gloss >45%. Produced by International Paper Kwidzyn.
- Polset offset paper - uncoated wood free, with matt surface, high degree of sealing, dimensional stability, alkaline reaction and high whiteness, of 80g/m2 density and 101 µm thickness. Produced by International Paper Kwidzyn.
- Semicastor Plus label paper with a density of 80 g/cm2, thickness of 6 µm, whiteness of 88% and gloss of 72%. Produced by mrea Specialty paper.

The size of the tested barcodes was determined (2 sizes):

- barcodes with a magnification factor of 0.8
- barcodes with a magnification factor of 1.3

The next step was to select the colours in which the barcodes were to be printed. The choice of colours is based on literature sources which provide a combination of colours readable by the barcode identification devices taking into account the required print contrast. The colour of the space was the white background of the substrate, while the colour of the dashes was chosen from among the primary colours (black, cyan) and secondary colours (green, blue) of the CMYK system.

The Institute of Logistics and Warehousing in Poznan has prepared an original barcode EAN 13 in the form of an electronic file.

The file was uploaded to the computer's memory and then sent for printing on previously prepared substrates by means of industrial printing devices. Electrophotographic tests were obtained from the Aficio 22386 RICOH printer, while Ink jet tests (ink spraying technique) were printed on the HP Color Ink Jet printer CP 1700, which is used to obtain the image by thermal inkjet printing with a regular drop (the so-called Ink jet drop on demand terminal).

A total of 48 barcode printing alternatives of 10 sheets of each type were tested, resulting in 480 barcodes to be tested. Each sample was identified by a number.

Both printing and experimental research have been carried out in a laboratory environment.

2.2. Research

In order to examine the influence of the printing technique, the base material, the colours in which the barcode was printed and the size of the barcode on its quality, the width of the dashes and their deviations were measured and the optical and dimensional parameters of the barcodes were evaluated with the use of a verifier.

2.2.1. Measurement of the Bar Width

A bar width measurement was carried out to test the match between the original and the print during the printing process. The research required taking a photograph of a fragment of the examined code at an appropriate magnification (Figure 1), which allowed to take measurements with an accuracy of 0.01mm. The photos were taken with OLYMPUS CAMEDIA C-3040 ZOOM camera connected to OLYMPUS SZ1145TR stereoscopic microscope with SZ-CTV adapter.

Figure 1. Photograph of an Inkjet printed black and white 1.3-code on label paper on a scale of 3,5

Source: own research

The photographs were taken with a microscope magnification of 6 for codes of size 0.8 and 3.5 for codes of size 1.3. Each time the same, narrowest line (modular) of each code was examined. The width was measured with the *Irys* program used for this type of measurements in the printing industry. After the calibration, 5 measurements of the width of the tested line were made at the same heights for all samples. The results were compared with the measured dimensions of the original bar.

2.2.2. Verification

The quality and legibility of the barcodes was checked by means of the REA PC-Scan/LD laboratory verifier based on the ANSI (American National Standards Institute) barcode quality verification method, which allowed to assess the optical and dimensional parameters of the tested barcodes. This method "...is based on a detailed analysis of the so-called reflection factor, emitted by the barcode scanner, from the barcode symbol depending on the linear distance across the symbol, i.e. it is correlated with the conditions encountered in barcode scanning equipment. ts purpose is to obtain a quick assessment of the barcode quality by analyzing the verification results, determining the possible reason for the inability to read the barcode or difficulties in reading the barcode (...).The ANSI method has been standardized (PN-EN 1635:1999 standard "Barcodes - Requirements for testing - Barcode symbols") and therefore the measurements performed on the verifiers of various companies using this method give similar results. (Training materials 2001)

The basis for evaluating the quality of a barcode symbol with this method is a detailed analysis of the so-called reflectance factor profile of the scanning beam in terms of the basic parameters used to assess the quality of the barcode, i.e.:

- *Decoding* - a parameter that specifies whether the correct symbol characters have been encountered when measuring edge distances to a similar edge within each symbol mark against so-called reference thresholds that are described in detail in the standards for each of the symbols.
- *Symbol contrast* (SC) - Indicates the difference between the highest value (R_{max}) and the lowest value (R_{min}) of the reflection factor measured in the symbol, including the bright margins to the left and right of the code.
- *Minimum reflection factor* (R_{min}) - under the condition that the light reflection factor from the lines of the code should be as low as possible and the reflection factor from the background of the code as high as possible, i.e. R_{min} should be less than or equal to half of the R_{max} value.
- *Minimum edge contrast* (EC_{min}) - edge contrast is the difference of reflection factor between the adjacent (bordering) line (Rb) and the space (Rs). The lowest value of this contrast found in the entire barcode symbol is the minimum edge contrast, which cannot be less than 15%.
- *Modulation* (MOD) - This parameter is determined by dividing the value of the minimum edge contrast (E_{min}) by the contrast of the symbol (SC).
- *Decodability* (V) is a measure of how close the dimensions inside the symbol are to their ideal (nominal) dimensions. Decodability is a part of the available stock that has not been used up (due to thinning or thickening of the lines and their movement in relation to each other) by the printing process and is thus available for the barcode scanning process. Barcode readers will find it easier to read symbols with higher decodability parameters than those with lower decodability.
- *Defects* (ERN) - anomalies in the reflection factor values found inside the lines, spaces and margins. They may be caused by ink spots on spaces and margins, or by faded printing on code lines. Defects are measured by the ratio of ERN_{max} (the highest ERN value found throughout the reflection factor profile of the scanning beam) to the contrast of the symbol (S.C.).

Each barcode tested shall have an overall symbol score in ANSI analysis corresponding to the average of the measurements of the 10 reflection factors profiles of the scanning beam. The assessment of each profile corresponds to the worst of the assessments obtained for each of the profile parameters. Values are measured and calculated in accordance with the specifications and formulae given in the standards. The quality is presented both as a percentage and as a quality assessment. Percentages of SA are assigned to quality assessments. According to CEN, the quality assessment may be between '0' and '4' or alternatively in ANSI between 'D' and 'A' or 'F' - disqualifying. The link between the CEN and ANSI assessments is shown in Table 1.

Table 1. Quality assessments of the ANSI method.

	ANSI	CEN	Symbol assessment
Very Good	A	4	3,51-4,0
Good	B	3	2,51-3,5
Generally legible	C	2	1,51-2,5
Sometimes legible	D	1	0,5-1,5
Incorrect	F	0	below 0,5

Source: Operating manual of the REA PC-Scan/LD barcode quality testing device.

The overall assessment of the symbol corresponds to the worst of the assessments obtained for each of the tested parameters. If it is lower than the minimum acceptable rating for the application, the analysis should look for parameters which have a lower rating than the assumed one. The reason for the downgrading shall be found and the error corrected.

The advantage of ANSI assessment is that it classifies the result of the verification through five quality assessments and defines additional important parameters (e.g. defects, modulation) that are not included in the traditional assessment.

3. RESEARCH RESULTS AND THEIR EXPLANATION

3.1. Results of Dash Width Measurement

The bars of the tested codes were printed in four colors: cyan, black, green and blue. The analysis of the results was carried out on the basis of determination of W_{min}, W_{max}, $W_{śr.}$, OS and PU of the width within the variant of the examined sample where:

W_{min} - minimum value,
W_{max} - maximum value,
$W_{śr.}$ - average value,
OS - Standard deviation,
PU - confidence intervals.

Deviations from the width of the Δd bar calculated from the following formula were also determined:

$$\Delta d = d_{zm.} - d_{oryg}$$

where

Δd - deviation from the width of the bar,
$d_{zm.}$ - the measured bar width,
$d_{oryg.}$ - the width of the bar of the original.

The analysis was carried out by comparing the width of the analysed bar with the dimensions of the width of the original bar, which are presented in Table 2.

Table 2. Width of the original line depending on the size of the tested barcodes.

Barcode size	Width of the bar [mm]	Tolerance [mm]
0.8	0,24	0,035
1.3	0,41	± 0,147

Source: Own elaboration based on General GS1 Specifications, www.gs1pl.org

The results show that the width values of the modular bar of the samples differed depending on the type of colour, printing technique and the paper on which the barcode was applied.

The values of the analyzed parameters differ from each other and from the original to a greater or lesser extent, which is best illustrated by the average deviation from the width of the bar and the size of the standard deviation. The studied modular bars showed an increase or decrease in width, therefore in the tables the results of Δd are positive or negative.

The width of the black modular bar of size 0.8 assumes the values of 0.197÷0.280 mm (with standard deviation 0.003÷0.029), while the values of codes 1.3 assume the values of 0.427÷0.480 (with standard deviation 0.007÷0.016). The largest deviations from the bar width were observed for 0.8 samples on offset paper printed with electrophotography, for which the average deviation from the bar width was 0.040 and samples printed on cardboard with ink-jet, for which this parameter was -0.043 (which indicated thinning in relation to the original). The other codes were within the tolerance range. The lines closest to the original were those on offset paper, with a magnification factor of 0.8 - ink-jet printed with 1.3 - and electrophotography printed.

