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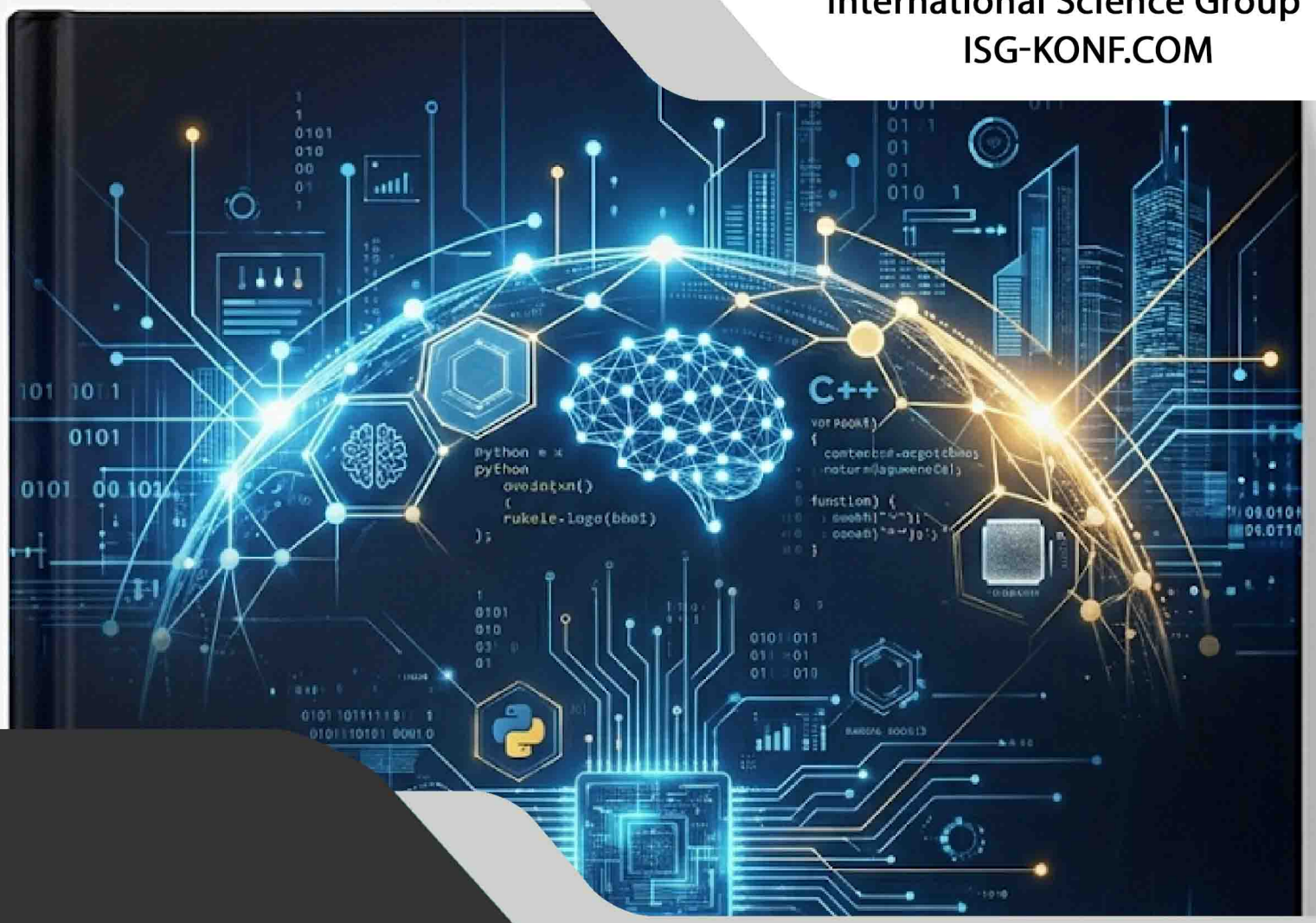

TECHNICAL AND COMPUTER SCIENCES: MODERN CHALLENGES, INNOVATIVE SOLUTIONS AT THE CROSSROADS OF DISCIPLINES AND MULTIDISCIPLINARY ANALYSIS

Collective monograph

ISBN 979-8-90214-595-0
DOI 10.46299/ISG.2026.MONO.TECH.1
BOSTON(USA)-2026

ISBN – 979-8-90214-595-0
DOI – 10.46299/ISG.2026.MONO.TECH.1

Technical and computer sciences: modern challenges, innovative solutions at the crossroads of disciplines and multidisciplinary analysis

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Boston 2026

Library of Congress Cataloging-in-Publication Data

ISBN – 979-8-90214-595-0
DOI – 10.46299/ISG.2026.MONO.TECH.1

Authors – Smirnova O., Votinov M., Ajdid Y., Klimko Y., Koshchii I., Mospan D., Khvalin D., Грабовський О., Кисельова О., Зіангірова Л., Жеребцова Л., Кузнєцова Л., Stoliarova T., Третяк В., Воронін В., Коломійцев О., Кривчун В., Крамар О., Andrushchak I., Rozum R., Bobko O., Romanyuk O., Prunenko D., Dolya O.

