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Development of enterprise reputation management in the sphere of medical services

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Abstract. Topicality of the theme is determined by the increased role and influence of patients on the formation of the reputation of healthcare organisations in the conditions of active use of social networks by patients as a source of information when choosing a doctor. The purpose of the article was to identify the specificity and stages of the process of development of enterprise reputation management in the sphere of medical services. In the process of achieving this purpose there were used such scientific research methods as logic generalisation, comparative analysis, synthesis, graphical method as well. For gathering the feedback from the patients, the survey method based on quantitative analysis of responses and net promoter score was used. The specifics of medical services and their types were substantiated as the main results of the research, as well as elements that determine the value of medical services for the consumers. The features and trends of reputation management in the field of medical services have been considered and the stages of the process of development of reputation management of the healthcare organisation have been substantiated. As a result of the propositions, considered in the article, it has become possible to solve the reputational contradictions at enterprises in the field of medical services. With the purpose of improving reputational management the algorithm for the application of Search engine reputation management technology elements was developed for the work with consumers' feedback. Practical meaning of the results is in increasing the effectiveness of reputational management and its development due to the implementation of elaborated algorithm into the process of everyday work with clients of healthcare organisation. It can be the basis for planning changes in business processes and operational management as well as for optimisation of the use of resources

Keywords: healthcare organisations; marketing in medicine; proceeding claims; specificity; consumer feedback

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INTRODUCTION

In today's difficult economic environment, enterprises face the need to adapt to changes quickly and flexibly in both internal and external environments. In the work [1] it is said that the economic crisis, caused by the global coronavirus pandemic in 2020-2021, highlighted the need to find new ways to communicate with consumers, and hence the importance of development of enterprises reputation management. Today, health care has a special role among the most important sectors of the economy. On the one hand, the state of health and working capacity of the population, the ability to provide employment for many groups of workers, the situation on the labor market, etc., depend on its effective functioning. On the other hand, the results of the medical enterprises functioning depend on their reputation. This determines the topicality of the development of reputation management at healthcare enterprises.

To form and maintain a reputation in this area, in a saturated market, it is not enough to develop a new quality product, set an optimal price for it and choose effective distribution channels. It is important to be able to resolve problems and contradictions faced by consumers, employees, partners, stakeholders, as well as internal contradictions in the enterprise. The main sign of development is the solution of contradictions. In the research [2] the authors described that the development of reputation management at healthcare enterprises means solving the contradictions associated with the formation of its reputation among consumers and stakeholders, as well as among its own employees. In this study, special

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attention is paid to those problems of the development of reputation management, which are related to solving contradiction in interaction with consumers. Examples of such contradictions are as follows: the high level of trust of patients to the brand of the clinic, but their dissatisfaction with the specific doctors of this clinic; the presence of a significant number of primary patients and spending of significant resources for their care. But there is insufficient number of regular consumers and the need to redistribute available resources and other contradictions. If reputation management solves these and similar contradictions, it can be considered as its development.

Reputation management is becoming an important component of management in various areas of modern business. Reputation can be considered as a type of intangible assets of the enterprise. The development of reputation management at healthcare enterprises is closely connected with the communication policy of these enterprises. In the research [3] it is said that the leading role belongs not only to marketers, but also to call center employees, administrators, sales department, and, above all, to the doctors. These categories of staff are in direct contact with consumers. An important problem of the development of reputation management is the understanding of the fact that the presence of negative consumer feedback is normal. The main condition for the development of a positive reputation is effective work with such feedback.

Reputation management of the enterprise will be successfully formed and developed if the manager has enough information about the features of the company's services. Enterprises in the field of medical services have certain features in the organisation of management, development and substantiation of communication policy.

The purpose of the article was to identify the specificity and stages of the process of development of enterprise reputation management in the sphere of medical services.

To achieve this purpose, the following tasks were solved: to identify features of medical services; analyse types of medical services; consider usefulness and value of medical services; analyse the stages of the process of development of enterprise reputation management and also SERM-technologies when organising the work with consumers' feedback on the basis of reputation management.

LITERATURE REVIEW

Reputation management has been the subject of research by many scholars. K. Campbell considers reputation management as the "effort to influence what and how stakeholders think of a brand or person. To a large extent, reputation management seeks to influence people sentiment by changing what they see during search, social, and other online interactions. Reputation management can also affect the offline world as well" [1]. O. Gonchar [2] analysed the reputation management of the enterprise in times of economic crisis, A. Zaverbnyj, Ju. Lomaga [3] considered the problems and prospects of formation of reputation management by Ukrainian enterprises and organisations in order to increase their competitiveness, O. Gromova, Ye. Bicheva [4] studied the methodological foundations of the formation of enterprise reputation management system. Special attention to the mediating role of hospital reputation in the effect of doctor reputation on patients' loyalty is paid in the work of authors M. Akbolat, A. Amarat, O. Unal [5]. J. Ziemba, S. Arenberg, H. Reustle, M. Allaf, D. Haldeman discovered the connection between consumers' perception of hospital reputation and quality of treatment [6]. "Foreign scientists considered many reasons for necessity to have good reputation. They declare that online reputation management is critically important for business. The truth is, having a great reputation can either make or break a business! Hiring someone to help you take control of your online image could be exactly what you need to repair your reputation and reinforce your brand with positive content and search results for people to find" [7]. Business reputation management is especially important for the enterprise which offers medical services.

It is important to pay special attention to the works in which the issues of development of reputation management in the medical field are covered. For example, Z. Ba, Y.C. Zhao, S. Song, Q. Zhu [8] studied the impact of the clinic's reputation as a charity and its social capital on the level of medical crowdfunding, the collection of donations for health needs and expenses. In the medical field, the concepts of trust and reputation are very closely linked. The influence of factors on patients' choice of physicians in online consultations, in the context of trust theory, was studied by Y. Gong, H. Wang, Q. Xia, L. Zheng, Y. Shi [9]. Approaches to building the online reputation among patients were considered by L. Kim, D.A. Tylor, K.Y. Chang [10]. S.A. Torabzadeh, R. Tavakkoli-Moghaddam, M. Samieinasab, M. Hamid [11] developed an algorithm for assessing and improving the performance of medical centers based on trust indicators. A separate guide, which covers issues of reputation management has been developed for professionals in the field of psychiatry [12].

In the context of reputational management of enterprises that provide medical services J. Chen and Ch. Wang examined the relationship between hospital ranking and healthcare spending [13]. These authors studied the influence of factors such as cost, location and reputation on the choice of health care provider for mothers and children after deciding to seek medical care.

Thus, the issue of reputation management is considered in modern works on both economics and medicine. However, insufficient attention is paid to the level of medical enterprises, as well as tools for the development of reputation management in the field of medical services. Despite the sufficient number of works devoted to the study of processes of formation and development of reputation management, there are still certain aspects of reputation management that deserve attention of scientists, which substantiates the relevance of the study.

MATERIALS AND METHODS

In the process of the research, the theoretical and practical materials, presented in the scientific works of Ukrainian and foreign economists, were analysed.

At the first stage of the study the importance of the development of reputation management for enterprises in the field of medical services was substantiated. For these purposes the logical generalisation method was used.

The second stage of the study was devoted to analysis of existing works on reputation management, including the field of health services. The method of comparative analysis was used to prove the insufficient coverage of the

stages of the process of development of reputation management in the medical field.

At the third stage, the peculiarities of medical services that influence the choice of measures for the development of reputation management were substantiated. The theoretical basis was the recognised features of services that distinguish them from goods. These included inseparability from the source, intangibility, inconsistency of quality, coincidence in time of production and consumption of the service, heterogeneity of services. These features were revealed in relation to the specifics of medical services. Taking into account the peculiarities of medical services, those elements that create value for the consumer were identified. At this stage, the methods of analysis and synthesis were used.

To distinguish the types of medical services from the consumer's point of view, a three-level model of the product was used according to Ph. Kotler and G. Armstrong, who proposed to separate the core product, actual product and augmented product [14]. This model provides an opportunity to understand where joint efforts can create added value to the product. An important point in the application of this model is also the creation of a framework to increase adaptability, competitiveness and substantiation of product differentiation. Using the method of logical generalisation and the basic provisions of this model, the levels of formation of the usefulness of medical services as a basis for the development of reputation management in the medical field were developed.

At the fourth stage the peculiarities and trends of development of reputation management at the enterprise in the field of medical services were determined. The method of analysis and synthesis, the method of comparative analysis were used for this purpose.

At the fifth stage of the study, the sequence of stages of development of reputation management at the enterprises of the medical services was developed. The graphic method was used to visualise these stages. In revealing the essence of the stages, special attention was paid to work with different types of consumer feedback and the use of SERM-technologies in the organisation of work with consumer feedback on the basis of reputation management. The leading role in determining the development of reputation management was played by the method of consumer surveys. This method was the basis for calculating the NPS index (net promoter score), which demonstrates the level of consumer loyalty. In the survey, consumers, who already have experience of interacting with a healthcare company, were asked only one question: "How likely would you recommend our clinic to your friends, acquaintances or relatives?". The question was scalable, so the survey results were obtained in points from 0 to 10. The survey was not completely anonymous. Patients could optionally indicate or not indicate their contact data. The need to provide the opportunity to indicate their contact data was due to the fact that otherwise it would be impossible to verify the authenticity of the complaint and give a response to it. After processing the survey results, the NPS index was calculated. This index was an information basis for determining the degree of consumer loyalty, their desire to make repeat purchases, positive or negative attitude to the purchase of additional services, willingness to recommend the clinic to their friends. Therefore, this index was determined by the method of survey (scale questions), as well as the method of arithmetic calculation. In general, it reflects the prospects of such a channel for the promotion of medical services as "Word of mouth". This channel of promotion is one of the most effective in the medical field.

All these methods are designed to improve approaches to interaction with consumers and improve the reputation of the enterprise in the field of medical services.

RESULTS AND DISCUSSION

Reputation for the medical services enterprises and doctors is the main factor influencing the flow of consumers and the positive perception of the medical brand by potential consumers. Reputation management is a system of activities aimed at managing a brand's reputation on the Internet and beyond.

Reputation management includes SERM – reputation management in search engines, including working with the negative comments in the network, creating positive feedback, etc., and PR – a set of methods to create and maintain a positive image of the product/company, long-term communication with consumers and partners [15].

The development of reputation management in the field of medical services is possible if you understand the essence of these services and their features.

The specifics of medical services are determined by certain characteristics that are inherent in all services, as well as the specifics of health care. Figure 1 shows the features of medical services that affect the choice of measures for the development of reputation management.

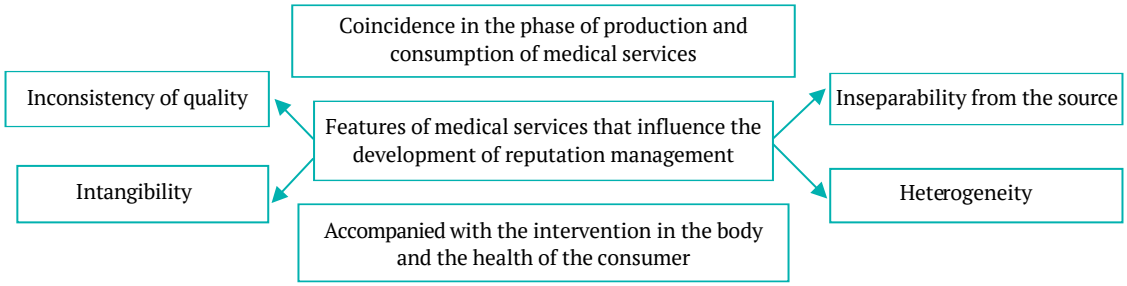

Figure 1. Features of medical services that influence the choice of measures for the development of reputation management

Source: compiled by the authors

The intangibility of medical services makes it impossible to demonstrate them to the consumer until the moment of provision. Moreover, the determination of the required amount of medical services is strictly individual. It usually occurs after direct contact between the medical doctor and the consumer of the medical service, which usually consists of several stages (conversation with the patient, visual, instrumental, laboratory examination, etc.).

Despite the coincidence in time of the phase of production and consumption of medical services, consumer participation in the production of medical services is insignificant compared to other types of services. It is limited only by their presence, providing the necessary information and careful implementation of all doctor's appointments. While the possibility of influencing the process and quality of medical care is minimal. The inseparability of the medical service from its source emphasises the paramount importance of the qualifications of doctors and other medical staff and other health professionals who are in direct contact with patients (consumers of medical services).

The degree of uncertainty in medical services is very high. Another specific characteristic should be a positive effect or, at the very least, safety for the health of the consumer. Most medical services are accompanied by human intervention, which requires the informed consent of the consumer of these services, often in writing. The heterogeneity of medical services determines the difficulties of standardising their quality and provision process. Issues of medical ethics and confidentiality of information obtained in the process of interaction with the consumer play an important role in the production of medical services. The choice of reputation management measures is determined by the specifics of medical services, as well as situations that create the need for these services.

First, medical services are those in which demand is passive. That is, consumers may not even suspect the existence of these services, or not consider them as an object to purchase, until there is an actual (often acute) need for these services. No one plans the disease in advance, as they plan a trip to the resort or a trip to a restaurant with friends. In some situations, people are even afraid to go to the doctor, for example, to the dentist, until the pain becomes unbearable. All this creates an attitude to medical services as those that are purchased forcibly. As a result, it is very difficult to persuade people to spend money on them because the campaign is active or because something may happen in the future. At the same time, when there is a need for medical services, they become a priority over all other purchases. From the point of view of classification, medical services can be pre-selection services, special demand services, and passive demand services, which are shown in Figure 2.

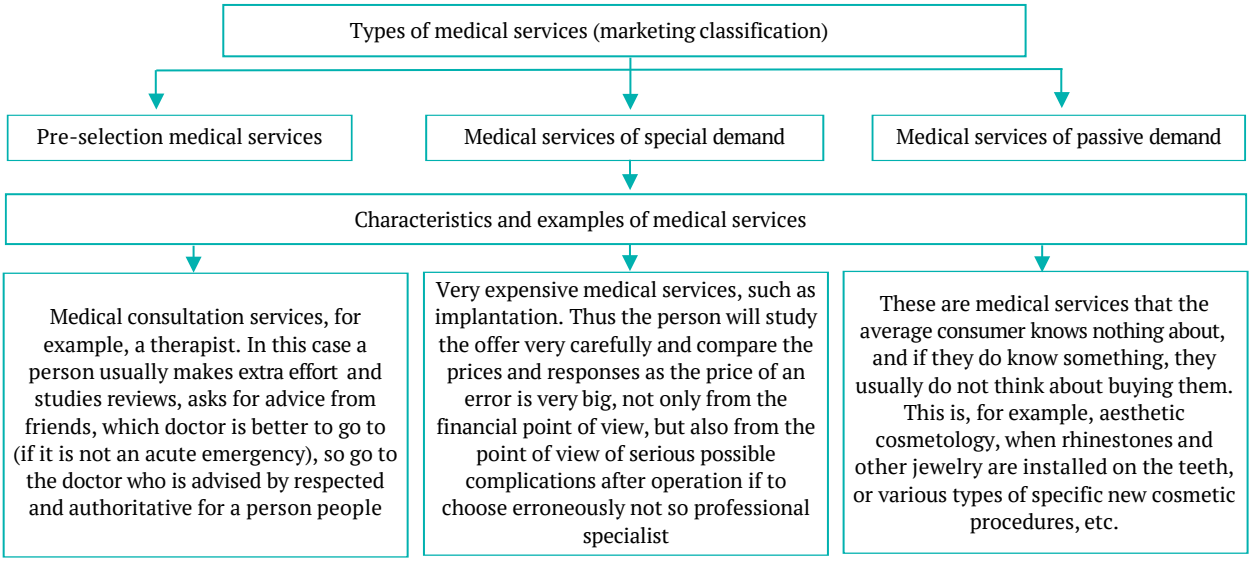

Figure 2. Types of medical services in terms of consumer demand

Source: compiled by the authors

The directions of development of reputation management in the field of medical services depend to some extent on the types of medical services and the perception of these services by consumers. The value and usefulness of medical services can be the basis for building the company's reputation in the field of medical services.

Second, reputation management is very closely linked to trust marketing, because the purchase of medical services of poor quality has vital consequences. This means that consumer decisions about purchasing medical services, especially in pediatrics, surgery, obstetrics, and other critical areas of medicine, are influenced not only by traditional factors such as price, brand and others. There are also a number of additional specific factors: the doctor's personality and trust in him, the recommendations of acquaintances and friends, etc. Third, consumers of medical centers and clinics cannot assess the quality of medical services in the same way as they assess the quality of other services (such as hairdressing or dry cleaning). This is because they do not have the professional knowledge that doctors have and sometimes do not understand the seriousness of their condition, as well as treatment protocols. Thus, the perception of patients (consumers) of the quality of medical services is a very subjective phenomenon.

Fourth, reputation management and communication policy in the field of medicine are still the prerogative of the private sector, although in the last few years, due to the spread of coronavirus, the public sector has become increasingly focused on communicating with patients and promoting certain topics.

Fifth, the main actor in the process of providing medical services, which can most effectively sell additional services and increase the average check, is the doctor who treats the patient, not the manager, as in other fields. It is the doctor who determines the amount of additional examination, the need for repeated visits, etc. Of course, doctors are guided by the Hippocratic oath and adhere to medical ethics, but if you need to undergo additional examinations, the patient (consumer) will not listen to the manager, he will listen the doctor.

Sixth, medical services are not bought "in stock" or under the influence of discounts, they are consumed when the need arises (except for some preventive examinations, or comprehensive programs designed for a long time). This causes the low efficiency and effectiveness of traditional promotions and discounts. In the field of medical services, the opposite principle sometimes applies, people believe that the lower the price of consulting a specialist, the lower is his/her qualification. Thus, sales promotion in the medical field has its own specifics.

Seventh, the marketing mix of health services includes 7P, that are product (medical service), price, promotion, place, physical evidence, people (health professionals) and process. Patients' (consumers') perception of the quality and value of medical services is important for the development of reputation management measures. According to the model of V.A. Zeithaml [16], the perception of the value of consumer services is influenced by the following factors: quality, intrinsic characteristics, external characteristics, price in monetary terms, price in non-monetary terms and time. Adaptation of this model to the specifics of medical services is shown in Figure 3.

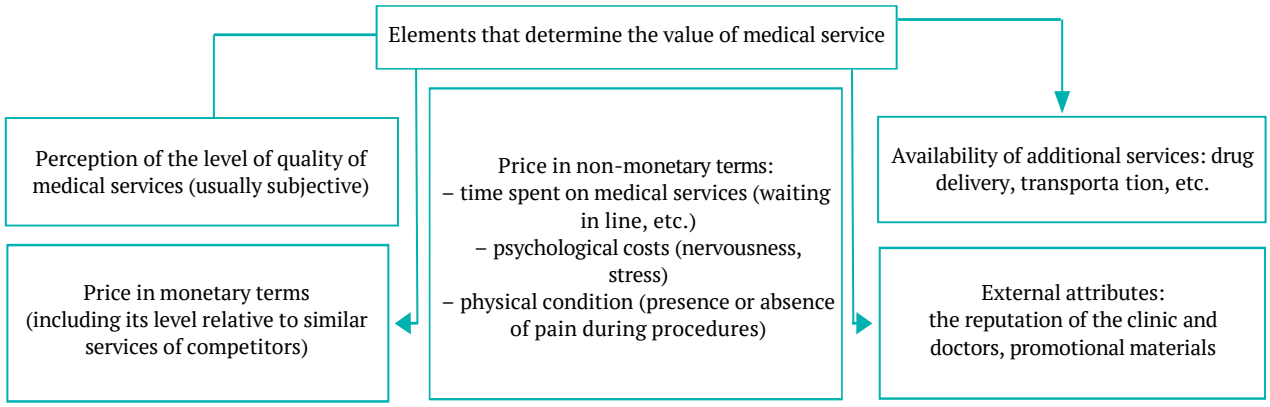

Figure 3. Elements that determine the value of medical services for the consumer
Source: compiled by the authors

Thus, the value of medical services for the consumer is determined primarily by its usefulness, as well as the presence of additional variations of the service. Variations of additional services should be considered within the model of Ph. Kotler and G. Armstrong, who developed three levels for consumer products: the core product, the actual product and the augmented product. The core product provides the consumer with key basic value and satisfies the basic need. According to Ph. Kotler and G. Armstrong "at the most basic level, the company asks, 'What is the consumer really buying? For example, people, who buy an Apple iPad, are buying more than just a tablet computer. They are buying productivity, and connectivity – a mobile and personal window to the world'" [17]. As for the actual product, it is considered in connection with the brand name, quality level, packaging, design, and characteristics of a particular product. The augmented product includes a few additional services, such as delivery and credit, after-sales service, warranty, etc. Let's consider the levels of the medical service according to the three-level model (Table 1).

