Technical sciences

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DEVELOPMENT OF A SYSTEM FOR PREDICTING THE QUALITY OF PRINTING PRODUCTS WITH ELEMENTS OF AUGMENTED REALITY

Printing products are an integral part of human life – both printed and electronic. Due to the variety of possible options, there is great competition in the market and the use of various technologies to create a competitive quality product and release among other options.

One of the new technologies that can be used for both printing products and electronic ones is augmented reality technology. It allows to combine the printed and digital worlds into a single competitive multimedia product, increasing the targeting of products for potential consumers and opportunities for market expansion.

This technology is implemented in the following way. On a special element that serves as its native augmented reality marker, the camera of the user's device is pointed and, in accordance with the recognition process embedded in the system option, this marker is read, encrypted in digital format, compared with an existing element in the database formed by the developer, and, in case of successful comparison, programming. digital content on the device screen. Thus, static information can become dynamic or even interactive in real time.

When developing printed products with augmented reality elements, special attention should be paid to their further use – lighting conditions, weather conditions, the presence of a protective element, humidity, static and flatness of the product, etc. In addition, the reliability of marker reading can be influenced by factors such as printing features – printing method, printing conditions, etc., characteristics of the printed material – color, thickness, surface texture, pigmentation, presence of additional coating, flexibility, etc., features of the inks used – viscosity, gloss, etc., as well as features of the marker itself, in particular the marker image as the most commonly used option – size, contrast with the background and the degree of detail of the marker pattern[1].

In case of incorrect selection of all necessary components of the recognition system (original-printed material-imprint-marker scanning system and methods and means of their measurement) in accordance with the operating conditions of the product, there is a possibility of a significant decrease in the reliability and durability of augmented reality markers even at the beginning of the operational period of the corresponding product, in particular, this is an increase in the number of failures and the probability of failures relative to the possible limit value.

That is why the development of a system for predicting the quality of prints of printed products with augmented reality markers is an important problem that requires in-depth research and a high-quality solution. This, in turn, will make it possible to create a system for normalizing the factors influencing the process of reading and recognizing augmented reality markers to obtain rational quantitative values of the quality indicators of the process of reproducing augmented reality elements depending on the operating conditions of printed products, which essentially determines the quality of any product with augmented reality.

To solve the task of developing a product quality prediction system with augmented reality elements, an in-depth analysis and study of the factors influencing the process of recognizing augmented reality markers was first conducted, with the determination of the degree of their influence and their importance in this process using expert evaluation methods and the method of hierarchies. As a result, a system of factors influencing the reliability of the system "original-printed material-imprint-marker scanning system and methods and means of their measurement" was developed using the graph

1 Baranova, Daryna and Skyba, Vasyl and Rozum, Tetiana and Zolotukhina, Kateryna, Ranking of Technologically Significant Factors Determining the Quality of Reproduction of Augmented Reality Elements (February 25, 2022). Eastern-European Journal of Enterprise Technologies, 1 (4 (115)), 51–65, 2022. DOI: https://doi.org/10.15587/1729-4061.2022.251225, Available at SSRN: ttps://ssrn.com/abstract=4068854. DOI: https://doi.org/10.15587/1729-4061.2022.251225.

method to determine the most important factors, among which the conditions of use and parameters of the image-marker itself can be noted (Fig. 1).

The next step was to analyze and systematize the criteria for the quality of recognition of augmented reality markers (Fig. 2), which is given in the work[2]. The most significant of them were established using the hierarchy method, in particular the parameters of the reliability of augmented reality markers (number of failures, probability of failure, reproduction speed, etc.).

Based on the conducted and described above research, to solve the problem of ensuring fail-safe scanning and recognition of augmented reality markers, the paper3 proposes to use problem-oriented tools in the form of an information system (IS) for monitoring and managing the processes of scanning and recognizing AR markers, taking into account the interaction of the design and technological parameters of the marker (size, detail, contrast of the marker and background), the printed material (color, flexibility, density, texture, resistance to external factors), paint (viscosity, gloss, transparency, resistance to external factors), etc.