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Published by Primedia eLaunch
https://primediaelaunch.com/

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Collection of scientific articles published is the scientific and practical publication, which contains scientific articles of students, graduate students, Candidates and Doctors of Sciences, research workers and practitioners from Europe and Ukraine. The articles contain the study, reflecting the processes and changes in the structure of modern science.

The recommended citation for this publication is:
Technical and computer sciences: modern challenges, innovative solutions at the crossroads of disciplines and multidisciplinary analysis: collective monograph / Smirnova O., Votinov M., Ajdid Y. – etc. – International Science Group. – Boston : Primedia eLaunch, 2026. 403 p. Available at : DOI – 10.46299/ ISG.2026.MONO.TECH.1

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SECTION 1. ARCHITECTURE AND URBAN PLANNING

DOI: 10.46299/ISG.2026.MONO.TECH.1.1.1

1.1 Methods of architectural forming modern educational institutions

In recent years, modern educational institutions were almost never created in the territory of the CIS, because they did not meet the proposed social requirements. Currently, the social situation is changing. People with high incomes appear. This encourages the formation of modern educational institutions, which are currently being built on an empirical level, mainly in the near abroad. In this regard, it is necessary to analyze their design experience (mainly objects from far abroad) and develop relevant recommendations. The formation of a person as a free, independent, and developed individual begins from birth. But the lion's share falls precisely on the period of study in schools. In addition to mental and physical development, children form spiritually. They develop their communication skills, imagination, thinking, sense of taste and style, and get to know the world through the surrounding environment. That's why it is so important to pay special attention to basic requirements, norms and rules when designing schools. After all, safety, health, and development are the main things in raising a child. Only in a comfortable and pleasant environment will the child be able to fully reveal all his strengths and talents.

The process of architectural formation of educational institutions puts forward special requirements for their planning and volume-spatial composition, which creates conditions for effective organization of the educational process, aesthetic, and physical development of students. The school of the third millennium should become the architectural environment where the harmonious personality of a child with a high level of education is formed based on modern technologies and the latest material and technical base. Examples of interesting architectural and landscape solutions of modern educational institutions, already implemented in the world, were analyzed according to identified criteria.

So interesting from an architectural point of view is the project of the school “The Nueva School”, California, USA (Fig. 1). This is an experimental school in which elements of landscape design relate to the school curriculum, creating open ecological spaces for children. The building integrates children into the environment at different levels. The ecological spaces of this school help teachers to carry out a wider interaction between science, nature, art, and society. The school has green roofs with California meadows recreated on them.

Figure 1. The school “The Nueva School”, California, USA. Source of the figure [1]

Another good example is the “Gstaad International School”, Montagola, Switzerland (Fig. 2). Unlike the previous school, this one looks like an ancient castle or someone's mountain residence. But this is a private school located in the mountains of Switzerland. An excellent example of how classical forms can be used in the architecture of modern educational institutions.

Figure 2. “Gstaad International School”, Switzerland. Source of the figure [2]

"Bobigny School" in the suburbs of Paris (France) is an example of the location of an educational institution in a dense urban development (Fig. 3). It is part of a large complex. Therefore, the main goal was to make the children as comfortable as possible and feel protected. This was achieved thanks to the elliptical shape of the building and the inner courtyards built around it. The walls of the building are lined with wood panels of different shades arranged in a mosaic pattern, which makes the building a prominent landmark in the area.

Figure 3. "Bobigny School", Paris, France. Source of the figure [3]

Another good example is the school of Design and Arts in Singapore (Fig. 4). The five-story building covers an area of 18,000 m^2 and is in a park with a unique natural environment. Spatial form, the building shell, is a kind of frame for the internal environment and its main architectural and expressive means. It is a plastic roof of a building covered with a lawn. A sinuous green roof frames the interior space, creating an oasis at the center of the complex.

Figure 4. School of Design and Arts in Singapore. Source of the figure [4]

Apart from its imposing and grandiose visual impact, a green roof also acts as a thermal insulator, lowering the temperature of the roof and creating a microclimate in the buildings, which is necessary for this tropical climate. The shape (the shell) predetermines the characteristic qualities of a limited space – absolute size, geometric appearance, the peculiar dynamism of the building and the degree of its isolation. The accent of the entire educational complex is a courtyard with a decorative pool and special walking alleys with plants.

It serves as an atrium and is clearly visible from all areas of the building. The glass façade absorbs the building's solar and thermal load while providing natural daylight to the creative spaces. Due to the glass walls, a visual flow of the internal spaces of the premises, as well as the landscape of the complex itself and the natural environment, is ensured. The line between the building's green roof and the surrounding landscape is blurred. The building's green roof also helps collect enough rainwater to meet the building's own irrigation needs. In addition, glass walls provide natural light into classrooms and studios, resulting in significant energy savings. The rooms, varying in shape and size, are made of natural materials and have a neutral palette, and include elements of flora and phytodesign.