Table 1. Three-level model of medical service according to Ph. Kotler and G. Armstrong

Level	Characteristics
Medical service according to the core value	Meeting basic health and safety needs
Actual medical service	Price of consultation, doctor's name, brand of clinic, location of clinic and convenience to reach, service inside, modern equipment, speed of service without queues, etc.
Augmented medical service	Availability of loyalty program – discounts for regular consumers, opportunity to purchase a subscription to the service of the family doctor therapist, etc., guarantee

Source: compiled by the authors

Based on this model, it is advisable to consider the process of forming the usefulness of medical services at different levels on the example of the service "consultation of the therapist (the family doctor)" (Fig. 4).

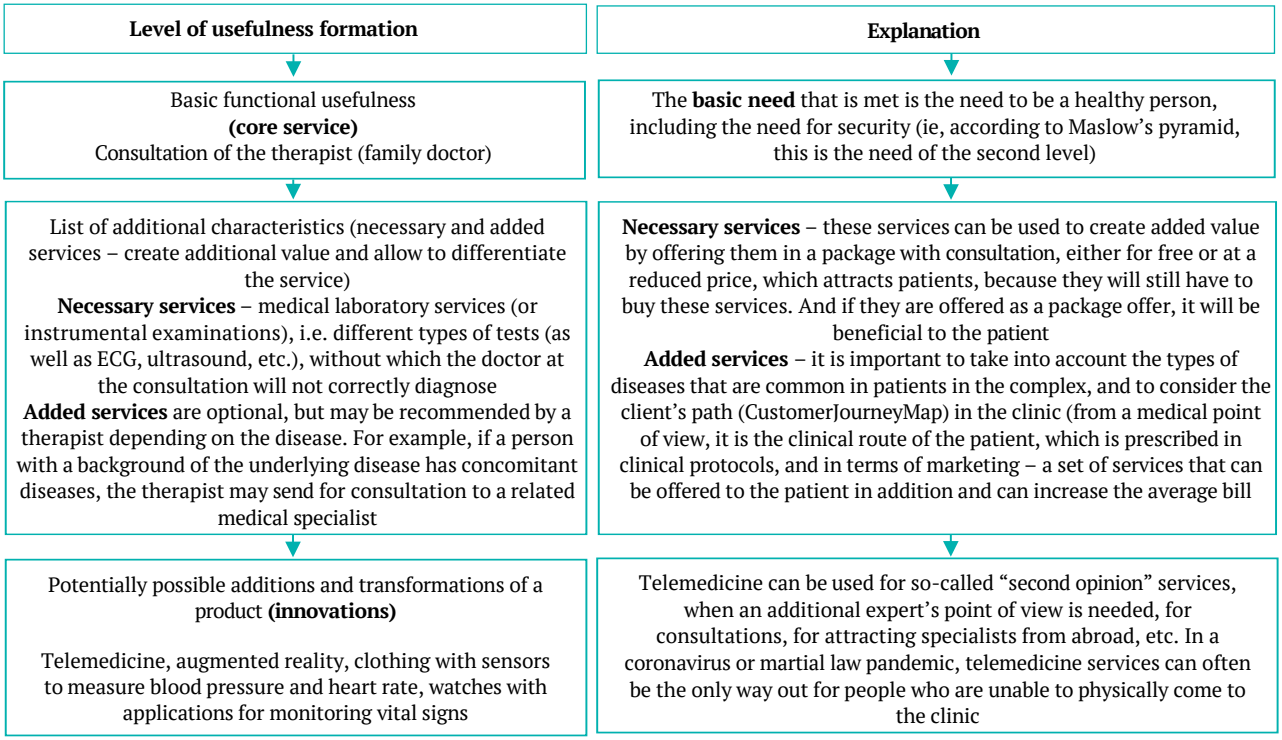

Figure 4. Levels of formation of usefulness of medical service as a basis of development of reputation management in the medical sphere

Source: compiled by the authors

The usefulness of medical services and their value are the basis for the development of reputation management in the field of medical services. When developing reputation management measures, it is necessary to emphasise the benefits of medical services that have a positive impact on the reputation of the company (clinic) that provides them.

The usefulness of medical services is often perceived ambiguously by consumers, as there are a number of additional factors that affect this perception. The following important contradictions related to the process of providing medical services and building the reputation of the clinic can be identified:

– quality treatment is sometimes not widely publicised, while some ineffective treatments may be mistaken for effective media coverage [17];

– qualified physicians who provide high-quality medical care may be ineffective communicators, have symptoms of emotional burnout, or be in a situation of ineffective management, with negative consequences for their reputation and the reputation of the clinic [18];

– the need to measure the level of consumer confidence, as it is closely linked to the reputation of the clinic and the doctor, and, at the same time, the difficulty of choosing objective indicators for such measurement [19].

Ways to resolve these contradictions are in the plane of development of reputation management. The choice of reputation management measures in the medical field depends on the characteristics of medical services, as well as current trends due to the coronavirus pandemic and scientific and technological progress, as shown in Table 2.

Table 2. Features and trends of reputation management in the sphere of medical services

Features based on the specifics of medical services	Trends caused by coronavirus pandemic and scientific and technological progress
The important role of content marketing, information publications that explain the nature and purpose of medical services, increase consumer confidence	Active use of online channels of communication with consumers, including those for the transmission of marketing information
The need to promote not only clinics, but also individual doctors, on whose expertise depends the level of expertise of the medical institution	Collaboration with pharmaceutical companies, manufacturers of mobile gadgets for health monitoring, pharmacies, etc.
The significant impact of doctors' communication skills on increasing sales of medical services highlights the role of internal communications and outreach to medical staff, conducting training on conflict management, etc.	Finding ways and tools to deliver medical information and services to consumers without the need to visit the clinic (sending the results of the analysis by e-mail, online consultations, mobile applications, etc.)

Table 2, Continued

Features based on the specifics of medical services	Trends caused by coronavirus pandemic and scientific and technological progress
Proper formation of expectations, reliable communication with patients about the parameters that the doctor can influence. It is not allowed to make promises that the doctor can't keep, not to create false expectations	Transforming the emphasis in healthcare advertising on the need to raise awareness about maintaining public health and protecting oneself from the dangers of the coronavirus pandemic
Efforts directed not so much at attraction as at retaining regular consumers who are willing to sincerely recommend the clinic and doctors to their friends and acquaintances	Gaining popularity through communication channels such as messengers and chatbots, the growing role of collaboration with mobile providers
Promotion of services based on the principles of evidence-based medicine, which declares the need and sufficiency of medical manipulation with the patient	Increasing the role of medical portals and aggregators in promoting medical services (their services replace the cost of SEO-optimisation of medical sites)
Adherence to ethics and socially responsible principles and emphasis on the physical and mental health of the patient as the end result	Increasing the importance of CRM-systems for analysing the effectiveness of communications and marketing activities
Motivation of patients to play an active role in the process of consumption of services. Creating conditions for patients to understand their own responsibility for the outcome of treatment. The doctor prescribes treatment, and the patient must carefully follow these appointments. That is, the result depends on both participants of the process	Emphasis on prevention of emotional burnout, stress, support of mental health, overcoming of fear in society in the formation of content and communication messages

Source: compiled by the authors

Taking into account the above trends, and taking into account the contradictions associated with the formation of the reputation of clinics and doctors, the authors of the paper propose stages of development of reputation management at health care enterprises (Fig. 5). At the first stage, it is advisable to conduct a reputation audit to identify inconsistencies and contradictions that exist at the enterprise in the field of medical services. Information and source data for such an audit can be obtained from both in-house staff and external experts. The most important source is the reports of the marketing department, or other department that works on a regular basis with consumer feedback and complaints. Not only doctors and medical staff, but also employees of call centers, the administrators, the sales department, etc. can play an important role both in the assessment and in the formation of reputation risks and contradictions. This stage ends with a list of contradictions, the elimination of which will improve the reputation of the enterprise.

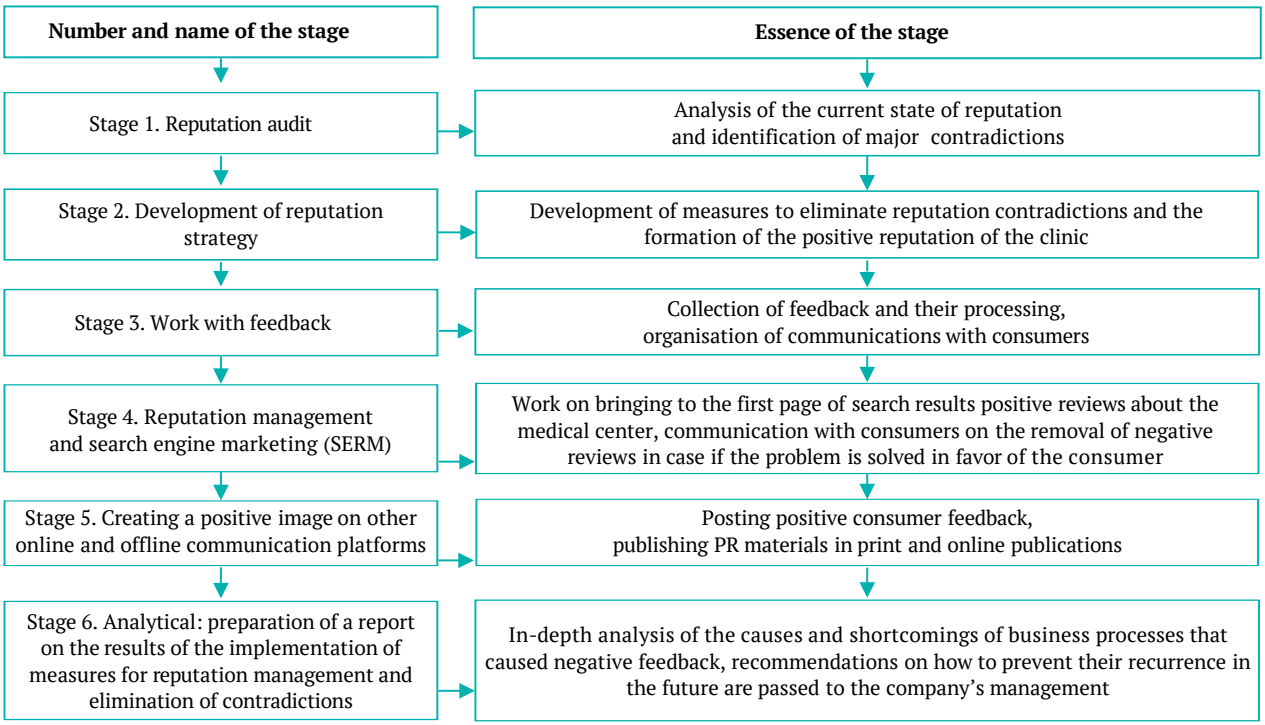

Figure 5. Stages of development of reputation management at enterprises of the sphere of medical services

Source: compiled by the authors

At the second stage, the strategy should be formed to eliminate the identified contradictions, and this strategy should include a number of measures for reputation management: improving the process of working with consumer feedback, modern SERM-technology, improving online and offline communications.

The third, fourth and fifth stages can be implemented gradually or simultaneously, depending on the capabilities of the enterprise and the availability of the necessary resources.

An obligatory final stage in the development of reputation management in medical enterprises is an analytical report on the effectiveness of the implementated measures. On the basis of such report, further actions to improve the company's reputation can be ajusted. It is important to systematically evaluate not only quantitative, but also qualitative indicators of the company's reputation. One such indicator is the NPS (net promoter score), which demonstrates the level of consumer loyalty. The importance of monitoring this indicator is caused by the fact that it shows the willingness of consumers to return to the clinic, as well as the desire to recommend it to friends and acquaintances. In the field of medical services, NPS demonstrates the potential of working with clients, their willingness to return. This indicator is closely related to such a promotion tool as "word of mouth". For the healthcare industry, this tool plays a leading role.

The basis of the "word of mouth" is consumer's feedback and reviews. Depending on the nature and the tone of such reviews, the reputation of the enterprise in the field of medical services is formed. The typology of reviews provides for their division into the following types: 1) positive or negative, 2) those that are seen only by employees of the medical center (channels of receipt: complaint registration journal, e-mail, medical center website, the call center, personal appeal to the department examination of the quality of treatment), or public (channels of receipt: feedback sites, forums, social networks, Google Maps and other public channels), 3) true or false. Depending on which groups the review belongs to, it is necessary to use different approaches in working with it. For example, Table 3 shows the difference in working with negative and positive reviews.

Table 3. The main steps and responsible persons who work with positive and negative consumer reviews (feedback)

Basic actions when working with feedback by their types	
Negative feedback	Positive feedback
1) Monitor and detect 2) Register 3) Conduct an internal investigation into the causes and truthfulness 4) Reply to the consumer 5) Take measures not to repeat in the future (possible penalty may be imposed on those who are responsible for the situation) 6) Negotiations with the consumer to withdraw the feedback, if he is satisfied with the resolution of the conflict	1) Collect (through questionnaires, etc.), accept (if the consumer wants to personally make an entry in the feedback book) or find (on social networks, websites) 2) Register 3) Post on the site, on the Internet, in social networks 4)Give the consumer a bonus (for example, a branded souvenir) 5) Reward the employee who received a positive feedback
Responsible persons for working with feedback	
Marketing department Medical unit management Line managers of departments that received feedback	Marketing Department, administrators Personnel Department Line managers of the departments that received feedback

Source: compiled by the authors

In addition, it should be noted that not all negative feedback can be solved out (if the consumer has not left the contact, or it is impossible to identify him). In this case, you should still answer them, but note that there is a lack of information to confirm the reality of the feedback and ask to leave contact. This is extremely important in cases when the feedback is public. If the consumer has been identified, and as a result of communication with him, the problem has been solved, and the consumer is satisfied, be sure to ask him to withdraw his negative feedback – this is the element of SERM, when the main goal is to remove negative feedback from the Internet network or reduce the public effect of negative feedback.

Figure 6 shows the algorithm for the use of elements of SERM-technology in the organisation of work with consumer feedback on the basis of reputation management.

The main result of this process is the solution of conflict and negative situations as a result of active communication with consumers. It should be noted that it is important to immediately classify and divide into groups all feedback from consumers, and then sort out each group of reviews differently.

This algorithm is just one of the measures that can be used to develop reputation management. Working with consumers' feedback resolves such reputation contradictions that are associated with ineffective communications with qualified physicians. This technology also increases the level of trust and loyalty of consumers, helps to engage them in the process of improving service in the provision of medical services.

The obtained results have scientific novelty, and they differ from the works in this field. F. Jabeen, Z. Hamid, A. Akhunzada, W. Abdul, S. Ghouzali in their work consider the leading role of trust and reputation management in healthcare. These authors substantiated that "the patient role has changed from a passive receiver to an active user of online health-related information" [20]. They analysed different approaches and methods of collecting feedback from patients, as well as possible vulnerabilities caused by consumer's opportunities of providing unreliable or malicious reports. The valuable results of the mentioned research are the elaborated trust and reputation system requirements for mitigating different attacks on this system (adaptive behavior, time sensitivity, context compatibility, reliability,

fear treatment of new users, changing identities, privacy and confidentiality, security, interoperability). But the mentioned requirements do not explain the mechanism of identification of attacks. That means that this mechanism has to be considered to understand which of consumers complains can be classified as attacks.

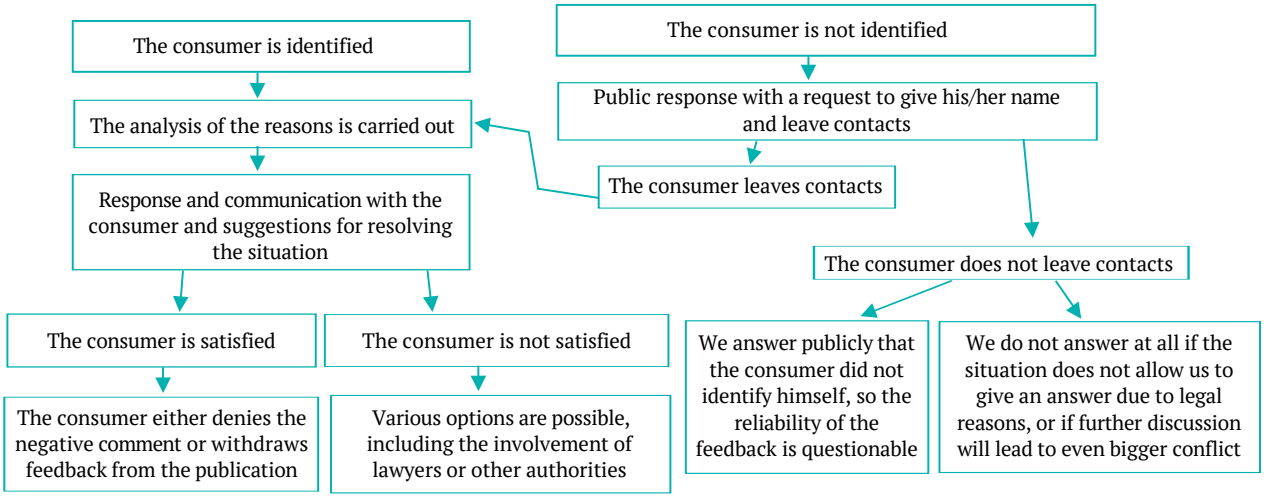

Figure 6. Algorithm of application of elements of SERM-technology when organising work with consumers' feedback on the basis of reputation management

Source: compiled by the authors

The connection between reputation of physicians and healthcare organisations and their activity in social nets is considered in the work of S. Mishra [21]. The author of this work considered the most beneficial and challenging aspects of patients connecting with physicians on Facebook (now Meta). Effective strategies for physicians who deal with challenging aspects of communications and formation of reputation on social networks are considered as well. Taking into account the practical issue of this work, it should be mentioned that, when healthcare organisations use social networks with the purpose of reputation management, they have to take into account the types of medical services. And it means that the types of medical services should be considered from the point of view of consumers' demand.

V. Chaudhri, T. Oomen, J. Pridmore and A. Joon [22] paid attention to problems of formation of reputation in healthcare sector using social networks. The authors elaborated CARE model of social media use where each dimension – C (control), A (accessibility), R (responsiveness) and E (engagement) has positive and negative sides. So, the scientific contribution of this research is in systematisation of four dimensions in dualistic perspective and assessment of the role of social media in reputation management of healthcare organisations.

J. Cordina and S. Greenberg discovered the role of information transparency in consumer decision-making in healthcare and its impact on the reputation of healthcare organisation [23].

In the short article devoted to the description of social media role in reputation management of healthcare organisations L. Vogel said that "the balance of power has shifted as social media has enabled conversations and comparisons across social and geographic divides" [24]. On the one hand, the big advantage of the article is in using a lot of practical cases and experts' points of view for substantiation of social media influence on reputation of clinics, but on the other hand, there is lack of fundamental research data as a basis for the conclusions.

Taking into account the mentioned above studies and the problems these studies have not considered, the presented results of this article are based on the survey of more than 2 000 patients' feedback. The distinction of the article in comparison with the described works of other authors is in the use of systematic approach to the study of patients' attitude and readiness to recommend the clinic to their friends, as well as description of elements of SERM-technology for reputation management in healthcare organisations.