The cyanide modular bar for samples of size 0.8 assumed average values of 0.252÷0.35 with a standard deviation of 0.003÷0.019. Within this group of barcodes, all sample variants printed with electrophotography were within the limits of the norm. The ink-jet tests, depending on the surface, were characterized by an increase in the width of the bar from 25% on offset paper to as much as 46% in the case of tests on label paper. The width of the sample bar of size 1.3 ranged from 0.414 to 0.452 (with a standard deviation of 0.005 to 0.013). All codes, regardless of the printing variant, were within the tolerance limits, and the closest to the original parameters was an electrophotography sample printed on offset paper - the average deviation from the bar width was 0.004mm, which represented an increase in the bar width of only 0.9%.

Green bar-coded samples 0.8 applied electrophotographically, assumed values on average at a level of 0.180÷1.189 mm (with a standard deviation of 0.006÷0.012), which meant a loss in the width of these bars by 22÷25% in relation to the original, while for ink-jet samples the values were 0.284÷0.361 mm (with a standard deviation of 0.010÷0.26), which indicated a significant increase in the width of the bars from 18% - on an offset base, to even 50% - on a label base. For the codes 1.3 regardless of the printing variant, the deviations from the width of the bars were negative, which indicates that the tested bars were thinner than the original. The average width of the bar of codes printed with electrophotography was 0.297÷0.380 (with a standard deviation of 0.024÷0.047). Loss of approximately 7% on cardboard up to 27% on label samples. In the ink-jet technique, changes were less noticeable. The average width of the bar ranged from 0.401 to 0.403 mm (with a slight deviation at the level of about 0.009).

The average width of the blue modular bar for codes 0.8 printed with electrophotography was 0.254÷0.263 (standard deviation of the sample 0.009÷0.020). The research confirmed that the width of this bar increased by 6% for label paper and by 10% for offset paper. The width of the bar of the codes of the same size but printed ink-jet was 0.269÷0.313 (with a deviation of 0.14÷0.16). The norm was exceeded by codes printed on offset paper (12% increase in the bar) and label paper (30%).

Symbols with a blue bar of codes size 1.3 were within tolerance regardless of the sample variant. They adopted values for electrophotography printing of 0.36÷0.411 (with a standard deviation of 0.13÷0.021). Tests on cardboard showed a much greater dispersion than on offset and label papers. The average width of the ink-jet printed blue bar in this size was 0.417÷0.422 mm (with a standard deviation of 0.009÷0.016). The increase in the width of bars for these samples was 1.7÷3%. The highest diversity of the results among the size 1.3 codes belonging to this group was observed for the samples printed with offset and electrophotography on label papers. The blue bars printed with electrophotography on Baltika paper obtained more similar results, for which the standard deviation is 0.017, while the width of the bar is on average 4% thicker than the original one.

3.2. Results of the review

For the verification results, quality thresholds, to which reference was made during the analysis, were developed on the basis of guidelines for barcode analysis and removal of causes and errors occurring in barcodes - "ANSI method for verifying the quality of barcodes", according to which particular parameters should receive the best grade - A (4) reaching values at the appropriate level.

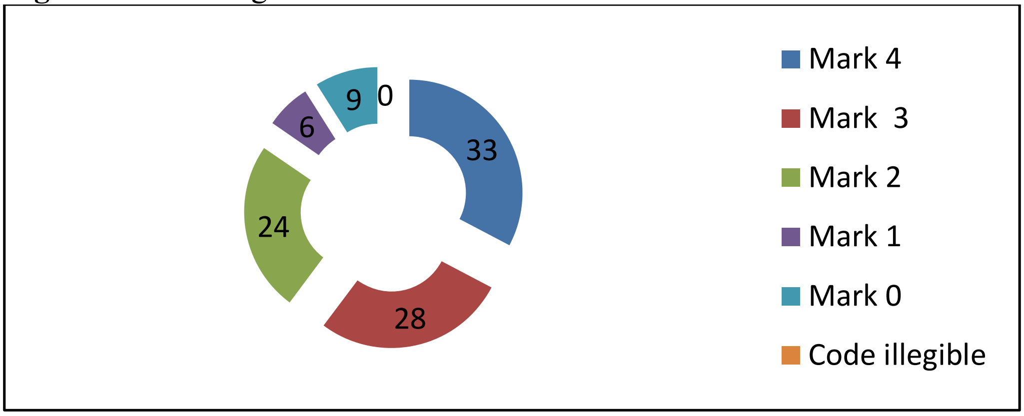
Table 3. Optimal values for particular parameters of barcodes in the assessment by the verifier