At the same time, the architecture of the buildings of illumination began to gain momentum and align with the main current architectural directions. So, today's schools, in addition to the initial function, also develop an aesthetic one, which instills in children even from childhood a sense of beauty and relish.

The main trends in everyday schools are:

– closeness to nature, selection of natural colors and materials;

– plenty of light and space;

– non-standard forms in the plans and unification of spaces;

– a selection of bright accent colors.

Thus, the changing architecture also changes the approach to the education and training of children. For example, the use of great studio offices, where there are children from different age-old groups, allows the child to show greater

communicativeness, the diversity of forms does not express such rage and stress as standard straightforward in terms of class and gives the child more freedom to express herself.

The use of natural motifs and materials in turn soothes and relaxes. In the natural environment, the student feels comfortable, and unconsciously gets acquainted with nature, its textures, and colors. However, in addition to such calm colors, bright accent colors are also used. With their harmonious and correct use, colors will not irritate and irritate the eye, but on the contrary, stimulate mental, analytical, and imaginative activity. Changing space in general also has a positive effect on the well-being and health of the child. Now classrooms are not just standard rooms that include a minimum of space and light, which inevitably leads to stress and even depression, they are moderately large, comfortable spaces with a lot of natural light, which gives the child a sense of freedom and peace.

An interesting example of a modern solution to the architecture of educational institutions is the Walden Dos school (Fig. 5).

Figure 5. Walden Dos school (interior and exterior). Source of the figure [5]

The location of the school is in the north-west of Mexico City. The project is based on the renovation, restoration and expansion of an existing school that required a new architectural design to match the educational program of the new owner. This became a great opportunity to develop a modern design of the school, providing a new image considering the complexities of its location.

Children fill this space. They are in courtyards, halls, auditoriums, and gardens. The planning structure of the object combines existing spaces with new ones. These spaces are constantly saturated with natural light. This allows them to transform during

the day and create new images. Such spaces replace dark corridors, which have now turned into cozy gardens with wonderful views. A constant visual connection between the inner and outer courtyard gives users a sense of security. It is necessary for the proper functioning of any school. Most of the classrooms are designed with a direct connection to the garden in the courtyard. This made it possible to spend active rest in any class and maintain a connection with nature. An important element in the design was the use of building materials with a low level of processing. The selected palette of colors is simple, which can be seen in the natural environment – wood, stone, water, vegetation, and light. They replace the classic bright and pastel colors that are in most schools.

Another modern example is the Liyuan School, located in the center of the city of Wuxi, China (Fig. 6). The building is divided into two parts. One on the south and one on the north side of the river. The campus has an innovative organization of space, which is divided into six buildings with different functions. The main connection between the southern and northern zones is a ribbon-shaped corridor at the level of the second floor. This corridor visually connects two separate areas and forms the plan of the school.

Figure 6. Liyuan School, Wuxi, China. Source of the figure [6]

In several parts of the project, space changes according to the dynamics of the corridor. The facade pattern resembles water waves. Its smoothness and dynamism create a relaxing atmosphere. The central courtyard, which is formed along the corridor, breaks the traditional school plan, creating various landscapes. The reading areas of the library and the lecture hall are irradiated by sunlight coming through several roof windows. The result is a comfortable indoor environment. The circular

plaza connecting the library to the central courtyard is an innovative type of public space for traditional Chinese architecture.

The next example is the Jean Moulin School (Fig. 7). The city of Revin is in the meanders of the Meuse River, surrounded by forest, steep hills and gentle slopes. Jean Moulin School was built at the dawn of the 60s. It was designed in an orthogonal configuration of three levels, according to the modern style, in the era of rationalism. Half a century later, the aging of the building and equipment necessitated their reconstruction. Therefore, in 2007, a competition for the reconstruction of the school was held in the region. The goal was to demolish and rebuild the entire school complex. Gradual implementation of the works was essential to have a limited impact on school activities.

Figure 7. Jean Moulin School. Source of the figure [7]

As a result, the analysis of practical experience revealed many architectural methods of formation, depending on the style of building, the character of its integration with surroundings, etc. Based on the analysis of the design of educational institutions, factors influencing their formation were determined. These are the following influencing factors: natural and geographical factors, socio-demographic factors, constructive factors, factors ensuring safety, factors of inclusivity, environmental factors, economic factors, aesthetic factors.