CONCLUSION

The main results of this scientific research are as follows:

– first, the specifics of medical services are substantiated, their types and elements that determine the value of medical services for the consumer are analysed. This made it possible to determine the levels of formation of the usefulness of medical services as a basis for the development of reputation management in the medical field;

– second, the features and trends of reputation management in the field of medical services are considered. These trends were taken into account when developing the development stages of reputation management at enterprises in the field of medical services;

– third, the stages of the process of development of reputation management of the enterprise are substantiated. The main result of the implementation of the specified stages is the resolution of reputation contradictions at enterprises in the field of medical services;

– fourth, the algorithm for the application of elements of SERM technology was developed in the organisation of work with consumer feedback on the basis of reputation management.

Given the leading role of such a channel for the promotion of medical services as "word of mouth", the article focuses on working with consumer feedback. This tool of reputation management provides long-term positive relationships with clients, their loyalty and willingness to recommend the clinic to their friends and acquaintances.

Reputation management is a way to success and competitiveness of the enterprise in the field of medical services.

Prospects for further research are related to the search for new methods for assessing the effectiveness of reputation management in social networks as well as to the elaboration of personalised approaches for communications with clients of healthcare organisations.

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Розвиток репутаційного менеджменту підприємства у сфері медичних послуг

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Анотація. У статті обґрунтовано значимість розвитку репутаційного менеджменту для удосконалення роботи підприємств у сфері медичних послуг. Актуальність теми визначається підвищенням ролі та впливу пацієнтів на формування репутації підприємств у сфері медичних послуг в умовах активного використання пацієнтами соціальних мереж як джерела інформації при виборі лікаря. Мета статті полягає в обґрунтуванні особливостей та етапів процесу розвитку репутаційного менеджменту на підприємстві сфери медичних послуг. У процесі досягнення поставленої мети були використані такі методи наукового дослідження, як логічне узагальнення, порівняльний аналіз, синтез, а також графічний метод. Для збору відгуків пацієнтів використовувався метод опитування пацієнтів, заснований на кількісному аналізі відповідей і NPS (нет промоутер скор). В якості основних результатів дослідження обґрунтовано специфіку медичних послуг та їх види, а також елементи, що визначають цінність медичних послуг для споживачів. Розглянуто особливості та тенденції репутаційного менеджменту у сфері надання медичних послуг та обґрунтовано етапи процесу розвитку репутаційного менеджменту організації охорони здоров'я. У результаті пропозицій, розглянутих у статті, стає можливим вирішення репутаційних протиріч на підприємствах сфери медичних послуг. З метою покращення репутаційного менеджменту розроблено алгоритм застосування елементів технології SERM (Search Engine Reputation Management) для роботи з відгуками споживачів. Практичне значення результатів полягає в підвищенні ефективності репутаційного менеджменту та його розвитку за рахунок впровадження розробленого алгоритму в процес повсякденної роботи з клієнтами медичної організації. Це може бути основою для планування змін у бізнес-процесах та операційному управлінні, а також для оптимізації використання ресурсів

Ключові слова: організації охорони здоров'я; маркетинг в медицині; робота зі скаргами; специфіка; відгуки споживачів

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Scientific approach to the formation of stakeholder interaction in the innovative economy

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Abstract. The relevance of involving stakeholders in the decision-making process is due to the need to identify, group and classify them based on their circumstances or views on potential business conditions that can be realised, which will allow predicting interaction with stakeholders in conditions of dynamic opportunities. The purpose of the study was to define stakeholder interaction as a normative concept with implementation practice that can stimulate the development of theory and provide practical application in practice. The basis of the formation of a scientific approach to the formation of the interaction of stakeholders in the innovative economy were such methods as structural and comparative analysis, the method of generalisation. A scientific approach to the formation of stakeholder interaction is proposed, which involves an integrated process of their interaction in an innovation network based on dynamic capabilities with elements of model variable analysis. This enables the adjustment of the elements of the innovation network, the nature of relations with stakeholders and promotes the evolution of commitment, relations and knowledge sharing between stakeholders, as well as the adjustment, reflection and adaptation of interaction with stakeholders and consists of: the formation of an information space to define the components of the innovation network and relationships in the process of stakeholder interaction; implementation of the process of interaction of stakeholders in conditions of dynamic opportunities; reasoned choice of management decisions regarding the impact on the interaction of stakeholders. The research findings reflect a stakeholder interaction framework based on a process of identification, organisation and transformation integrated into co-creation and value, innovation network and knowledge sharing. The obtained results can be applied in the practical activities of state authorities and local governments, higher educational institutions, state enterprises, organisations and institutions, private entrepreneurial structures in the formation of intellectual, scientific resources and information technologies, effective use and qualitative improvement of all factors of production, which will contribute development of a new quality of public-state relations

Keywords: innovation network; knowledge exchange; business relations; identification; organisation; transformation

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INTRODUCTION

Economic development is impossible without taking into account the innovation factor. Since the beginning of the 90s, the scientific world began to realise the phenomenon of innovative and technological globalisation, and thereafter, significant shifts took place in international economic development that required state regulation.

The 17 sustainable development goals (SDGs), which are defined by the United Nations [1], are aimed at stimulating action to solve the global problems of mankind. The SDGs engage governments, which can act through policy and regulation development, as well as private initiatives to conduct research based on societal values, needs and expectations. Enormous tasks are emerging that cover a large number of people not only in one country, but also beyond its borders, affect international communities and the planet as a whole, requiring joint efforts to solve them.

Education, science and innovation require new methods of managing innovative development, which include wider involvement of stakeholders in the decision-making process, anticipation of society's needs and reflection of problems. Stakeholder engagement aimed at strengthening the means of implementation and activation of the Global Partnership for Sustainable Development can be a means of mobilising and sharing knowledge, experience, technology and financial resources. Despite the essence of stakeholders in the innovation economy, there is still little

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research on their involvement. The results of previous studies [2-4] are represented by management processes with a strong regulatory burden without clear practical guidance on implementation tools. Despite the general recognition of the importance of involving stakeholders, anticipating their needs and analysing their feedback in support of new solutions proposed to society, many questions remain regarding the quantitative and qualitative characteristics of stakeholders in the innovative economy.

A large number of studies [5-7] within the innovative economy are focused on the identification of stakeholders of current activities, but there is a need to identify potential and indirect stakeholders. The need to define, group, and grade stakeholders based on their circumstances or view of potential business conditions that may be realised will allow to predict engagement with stakeholders in the context of dynamic opportunities. Stakeholder influence may vary at different stages of the activity, depending on the ability to make decisions about the activity and implement a stakeholder management strategy.

The aim of the article was to define a scientific approach to the formation of stakeholder interaction in the innovative economy that can stimulate stakeholder engagement in practice.

In accordance with the goal, the following tasks were set: to determine the components of the innovation network and relations in the process of stakeholder interaction; to group stakeholders by the level of involvement (degree of commitment/participation/influence on the activity), types of connection with the activity for each of the stakeholders and the purpose/results of such activity; to organise a process of interaction with stakeholders, based on dynamic possibilities; to determine approaches to management decision-making regarding the identification, organisation and transformation of stakeholders.

LITERATURE REVIEW

Current innovation trends and global processes of internationalisation and globalisation create the conditions under which economic actors are forced to interact with a wide range of stakeholders and make decisions to take into consideration their interests. Today, approaches, methods and tools for assessing the levels of interaction of stakeholders differ according to schools and concepts. A large number of stakeholder definitions do not give a clear understanding of what the term really means. Establishing the boundaries of the concept will significantly help to solve a number of problems posed by researchers in this field.

The origin and development of the concept of stakeholders lies in the literature on social, economic and business science. An analysis of the development of the theory of stakeholders, which passed the stages of evolutionary development in accordance with the development of economic systems, business processes and were transformed according to the criteria for their identification and management is presented in Table 1.

Table 1. Development of stakeholder theory

Author (period)	The level of development of the theory
W.B. Galli (1956) [8]	The stakeholder concept is central to business theory, but does not define the essence of the stakeholder concept.
Stanford Research Institute (1963) [9]	The management's attention is focused on the concept of representing shareholders as a single group and determining its sensitivity.
E. Freeman (1984) [10]	Continuing the concept of shareholders, it is extended to other parties as well, namely consumers, workers, suppliers, governments, competitors, consumer advocates, environmentalists, special interest groups and the media. If someone has an interest in an activity, he can influence it or try to influence it.
M. E.B. Clarkson (1995) [2]	The social effectiveness of the corporation depends on the system of managing the corporation's relations with its stakeholders.
Y. Fassin (2009) [5]	Stakeholder management is presented from the perspective of translating ethics into management practice and strategy, identifying customers as both internal and external stakeholders.
P. Littau (2010) [6]	Stakeholders in the project management process were considered. The directions of stakeholder theory are determined by the project strategy.
S. Miles (2011) [4; 7]	Stakeholder theory is considered for different organisations, organisational forms and domains, such as individuals, projects and public institutions, as well as in politics.
Guidance on project management (ISO 21500:2012) [11]	To increase the likelihood of project success, project stakeholders, including the organisation in which the project is implemented, should be described in sufficient detail. Stakeholder roles and responsibilities can be defined in relation to their project and organisational goals.
PMBOK Guide (Project Management Institute, 2013) [12; 13]	The theory of interested parties has been improved on the basis of its isolation as a separate field of knowledge, and before that it was part of the theory of communications.
Requirements Management: A Practice Guide PMI (2016) [14]	Orientation on the involvement of stakeholders and cooperation with the customer; allows you to scale the project according to the requirements, while keeping it flexible.

Source: compiled by the author

Summarising research on stakeholder development makes it possible to identify different directions and draw the following conclusions:

1) the activity/organisation/project has relations with a large number of stakeholders who make up an appropriate environment (external and internal) and influence management decisions.

A systematic literature review was conducted to explore stakeholder relationships, pressures and sustainable management practices. The literature review shows that

there are three main theoretical frameworks for the study of stakeholder interaction: from the perspective of service improvement [15], as marketing and customer satisfaction [16] and technological innovation and management [17; 18].

S.M.R. Shams, D. Vrontis, R. Chaudhuri, G. Chavan, M.R. Czinkota [19] reviews current research in the entrepreneurship literature related to innovation management (IM), stakeholder engagement (SE) and entrepreneurship development (ED).

In addition, the use of stakeholder theory is dominant, followed by the use of institutional theory.

2) stakeholder theory studies the nature of relationships.

Lea Fobbe and Per Hilletofth [3] consider interaction with stakeholders as an important component of sustainable business models.

Traditional innovation, which is focused on obtaining profit for the enterprise, has turned into innovation based on interaction in the process of co-creation, where consumers are involved in the process of defining and creating value [20; 21].

3) the interests of all stakeholders can potentially be taken into account and satisfied.

Stakeholder interaction research is aimed at gradually realising the needs and expectations of each stakeholder in relation to the needs and expectations of other stakeholders, as well as the potential role of each stakeholder [22].

S. Takahashi and V.P. Takahashi [23] provided a proposal for an integrated process of interaction with several stakeholders based on the analysis of model variables. They also contribute to an evolution in commitment, in relationships and in the exchange of knowledge between stakeholders, as well as in anticipating and evaluating their interests.

4) the theory accepts management decisions.

P. Pluchinotta, G. Salvia [24] tried to understand stakeholders' perception of system boundaries and problem structuring, as well as their potential impact on decision-making by systematically comparing causal maps of different stakeholder groups around a common problem. A. Zingraff-Hamed, F. Hüesker, G. Lupp, C. Begg, J. Huang, A. Oen, Z. Vojinovic, C. Kuhlicke, S. Pauleit [25] used systematic methods to identify relevant stakeholders, which are crucial to enhance planning efficiency, reduce bottlenecks and time, and are paramount for business system planning, design, and implementation.

MATERIALS AND METHODS

The presented scientific approach was based on analysis methods and is presented in a logical sequence. First, a synthesis was used, which allows to reveal and show complementarity between the studied parameters. Furthermore, the structuring of development stages takes into account the behaviour of variables in the corresponding phases with the adoption of the process of identification, organisation and transformation as an integrating dimension.

Systematic and interdisciplinary approaches to formation of stakeholder interaction in the innovative economy became the methodological basis for achieving this goal. The structural analysis made it possible to determine certain regularities, according to which all processes and phenomena can be classified into groups, singling out their features, as a result of which Structuring stakeholder theories according to different levels of economic aggregation was obtained.

In addition, taking into account the dynamism of socio-economic phenomena, with the help of the generalisation method, it is possible to generalise them into certain groups based on similar characteristics.

The analysis also allows to evaluate the phenomenon not separately, but taking into account the influence of the external environment on it. One positive consequence of using these methods is the broad functionality of their results.

Using the method of logical generalisation, a sequence of actions was formed to establish structural relationships between variables or elements of scientific approach to the formation of stakeholder interaction in the innovative economy.

RESULTS AND DISCUSSION

Formation of the information space for determining the components of the innovation network and relations in the process of stakeholder interaction

Building an optimal model of stakeholder interaction should take into account the transformational processes currently taking place all over the world, which significantly change the directions of development and purpose of activities. The solution to this problem is carried out within the network structures of interaction in the field of educational, research, information technology, business and other types of activities. Therefore, issues related to the system of formation and determination of appropriate forms and types of stakeholder interaction are relevant.

However, the methodological base, which allows to reveal and analyse contradictions in the study of economic relations between institutions and science and the business environment, is not fully formed. This fact proves the need to develop scientific and methodological support for the formation and implementation of stakeholder interaction, taking into consideration dynamic changes, goals that must be achieved by the subjects of relations, and opportunities for their implementation. For this, a scientific approach to the formation of stakeholder interaction is proposed, which consists of 3 blocks (Fig. 1).

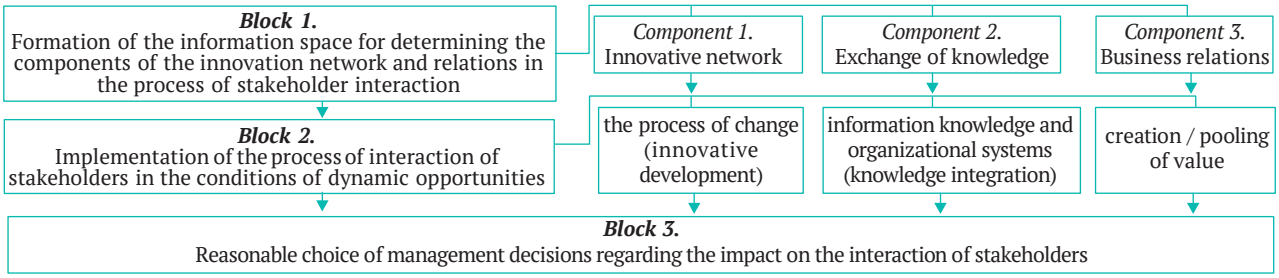

Figure 1. A scientific approach to the formation of stakeholder interaction in the innovative economy

Source: developed by the author

In accordance with ***Block 1*** (Fig. 1), a study of Ukrainian and foreign experience in the development of forms of stakeholder interaction was carried out in accordance with the structure of the innovation network, requirements for knowledge exchange and specifics of business relations.

In interaction with stakeholders, before changing the configuration of the network itself or existing processes, it is advisable to determine the evolution in obligations, in relations and in the exchange of knowledge between stakeholders (Table 2).

Table 2. Structuring stakeholder theories according to different levels of economic aggregation

Criterion for the development of stakeholder theories			
the number of people who can be attributed to stakeholders	degree and direction of influence betw een stakeholders and business	management tools and value-targets of performance in interaction	the extent of identification of stakeholders in relation to the levels of economic processes and systems, restrictions on the organisational scope of activities
W.B. Galli (1956) [8]	-	-	-
Stanford Research Institute (1963) [9]	-	-	-
E. Freeman (1984) [10]	-	-	-
-	M.B.E. Clarkson (1995) [2]	-	-
-	-	Y. Fassin (2009) [5]	-
-	-	-	P. Littau (2010) [6]
-	-	-	S. Miles (2011) [7]
-	-	Guidance on project management (ISO 21500:2012) [11]	
-	PMBOK Guide (Project Management Institute, 2013) [12; 13]		
Requirements Management: A Practice Guide PMI (2016) [14]			

Source: developed by the author

The considered theories are grouped in a visual-spatial logical way. This made it possible to organise the theories of stakeholder development according to their coverage of the criteria for their identification and management. The result of the grouping will allow stakeholders to be differentiated according to the scope of the activity (for project, business or government), the type of activity or content area, or the specific type of relationship to the activity. A specific activity can be a task, a project, a program, an enterprise of a corporation or a state body, and even determine specific cases of behaviour of individuals.

The key point is to identify and separate both the level of involvement and the type of connection that different stakeholders may have. Morphological analysis determines the level of involvement (the degree of commitment and non-commitment to the activity taking place), the types of connection with the activity for each of the stakeholders, and the purpose/results of such an activity (Table 3).

Table 3. Morphological analysis of stakeholders according to the structure of the innovation network and relations in the process of interaction

Subject (innovation network)	Level of participation (knowledge sharing)	Type of communication (business relationship)	Goal/outcome
-	their ownership based on the following attributes: authority to influence the firm, legitimacy of relations with the firm, and urgency of the claim against the firm		-
	life, environment or business is affected by three spatial scales and beyond accepted constructs	directly and/or indirectly involved in the selected scales and beyond	
	has or claims ownership, rights or interests	-	in the corporation and its activities
individuals and institutions	have a stake or claim, interest		regarding the company
different / another clientele	interested		in the results of the project
plaintiffs / the claimants	-	have contracts	-
individuals or groups of individuals	can affect or is affected by	-	achievement of organisational goals
	with legitimate interests		in procedural and/or material aspects of corporate activity
	requires sacrifices or contributions on the part of participants	voluntarily accept the benefits of a mutually beneficial cooperation scheme	-
	are inadvertently exposed to risk	arises in connection with the company's actions	

Table 3, Continued

Subject (innovation network)	Level of participation (knowledge sharing)	Type of communication (business relationship)	Goal/outcome
an individual, group or organisation	has an interest in, or is influenced by, or may be influenced by	-	any aspect of a project, program or portfolio
groups	-	in a relationship	with the organisation

Source: developed by the author

The time is different for each level of involvement. Direct participants (immediate interested parties) or managers start, observers or secondary interested parties can feel the impact in the process or for the results of the activity, the end users feel the impact from the results of the activity (which should exclude negative impacts during which there are persons covered). secondary stakeholders as a secondary category).

The resulting morphological analysis is intended to determine the power of influence, legitimacy and necessarily takes into account dynamism. The dynamics of determining the urgency of solving the problems of the interested party depends on the activity.

Implementation of the process of interaction of stakeholders in the conditions of dynamic opportunities

The process of attracting interesting pages, taking into account the dynamics of influence, is the ability to shape, combine and change internal and external conditions to be able to describe a rapidly changing environment in the process of work. Therefore, in accordance with ***Block 2*** (Fig. 1), this process is divided into three phases: identification interaction, organisation of interaction and transformation of interaction (Fig. 2). Thus, identification, organisation and transformation are unifying elements of these processes, which involves theoretical and practical justification.