The paper4 presents the methodological foundations of creating an information system to solve such a problem as the fail-safe process of recognizing an augmented reality marker (Fig. 3). The computational core of the presented methodology is mathematical models that will allow determining the differences between the input data and the measured experimental data in the system database and, on this basis, predicting the quality of reproduction of augmented reality elements.

The use of IS of this type will allow to increase the reliability of the process of recognition of the augmented reality marker and to determine rational criteria for the quality of the development of the AR marker, taking into account the most significant factors of influence. The use of object-oriented methods allows to develop IS of the type «determination of marker quality parameters – means of controlling deviations of AR marker indicators from normative values – a system for predicting product durability»[3].

2 Baranova D. I. (2022). Criteria for correct reproduction of augmented reality elements in printed products. *Printing technology and techniques, 1*(75), 48-58. DOI: https://doi.org/10.20535/2077-7264.1(75).2022.263551

3 Shtefan Ye. V.& Baranova D. I. (2022). Problem-oriented means of ensuring the quality of AR technologies. TK-2022, Lutsk, May 28-30, 2022. (P. 218-219)

4 Palyukh O. O. (2021). Theoretical and practical principles of technological quality assurance of book products. PhD dissertation (Machines and processes of printing production). National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute», Kyiv.

To develop measures to improve the quality of printing design of printing products with elements of augmented reality within the proposed information system (Fig. 3), methods for predicting the quality of scanning and recognizing the corresponding AR markers were considered. Quantitative assessment of the quality of recognition of augmented reality markers was carried out based on the analysis of the corresponding indicators based on the methodology.

In accordance with the established priority quality criteria for the outlined process, the reliability indicator of the AR marker scanning and recognition process was chosen as the main output parameter of the developed quality prediction system, which determines the property of the product to maintain over time (within the established limits) the ability to perform the required functions in the specified modes and conditions of use, storage and transportation of the specified type of printing products. This indicator determines the integral properties of this type of product, as well as the degree and nature of changes that occur during its life cycle.

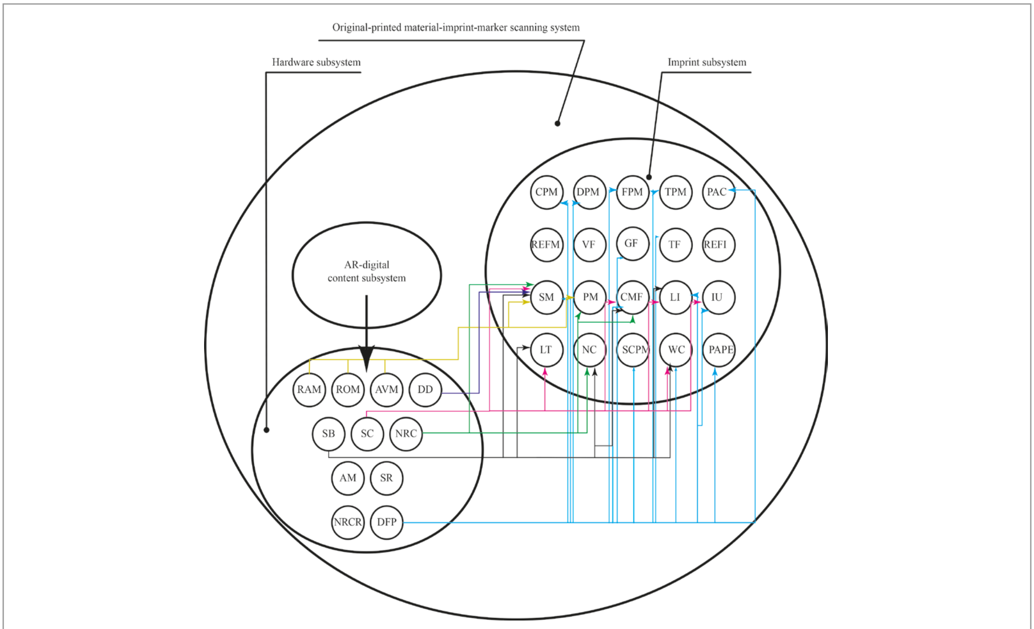

Fig. 1. The system «original-printed material-imprint-marker scanning system and methods and means of their measurement» and the relationships between its constituent elements1

Thus, the determination of product reliability indicators is based on the concept of its performance, which in turn is defined by the concept of «failure». Failure in this case uniquely determines the state of the product, which consists in a possible violation of its operability (partial or complete). Therefore, it is advisable to conduct research and forecast the quality of products with elements of augmented reality by analyzing the possible flow of failures in the process of reproducing the marker.