The development of volume-planning solutions of school institutions is the first stage of their design. It is based on comprehensive consideration of multifaceted

requirements – functional, physical, and technical, constructive, architectural-artistic, and economic. The formation of volume-planning decisions of buildings is determined by the following main factors:

• the functional process and the composition of premises established on its basis, geometric parameters, requirements for their grouping, interconnection with the conditions of unification of planning and structural elements;

• urban planning and natural climatic conditions, including features of the construction site, its relief surrounding the building, as well as landscape and other characteristics of the area;

• structural features of the designed building, related to the size of spans, height and other geometric parameters, material of load-bearing and enclosing structures;

• architectural and artistic tasks in connection with the social meaning and significance of the school building in the building ensemble;

In tasks for the design of school buildings, the composition of working and service premises, their capacity or throughput, areas, heights and proposed functional and physical and technical requirements are given. Their parameters are calculated based on established volumetric planning standards.

In the buildings of school institutions, the following functional groups of premises are provided: classes and classrooms; educational and industrial; physical culture and sports; library; club and entertainment; nutrition; medical care; administrative and service; auxiliary (lobby, wardrobes, recreation, bathrooms, pantries).

In addition to the main groups of premises, other premises may be included in the functional structure of the educational institution in accordance with technological requirements. The list and areas of the premises are determined by the design task, considering the number of students, the staff schedule of administrative teaching and support staff, curricula, and the peculiarities of the organization of the educational process.

Buildings of secondary schools must be designed considering the following functional requirements:

a) educational premises are grouped into educational sections according to age and educational and technological characteristics:

• educational sections for 1st grades (six-, seven-year-olds), which combine the premises of no more than two parallel classes, with recreation, dressing rooms and sanitary units;

• educational sections of the 2nd-4th grades consisting of no more than six classrooms, a workshop for labor training, a universal room for extended day groups, dressing rooms, recreational rooms and sanitary units;

• educational sections of grades 5-12, which include universal and specialized study rooms, laboratory rooms, and recreational facilities; it is allowed to place sanitary units outside the educational sections (in two-story buildings, sanitary units can be located on one of the floors in a concentrated manner);

b) educational sections of 1st, 2nd-4th grades must be separate and inaccessible to students of other age groups;

c) educational sections and general school groups of premises can be in a general compact building of a centralized type or in interconnected functional blocks.

In specialized schools with individual educational technology, a different construction of the functional and planning structure of the house is allowed, which is established by the design task.

Physical culture and sports halls should be placed no higher than the second floor, it is not allowed to place them above educational premises, provide for passages to the physical culture and sports halls through classroom and sleeping groups of rooms, as well as passages to changing rooms and sanitary and domestic premises through the physical culture and sports hall.

In the conditions of reconstruction, physical culture and sports halls are allowed to be placed above educational premises, provided that appropriate measures are taken to protect against noise and vibration in accordance with the requirements.

In the conditions of dense buildings, it is allowed to place physical culture and sports halls one above the other. Buildings should be no more than 3 stories high (in large and the largest cities, except for areas with a seismicity of 7-8 points, the construction of 4-story school buildings is allowed).

An increase in the number of floors of buildings is allowed in the case of urban planning justification.

The height of the floors of the educational premises is set because the height of the educational premises from the floor to the ceiling should be taken at least 3.3 m. In the conditions of reconstruction, it is allowed to take the height of the educational premises from the floor to the ceiling of 3 m.

The height of the floors on which there are auditoriums with a capacity of 50 seats and more, recreation halls, computer rooms, laboratories, and workshops with large-sized equipment, as well as assembly halls and physical culture and sports facilities are accepted according to technological, hygienic, and architectural and compositional requirements, but not less than 4.2 m.

In the underground floors, it is allowed to place bookstores, training shooting ranges, storerooms, in addition to premises for storing flammable and combustible liquids and materials, engineering and technical premises.

Areas of auxiliary premises at educational and production workshops are accepted in accordance with the design task.

For health purposes in educational institutions, it is recommended to provide a gym or an area with exercise equipment in a physical culture and sports hall at the rate of at least 6 m^2 per person in the hall (at the expense of the total area of physical culture and sports halls).

When designing club and performance spaces of educational institutions, it is necessary to consider the requirements of building regulations.

The capacity of assembly halls in school institutions should be at least:

– in primary schools (1st-4th grades) – 1/2 of the contingent of students;

– in general educational institutions of the II-III degrees (grades 5-12) and technical vocational schools – 1/3 of the contingent of students (in rural settlements – 1/2 of the contingent of students).

The planning and equipment of the premises of the assembly hall should ensure the possibility of holding conferences, meetings, concerts, showing films and other forms of cultural, educational and club work.

Canteens and buffets should be provided in all educational institutions. The requirements for their design are determined by the design task considering construction requirements. The vestibule, cloakroom and sanitary units are calculated for the number of students, administrative and teaching staff and service personnel located in the building. Changing rooms for students are arranged separately from changing rooms for teachers and staff.

When developing volume-planning solutions for building educational institutions for construction in different natural and climatic regions, it is necessary to consider their features in accordance with building regulations. The buildings of secondary schools are located no closer than 25 m from the red line. The distance from the boundary of school plots to the walls of residential buildings with entrances and windows is accepted to be at least 10 m, from school buildings to residential and public buildings and structures – in accordance with the norms of insolation, natural lighting, and noise protection.