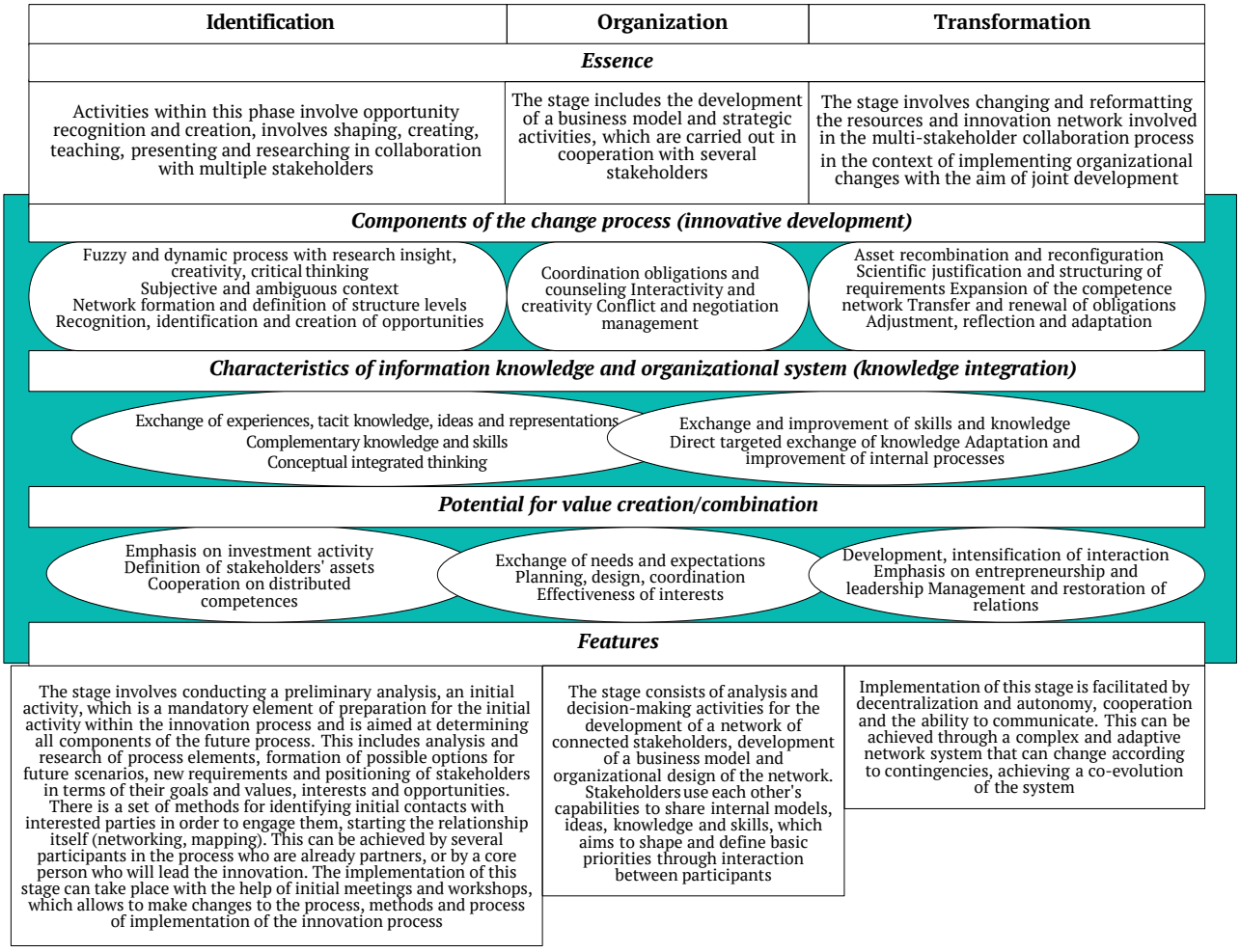

Figure 2. Implementation of the process of interaction of stakeholders in the conditions of dynamic opportunities

Source: developed by the author

Figure 2 shows the transformation of values (material-valuable and intellectual-knowledge), which is ensured by the success of the stages of stakeholder interaction in the innovative economy, taking into account the development of potential, current and realised value. This involves mapping elements of processes based on innovative development, based on interaction and transformation of knowledge, opportunities, values. As a result, a multidimensional integrated model is formed.

Figure 2 shows the process of integrating system elements within the stages of innovation development and value creation. It also demonstrates the integration of the intellectual and the material resources, the division of subjective/potential and actual possibilities, the transition from conceptual to concrete value. The change of uncertain and subjective aspects in the process of evolution is associated with the exchange of explicit knowledge, the distribution of obligations, which contributes to the involvement of the necessary stakeholders.

Interaction between stakeholders involves changing the configuration of the network or existing processes, which allows the development of relationships taking into account the obligations, responsibilities, exchange of knowledge and values between stakeholders. That is, the presented elements of the system are integrative to provide for the definition, organisation and management of stakeholders as theoretical as practical point of view.

Thus, the process of stakeholder interaction involves taking into account dynamic opportunities, which is aimed at the elements of creation, unification and change of internal and external factors, in the conditions of a changing environment.

Reasonable choice of management decisions regarding the impact on the interaction of stakeholders

Based on ***Block 3*** (Fig. 1), it is proposed to make a reasoned choice of method to make managerial decisions regarding the identification, organisation and transformation of stakeholders in accordance with the prospects, conditions and opportunities for the implementation of such relations (Fig. 3).

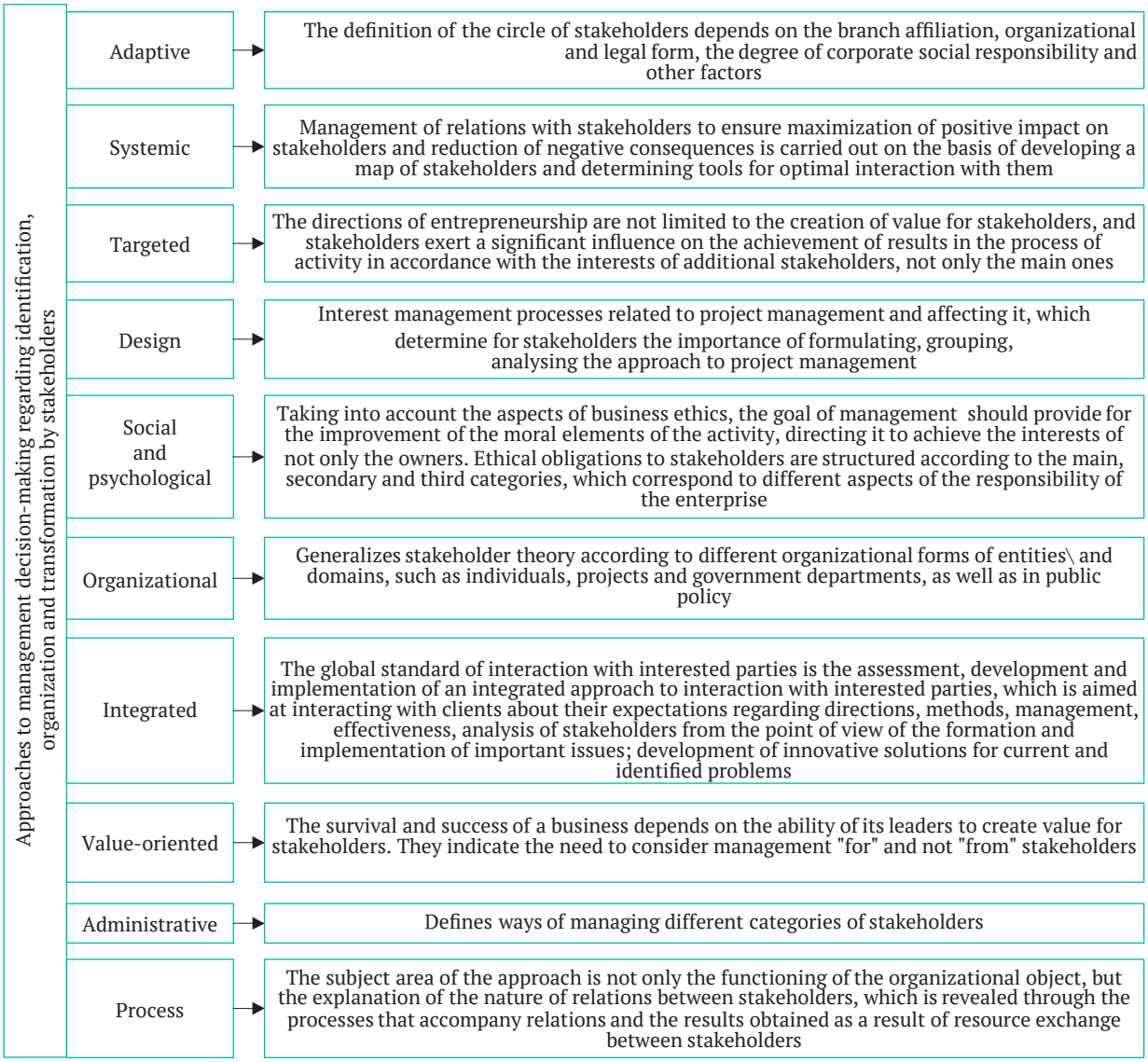

Figure 3. Methods to management decision making regarding identification, organisation and transformation of stakeholders

Source: developed by the author

According to the proposed, it is efficient to choose a method that will be optimal taking into consideration the existing conditions. The third block, on the basis of previous analytical studies, involves making a management decision regarding the choice of a method among the possible ones for one or another group of stakeholders. Based on the choice made, monitoring of stakeholders is carried out in order to detect their possible change, as well as a change in their interests and influence, their priority, which is expedient in the conditions of dynamic opportunities. Hence, a managerial decision is made to change the interaction strategy. Furthermore, the implementation of the chosen interaction strategy, its effectiveness and timing are checked and the correction is made.

This fact proves the need to develop scientific and methodological support for the formation and implementation of stakeholder interaction, taking into consideration dynamic changes, goals that must be achieved by the subjects of relations, and opportunities for their implementation. For this, a scientific approach to the formation of stakeholder interaction is proposed, which consists of 3 blocks.

Block 1 (Fig. 1) describes national and foreign experience in the development of forms of stakeholder interaction was carried out in accordance with the structure of the innovation network, requirements for knowledge exchange and specifics of business relations. Morphological analysis determines the level of involvement (the degree of commitment and non-commitment to the activity taking place), the types of connection with the activity for each of the stakeholders, and the purpose/results of such an activity.

Block 2 (Fig. 1) is divided into three phases: interaction identification, interaction organisation, and interaction transformation. The interaction of stakeholders from the initial processes (identification and organisation) to the transformation of interaction is presented in the article. Processes of value creation and acquisition, development of innovations and integration/exchange of knowledge are disclosed. As a theoretical contribution, the results of the research provide an integrated study of different types of dynamic capabilities about the need to investigate the connections or relationships between types of dynamic capabilities.

The Block 3 (Fig. 1) involves making a management decision regarding the choice of a method among the possible ones for one or another group of stakeholders, based on the choice made, monitoring of stakeholders is carried out in order to detect their possible change, as well as a change in their interests and influence, their priority, which is expedient in the conditions of dynamic opportunities.

Thus, in contrast to existing studies, new hypotheses and scientific tasks in the theory of stakeholders were formulated, appropriate directions and appropriate methods were chosen for their solution, which allows for effective system analysis, selection of a conceptual model of the information system environment based on mathematical models and methods decision-making, parameterisation of the components of the intelligent decision-making support system.

A large amount of research in the framework of the innovation economy focuses on the identification of stakeholders of current activities, but there is a need to identify potential and indirect stakeholders. Most of the scientists' research is devoted to the descriptive analysis of the evolution of documents devoted to the study of stakeholders. The works highlight the thematic groups of open innovation, consumer-oriented analysis, service ecosystem and service innovation, as well as two new trends: servitisation and the sharing economy [18; 21]. On the basis of the presented results, the evolution of stakeholder research is identified and characterised, but as a result of the value transformation with the evolution from potential to realised, which is ensured by the successful passage of the phases of identification, organisation and transformation into identified stakeholder interaction.

Also, based on the systematisation of literature, on the basis of which the organisational and modernising factors of the variables that affect the relationship between stakeholders were selected [21] levels were formed participation and types of communication that different interested parties can have, which further determines the level of involvement (the degree of commitment and non-commitment to the activity taking place), the types of communication with the activity for each of the stakeholders and the purpose/results of such activity. The use of the specified influencing factors made it possible to determine the dynamic possibilities of the system of interaction of stakeholders, its ability to form, transform and integrate values in the conditions of a changing environment.

Scientists also proposed an integrated approach to identifying stakeholders by grouping and structuring their problems based on a combination of qualitative and quantitative analysis [24]. Quantitative analysis presented the formation of thematic groups [18] and influencing factors on stakeholders [21] supplemented by modelling of dynamic possibilities of interaction between stakeholders and aimed at the formation of sustainable management methods in the decision-making process. Qualitative analysis, which involves the identification and structuring of key problems for certain types of stakeholders, and their generalisation by forming cause-and-effect relationships around one common problem. These processes are represented and complemented by aspects of innovation development, namely co-evolution, value creation and sharing, stakeholder capabilities and innovation network structural elements, providing a multi-dimensional integrated model of knowledge integration/exchange, stakeholder capabilities and innovation network structural elements ensured by the success of interaction stages stakeholders in the innovative economy with the evolution of potential value.

Studies that focus on planning and management decision-making processes in stakeholder interaction [19; 25] involve the formation of models of polycentric governance and co-creation. The proposed methodical approach involves making a managerial decision regarding the choice of method among a possible certain group of stakeholders in order to identify their possible change in their interests and influence, a priority that is expedient in the conditions of dynamic opportunities.

CONCLUSION

On the basis of the conducted research, a scientific approach to the formation of stakeholder interaction is proposed, which, unlike the existing ones, takes into account the multidimensionality and dynamics of the characteristics of stakeholders. Taking into consideration the fact that the dynamic possibilities of interaction of stakeholders

require reflection and adjustment, approaches to management decision-making regarding the identification, organisation and transformation of stakeholders.

Thus, the proposed scientific approach to the formation of stakeholder interaction allows us to consider the evolution in the practice of stakeholder interaction in a pluralistic context, seeking to overcome antagonisms and internal needs, synthesising in an integrated approach organisational processes that support interaction with stakeholders within the innovation network, since dynamic opportunities are integrative processes. A scientific approach to the formation of stakeholder interaction is proposed, which consists of 3 blocks (formation of the information space for determining the components of the innovation network and relations in the process of stakeholder interaction; implementation of the process of interaction of stakeholders in the conditions of dynamic opportunities; reasonable choice of management decisions regarding the impact on the interaction of stakeholders).

The use of this scientific approach to the formation of stakeholder interaction in the innovative economy has the following advantages: the main characteristics of innovation networks and their structural aspects of stakeholder interaction are defined; interconnected processes in innovation networks are structured; the dynamic capabilities of stakeholder interaction processes are taken into account according to their phase (identification, organisation or transformation); the potential, some limitations and directions of interaction management are outlined.

The interaction of stakeholders is important for achieving the SDGs, which determines the relevance of further research.

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Науковий підхід до формування взаємодії стейкхолдерів в інноваційній економіці

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Анотація. Актуальність дослідження визначається тим, що освіта та наука потребують нових методів управління інноваційним розвитком, що передбачає залучення стейкхолдерів до процесу прийняття рішень. Вплив стейкхолдерів може відрізнятися на різних етапах діяльності, залежно від здатності приймати рішення. Метою дослідження було визначення взаємодії стейкхолдерів як нормативну концепцію з практикою впровадження, що може стимулювати розвиток теорії та забезпечувати практичне застосування на практиці. Основою формування наукового підходу до формування взаємодії стейкхолдерів в інноваційній економіці були такі методи, як структурний й компаративний аналіз, метод узагальнення. Запропоновано науковий підхід до формування взаємодії стейкхолдерів, який передбачає інтегрований процес їх взаємодії в інноваційній мережі на основі динамічних можливостей з елементами аналізу модельних змінних. Це дає змогу коригувати елементи інноваційної мережі, характер відносин із зацікавленими сторонами та сприяє еволюції прихильності, відносин та обміну знаннями між зацікавленими сторонами, а також коригування, рефлексії та адаптації взаємодії із зацікавленими сторонами та складається з: формування інформаційного простору для визначення складових інноваційної мережі та відносин у процесі взаємодії стейкхолдерів; здійснення процесу взаємодії стейкхолдерів в умовах динамічних можливостей; обґрунтованого вибору управлінських рішень щодо впливу на взаємодію стейкхолдерів. Результати дослідження відображають структуру взаємодії стейкхолдерів, засновану на процесі ідентифікації, організації та трансформації, інтегрованих у спільне створення та цінність, інноваційну мережу та обмін знаннями. Отримані результати можуть бути застосовані в практичній діяльності органів державної влади та місцевого самоврядування, вищих навчальних закладів, державних підприємств, організацій та установ, приватних підприємницьких структур при формуванні інтелектуальних, наукових ресурсів та інформаційних технологій, ефективному використанні та якісному вдосконаленні всіх факторів виробництва, що сприятиме розвитку нової якості суспільно-державних відносин

Ключові слова: інноваційна мережа; обмін знаннями; ділові відносини; ідентифікація; організація; трансформація

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Improvement of line image reproduction in the system of prepress engineer work

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Abstract. In order to optimise the process of prepress engineer work, it is necessary to provide a high-quality display of the line image, which ensures the most accurate transfer of the geometric dimensions of individual elements. The purpose of the article was to determine the degree of influence of the binarization threshold on the resolution value of raster line images. The experiments were based on the use of general scientific methods of analysis, generalisation, classification, deduction. To assess the quality of line image reproduction in this paper, photoforms were employed using a line test object which was designed as an accurate photograph with the use of an optical density distribution profile. The paper examines the influence of various parameters of raster structures on the playback quality of reproductions. The specifics of using a photo output device as the main link, which ensures the reproduction quality of image details, have been determined. The geometry of the raster structure when using rotation angles with rational tangents has been analysed. Features of the Accurate Screening technology have been systematised. The difference between "rational" and "irrational" rasterization methods has been considered. The main aspects of the use of line details in the reproduction process have been considered. The proposed method for assessing the quality of a line image reproduction with an uneven edge has been called the "signal-to-noise ratio" method, and it has been concluded that the scanning stage affects the quality of image reproduction to a greater extent than the photo output. The practical result of the work is the development of recommendations that can find practical application in reproduction processes. The developed binarization algorithms allow processing of images with significant zonal brightness unevenness, with monotonous brightness areas, and highly noisy images

Keywords: resolution; binarization; scanning resolution; line originals; raster line frequency

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INTRODUCTION

The need to obtain a clear, high-quality reproduction and high-quality line details reproduction of the image, which can be either single or a part of group lines of periodic grids, determines the relevance of the topic of this paper. In the process of reproducing line originals, the main task is usually to accurately convey the geometric dimensions of the line elements. With poor geometric accuracy, lines may be distorted in the reproduction process, this is especially noticeable for small details.

The interval of optical densities between the reproduced transparent and opaque areas of the photoforms should be sufficient to ensure the protection of the mould material from the effects of radiation in the subsequent copying process. As the size of the part decreases, the optical density of the part also decreases. Combined with distortions of geometric accuracy, this can lead to the complete disappearance of small lines in the reproduction process. The sharpness of boundaries may be lost when playing back an analogue image, especially if the contrast ratio is insufficient. When reproducing line details in the system of element-by-element image processing (SEIP) on photoforms and further on printed prints, the well-known effect of reproducing line originals in SEIP is revealed, manifested in the formation of a stepped boundary structure during discrete line formation. In each row, the details of the image may have a sharp U-shaped transition at the boundary, but depending on the mutual orientation of the scanning direction and the location of the line element, when being visually assessed, a rectilinear continuous boundary of contours and lines can be distorted to a greater or lesser extent, affecting the quality of the perceived image.

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Together, all these parameters – geometric accuracy, optical density interval, structure of the edges of object boundaries and line details, image contrast – can determine the image clarity. Currently, there is no systematic data on this problem, so this topic is relevant.

Scientific works [1-3] develop the problem of analysing print quality depending on the specifics of technological aspects of image reproduction mechanisms. But, these works do not consider the concept and possibilities of entering information that affects the image clarity.

Studies [4-6] develop the principles of image discretisation into different raster dots of the same distance. But these studies lack the list and analysis of the principles of how to build adaptive colour separation.

The issues of obtaining images in various registration systems, when transmitting visual information through communication channels, are raised in works [7-9]. However, these works lack recommendations regarding the assessment of methods of image discretisation and quantisation.