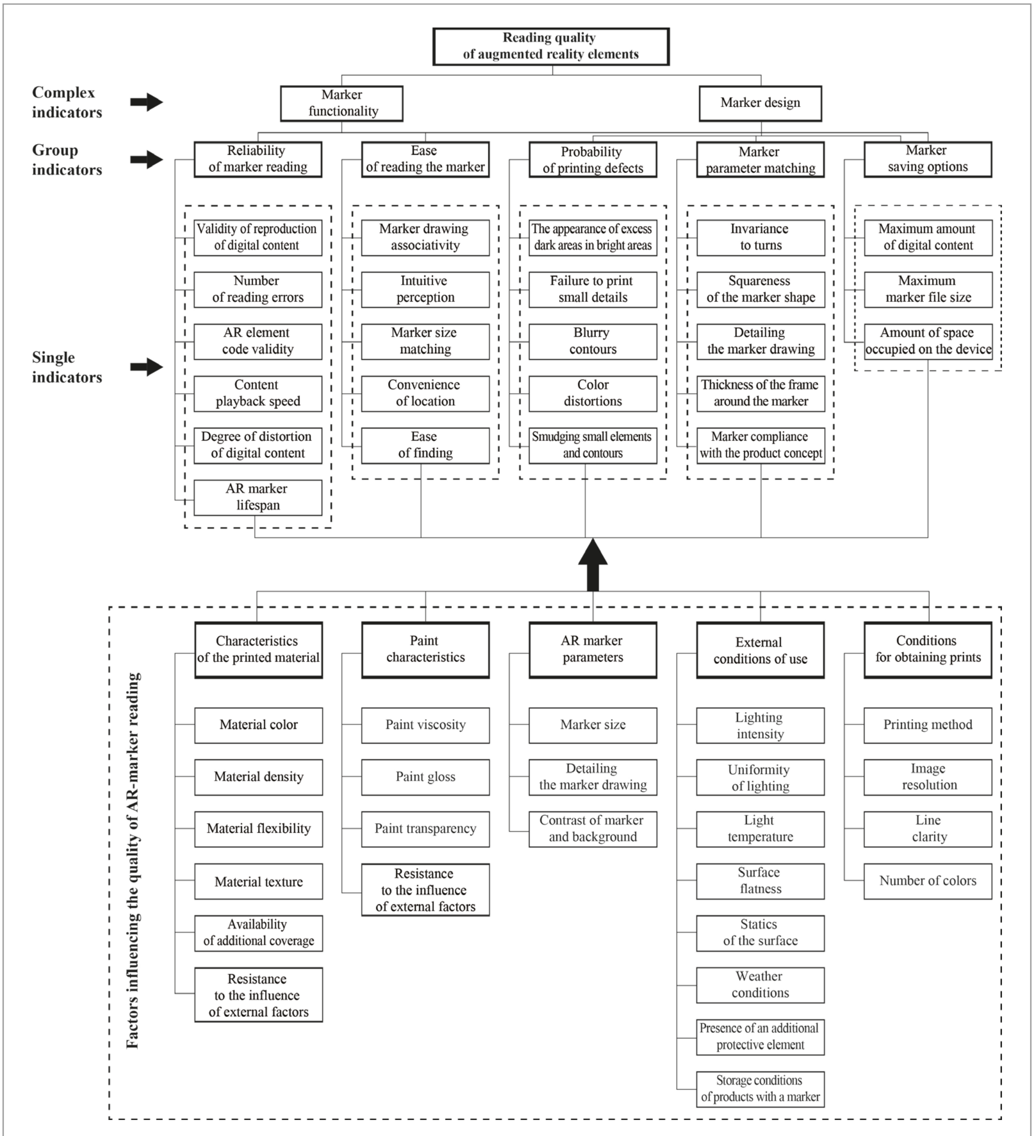

Fig. 2. Hierarchy of quality indicators for the process of scanning and recognizing augmented reality markers

Failure of an element is a random phenomenon, but the appearance of any failure is caused by defects in the source materials; aging processes; external factors; design and technological defects; operating mode, etc. Therefore, it was advisable to use statistical methods to study failures. This allowed us to determine quantitative indicators of product reliability.