A protective strip of land (trees, bushes, lawn) with a width of at least 1.5 m should be provided along the perimeter of the land plot, and at least 3 m on the side of the streets. Tall trees should be planted at a distance of at least 10 m from the walls with windows of educational premises, and bushes at a distance of at least 5 m. The land plot is divided into the following functional zones: educational; educational and industrial; educational and research; physical culture and research; physical education and sports; recreation; agricultural (for schools in rural areas); residential.

The physical culture and sports zone should be placed next to the educational area, but not from the side of the windows of the primary school rooms. Playgrounds

for playing with a ball and throwing sports equipment should be placed at a distance of at least 25 m from the windows of educational and educational and auxiliary premises of buildings, and playgrounds for other types of physical education at a distance of at least 10 m. Sports playgrounds must have a hard surface. It is forbidden to hold classes on wet surfaces that have bumps and potholes. It is better to place sports grounds lengthwise from north to south. Physical culture grounds must be fenced off from each other with green plantings.

An effective means of increasing the efficiency of the school network is the use of multifunctional types of school buildings, which are formed based on interdepartmental integration of the institution of general secondary education and other institutions of cultural and household services.

The effectiveness of integration is confirmed by the domestic and foreign experience of the operation of multifunctional public buildings. The use of multifunctional types of school buildings creates prerequisites for the functioning of the institution of general secondary education as a cultural and educational institution, contributes to the growth of its social role. The generalization of the foreign practice of designing and building schools made it possible to identify methods of forming buildings of general secondary education institutions, which are aimed at increasing the efficiency of their operation:

– inclusion of internal courtyards in spatial and planning decisions of schools with the possibility of setting up an open seasonal garden or a covered winter garden, to create an additional safe recreational learning space;

– the use of a frame structural system, which makes it possible to re-plan buildings;

– arrangement of overhead light for additional lighting of corridors and recreation areas. Maximum use of external wall surfaces with window openings for educational spaces, which will allow creating more compact planning solutions for school buildings due to partial or complete exclusion of side lighting in corridors and recreation areas;

– arrangement in school buildings of an assembly hall with the possibility of lifting seats for spectators, which can be used not only for school-wide ceremonial events, but also as lecture halls and cinema halls for showing educational films;

– unification of educational premises of the same functional purpose into one module. So, for example, the art module forms a hall for spectators, halls for music lessons, premises of a school theater; module of applied technologies (cabinets of various areas of creative activity, including fine arts, sculpting, design, etc.); natural science module (physics, chemistry, biology offices, laboratories, experimental sites); sports module (several sports halls, including a hall for team games, a gym, a fitness hall, changing rooms, showers, coaching rooms); administrative module; library-media module (media center); the dining room module (often interlocked with the atrium or dining hall modules of the dining room); module of technical premises;

– lighting with second light, for example, through the space of the atrium, in combination with artificial lighting, the premises of laboratories, teachers', computer classrooms, media library.

Each educational institution should have a distinct architectural and spatial appearance, decided within the framework of the project idea. Often this idea boils down to the organization of a comfortable architectural environment in the structure of interior and exterior spaces. The task of creating and preserving a small personal space for each student comes to the fore. This reflects interests, needs of students, and contributes to successful harmonious development.

There is art and aesthetics in the architectural and landscape formation of the territory of any educational institution (Fig. 8). Architecture and landscape architecture is an art in which there is composition, artistic techniques, an idea, etc. There are three main methods of planning the territories near modern educational institutions: regular, landscape, mixed. All these three methods can be used to create the landscape of the territory of the modern educational institution.

The architecture and exterior of the educational institution can be different.

These can be clear geometric shapes or smooth irrational outlines. The educational institution can stand out among the buildings or completely merge with it. It can have a bright exterior or, on the contrary, restrained colors. In current world, the landscape and architecture of schools are closely related to the curriculum or function of the school. This gives rise to unusual and truly unique solutions.

As a result of the analysis, the following main methods of forming modern educational institutions were determined:

– display of the historical and cultural context location of school building,

– creation of unique image of school environment by means of design,

– bringing the elements and symbols of nature to the space of the school,

– simulation of emotional state using sculpture compositions,

– adaptation of the object to changing requirements;

– formation of a barrier-free architectural environment and ensuring safety in the structure of the object's interior and exterior spaces;

– modern shaping of the architectural volume of the building due to the development of its structures;

– rational functional filling of the object;

– provision of high-quality indicators of individual personal and educational space.