Scientific works [10-12] consider the features of reproducing a line image for digital printing. But these works do not provide the results of the study of the sharp properties of a raster line image when using various raster structures.

Aspects of automation and information support of reproductive processes are given in studies [13-15]. However, these works lack the study of the mechanism of digital data processing in order to obtain reproduction.

Problems of colour transformation are analysed in studies [16-18]. However, these works do not take into account the influence of the binarization threshold on the image resolution.

The main aspects of colour representation modelling in different colour systems are given in work [20]. But these studies do not contain consideration of key aspects for adjusting equipment to achieve the required quality of colour image reproduction. Thus, this article was to study the degree of influence of the binarization threshold on the resolution value of raster line images.

The novelty of the work consists in building a model of data flows in the reproduction system, which allows analysing information about the parameters of the printing process and adjusting the equipment settings to achieve the required quality of colour image reproduction.

MATERIALS AND METHODS

To achieve this goal, the article uses the following research methods:

1. Generalisation. Using this method, an experiment has been conducted in which the influence of the raster structure on binarization algorithms has been studied.

2. Classification. Using this method, noise sources in the binary channel acting on the periphery of the binary image, have been investigated;

3. Deduction. Using this method, noise research has been carried out. In real physical systems and complex production processes, noise plays an important role, usually a negative one, because it leads to errors, resulting in undesirable properties;

4. Analysis. This method made it possible to describe the process of printing a pictorial original, for which a photoform was applied using a line test object. This scheme allows identifying characteristic components such as, for example, a binary channel, which is the basis for studying the noise immunity of binarization algorithms.

To study the robustness of binarization algorithms in relation to the printing process, a binary channel model with erasing noise has been introduced. This model, where two input signals 0 and 1 with some probability are converted into one, is well-known in information theory.

Such a noise model has not been considered for digital image conversion. In this model, the channel is a printing device whose input is a binary image obtained from a halftone, and whose output is "paper", where the "paint" reproduces the binary image. The elements "paint" and "paper" can have different implementations, for example, it is possible to talk about electronic paper or ink based on modern technologies. However, the methods of reproducing a halftone or colour image do not change.

In this work, to assess the quality of a line image reproduction, photoforms have been made with the use of a line test object (TO) made by the method of accurate photography. These photo- forms have a profile of optical density distribution. TO consists of 25 groups of lines. Each of these line groups contains a set of lines located at the angles of 0°, 45°, 90°, 135° to the direction of line scanning, which allows analysis for the lines with different spatial orientation. Three groups of lines – 1st, 11th and 21st – were chosen for the research, the sizes of the lines in these groups were measured with a microscope.

RESULTS AND DISCUSSION

Analysis of image detail reproduction using a photo output device

The main link that affects the quality of image detail reproduction is the photo output device, which consists of a raster image processing processor (RIP – Raster Image Processor) and a recording device (RD). Possible options for RIP implementation are a separate electronic device or a program or interface card of a personal computer [10]. It perceives a stripe image recorded in TIFF, PostScript, EPS or PDF format, which contains vector and raster information, and converts the information expressed in this form into bitmaps. In printing, the main data encoding standard is the PostScript graphic language developed by Adobe. As a result of processing in RIP, bitmaps contain information about the size and shape of a line or raster dot, about the angle of rotation of a raster structure. The raster structure is formed according to the matrix-specified transformation entered into the RIP memory.

The task of RIP is the formation of a pixel grid, on the background of which a grid of a raster structure is being formed, the size of its elements will depend on the size and shape of the recording spot (corresponds to the size of the spot of the laser beam), and recording resolution. The value of the dimensions of the image details generated in the photo output device (POD) should match the values actually obtained on the photo material. Theoretically, such a match is relatively easily achieved if the diameter of the laser beam is clearly correlated with the established resolution of the POD when the following condition is met:

$$d_l = 2.54/R, \quad (1)$$

where R is resolution (dpi); 2.54 is the conversion factor from inches to centimetres.

If this condition is not met, the photo output becomes non-linear, i.e., in order to obtain the required value of the line dimensions of the parts and raster dots, it is necessary to take into account the obtained distortions. The greater the discrepancy between the diameter of the laser beam and the output resolution, the greater the nonlinearity. Nonlinearity leads to an increase in the size of the raster dot, distortion of the characteristic curve, changes in the size of line details, loss of time for linearization (calibration) of the POD and, ultimately, to a high probability of the defect.

So, in the process of research, the elementary raster structure has been considered as a simple square that can be rotated to a random angle. In the process of digital rasterization, a single raster structure must actually be examined from the standpoint that it is a two-dimensional grid of individual pixels. The reason for this consideration of the raster structure is the fact that pixel structures with truncated elements cannot be obtained. In the case of a single raster structure form with the correct square parameters, the desired result can be obtained when using a rotation angle of 0° (Fig. 1).

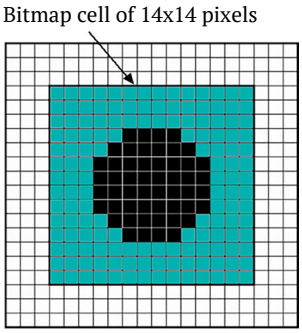

Figure 1. Raster structure of 14x1=196 pixels
Source: [8]

In the case of raster structure rotations, all corners become "occupied" with neighbouring pixels. Angles that have an integer pixel distance both vertically and horizontally are considered acceptable (Fig. 2).

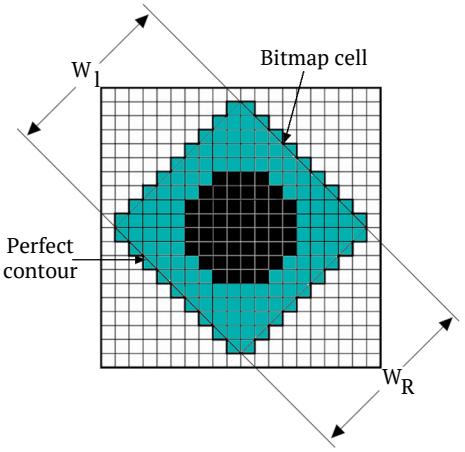

Figure 2. Raster structure at an angle of 45°. Its contour differs from the ideal raster structure
Source: [8]

The process of rasterization is called Rational-Tangent rasterization (RT). A graphical representation of the RT-rasterization process is shown in Figure 3.

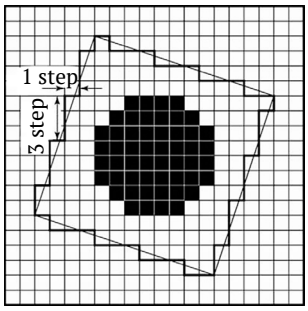

Figure 3. The geometry of the raster structure, changed in the process of RT-rasterization
Source: [8]

The results of the displacement in the process of RT-rasterization are given in the Table 1.

Table 1. Specificity of raster line frequency resulting from RT-rasterization

Paint	Angle of rotation	Raster line frequency
Yellow	0.0°	50.0 line/cm
Blue	18.4°	52.7 line/cm
Black	45.0°	47.1 line/cm
Purple	71.6°	52.7 line/cm

Source: [2]

Adobe developed Accurate Screens as part of PostScript (Level 1) and PostScript (Level 2). Adobe's competitors offered the following technological solutions to support RT-rasterization: Heidelberg developed the HQS (Higher Quality Screening) system, Agfa Corporation created the Balanced Screening technology.

Rasterization analysis by irrational tangents

The difference between the methods of "rational" and "irrational" rasterization is determined by the specific features of rational and irrational numbers.

In the case of "irrational" rasterization, a matrix with precisely defined distances between the centres of raster dots is used. In the case of "irrational" rasterization, the raster dot changes according to the mechanism of pixel changes.

While with amplitude-modulated rasterization (AM-rasterization) individual raster dots are located at equal distances from each other and only their sizes (amplitude) change, when using the method of frequency-modulated rasterization (FM-rasterization) the raster dots have the same dimensions, but they are randomly distributed on the printed surface.

The processing of digital data in order to obtain reproduction in many cases leads to completely new forms of organisation of production (as mentioned at the beginning of this section). These changes made to various digital data flow control systems (Workflow) gave a new sound to the sample and digital colour sample.

One of the traditional phenomena for polygraph reproduction is the appearance of moiré. The moiré phenomenon is based on the fact that when summing signals (electrical, optical, etc.), the resulting signal contains a low-frequency difference component.

To reproduce monochrome products, the recommended regular structure angle should be close to 45 degrees from the horizontal image. This complicates the visual perception of the raster image structure on the print and thereby positively affects the perception of the image as a whole.

To minimise moiré in the conditions of autotype synthesis, a change in the rotation angles of raster structures is used. At the same time, the rasters for contrasting colours (black, blue and purple) form a moiré of a shorter period, because they are separated from each other by 30 degrees. The raster for the yellow paint form, which is at an angle of 15 degrees to the other two, gives a lower frequency, but barely noticeable moiré due to the low visual contrast of the yellow paint (although it is the cause of the visually visible moiré, under standard rasterization conditions).

So, the following are used as standard raster rotation angles in printing:

0° – for yellow paint;
45° – for black paint;
15° – for blue paint;
75° – for purple paint.

In some cases, the interaction of the drawing structure and the periodic raster structure can be observed, which depends on the width of the detail, the relative location of the image details and the direction of the raster structure. In printing, this phenomenon is called object moiré, and it must be taken into account when developing the technique and evaluating the obtained results. The angles that determine the mutual orientation of the detail and the raster structure can be different, therefore the object moiré can be different.

When assessing the reproduction of line details with the help of periodic boundaries, it is necessary to take into account the possible occurrence of object moiré between these boundaries and the raster structure located at these angles. This is a question that also needs research.

When displaying visual information, the problem of accurate transmission of small details arises. Real information display systems always have some blurring, which manifests itself in the fact that an infinitely larger impulse, applied to an infinitely small space and called a b-function, is reproduced by the system no longer in the form of a b-function, but by a blur spot which is characteristic of this system (or its separate link). Among the practically important tasks there is the calculation of the intensity distribution in the image of a single line detail reproduced in the system or in its separate links with blurring. For example, for POD, among other factors affecting the quality of the microstripe image, there is a characteristic due to the transmission properties of the "exposure beam-recording medium" system. Experimental studies to assess the transmission characteristics of such a system have proven the suitability of this method.

The definition of the FPM by the edge function (EF) is of interest, firstly, because the edge of the detail is an object that is easy to manufacture, and secondly, because it becomes possible to define the FPM from ready-made images in which there is no test-object, since the edge is on many objects (corners of buildings, pipes, etc.).

Assessment of the reproduction quality of a line image

The work [4] proposes methods for assessing the FPM of photographic materials using the raster method, which provide the possibility of assessing the FPM for high-contrast images. When measuring the FPM of materials by this method, light is printed on them by the contact method, it is a linear raster with a ratio of transparent and opaque lines of 1:1, which has a constant frequency. The conditions of the experiment are close to those investigated in this work. Prints of a linear raster and a stepped wedge are obtained on contrast photographic film and, after measuring the optical densities of the original wedge, as well as halftone and raster wedges, characteristic curves are being constructed.

The need to move from one function to another is due to the fact that, with the essentially identical information content of different functions, they have different practical properties. For example, the important properties of TNF include, first, the relative convenience of its assessment, and second, with the use of TNF, the transfer characteristic of the system can be easily calculated from the known TNF of individual links. With the use of TNF, it is possible to separate the influence of different links of the TNF system and it can be determined using relevant experimental data, or by calculation according to the known line blur function (LBF) or CF, TNF determines the value of the contrast transmission coefficient of a one-dimensional grid with a sinusoidal distribution of intensity that depends on the spatial frequency of the grid.

Sizes of lines in groups of lines were measured using a microscope and are presented in Table. 2.

Table 2. Sizes of lines and gaps of the studied groups on the original, μm

	Angle 135°		Angle 0°		Angle 90°		Angle 45°	
	Line	Gap	Line	Gap	Line	Gap	Line	Gap
1 group	173.4	184	174.6	183.5	175.5	181.8	171	187
11 group	98.7	101.7	98.7	102.6	96.3	102.9	97.8	102.9
21 group	52.8	56.4	53.7	57.3	54	58.2	54.3	56.7

Source: made by the authors based on [4]

With the use of the obtained photoforms, an assessment of the impact of scanning parameters and line image output on the final quality of its reproduction has been carried out. Scanning was made on a flatbed scanner with the change of:

– scanning resolution R_B -800 ppi, 1520 ppi, 2500 ppi;
– binarization threshold T: 50%, 60%, 70%, 80%;
– scanning functions: Good, High, Excellent, 4 times Excellent.

The physical meaning of the "scanning function" parameter is not clearly defined, probably these functions differ in the organisation of the sharpening processes during scanning, in the accuracy of reading and in the speed of the signal processing. According to the results of line size measurements with a measuring microscope, curves were constructed for three size groups, characterising the dependence of the obtained line width on its spatial orientation and binarization threshold. As a sample, Figures 4-6 present dependences for three size groups at RB=800 ppi and RB=2540 dpi.

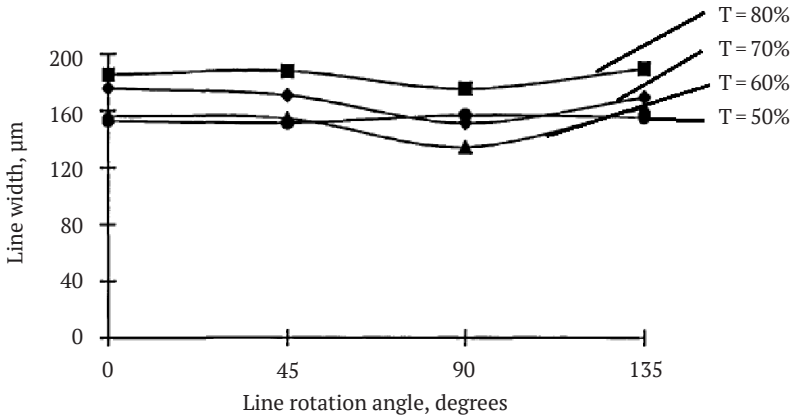

Figure 4. Dependence of the T line width on the photoform for the 1st group on the spatial position of the line at the values of binarization threshold RB=800 ppi

Source: made by the authors

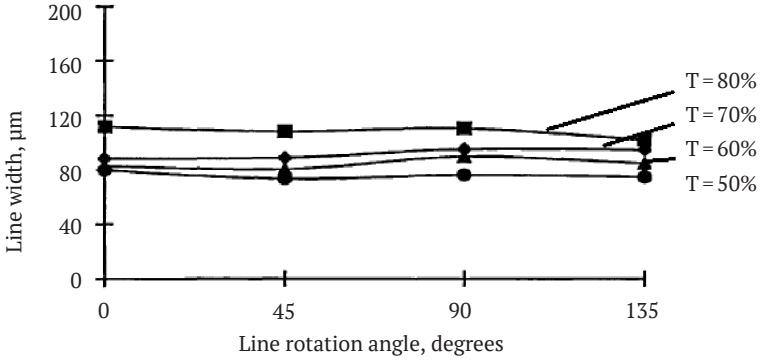

Figure 5. Dependence of the T line width on the photoform for the 11th group on the spatial position of the line at the values of binarization threshold RB=1520 ppi

Source: made by the authors

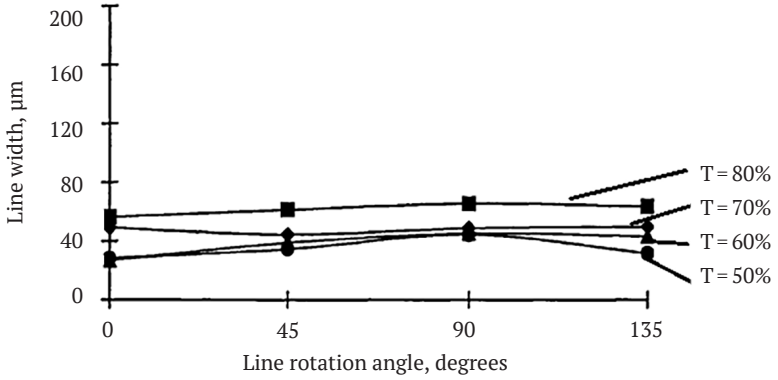

Figure 6. Dependence of the T line width on the photoform for the 21st group on the spatial position of the line at the values of binarization threshold RB=2500 ppi

Source: made by the authors

The analysis of the experimental data showed that the "binarization threshold" parameter has the greatest influence on the dimensional resolution. In modern photo-printing systems, a rather sharp border of micro-line elements along and across the recording terms is ensured due to the high contrast ratio (y>-8) and the relatively high resolution of the photo material, resulting in the maximum optical density. However, with other line orientations, there is a loss of reproduction quality, caused mainly by a violation of the homogeneity of the line, its breakdown into fragments that form the stepped structure of the image.

Therefore, data on the line width with the part width measured by visual averaging can be considered as approximate, in particular, for lines at 45° and 135° angles. The use of such a criterion as "width of the detail" for a direct assessment of the reproduction accuracy seems time-consuming and quite ambiguous in the presence of a stepped boundary structure of the line detail, loss of line continuity.

The proposed methodical recommendations regarding the improvement of line image reproduction in the system of prepress engineer work continue the author's research [13; 15] on issues of information support of printing production processes. The developed technique can be used to analyse the resolution of raster line images, research possible deviations in the process of raster optimisation, and perform an assessment of reproduction quality.

The developed technique solves the problematic part of managing the processes of prepress preparation of printed products in terms of assessing the accuracy of line image reproduction. This is achieved due to the methodology developed by the authors for optimising the "signal-to-noise" ratio when assessing the reproduction quality of the line image with an uneven edge. At the same time, the authors found that the scanning stage affects the quality of image reproduction to a greater extent than the process of photo output.

This work, as well as studies [2; 9; 12], analysed the reproduction of image details using a photo output device. It considers an elementary raster structure in the form of a simple square with the possibility of subsequent return to an arbitrary angle. However, the mentioned studies [2; 9; 12] do not take into account the aspect of digital rasterization, in which the elementary raster structure must be implemented in the form of a two-dimensional pixel grid. At the same time, it is impossible to obtain partially truncated pixel structures.

This research analyses the specifics of digital data processing in order to obtain reproduction. Studies [1; 5; 8] offer various ready-made information systems to implement the task of processing large arrays of digital data. However, this work, unlike studies [1; 5; 8] analyses the Accurate Screening technology, investigates electronic rasterization according to the Accurate Screening method, considers the features of the PixelBurst coprocessor, which performs offloading functions of the main RIP processor.

The results of this research make it possible to overcome the phenomenon of moiré, which occurs as noise when summing up electrical, optical and other types of signals. At the same time, the resulting signal is a low-frequency difference component. Scientific articles [14; 20], in contrast to this research, give an overview of the processes of line image optimisation without taking into account the moiré effect.

This work, as well as studies [3; 19] used photoforms to assess the quality of rasterization. However, a distinctive feature of this work is the fact that in order to carry out an experiment, it used manufactured photoforms based on a line test object, which was created by the method of accurate photography.

The obtained results of the research on the development of a methodology for assessing the quality of line image reproduction are adequate within the limits of prepress printing production.

The limitations of the created methodology to conduct a study of the degree of how binarization threshold influences the resolution of raster line images were that it does not take into account the possible situations of uncertainty that may arise in the process of measuring line sizes with a measuring microscope for different size groups.

In addition, errors are possible when using a flatbed scanner to assess the impact of scanning parameters and line image output on the final quality of its reproduction. It is possible to overcome these errors due to the involvement of experts, but this, in turn, can lead to the subjectivity of the obtained results of analysing the resolution of raster line images.

CONCLUSION

This research was based on the fact that studying the instability of the printing process is of great practical interest, for example, in order to predict the result at the stage of prepress. To solve these problems, the market offers a huge number of products that lead to increasing stability. However, the question remains open, there are defective copies with certain defects in circulations. It is not possible to completely eliminate defects, but by choosing the correct components of the printing process, in particular by choosing a noise-resistant binarization algorithm, the likelihood of defects can be reduced.