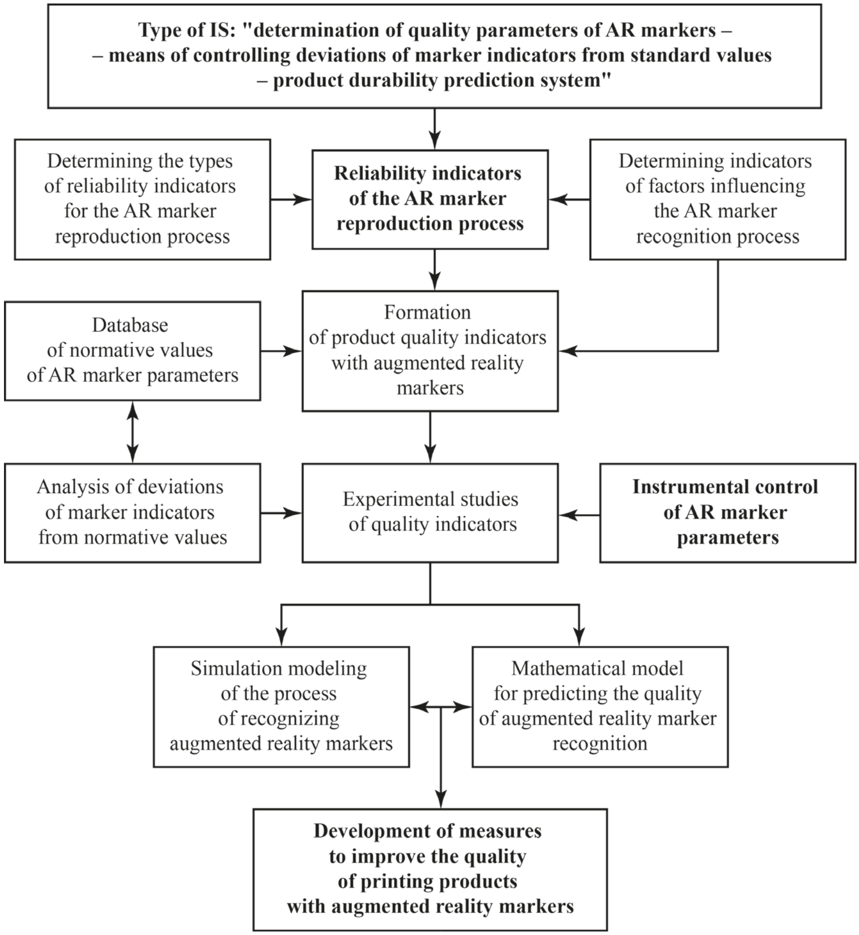

Fig. 3. Scheme of the developed information system of the type “determination of marker quality parameters – means of controlling deviations of AR marker indicators from standard values – product durability prediction system”

For the study, the main types of failures within the life cycle of printing products with elements of augmented reality were considered:

a) the marker is not recognized (the marker image is not perceived by the device camera as an AR marker);
b) digital content is reproduced with errors (there are errors in the test/illustration/animation, sound/video information);

c) the marker is recognized, but the digital content is not reproduced (digital content is not played or is absent at all).

The first type of failure is the most common and can occur during long-term operation of the marker, the other two types are more related to the correctness of writing the marker code and the operation of the software and data server.

When considering specific examples, a methodology for predicting the quality of printing products with elements of augmented reality has been developed. The methodology is based on the use of mathematical modeling of the failure flow during the operation of AR markers for specific products (Fig. 4).