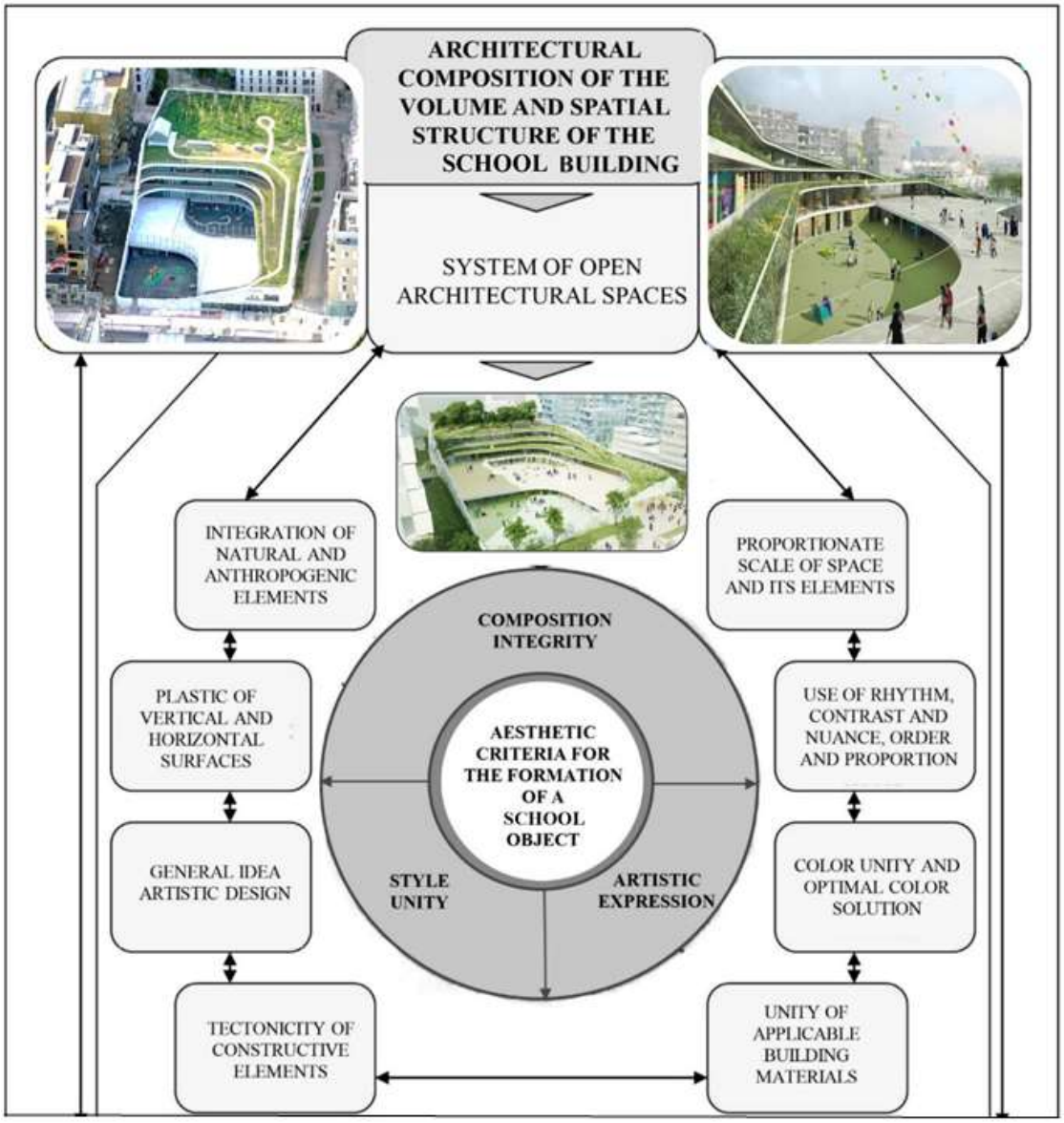


Figure 8. Aesthetic features of educational institutions. Source of the figure [8]

Therefore, to design modern educational institutions, it is worth using a variety of compositional and artistic means – greening of surfaces of buildings, the use of kinetic facades and their complex configuration. The creation of educational institutions with the optimal organization of their volume-planning and architectural-environmental characteristics will allow them to best meet modern design requirements. This approach will create a comfortable architectural environment with a system of various design spaces. This will have a positive effect on the consciousness of students. It will improve aesthetic, ecological characteristics of a building and the urban environment and ensure their development in the future.

SECTION 2. CHEMISTRY

DOI: 10.46299/ISG.2026.MONO.TECH.1.2.1

2.1 A new approach to the synthesis of nitrogen-containing heterocycles

2.1.1. Synthesis of tetrahydropyrimidines using carboxylic acid derivatives as the methylenecarbonyl component

2.1.1.1. Introduction

At the end of the 19th century, the synthesis of 3,4-dihydropyrimidin-2-(1H)-ones of the general formula (1) was carried out by the condensation method of an aromatic aldehyde, urea and acetoacetic ester [9] (Fig. 1).