The study of technological aspects of image formation as a result of binarization and raster process implementation made it possible to conclude that image clarity can be achieved by increasing such indicators as the regularity of raster structures, the spatial location of image details in relation to the direction of scanning and the angle of the raster structure rotation, shape and size of a raster dot, input-output resolution ratio, quality factor value combined with castration frequency.

In computer publishing, the "binarization threshold" has the greatest effect on the dimensional accuracy of a binary line image. Special attention should be paid to the correct choice of the binarization threshold as the main condition for ensuring the accuracy of binary line image reproduction.

A modification of the investigated algorithm has been proposed, which uses the randomisation process to improve the visual quality of the binary image.

As a result, there is a binary channel with a binary image in digital form, where zeros and ones at the input are converted into zeros and ones at the output, with the presence or absence of a printed element on paper. In a binary channel, both input symbols are converted into one.

The scientific result of the article is the research systematisation of the influence of binarization parameters on the result of line and raster image reproduction. The

obtained binarization values make it possible to increase the contrast, highlight low-contrast details in line images, and improve their visual quality.

The direction of further research may be the development of a comprehensive assessment of reproduction processes.

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Покращення відтворення штрихового зображення в системі роботи препрес-інженера

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Анотація. Для оптимізації процесу роботи препрес-інженера слід забезпечувати якісне відображення штрихового зображення, що забезпечує максимально точне передання геометричних розмірів окремих елементів. Метою статті було визначення ступеня впливу порога бінаризації на величину роздільної здатності растрових штрихових зображень. Проведення експериментів ґрунтувалося на використанні загальнонаукових методів аналізу, узагальнення, класифікації, дедукції. Для оцінки якості відтворення штрихового зображення у даній роботі було використано фотоформи з використанням штрихового тест-об'єкта, який був розроблений як точна фотографія з використанням профілю розподілу оптичної щільності. В роботі досліджено вплив різних параметрів растрових структур на якість відтворення репродукцій. Визначено специфіку використання фотовивідного пристрою як головної ланки, яка забезпечує якість відтворення деталей зображення. Проаналізовано геометрію растрової структури при використанні кутів повороту з раціональними тангенсами. Систематизовано особливості технології Accurate Screening. Розглянуто відмінність методів «раціонального» і «ірраціонального» растрування. Розглянуто основні аспекти використанні штрихових деталей у репродукційному процесі. Запропонована методика для оцінки якості відтворення штрихового зображення з нерівним краєм, названа методикою «відношення сигнал-шум» та зроблено висновок, що на якість відтворення зображення в більшій мірі, ніж фотовивід, впливає стадія сканування. Практичним результатом роботи є розроблення рекомендацій які можуть знайти застосування у практичній діяльності при проведенні репродукційного процесів. Розроблені алгоритми бінаризації дозволяють проводити обробку зображень із значною зональною нерівномірністю яскравості, з монотонними областями яскравості, з сильно зашумленими зображеннями

Ключові слова: роздільна здатність; бінаризація; дозвіл сканування; штрихові оригінали; лініатура растрів

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Visualization of algorithms on graphs with a large number of vertices: The features of applications design

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Abstract. The task of visualization of large graphs as a special data structure and algorithms on them is considered by scientists and practitioners as a complex and non-trivial problem. The analysis of scientific works and existing software applications that implement similar functions of the subject domain testifies the relevance of expanding exploration in the lines of identifying the features of the development of applications for the visualization of large graphs and algorithms on them. The formulation of features and recommendations for the development of such software and presentation of the software module designed by the authors is the aim of the article. In the course of the work, the main features of the development of a program for the visualization of graphs with a large number of vertices were identified and formulated using methods of analysis and graph theory. Special recommendations on the essence of each of the stages of development of such applications were provided and those steps that are most important for developers in terms of the complexity of processing and visualization of large graphs, metrics of their layout in the application screen, etc. were identified. A software module developed by the authors, that provides a unified application programming interface for visualizing any algorithm on graphs, which allows to save time working on utility software and focus more on solving algorithmic problems is also presented. The presented module was developed by the authors taking into account the identified recommendations. A comparative analysis of the developed software module and analogues was carried out, which proved the extended functionality of the module for the visualization of graphs with a large number of vertices. The module is a practically valuable tool for data structures researchers and other experts working on graph algorithms, since it enables data visualization at debugging software and simplifies the analysis of large data structures

Keywords: large graphs; problems of algorithms visualization; a module for visualization of algorithms on graphs; graph layout; unified Application Programming Interface

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INTRODUCTION

Graph theory makes a powerful theoretical basis for modelling relationships between objects and solving variety of practical problems in different subject domains. In computer science, graphs are one of the most common and widely used data structures. Current complex scientific and technical problems expect to store and process huge data amount for their solutions. By far, a lot of graph algorithms have been developed which enable to solve great range of problems: from search of the shortest ways to the optimisation and numerical problems.

There are some cases, when it is quite complicated to use or modify the algorithm without its visualization which gets even more urgent when the problem expects using graphs with big number of vertexes (and edges, correspondingly). For instance, the graph representation of the car network of a developed European state or a big university social network may demand tens of thousands graph vertexes and edges.

Thus, it makes obvious the urgency of the extension of the investigations in the lines of revealing core development features of the applications which enable visualization of big graphs and design of a module providing unified Application Programming Interface (API) for visualization of any graph algorithm.

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According to studies [1; 2], a graph with large number of vertices (or so called "large graph") is a graph with approximately 10K vertices and/or edges. The way the graph is presented on the screen is called graph layout. In fact, this is the result of a graph visualization algorithm that positioned all the vertices on the screen.

The researchers D. Lande and I. Subach [1], V. Babkov, M. Serik [2], O. Demianchuk [3] emphasize core problems of large graphs visualization, which are readability, speed and algorithmic complexity. In this context, the researchers S. Iguana [4], F. Beck [5], A. Noack [6] emphasize the difficulties of aesthetic metrics determination for the criteria of "good" layout.

There are distinguished three main ways to visualize a graph: dimension reduction approach [4; 5], force-directed and energy-based approach [6], and features-based layout which are analysed in terms of speed concerns in the papers [7-9], where it is admitted that graph visualization algorithms mostly have bad algorithmic complexity (quadratic or cube one).

Thus, the analysis of the research papers [1; 3; 4] and existing applications which implement similar functions of the subject domain [4; 9] enables to testify, that despite the variety of scientific papers related to graph visualization problems, and, consequently, the number of software applications based on those researches, none of them has an option to visualize advanced or custom algorithms using API. The best analogues that have been found, could only display predefined algorithms and usually only basic ones (Depth First Search (DFS) [10], Dijkstra [11], etc.). They do not have sufficient functionality that can be used mostly for educational purposes.

Therefore, it can be concluded that the proceeding and visualization of large graphs is an urgent issue. In addition, in some cases graph data can be dependent on external factors and the basic algorithm should be modified to tackle the problem properly, which often causes new mistakes and bugs. The most efficient way to find them is to represent the data visually. Development of such applications is really time-consuming and focuses rather on implementing utility applications than working on real tasks solving.

Thus, the aim of this work was to reveal the core development features of an application for visualization of graphs with large number of vertices, and represent the authors' software module that provides a unified API to visualize any graph algorithm to save time working on utility software and focus more on solving problems.

MATERIALS AND METHODS

The set of theoretical and practical methods were used during the work. The theoretical literature analysis allowed to reveal the challenges of visualization of graphs with large number of vertices and the development of an application for this purpose.

Graph theory methods and exactly graph visualization algorithms were used at the initial stages of the application design and were taken into account at the formulation of the core features of its development.

There were used three main ways to visualize a graph which are characterised below: force-directed and energy-based approach, dimension reduction approach, and features-based layout. Force-directed and energy-based approach includes the family of methods based on physical systems simulation. Vertices are treated as charged particles that repulse each other, and edges model elastic strings. These methods simulate the dynamics of this system or find out a minimum of energy. Important methods of this family are ForceAtlas [9], Fruchterman-Reingold [10], Kamada-Kawai [11] and OpenOrd [12]. The last one uses optimisation techniques to speed up computation. As a useful side effect, graph gets more clustered. Such methods typically provide good result, and final plots reflect the graph layout very well. However, they are also computationally hard and have a lot of parameters to adjust, which was taken into consideration at their usage.

According to dimension reduction approach [4], a graph can be defined as an adjacency matrix $N \times N$, where N is the number of nodes. This matrix can also be considered as a table of N objects in N-dimensional space. This representation allows to use general-purpose dimension-reduction methods (UMAP, tSNE, PCA, and others). Another way to do it is to calculate theoretical distances between nodes and then to conserve proportion moving to lower-dimensional space. The ideas of this approach were also relevantly used at the appropriate stages of the application design discussed below. Approach of features-based layout is based on the idea that graph data reflect some objects of the real world. Thus, vertices and edges can have their own features according to object properties, real-life conditions, etc. Therefore, these features were used to represent them on the plane. It was possible to deal with node features as with usual tabular data using dimension reduction approaches or drawing a scatter plot for pairs of features.

It is important to emphasise the problems of these approaches implementation which arise in terms of speed concerns. For instance, one of the most common algorithms from force-directed set of algorithms, the Fruchterman-Reingold [10], in its regular variant has a total runtime of $O(|V|^2+|E|)$, where $|V|$ is the number of vertices in a graph and $|E|$ is the number of edges connecting the vertices. The grid-variant of this algorithm allows to reduce its runtime to $O(|V|+|E|)$: it divides the graph plot area into a grid of squares and applies repulsion forces between the nodes inside of adjacent squares, excluding the iteration of nodes further away. However, it is admitted that this runtime is only achieved in a best-case scenario, remaining quadratic for the worst-case scenario. Among the force-directed family, it was also developed the GEM algorithm [6] with the expectation to outperform in terms of runtime both the Kamada-Kawai algorithm and the Fruchterman-Reingold algorithm. According to [12-14], the total runtime of the GEM algorithm is $O(|V|(|V|^2+|E|))$.

Similar level of complexity is inherited also to the algorithms of dimension reduction approach. For instance, Principle Component Analysis (PCA) algorithm has two computationally crucial steps: computing the covariance matrix and computing the eigenvalue decomposition of the covariance matrix. The computational complexity of the covariance matrix computations is $O(NM \times \min(N, M))$, which is a result of multiplying two matrices of size $M \times N$ and $N \times M$, respectively. The worst-case complexity of the algorithms of eigenvalue decomposition is $O(M^3)$ for a matrix of size $M \times M$. Therefore, the overall complexity can be estimated as $O(NM \times \min(N, M)+M^3$ [15].

At the stage of design and development of the said module contemporary specialised software and systems such as Figma, Simple and Fast Multimedia Library (SFML), Texus' Graphical User Interface (TGUI) library, and C++ were used. The peculiarities of their usage are described in details in the relevant subsections of the work.

RESULTS AND DISCUSSION

The core features development of an application for visualization of graphs with large number of vertices can be formulated and characterised as following steps.

One of the basic steps for such an application is to provide users an ability to build a graph which later will be used for algorithm visualization. The three most common ways to represent a graph using data structures are adjacency list, adjacency matrix, and incidence matrix. Graph data structures comparison for each of three ways in terms of complexity of basic operations (graph storing, addition (removing) of a vertex, addition (removing) of an edge, etc.) are given in the Table 1 using big O notation ($|V|$ is the number of vertices in a graph and $|E|$ is the number of edges connecting the vertices).

Table 1. Graph data structures comparison for each of three ways of representation

	Adjacency list	Adjacency matrix	Incidence matrix
Store graph	$O(\|V\|+\|E\|)$	$O(\|V\|^2)$	$O(\|V\| \cdot \|E\|)$
Add vertex	$O(1)$	$O(\|V\|^2)$	$O(\|V\| \cdot \|E\|)$
Add edge	$O(1)$	$O(1)$	$O(\|V\| \cdot \|E\|)$
Remove vertex	$O(\|E\|)$	$O(\|V\|^2)$	$O(\|V\| \cdot \|E\|)$
Remove edge	$O(\|V\|)$	$O(1)$	$O(\|V\| \cdot \|E\|)$
Adjacency check	$O(\|V\|)$	$O(1)$	$O(\|E\|)$
Conclusions	Slow to remove vertices and edges, as it is necessary to find all vertices or edges	Slow to add or remove vertices, as matrix must be resized/ copied	Slow to add or remove vertices and edges, as matrix must be resized/copied

Source: developed by the authors based on [14-16]

The core peculiarity of this step which should be taken into account is the following. Since graphs used by the potential application are expected to have a large size (>10 000 vertices) it is crucial not to have a storage overhead. For this reason, an adjacency list is a preferred way to store graph data.

Graph visualization itself, being a complicated problem, determines its own peculiarities which should be minded by the developers. The application on this purpose should at least implement feature-based layouts. At the same time, support of other methods would be recommended for advanced versions of the application.

As it is expected to visualize a custom algorithm on a graph, it is necessary to provide users with such an ability. For this reason, there should be realised an API that helps to create an algorithm steps file to reproduce these steps later in the application.

One of the important features of such applications development is prediction of its possible using for educational purposes and for quick verification of basic graph properties such as connectivity, looking for bridges, etc. In this context, it is recommended to implement some basic graph algorithms like Breadth First Search (BFS) [17], DFS, etc.

In this context, it is also relevant to follow the criteria of "good" graph layout. It is important to apply some aesthetic metrics offered in research [4]:

(1) There should be minimum of edges intersection, as too many intersections make the layout look messy.

(2) Adjacent vertices should be closer to each other than not adjacent ones, as connected nodes in such a way will look also closer, which is true in graph by definition.

(3) The set of vertices (communities) should be grouped into clusters and they should look like a dense cloud.

(4) There should be minimum of edges and nodes overlapping.

Other researchers [5; 6] also formulated additional aesthetic criteria for graph visualization, such as reduction of visual clutter, reduction of spatial aliases and maximisation of compactness. It is also concluded that in real practical use, some of these criteria are in conflict with each other.

In terms of proving the choice of the technological tools for the application development, it is relevant to keep in mind some ideas. One of the important features of the application functionality is to make it easier to debug different algorithm implementations. Since different developers can use different Operational Systems, it will be a right decision to make the software cross-platform. On the other hand, the application of this purpose is going to deal with huge amount of data and to have the options for potential extension in the future. Therefore, requirements for the programming language include high performance and preferably it should be object-oriented to simplify the introduction of new features. Thus, all of these requirements are met by C++ [18]. Since C++ standard library does not provide tools for work with graphics, there should be a set of libraries chosen for this purpose. In particular, SFML [19] is helpful to create a display window and most of the graphics. TGUI [20] library allows to provide a proper user interface.

Both of these libraries support multiple platforms which is essential for a tool like this. The list of supported platforms includes Windows, Linux, macOS, and even Android is partially supported.

Development is preferably to be performed using a Linux-based operating system, as it provides a lot of tools [21] to facilitate the development process.

The application of such a purpose has to be open-source, due to the important benefits of this approach: users from all over the world can contribute to the tool development, there is feedback mechanism on both implementation details and code quality, possibility for end-users to modify the application according to their needs.

The revealed and formulated features of development of the applications for visualization of graphs with large

number of vertices made a necessary theoretical and technological base for design of a module that provides a unified API to visualize any graph algorithm to save time working on utility software and focus more on solving problems.

Developed module does not contain any databases, as they are not applicable in this scenario. Instead of it, data interchange formats and solutions are applied, as it was presented above. A graph is represented in a text format and visualization steps include two core stages.

At the first stage, the graph is stored in a METIS-based graph representation format, which is going to be extended since the module is expected to cover all possible graph types in future. Possible options for graph types that will be supported are: directed/undirected, edge-weighted, node-weighted.

As it was pointed out, since proceeding graphs are expected to have over >10 000 vertices and are not going to be stored overhead, an adjacency list was chosen as a way to store graph data.

A graph $G=(V,E)$ with N vertices is stored in plain text format in a file with N+1 lines. First line contains two integers N and F that specify vertex number and a graph format.

Since there are several possible combinations of graph types (which can be extended later), it was decided to use a common programming technique to store this information in a single integer where each bit specifies whether some feature is used or not. For example, if one attribute has a value of 0x08 and another one 0x02 to specify that the graph will use both of them, a bit-wise OR is applied to these values and the resulting number (10 in this case) will be stored as a graph type. All these calculations will be definitely done behind the scenes and the user will be provided with a user-friendly API. If the graph edges are weighted value should contain 0x01, in case of node weights 0x02, if the nodes' position can be specified via coordinates (can be used in case of feature-based layouts and also to restore vertex positions after the graph building stage) 0x04, directed graphs contain 0x08.

The remaining N lines of the file store information about the current graph structure. In particular, the i-th line contains information about the i-th vertex. Depending on the value of F, the information stored in each line is somewhat different. In the most general form (when F=15) each line has the following structure:

$$c\,x\,y\,v_1\,w_1\,v_2\,w_2\ldots, \quad (1)$$

where c – node weight, xy – corresponding coordinates on the plane, v_i – vertex adjacent to the current one and w_i – weight of the edge to the adjacent vertex.

Next, visualization step, which collects information about every pass of the visualization process (for example, highlighting vertices and nodes). Some algorithms may require more sophisticated situations to visualize (such as partitioning levels [22]), but the majority of algorithms do not need it. Thus, provided functionality of a module is sufficient.

To enhance user experience, the API provides an opportunity to combine several visualization steps into groups. It is caused by the fact that, if for the sake of simplicity, there was used BFS [22] as an algorithm to analyse, there is no need to examine every topology check, and it will be enough to observe the state of the graph only after every algorithm iteration. JavaScrip Object Notation (JSON) as a data storing approach was preferred to native one, as it allows serialization of custom objects and also supports arrays, which is crucial in this case.

Following the formulated features of technological tools, the module was developed by the authors in C++ language with attraction of SFML and TGUI libraries, and using a Linux-based operating system.

In this part of the work the developed module is characterised.

Since the module architecture is complex and it is hard to see all the details in one diagram, every software component is discussed separately.

The starting point of the program is the Application class which structure is presented in Figure 1 in the form of diagram and built by the authors in the course of the module design. It contains the main loop, handles the framerate, and delegates user events to other classes. Window class gathers user events, and handles camera movement and everything related to updating and displaying the main window of the application. To keep the user's screen clean and not messy the program is working in a single-window instance and creates additional windows only to notify user about wrong usage of the software. StateManager allows to transit application from one state to another.

There are three main states which correspond to three main screens of the application:

1) MainMenuState is a simple screen that allows choosing whether the user wants to run a graph visualizer or a graph builder;

2) GraphBuilderState (Fig. 2) is a screen that allows users to build a graph manually. It has several modes such as 'Hand', 'Add vertex', 'Add edge'. It is much easier to build a graph using a UI tool rather than writing down raw values into a plain text file.

3) VisualizationState, which is the most complicated part of the module. It includes graph layout algorithms, and sample graph algorithms to demonstrate the work of the application and allows to visualize an algorithm provided by the user.

IGraphAlgorithm interface is used for predefined algorithms within the program. For example, as shown in Figure 3, there are two basic algorithms that were implemented for software testing purposes. Both of them implement run() method which executes the algorithm using the provided graph and returns a record for the visualization process.

Graph class contains an adjacency list which is essentially a vector of vertices. Each vertex contains a list of outgoing topologies (in other words, all adjacent vertices), and a colour specified to this vertex. Graph class also includes ResourceProvider which is a useful utility that provides shapes for vertices and edges.

AlgorithmRecorder class is designed to store and to replay the visualization process on a graph. This class is also provided in the application's API in order to allow users to create algorithm steps data.

The module developed according to the core features formulated above was tested on purpose of verification of its functional requirements. As a result, it was possible to conclude that the designed software module meets all of them.

The developed module is implemented on the basis of a desktop application (exactly the Ubuntu 20.04 distribution), which is one of the most popular Linux-based distributions.