When developing the information model (Fig. 4), a study of the field of augmented reality was conducted and an experiment was conducted, the features and course of which are described in the work[5]. To evaluate the results obtained and further predict the correctness of the recognition of augmented reality markers, the inoperable state of the product was recorded, which is due to the non-recognition of the AR marker. In this case, a delay in the reproduction of digital content of more than 7-8 s was considered a failure, taking into account the most severe operating conditions of the product[5].

The analytical model of the process of predicting the occurrence of failure was based on the provisions of probability theory and statistical mathematics. This model allowed us to analyze and determine the peak points of marker failures on the samples involved in the experiment, in accordance with their operational indicators. With its help, using an algorithmic model, the mathematical expectation of the occurrence of marker failures during their operation was determined, as well as a certain law according to which such a failure occurred.

The algorithmic model consists of the following stages:

1. Dividing the found time delays for each marker into certain intervals, in which the probability of failure, failure-free operation and other reliability indicators will be determined.
2. Determining the average sample time to failure in a certain interval, which will allow us to determine the average time until the next failure occurs in the interval under consideration.

5 Baranova D. I. (2025). Improving the technology for reproducing augmented reality markers on printed outdoor advertising products. PhD dissertation (Publishing and printing). National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute», Kyiv.

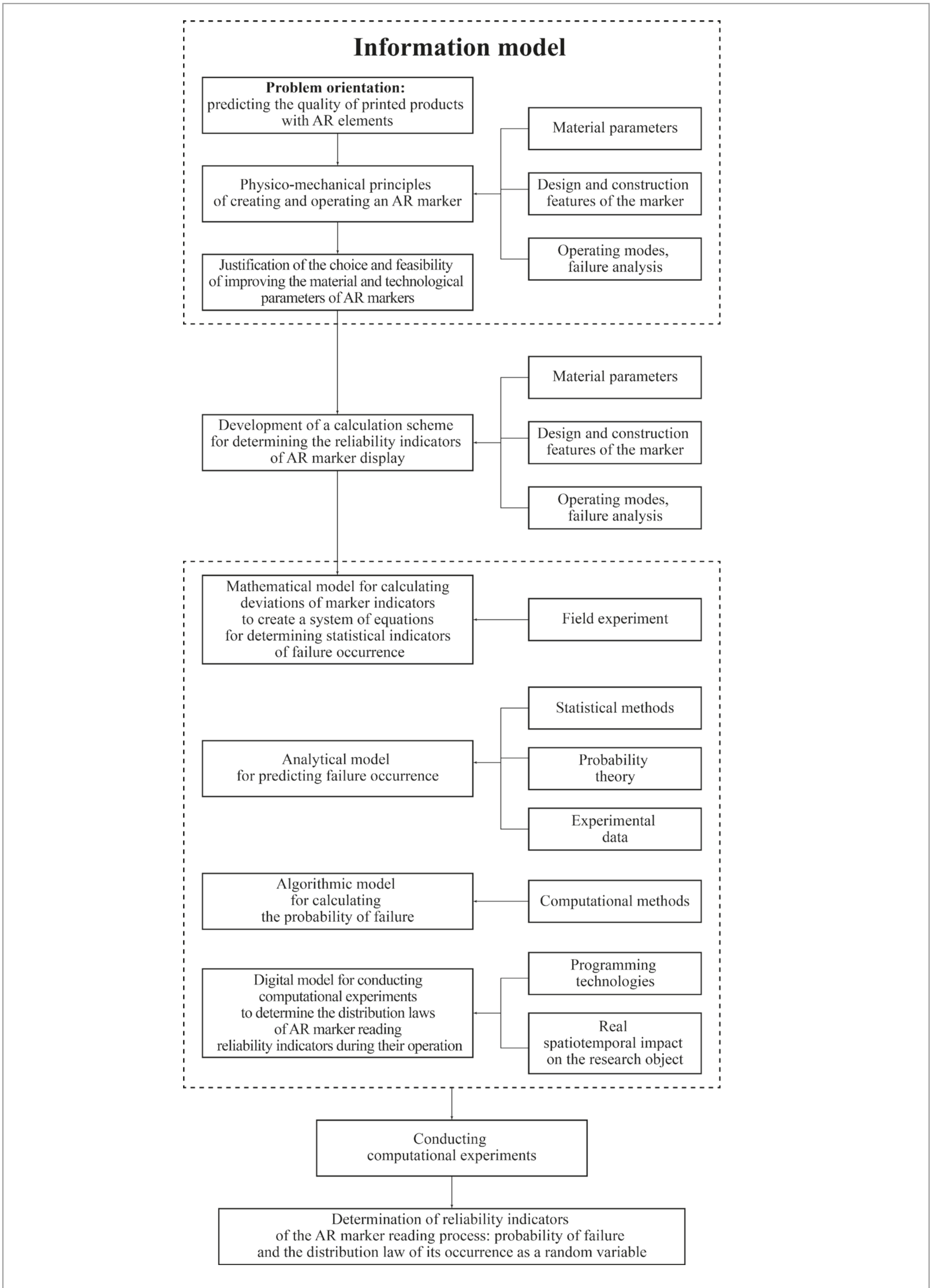

Fig. 4. Diagram of the object model of the process of predicting the quality of AR markers

3. Calculating the failure frequency, which will allow us to see in which of the intervals such a failure occurs more often, and, therefore, the product is more worn and less reliable.
4. Determining the probability of failure and the probability of failure-free operation.