Parameter	Optimal value
Decoding	A(4)
Symbol contrast (SC)	A(4) ≥ 70%
Minimum Reflection factor $R_{min.}$	A(4) $R_{min.} \leq 0,5\ R_{max}$
Minimum Edge contrast ($EC_{min)}$	A (4) $EC_{min.} \geq 15\%$
Modulation	A(4) ≥ 70
Defects (ERN)	A(4) ≤ 0.15
Decodability	A(4) ≥0,62

Source: Own study based on the instruction *ANSI barcode verification method* by Institute of Logistics and Warehousing Poznań, 2001.

The collected results of the barcode verification process showed quite large variations in the overall symbol evaluation depending on the printing criteria, i.e. symbol size, printing technique, substrate, colour of the bars.

Figure 2. Percentage of individual assessments



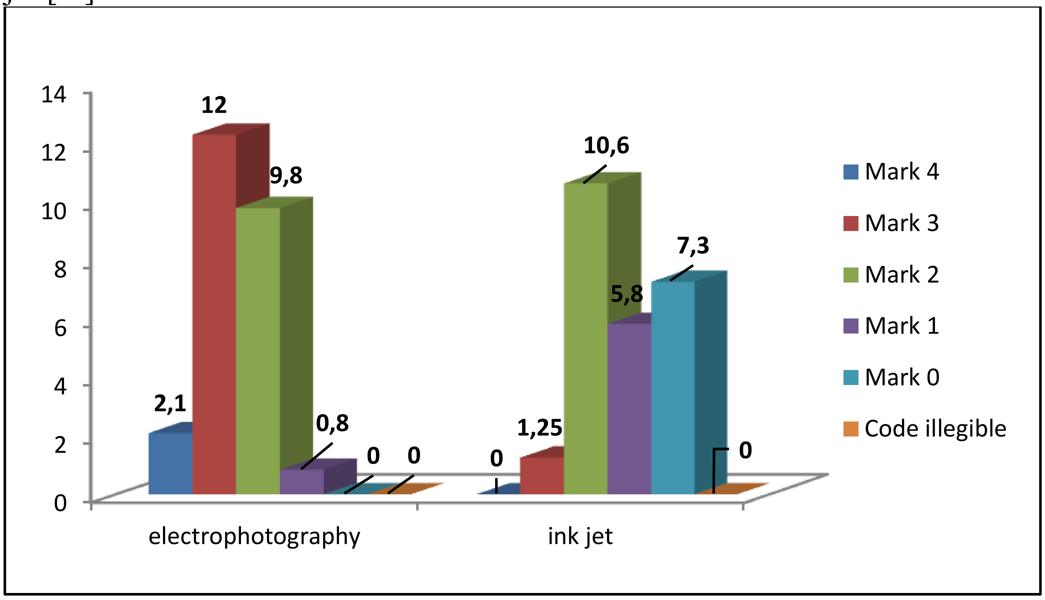
Source: own research

All samples were readable by the verifier. The highest score - A(4) was given to 33% of the tested samples, B(3) to 28%, C(2) to 24%, D(1) to 6% and as many as 9% was given F(0).

The size of the barcodes had a great influence on the reading quality - as shown in Figs. 2 and 3. A much higher percentage of samples with the best marks were symbols in the size of 1.3 - 20% were samples printed with electrophotography and 11% with ink-jet. Among the barcodes of size 0.8, only 2% received such an evaluation and these were the barcodes printed with electrophotography.