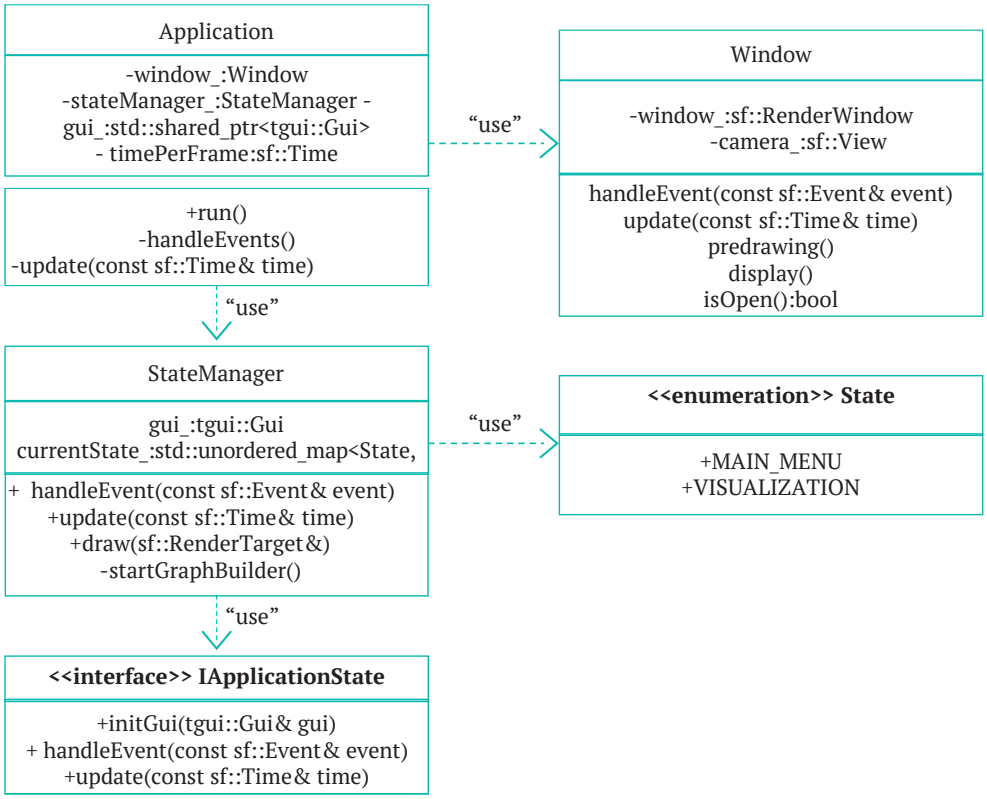

Figure 1. Diagram of fundamental classes

Source: developed by the authors in the course of the module design

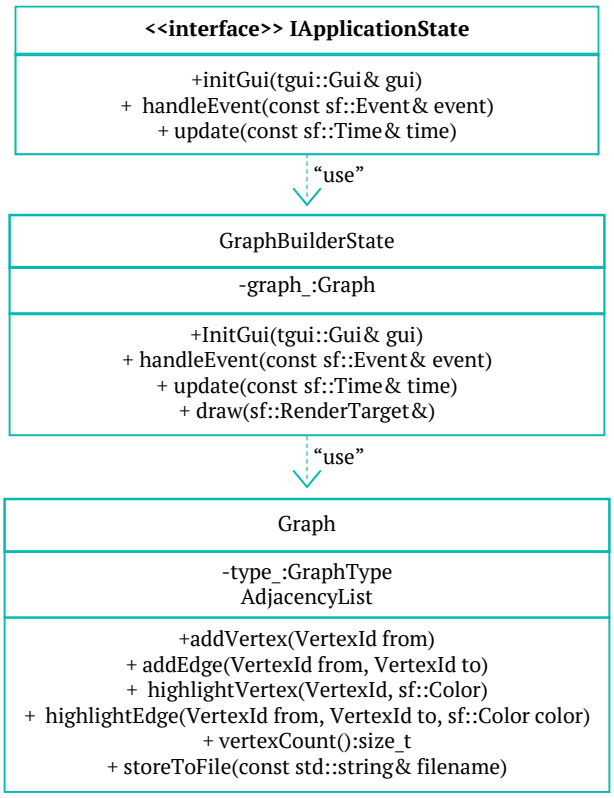

Figure 2. Diagram of GraphBuilderState

Source: developed by the authors in the course of the module design

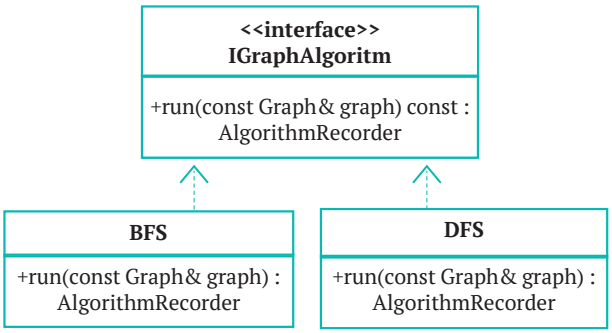

Figure 3. Diagram of IGraphAlgorithm interface

Source: developed by the authors in the course of the module design

According to the set goals, the core development features of an application for visualization of graphs with large number of vertices are revealed and formulated, which is a unique result that has not been highlighted in the research sources before.

The formulated features of development of the applications were used as a theoretical and technological base for design of the software module (presented above) that provides a unified API to visualize any graph algorithm to save time working on utility software and focus more on solving problems. In terms of practical significance of the work, the module designed following the said features and peculiarities makes a valuable tool for data scientists and other experts who are specialised in working on graph algorithms, as it enables data visualization for debugging and analysing large data structures.

In comparison with other applications that realize similar functions of the subject domain which characteristics are covered in [4; 9; 12; 23], the developed module has advanced functionality in terms of visualization of graphs with large number of vertices, that can be characterised as follows.

The module provides reading graph from a file: a properly written graph data is read and displayed successfully. In case of incorrectly written/corrupted file, the user is notified that file doesn't meet file format requirements.

API to write graphs and algorithm steps to corresponding files programmatically is realized, and it works properly producing valid files.

Algorithm provided by a user is visualized correctly. In case of invalid file, the proper notification is displayed.

A graph is built with the help of graph builder, and manual building of files is present. Manually built graph can be stored in a hard drive correctly. Sample algorithms (BFS and DFS) are provided for visualization tool. Both of them validate input and warn user in case of invalid input.

Random graph generation is also provided by the module and works properly: graph can be generated with predefined number of vertices and edges; advanced graph layout visualization algorithms is implemented; Fruchterman-Reingold layout is calculated correctly.

Selected episodes of the module work according to its functionality are presented in Figures 4-7.

Comparative characteristic of the developed software module with other applications which realise similar functions of the subject domain is generalised in the Table 2. The characteristic is done based on the papers [4; 9; 12; 23] and the module functionality presented above.

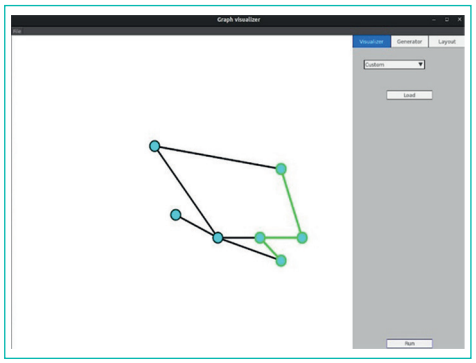

Figure 4. Algorithm visualized using external API

Source: developed by the authors

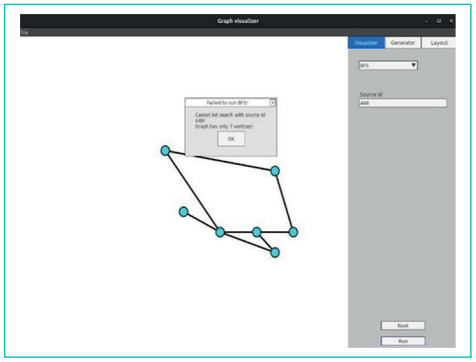

Figure 5. BFS algorithm input validation

Source: developed by the authors

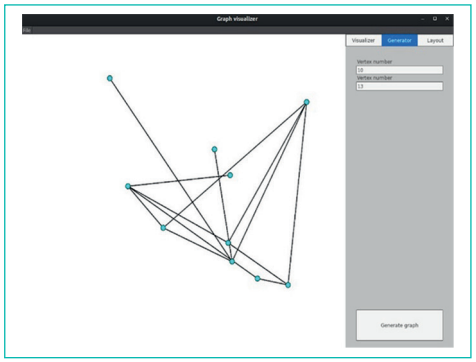

Figure 6. Randomly generated graph

Source: developed by the authors

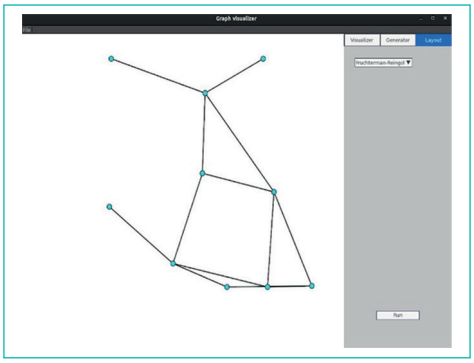

Figure 7. Result of applying Fruchterman-Reingold layout

Source: developed by the authors

Table 2. Comparative characteristic of the developed software module with analogues

Application name	Visualgo	USFCA visualizer	Gephi	Graphia	Developed software module
Platform	Web application	Web application	Desktop (Windows/ MacOS/Linux)	Desktop (Windows/ Linux)	Desktop (the Ubuntu 20.04 distribution)
Inputs a custom graph	Only manual	No	Yes	Only converting graph formats of other applications	Yes
Visualizes predefined algorithms	Yes	Yes	No	Yes	Yes
Supports different types of graph visualization	No	No	Yes	It has only one force-directed layout and very limited ways to tune it	Yes
Reads graph from a file and visualizes it	No	No	No	No	Yes
API to write graphs and algorithm steps to corresponding files	No	No	No	No	Yes
A graph is built with the help of graph builder, and manual building of files	No	No	No	No	Yes
User's algorithm is visualized	No	No	No	No	Yes
Notes	Not applicable for big graphs due to support of only manual input. It is seen as a good educational tool.	Poor functionality. Can be used only to get familiar with some basic algorithms, but the previous analogue deals with it much better.	Advanced visualization tool. Extremely good for data scientists. However, does not provide algorithm visualization.	Rendering options are not good for large graphs.	Performed using Linux-based operating system and all advantages of C++. Implements feature-based layouts, at the same time, supporting other methods. Has advanced functionality in terms of visualization of user's large graphs and their algorithms.

Source: developed by the authors

The table analysis testifies that the developed module has advanced functionality in terms of visualization of graphs with large number of vertices in comparing with the analogues presented in the papers.

CONCLUSION

According to the aim of the work, the main features of the development of an application for visualization of graphs with large number of vertices were revealed and formulated. The core steps of the applications development along with their characteristics recommended to mind in the progress of design of such software were distinguished and detailed.

The software module designed by the authors following the mentioned above features is presented with the details of its development and characteristics of its core functions. It provides a unified API to visualize any graph algorithm to save time working on utility software and focus more on solving problems. Therefore, in practical aspects, the developed and presented software module makes a valuable tool for data scientists and other experts who are specialised in working on graph algorithms, as it enables data visualization for debugging and analysing large data structures.

In addition, the comparative analysis of the developed module and the analogues has been realised in the paper.

The analysis testifies that the authors' software module has advanced functionality in terms of visualization of graphs with large number of vertices.

The developed software has lots of points for an extension due to its well-designed interface and topic depth. There can be applied new layout algorithms, and extended support for other graph features such as multilevel partitioning, multigraphs, etc. Nevertheless, performance improvements will be crucial to support graphs with even bigger amounts of vertices and edges. In addition, the tool can be optimised (for example OpenGL can be used instead of SFML) in order to work with graphics on a lower level. The mentioned extensions can prove the prospect of further research.

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Візуалізація алгоритмів на графах з великою кількістю вершин: особливості проєктування застосунків

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Анотація. Завдання візуалізації великих графів як спеціальної структури даних та алгоритмів на них розглядається вченими і практиками як складна і нетривіальна проблема. Аналіз наукових робіт та існуючих програмних додатків, що реалізують подібні функції предметної області, засвідчує актуальність розширення розвідок у напрямках виявлення особливостей розробки додатків для візуалізації великих графів та алгоритмів на них. Формулювання особливостей і рекомендацій щодо розробки такого програмного забезпечення та представлення спроєктованого авторами програмного модуля є метою статті. У ході роботи за допомогою методів аналізу та теорії графів виявлено та сформульовано основні особливості розробки програми для візуалізації графів з великою кількістю вершин. Надано окремі рекомендації щодо сутності кожного з етапів розробки таких додатків та виявлено ті кроки, які є найбільш важливими для розробників у термінах складності обробки та візуалізації великих графів, метрик їх розташування на екрані додатку тощо. Також представлено розроблений авторами модуль, який забезпечує уніфікований інтерфейс програмування додатків для візуалізації будь-якого алгоритму на графах, що дозволяє заощадити час на роботі над службовим програмним забезпеченням і більше зосередитися на розв'язанні алгоритмічних задач. Представлений модуль розроблено авторами з урахуванням виявлених особливостей та рекомендацій. Проведено порівняльний аналіз розробленого програмного модуля та аналогів, який засвідчив розширену функціональність модуля щодо візуалізації графів з великою кількістю вершин. Модуль є практично значущим інструментом для дослідників у галузі структур даних та інших експертів, які працюють над алгоритмами на графах, оскільки дає змогу візуалізувати дані при налагодженні програмного забезпечення та спрощує аналіз великих структур даних

Ключові слова: великі графи; проблеми унаочнення алгоритмів; модуль візуалізації алгоритмів на графах; компонування графа; уніфікований програмний інтерфейс

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Expert assessment of socially responsible activities of enterprises using the goal tree method on the example of the printing industry

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Abstract. Socially responsible activities of enterprises are difficult to measure and, as a consequence, to diagnose. The most common method of evaluating socially responsible activities of an enterprise is expert evaluation. The disadvantage of this method is the high level of subjectivity and intuitiveness. The specified problem determined the purpose of the research – to develop an approach to evaluate the results of enterprises' activities in the aspect of social responsibility, which would allow to involve experts only at the stage of formalising social responsibility norms, and the actual level of fulfilment of these norms should be calculated not by expert means, but on the basis of objective data on the enterprise's activities. To fulfil the set aim, the work developed an approach to evaluate socially responsible activities of enterprises based on the application of the goal tree method. The paper proposes a procedure for building and quantitative analysis of a goal tree in the aspect of social responsibility, which involves taking into account: 1) expert assessments of social responsibility norms; 2) objective data on compliance with the norms of social responsibility at the analysed enterprise; 3) expert evaluations of the enterprise's capabilities to comply with these norms; 4) values of parameters of the external environment that affect these capabilities. The procedure for building and quantitative analysis of a goal tree in the aspect of social responsibility is demonstrated on the example of the printing industry. The proposed approach allows: to evaluate social results of the company's activity; to analyse problems and external limitations in the aspect of social responsibility; to formulate tasks of reducing external limitations on the enterprise's capability to fulfil the norms of social responsibility. This will contribute to increasing the efficiency of the decision-making process for managing results of the enterprise's socially responsible activities

Keywords: results; external limitations; tree method; analysis of capabilities

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INTRODUCTION

One of the actual aspects of analysis of enterprise activities is the aspect of social responsibility. The complexity of this subject of the analysis lies in the fact that socially responsible activities of an enterprise (SRAE) are difficult to measure and, as a result, to diagnose. There are many reasons for this: duties of enterprises to the society are contradictory and change over time, and information about the performance of the duties is lacking. But it is difficult to improve what cannot be measured. Therefore, researchers have made efforts, which have resulted in an acceptable approach to the assessment of SRAE, which allows to take into account the systematisation of the phenomenon and the lack of objective information. According to this approach, the performance of enterprises in the aspect of social responsibility are described by a vector of characteristics that meet different objectives in this area; to obtain a generalised estimate, the vector of characteristics is scalarised; to take into account the hierarchy of tasks in the field of social responsibility, the analytic hierarchy process is used [1; 2]. To reduce the number of characteristics describing SRAE factor analysis is used [3]. Assessments of characteristics of enterprises' performance in the aspect of social responsibility are mostly revealed through expert evaluation [4].

The most common methods of identifying the values of the performance of enterprises in the aspect of social responsibility are the follows:

1) questionnaires of external and internal stakeholders of the analysed enterprises ([5-7]);

2) content analysis of corporate reports, publications and interviews of managers (used, for example, in [5]).

The application of the method of content analysis for measuring SRAE is considered in detail in the study [8].

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The idea of the approach is to count the number of words, sentences or whole articles on the topic of social responsibility in the total volume of publications of the analysed organisation. The method is based on the hypothesis that the number of publications on the topic of social responsibility reflects the importance of this topic for the organisation [9]. The disadvantage of this approach is that the content analysis of corporate reports and publications allows us to draw conclusions only about the published information, and not about the actual activities of the enterprise.

Interviews and questionnaires of external and internal stakeholders of the analysed enterprises were used, for example, in [5-7]. In [5] analysis of determinants of social performance of banks was based on the results of questionnaires and semi-structured interviews with managers of banking institutions. In [6] measuring of effectiveness of corporate social responsibility initiatives in the mining industry was carried out on the basis of surveys of households in mining communities. In [7] for analysing the value of corporate social responsibility for various stakeholders a survey of purchasing / sales representatives and managers was used (because these employees are the most credible to assess relationships with suppliers and customers).

Stakeholder questionnaires are the basis of the reputation index method [4]. The essence of the method is that competent observers (experts) make a rating of firms according to several criteria. For example, a Fortune rating is based on the results of a survey of a company's employees and an expert assessment of corporate culture policy and personnel policy.

The issue of forming methodological support for the questionnaire of internal stakeholders is considered in work [4]. The paper forms a list of characteristics according to which it is recommended to evaluate corporate socially responsible activities (according to the employees of the organisations that were interviewed). But the disadvantage of the study is that the proposed characteristics involve evaluation only with the help of expert judgments, and they allow for different interpretations. For example, the list contains the following characteristics: "The management of our company is primarily concerned with employees' needs and wants"; "The managerial decisions related with the employees are usually fair".

In general, the shortcomings of existing approach to assessing the socially responsible activities of an enterprise through a survey of stakeholders are: high level of intuitiveness and subjectivity; high level of experts' errors due to the complexity of the tasks (questions); high level of generalisation; insufficient validity of criteria of evaluation.

Based on the above, the purpose of this study was to improve the approach to assessing socially responsible activities of enterprises in such a way that the assessment is carried out on the basis of expert assessments of social responsibility requirements and objective data on fulfilment of these requirements at the analysed enterprise.

The purpose involved the following tasks: 1) to develop a procedure for quantitative analysis of the improved version of a goal tree of socially responsible activities of an enterprise, based on the formalisation of the requirements of social responsibility; 2) to take into account the existence of external restrictions on the ability of an enterprise to meet the requirements of social responsibility in the developed procedure; 3) to demonstrate the procedure of quantitative analysis of the improved goal tree of socially responsible activities of an enterprise on the example of the printing industry.

MATERIALS AND METHODS

This paper was based on the definition of socially responsible activities of an enterprise, proposed in [10]. According to this definition, socially responsible activities meet not only the requirements of the law, but also the norms of socially responsible behaviour of enterprises. So it is possible to distinguish socially responsible activity from activity which is not such, using the analysis of observance of social responsibility norms. In fact, compliance with social responsibility norms characterises only the external manifestation of socially responsible activities without taking into account the criteria for decision-making at the enterprise [10]. But in this study, the differences between external and internal manifestations of socially responsible activity were not considered.