5. Determining statistical data – mathematical expectation, variance, standard deviation and coefficient of variation for the entire interval under consideration.
6. Determining the function (regularity) of the density distribution of failure of samples.

Based on the developed methodology, a study was conducted to investigate the influence of priority parameters on the recognition of augmented reality markers5. The recognition time values for 140 samples were obtained. The results of comprehensive observations are given in Table 1.

Table 1

Results of product failure flow observations

Failure type	**Time to recognize an AR marker, s**													
Content playback delay of more than 7-8 seconds.	12	4	1	16	5	9	14	2	5	7	2	13	16	16
	11	7	19	19	2	6	9	5	2	3	10	6	4	20
	8	16	16	10	9	20	18	3	10	15	8	3	10	4
	13	7	10	1	2	11	8	16	12	13	11	10	1	18
	14	5	6	7	14	12	15	4	2	10	18	18	10	11
	11	6	7	6	2	15	1	3	5	14	20	18	2	20
	9	7	9	7	17	13	9	16	16	19	2	10	4	17
	15	6	7	8	13	6	18	1	3	17	20	2	20	17
	6	18	12	10	16	18	12	9	16	5	16	17	8	3
	15	13	4	3	15	3	12	18	10	1	19	8	9	19

The obtained data was then distributed into time intervals to determine the probability of failures occurring in them. The result is given in Table 2.

Next, the probability of failure was analyzed using the algorithmic model proposed above. The implementation of the algorithmic model using MS EXCEL tools allowed the development of the corresponding digital model «BAR-REAL1».

Table 2

Time intervals

Type of failures	Time intervals	
1 – not recognizing markers	1	3
	4	6
	7	9
	10	12
	13	15
	16	18
	19	21

Using the developed digital model, computational experiments were conducted, the results of which are given in Table 3.

The variance and mathematical expectation were also estimated, and the standard deviation and coefficient of variation were determined.

Table 3

Results of the study of the failure probability

Interval boundaries		Average operating time	Number of failures in the interval	Failure frequency	Probability of failure	Probability of failure-free operation
1	3	3,5	2	2	0,0222	0,0222
4	6	6,5	5	5	0,0556	0,0778
7	9	9,5	8	8	0,0889	0,1667
10	12	12,5	11	15	0,1667	0,3333
13	15	16	14	15	0,1667	0,5000
16	18	19,5	17	20	0,2222	0,7222
19	21	22,5	20	25	0,2778	1,0000
∑			90	1,0000		
Expectation			53,7111			
Variance			58,6939			
Standard deviation			7,6612			
Coefficient of variation			64,3614			