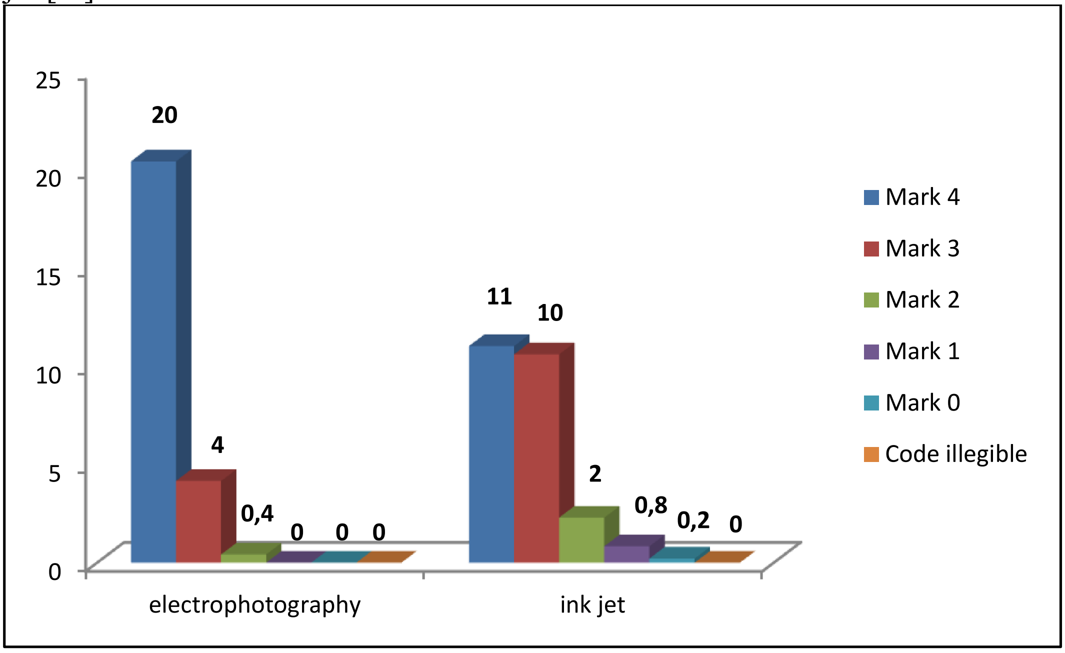
The lowest scores were given to ink-jet barcodes of size 0.8 - over 7% of the analyzed sample scored F(0) and nearly 6% to D(1).

Figure 3. Evaluation of size 0.8 barcodes printed with electrophotography and ink-jet [%]



Source: own research

Figure 4. Evaluation of size 1.3 barcodes printed with electrophotography and ink-jet [%]



Source: own research

Table 4 summarizes the results of the tests based on the average ANSI rating for particular printing variants, which shows that the best grades were obtained by barcodes of size 1.3 printed electrophotographically on Alaska paper later labelled, which regardless of the colour of the bars received the highest grades. On the other hand, the classification of samples on the same paper is completely different, when it comes to those of size 0.8 printed by the ink-jet in green and blue color of the bars.

Barcode symbols with an overall rating of 3.5 or better are of the highest quality and provide the highest reading reliability.

Symbols evaluated between 2.5 and 3.4 were characterized by modulation between 62 and 68%, defect between 16 and 19%, and decodability errors between 43 and 60%. Depending on the level of the indicated parameters, these errors resulted from slight changes in contrast, average deviation from the width of the line and faded prints. Codes with this assessment, if scanned in a single path, may need to be re-scanned to decode.

For symbols with a rating of between 1.5 and 2.4, modulation assumed values in the range of 41-65%, defect 16-20% and decodability 45-59%. Deviations from the width and edge of the line as well as the contrast of the printout on the basis of which modulation was assessed most often at the level of C (2) had an impact on the lowering of the evaluation of parameters of some of these codes. Barcodes with this overall assessment are more likely to have to be re-scanned than symbols with a higher rating. In order to increase readability, devices should be used that provide multiple scanning paths across the symbol, or a system should be prepared allowing more frequent re-scan attempts.