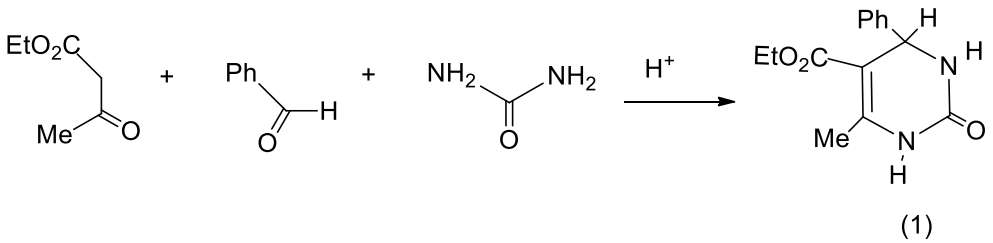


Fig. 1. Synthesis of 3,4-dihydropyrimidin-2-(1H)-ones of general formula (1) by the condensation method of aromatic aldehyde, urea and acetoacetic ester [9].

This reaction is currently undergoing a new stage of development. It was found that the condensation of acetoacetic ester with urea and benzaldehyde produces 6-methyl-4-phenyl-2-oxo-1,2,3,4-tetrahydropyrimidine ethylcarboxylate (1). An identical product can be obtained: a) by the interaction of benzaldehyde with β-carbamidocrotone ester, b) by the reaction of benzylidenediureid with acetoacetic ester, c) by the condensation of α-benzalacetoacetate with urea. These counter-synthesises have unambiguously proven the structure of substance (1).

The next article devoted to this cyclocondensation was published only in 1929 [10]. In the early 1930s, attention was paid to this reaction by Folkes, Hartwood and Johnson [11]. They proposed a modified method for its implementation, thanks to which it was possible to expand the range of reagents and increase the yields of products. In the

following years, by the end of the 1930s, only about a dozen publications on this topic were published. With the development of pharmaceutical chemistry, interest in tetrahydropyrimidine derivatives began to grow. Reviews were published [12-14]. The number of articles since the early 1970s has reached over a hundred.

The fact that the reaction is three-component makes it possible to vary the structure of its products. Thus, as methylenecarbonyl components, derivatives of β-ketocarboxylic acids, β-diketones, α-nitro-, α-aryl- and some α-heteryl ketones and aldehydes were used. As aldehydes, aromatic and heteroaromatic, some aliphatic. Substituted and unsubstituted ureas, thioureas, and guanidines were introduced into the reaction.

The aim of this work was to obtain and study the products of the heterocyclization reaction using carboxy derivatives of pyruvic acid as methylenecarbonyl components.

2.1.1.2. Literature Review

2.1.1.2.1. Physiological Activity of Condensation Products

Tetrahydropyrimidines (THPs) have a wide range of physiological activities. In the 1930s, their simplest representatives, for example (2a), were patented as insecticides [15]. Later, an effective antiviral drug, nitracin (3a), was discovered [16]. Tetrahydropyrimidines have shown themselves as antitumor agents [17, 18].

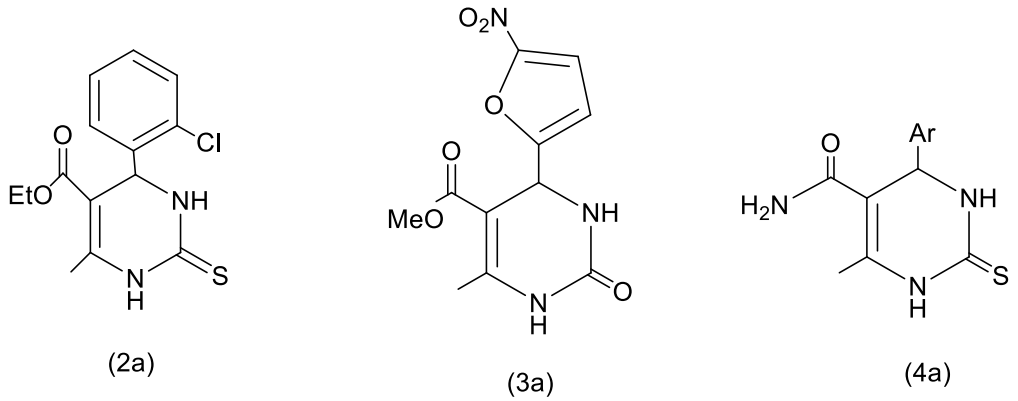


Fig. 2. Tetrahydropyrimidines (THPs) that have physiological activity [15-19].

Compounds of type (4a) have antipyretic properties and are anticoagulants [19] (Fig. 2).

However, the greatest interest in THPs is as antihypertensive agents, for example, nifedipine analogues (6a) and (7a) [20, 21]. Particularly active in this area are the N-3-substituted sproks: (8a) and (9a) [22] (Fig. 3).