Social responsibility norms are formed in each specific period of time under the influence of existing social problems, recommendations of public and expert organisations on measures to support sustainable development, existing agreements within the social partnership and leading business practices. Analysis of information sources showed that descriptions of tasks and norms of social responsibility in various industries could be found in the Environmental, Health, and Safety Guidelines, developed by the International Finance Corporation (IFC). The Guidelines contains examples of good international practice in the industries. In particular, the IFC Environmental, Health, and Safety Guidelines for Printing can be sources for social responsibility norms for printing companies [11]. In addition, tasks and norms of social responsibility can be found in non-financial reporting standards, the current analysis of which is given in [12].

The proposed approach is based on the improved procedure of quantitative analysis of the tree of enterprise's goals, which is supplemented by stages aimed at formalising the norms of social responsibility. In addition, the improved procedure provides for the assessment of existing external restrictions on the ability of enterprises to comply with these norms. The proposed approach is intended for use at the diagnostic stage of the decision-making process for managing results of enterprises' socially responsible activities. The use of the modified goal tree allows: to obtain a general assessment of the level of compliance with social responsibility norms at the enterprise, taking into account specifics of industries and separate enterprises; identify problems in the hierarchy of tasks of the enterprise in the field of social responsibility; identify external limitations on the enterprise's ability to fulfil social responsibility norms; formulate a set of measures aimed at increasing the level of using the enterprise's available opportunities in the field of social responsibility; formulate a set of measures to influence the enterprise's stakeholders in order to weaken external restrictions on the enterprise's capabilities in the field of social responsibility. The procedure for building and quantitative analysis of the modified goal tree is demonstrated on the example of a printing enterprise.

RESULTS AND DISCUSSION

As noted above, one of the shortcomings of existing approach to assessing corporate social responsibility through stakeholder surveys is the high level of expert error due to the complexity of the evaluation procedure. The procedure stipulates that experts must assess the level of compliance by the company with the requirements of social responsibility, although both the requirements and the results of their implementation at the company are poorly formalised. Moreover, experts may have significantly different ideas about the requirements themselves and their implementation at the enterprise.

In order to partially neutralise this problem, it is proposed to divide the process of evaluating the results of an enterprise to meet the requirements of social responsibility into two subprocesses:

1) assessment of the requirements of social responsibility (at the current stage of development of society, equipment and technology);

2) evaluation of the results of an enterprise to meet the identified requirements.

The first sub-process involves the use of expert evaluation.

The second subprocess involves the use of mostly objective data on the activities of the enterprise.

To calculate the generalised assessment of SRAE on the basis of expert assessments of social responsibility requirements and objective data on the results of the enterprise, it is proposed to use the method of a goal tree, which will take into account the hierarchy of SRAE tasks. The rules for building a tree of social responsibility goals are as follows:

1. The upper (first) level of the hierarchy corresponds to the general goal, which is to comply with the norms of socially responsible behaviour of an enterprise.

2. The second level of the hierarchy contains the objectives that correspond to the main aspects of social responsibility defined in ISO 26000 [13]: human rights; labour practices; environment; fair operating practices; consumer issues; community involvement and development.

3. The third and subsequent levels of the hierarchy contain the tasks that must be performed to achieve the goals of the second level.

4. For lower-level tasks, experts set social responsibility norms, formulated as descriptions of good practices that have become widespread in the country and in the world. An example of a fragment of a goal tree for compliance with social responsibility norms of the printing company is shown in Figure 1.

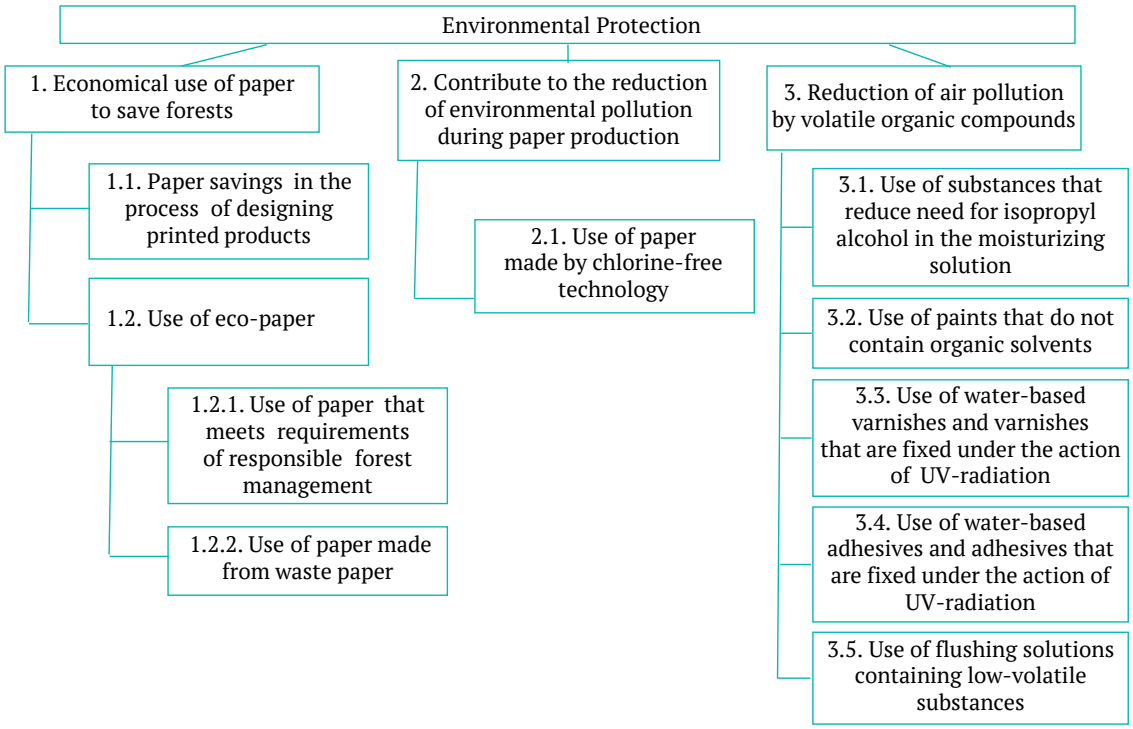

Figure 1. A fragment of a goal tree for compliance with social responsibility in the printing industry

Source: developed by the author based on [11]

The main component of the process of evaluating the socially responsible activities of an enterprise with the help of a goal tree is the procedure of quantitative analysis of the constructed tree. Based on the purpose of the study, it is proposed to supplement the existing procedure of quantitative analysis with steps aimed at formalising social responsibility norms. Then the proposed procedure for quantitative analysis of a goal tree for compliance with social responsibility norms will contain the following steps:

1. Stage of formation of goals and tasks in the aspect of social responsibility.

1.1. For all goals, tasks and norms located in the hierarchy of the goal tree, experts assign coefficients of relative weight $V_i \hat{I} [0,1]$, $i \in I$. The sum of weighting coefficients for all elements of the goal tree, which are subordinate to one element of a higher level, should be equal to one.

1.2. For each social responsibility norm on the goal tree, experts should formalise the rule of calculating the

level of implementation of this norm on the basis of indicators of the enterprise performance that can be measured.

A typical formula for calculating the level of fulfilment of the norm is the following (for stimulant indicators):

$$D_i = \frac{F_i}{N_i}, i \in I^N, \quad (1)$$

where D_i – the level of fulfilment of the social responsibility norm i; N_i – normative value of the indicator, which, according to experts, characterises the activities of the enterprise in the aspect of fulfilment of the social responsibility norm i; F_i – the actual value of this indicator; I^N a subset of the goal tree elements, which describe social responsibility norms.

Examples of rules for calculating the level of fulfilment of social responsibility norms in the printing industry are given in Table. 1. Note that the rules for calculating the level of compliance can be built on the use of linguistic variables and fuzzy inference.

Table 1. Examples of the rules for calculating the implementation of social responsibility norms in the printing industry

Norms of socially responsible behaviour (from the goal tree shown in Figure 1)	Relevant indicators of the enterprise's performance	Rules for calculating the actual level of compliance with norms
1.1. Paper savings in the process of designing printed products	F_{11} – percentage of printed products with economic design	$D_{11}=F_{11}/N_{11}$, where N_{11} – normative percentage of printed products with economic design
1.2.1. Use of paper that meets requirements of responsible forest management	F_{121} – percentage of paper with the certificate of responsible forest management in the total amount of used paper from primary raw materials	$D_{121}=F_{121}/N_{121}$, where N_{121} – normative percentage of paper with the certificate of responsible forest management
1.2.2. Use of paper made from waste paper	F_{122} – percentage of paper made from waste paper in the total amount of paper used	$D_{122}=F_{122}/N_{122}$, where N_{122} – normative percentage of paper made from waste paper

Source: developed by the author

1.3. Experts set normative values N_i, $i \in I^N$ for all social responsibility norms contained in the goal tree. These values describe the requirements that society imposes on enterprises at the current stage of development of the industry.

2. The stage of determining the actual level of achievement of goals.

2.1. Accounting of objective data $\{F_i | i \in I^N\}$ is carried out, and on this basis the level of performance of each norm of social responsibility is calculated according to the formula (1).

2.2. The degree of achievement of each element of the goal tree is calculated on the basis of the values of weighting coefficients $\{V_i | i \in I\}$ and estimates of the level of compliance with social responsibility norms $\{D_i | i \in I^N\}$:

$$D_i = \sum_{j \in J^i} V_j \cdot D_j, i \in \setminus I^N, \quad (2)$$

where J^i – the set of numbers of the goal tree elements, which are subordinate to the element i.

3. Stage of analysis of external constraints.

An important task of the analysis of socially responsible activities of an enterprise is to assess the opportunities of the enterprise to comply with various norms of social responsibility. Such opportunities are partly determined by external conditions and are associated with certain decisions by different groups of external stakeholders. For example, a necessary condition for reducing the use of isopropyl alcohol in the printing process is the availability of substitutes for this substance in the market of printing expendable materials. And the amount of recycled paper used in the printing process depends on the corresponding demand from consumers. Therefore, for each norm of social responsibility, experts must assess the maximum possible level of implementation of this norm under existing external constraints.

Thus, for each social responsibility norm contained in the built goal tree experts need to do the following:

a) to identify a set of parameters of external environment that affect the ability of the enterprise to implement the analysed norm;

b) to build a function of the dependence of the level of the analysed norm implementation on the value of the identified parameters of external environment:

$$D_i^m = f(Z_i), i \in I^N, \quad (3)$$

where D_i^m – the maximum possible level of compliance by the enterprise with the norm i, subject to existing external constraints; Z_i – vector of parameters of external environment that affect the ability of the enterprise to comply with norm i;

c) to assess the factual values of the identified parameters of external environment Z_i;

d) calculate the maximum possible level of implementation of the analysed norm for the available values of parameters of external environment.

On the basis of the performed calculations the maximum possible level of achievement of the general goal of the enterprise in the aspect of social responsibility on condition of available values of parameters of external environment can be defined.

The analysis will allow to adjust the enterprise's goals in the aspect of social responsibility by coordinating them with the available opportunities. It will also allow to formulate tasks on the impact on the external environment of the enterprise in order to reduce its negative impact on the ability of the enterprise in the field of social responsibility.

Examples of functions of dependence of the level of compliance with social responsibility norms on the parameters of the external environment in the printing industry are given in Table 2.

Table 2. Examples of functions of dependence of the level of implementation of social responsibility norms on the parameters of the external environment in the printing industry

Norms of socially responsible behaviour (from the goal tree shown in Figure 1)	External condition	Rules for calculating the maximum possible level of compliance with the norm depending on parameters of the external environment
1.1. Paper savings in the process of designing printed products	Consent of customers of printed products for eco-design	$D_{11}^{m}=Z_{11}/N_{11}$, where D_{11}^{m}– the maximum possible level of compliance with the analysed norm on condition of existing attitude of printed products customers to eco-design; Z_{11} – expert assessment of the percentage of printed products with eco-design, to which customers may agree
1.2.1. Use of paper that meets requirements of responsible forest management	Consent of printed products customers to the use of paper with a certificate of responsible forest management	$D_{121}^{m}=Z_{121}/N_{121}$, where D_{121}^{m} – the maximum possible level of compliance with the analysed norm on condition of existing attitude of printed products customers to the use of paper with a certificate of responsible forest management; where Z_{121} – expert assessment of the percentage of paper with the certificate of responsible forest management in the total amount of used paper from primary raw materials, to which customers may agree
1.2.2. Use of paper made from waste paper	Consent of printed products customers to the use of paper made from waste paper	$D_{122}^{m}=Z_{122}/N_{122}$, where D_{122}^{m} – the maximum possible level of compliance with the analysed norm on condition of existing attitude of printed products customers to the use of paper made from waste paper; where Z_{122} – expert assessment of the percentage of paper made from waste paper in the total amount of used paper, to which customers may agree

Source: developed by the author

Let's compare the approach proposed in this work with other approaches to the evaluation of SRAE. In approaches for SRAE evaluation the following features differ: a list of social responsibility tasks that are taken into account; a list of characteristics that describe the results of these tasks [14]; objectivity of the values of the characteristics (objective data or expert opinions); methods of converting a vector of results into a scalar complex indicator (according to [15], one of the main obstacles in constructing a generalised scalar indicator is the problem of weighing partial results).

Let's make a comparison according to the specified characteristics:

1. Comparison of social responsibility tasks that are taken into account.

Tasks of social responsibility, which are taken into account when evaluating SRAE, characterise the responsibility of business to different groups of stakeholders (to one group or several). The set of tasks is mostly formed by researchers themselves. Thus, in [16], the image of corporate social responsibility is measured from the point of view of customers, in [17] – from the point of view of employees. In [18] corporate social responsibility practices are evaluated in a large number of directions, namely: from the perspective of shareholders, customers, employees, suppliers, other stakeholders, as well as from the perspective of ethics, environment, jurisprudence, human rights and society. In the developed approach, it is proposed to use tasks that correspond to the main topics and problems of social responsibility, which are given in the ISO 26000 Standard [13] and determined as a result of the work of experts from more than 90 countries and 40 international and regional organisations.

2. Comparison of methods of calculating the integral assessment of the SRAE.

In the proposed approach, the integrated assessment of SRAE is calculated on the bases of hierarchy of tasks, taking into account the assessment of the importance of each task. Coefficients of importance of the tasks located on the goal tree can be calculated using the Analytic Hierarchy Process, which involves a pairwise comparison of the hierarchy elements. The Analytic Hierarchy Process is a common method of determining importance coefficients for criteria for evaluating alternatives. This method is used to calculate the integrated assessment of SRAE, for example, in [19; 20]. The difference between the calculation of the integrated assessment of the SRAE using the modified goal tree is that the calculation is based on a comparison of the actual state of affairs at the enterprise with the norms of social responsibility.

3. Comparison by objectivity of the values of the used characteristics.

In many works the evaluation of SRAE is carried out on the basis of a questionnaire method, which is used to identify the judgments of external and internal stakeholders. So, for example, in studies [4; 17], the assessment of socially responsible activities of enterprises and organisations reflects the perception of SRAE by employees of the analysed enterprises and organisations. The approach proposed in this article involves assessing the level of compliance with social responsibility norms based on objective data on the results of enterprise activity. Expert judgments are used at the stage of formalisation of social responsibility norms, as well as at the stage of formalisation of the dependence of the enterprise's capability to fulfil these norms on the parameters of the external and internal environment.

The advantage of the proposed approach is that it allows to take into account:

1. The hierarchy of tasks of the enterprise in the field of social responsibility and the relative importance of each task. This allows not only to obtain a general assessment of SRAE, but also to evaluate the results of separate areas of social responsibility implementation at the enterprise. The detailing of tasks allows to take into account specifics of industries and separate enterprises.

2. Expert assessments of norms of social responsibility. Taking into account the norms of social responsibility allows to compare social results of the enterprise's activity with the actual requirements that society places on business.

3. Expert assessments of the enterprise's capabilities to fulfil the norms of social responsibility under existing restrictions imposed by the external environment. Taking into account the enterprise's capabilities to fulfil the norms of social responsibility is important for correct setting the social goals of the enterprise's activities. Identifying constraints imposed by the external environment allows to set tasks for eliminating these constraints (in particular, to plan the impact on stakeholders whose decisions limit the enterprise's ability to fulfil the norms of social responsibility).

4. Objective data on the results of the enterprise's activities. The use of objective data makes it possible to reduce the level of subjectivity of the obtained evaluation of the SRAE.

The disadvantage of the proposed approach is that the tasks set before experts remain complex and require experts to have in-depth knowledge in the field of production technologies and modern social responsibility practices in the analysed sectors of material and non-material production.

CONCLUSION

The paper proposes an approach to expert evaluation of socially responsible activities of enterprises by applying a modified goal tree, which contains expert evaluations of norms of social responsibility and objective data on compliance with these norms at the analysed enterprise. Compared to traditional approaches the proposed approach simplifies the task offered to experts. Experts do not estimate the level of socially responsible activities of the enterprise, but formalise the existing norms of socially responsible behaviour. Such a simplification will help increase the accuracy of assessing the level of implementation of social responsibility at enterprises.

Assessment of the level of fulfilment of social responsibility norms in the study was carried out using the goal tree method, which is the basis of the analytic hierarchy process. A goal tree is a structured set of goals of the organisation, built on a hierarchical principle. Quantitative analysis of a goal tree is aimed at assessing the level of achievement of the overall goal and the goals of each level. In order to make the goal tree method suitable for assessing socially responsible activities of an enterprise, its modification was carried out. The modified goal tree allows to take into account: norms of social responsibility; the level of implementation of these norms at the enterprise; external restrictions on the enterprise's capability to comply with these norms. Thus, with the help of the proposed approach, it is possible not only to assess the level of implementation of social responsibility at the enterprise, but also to carry out an analysis of internal problems and external restrictions in the sphere of socially responsible activities.

The developed approach is demonstrated on the example of the printing industry. But the considered example is fragmentary. The construction and quantitative analysis of a complete goal tree of socially responsible activities of an enterprise needs to be considered in further research.

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Експертне оцінювання соціально відповідальної діяльності підприємств за допомогою метода дерева цілей на прикладі поліграфічної галузі

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Анотація. Соціально відповідальна діяльність підприємства погано піддається вимірюванню і, як наслідок, діагностиці. Основним методом оцінювання результатів діяльності підприємств в аспекті соціальної відповідальності є експертне оцінювання. Недоліком цього методу є високий рівень суб'єктивності та інтуїтивності. Зазначена актуальна проблема визначила мету дослідження – розробити такий підхід до оцінювання результатів діяльності підприємств в аспекті соціальної відповідальності, який би дозволив залучати експертів тільки на стадії формалізації норм соціальної відповідальності, а фактичний рівень виконання цих норм розраховувати не експертним шляхом, а на основі об'єктивних даних про діяльність підприємства. Для виконання поставленої мети у роботі розроблено підхід до оцінювання соціально відповідальної діяльності підприємства на основі застосування метода дерева цілей. Запропоновано процедуру побудови та кількісного аналізу дерева цілей соціальної відповідальності, яка передбачає врахування: 1) експертних оцінок норм соціальної відповідальності; 2) об'єктивних даних щодо дотримання норм соціальної відповідальності на аналізованому підприємстві; 3) експертних оцінок спроможностей підприємства щодо виконання цих норм; 4) значень параметрів зовнішнього середовища, які впливають на ці спроможності. Процедуру побудови та кількісного аналізу дерева цілей соціальної відповідальності продемонстровано на прикладі поліграфічної галузі. Запропонований підхід дозволяє оцінити соціальні результати діяльності підприємства, здійснити аналіз «вузьких місць» і зовнішніх обмежень в аспекті соціальної відповідальності, а також сформулювати завдання щодо послаблення зовнішніх обмежень на спроможності підприємства щодо виконання норм соціальної відповідальності. Це сприятиме підвищенню ефективності процесу прийняття рішень з управління результатами соціально відповідальної діяльності підприємства

Ключові слова: результати; зовнішні обмеження; дерево цілей; аналіз спроможностей

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