The next step was to construct a failure occurrence graph (Fig. 5). As can be seen from the figure, the failure distribution density of samples with augmented reality elements used for the study is performed according to the law of normal distribution, namely: according to the Weibull law. Accordingly, the lowest probability of failure occurs in the interval 3-7 s. This result was characteristic of prints that were either just received or have a service life of up to 1 month (under the most favorable conditions). The marker image accordingly remained clear and corresponded to the original layout in all characteristics (size, color, detail of the pattern, symmetry/invariance of the marker), which allowed the recognition and reproduction of markers within the limits specified above without the appearance of a large number of failures (up to 25-30 for every 7 days of the study). The largest number of failures appeared in the interval 13-15 s. This result corresponded to samples with a longer shelf life – 3 months or more, which is explained by the intense influence of usage conditions (level of illumination, humidity, weather conditions, presence/absence of a protective element) on the reliability and durability of the markers.

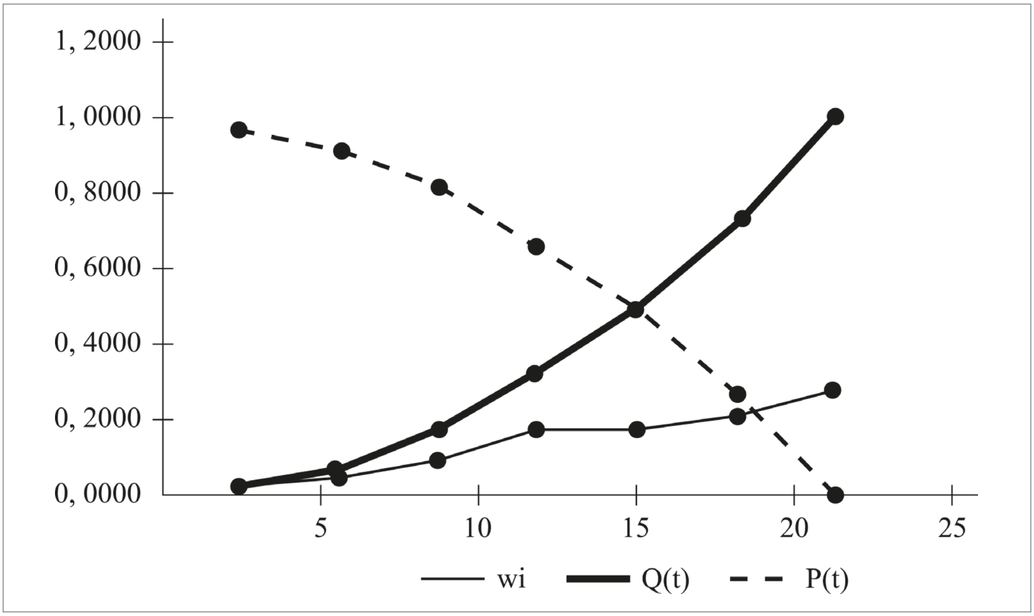

Fig. 5. Density function of the failure distribution of samples

Based on the conducted research, as well as the evaluation of the obtained results according to the above-described methodology, a system for normalizing marker indicators was developed in accordance with the conditions of use and features of printing of printing products, namely street advertising products, in particular posters, city lights and billboards as the most common variants of this type of products5. The obtained results will become the basis for further research to develop a generalized system for predicting the quality indicators (failure-free and durability) of reading augmented reality markers for a larger range of printed products, in particular packaging and textile products as the least studied areas of application of augmented reality along with street advertising products. This will allow normalizing the characteristics of the manufacturing process of products with elements of augmented reality for the manufacture of reliable and durable variants.

Conclusions

1. An analysis of the forecasting information system and its main parts was carried out, which helped to build an object model of the process of predicting the quality of AR markers, and its main components and their characteristics were noted.
2. The main tools of the object model were determined
3. An experiment was conducted on the used printed products with augmented reality elements with different service life and the results obtained were processed using the specified elements of the object model.
4. The law of sample failure distribution was determined – according to the Weibull law.
5. A system for normalizing marker indicators was developed in accordance with the conditions of use and features of printing of printing products, namely street advertising products, in particular posters, city lights and billboards as the most common variants of this type of products.

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