Table 4. Summary of tested samples according to average ANSI score

Colour No.	Code size	Printing technique	Paper type	Colour of the bars	Average score (10 attempts)	Colour No.	Code size	Printing technique	Paper type	Colour of the bars	Average score (10 attempts)
1	1.3	electrophotography	cardboard	black	**4**	25	0.8	electrophotography	offset	black	**2,9**
2	1.3	electrophotography	cardboard	cyan	**4**	26	1.3	ink jet	label	bblack	**2,9**
3	1.3	electrophotography	cardboard	green	**4**	27	1.3	ink jet	cardboard	bblack	**2,8**
4	1.3	electrophotography	cardboard	blue	**4**	28	1.3	ink jet	offset	cyan	**2,8**
5	1.3	ink jet	cardboard	cyan	**4**	29	1.3	ink jet	label	blue	**2,8**
6	1.3	electrophotography	offset	black	**3,9**	30	0.8	electrophotography	cardboard	blue	**2,5**
7	1.3	electrophotography	label	cyan	**3,9**	31	0.8	electrophotography	cardboard	cyan	**2,3**
8	1.3	electrophotography	label	green	**3,9**	32	0.8	electrophotography	label	blue	**2,2**
9	1.3	electrophotography	label	blue	**3,9**	33	0.8	ink jet	offset	black	**2,2**
10	1.3	electrophotography	offset	cyan	**3,8**	34	0.8	electrophotography	label	cyan	**2,1**
11	1.3	ink jet	cardboard	blue	**3,7**	35	1.3	ink jet	label	green	**2,1**
12	1.3	ink jet	ooffset	black	**3,7**	36	0.8	electrophotography	offset	cyan	**1,9**
13	0.8	electrophotography	cardboard	black	**3,6**	37	0.8	ink jet	cardboard	black	**1,9**
14	1.3	electrophotography	llabel	black	**3,6**	38	0.8	electrophotography	ooffset	blue	**1,8**
15	1.3	ink jet	offset	blue	**3,6**	39	0.8	ink jet	ooffset	cyan	**1,7**
16	1.3	electrophotography	offset	green	**3,5**	40	0.8	ink jet	ooffset	green	**1,7**
17	1.3	ink jet	ardboard	green	**3,4**	41	0.8	ink jet	llabel	cyan	**1,5**
18	0.8	electrophotography	ardboard	green	**3,1**	42	0.8	ink jet	cardboard	cyan	**1,4**
19	0.8	electrophotography	label	green	**3,1**	43	0.8	ink jet	alabel	black	**1,4**
20	1.3	electrophotography	ooffset	blue	**3,1**	44	0.8	ink jet	cardboard	green	**0,7**
21	1.3	ink jet	ooffset	green	**3,1**	45	0.8	ink jet	ooffset	blue	**0,6**
22	1.3	ink jet	llabel	cyan	**3,1**	46	0.8	ink jet	ccardboard	blue	**0,5**
23	0.8	electrophotography	ooffset	green	**3**	47	0.8	ink jet	llabel	blue	**0,2**
24	0.8	electrophotography	llabel	black	**3**	48	0.8	ink jet	llabel	green	**0**

Source: own research

Symbols with a rating of between 0.5 and 1.4 had the highest error rate in terms of decodability, which was between 26 and 35%. The reason for such low assessment was significant deviations from the width of the lines and from the edges of the lines. In addition, 16% defects are evidence of numerous spots and faded printing. Symbols with this evaluation should be read by devices that provide multiple, overlapping scanning paths across the symbol (e.g. counter scanner), but before accepting a particular application for symbols with this evaluation, the type of barcode scanner used should be tested to determine whether the readers are within acceptable limits.

Symbols evaluated below 0.5 were characterised by numerous errors in the analysed parameters, resulting in an F(0) score. Barcodes with this evaluation have a proportionately high number of 'faulty' reflection profiles of the scanning beam and are unlikely to be read correctly by any reading equipment.

4. CONCLUSION

The quality of the barcodes is primarily influenced by the size and printing technique, the substrate and the colour of the bars. Research has confirmed that reproduction of smaller elements is much less accurate given the tolerance of barcode reading devices for 0.8 size symbols, and has indicated greater dash-width overruns depending on the sample variant.

The nature of the changes was determined by the technical capabilities of printing machines and the type of substrate on which the barcode was applied - e.g. too high or too low absorbability of the substrate.

The smallest losses were recorded in the barcodes with black and cyan lines, the largest with blue and green lines. The green and blue colours are secondary and are the result of an overlapping of two primary colours (blue = magenta + cyan, green = cyan + yellow). When printing barcodes in colour, it is important that the individual print components fit precisely, especially for the secondary colours, which are obtained by overlapping the primary colours. As a result, additional dashes in other colors may appear in the code symbolism. This is a problem if these lines are wide enough to interfere with the continuity of barcode reading. The nature of the changes was determined by the technical capabilities of printing machines and the type of substrate on which the barcode was applied - too much or too little absorbability of the substrate.

The results of the research show that digital printing techniques, especially electrophotography, can compete with traditional techniques.

Poor quality of ink-jet printing may result primarily from the very principle of printing with this method. Characters and symbols printed in this way have a point structure, which can affect the structure of the barcodes and the accuracy of their reproduction, this is due to the ink spilling on the paper.

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