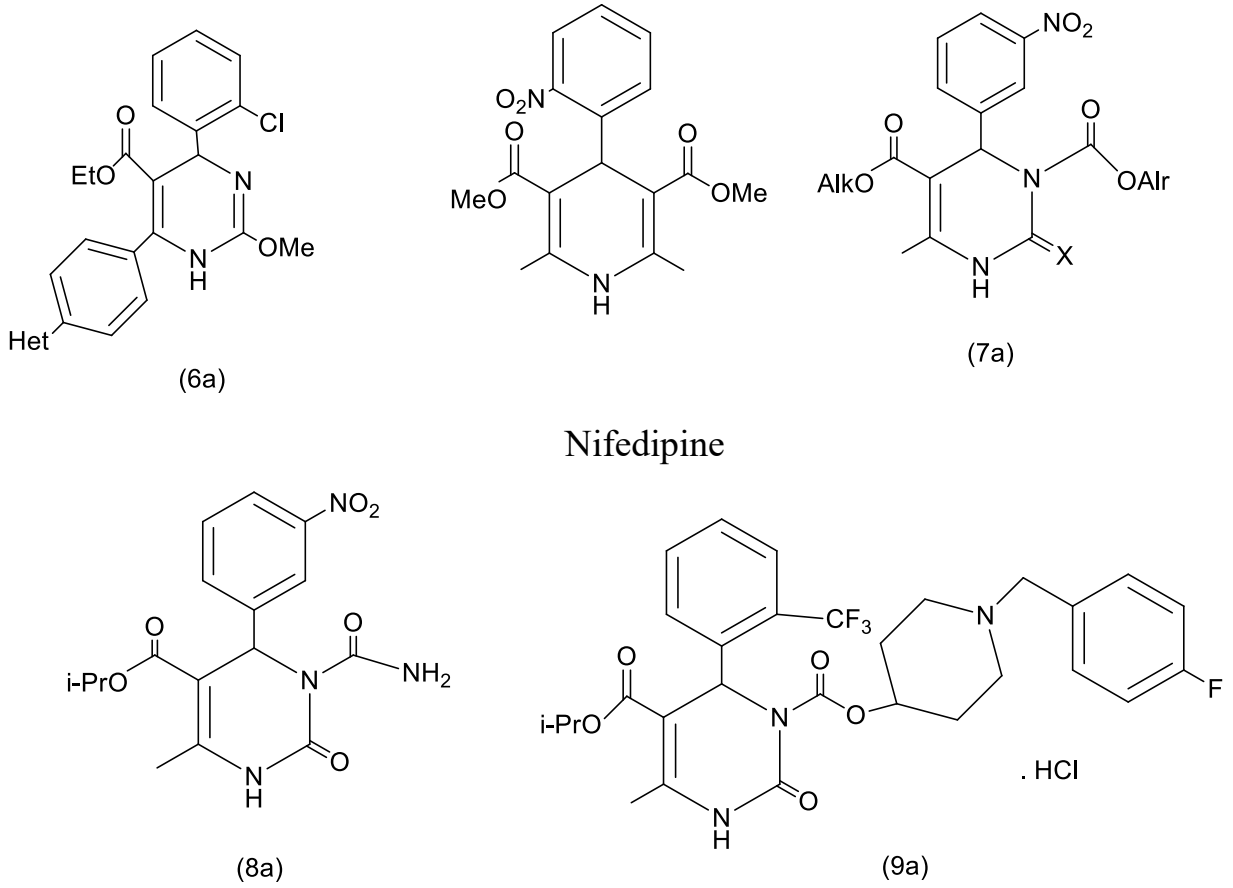
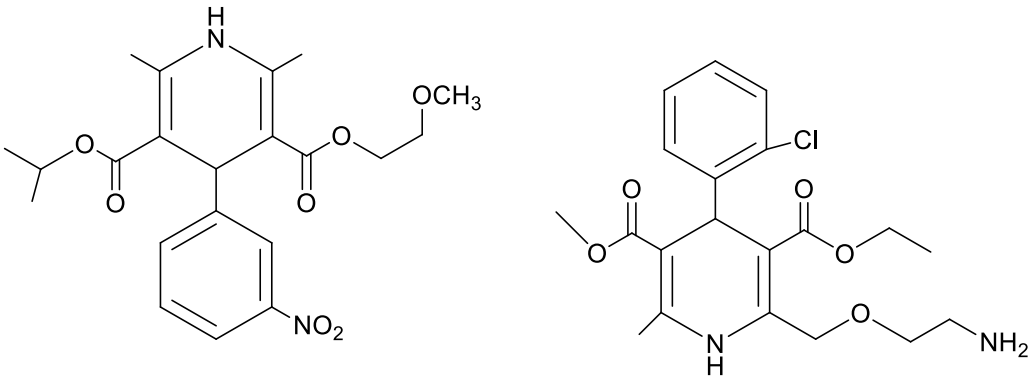


Fig. 3. Particularly active TGPs [20-22].

The ability of dihydropyrimidines to block calcium ion channels has been described. 1,4-Dihydropyrimidines (nifedipine, nitrendipine, nimodipine, amlodipine, lacidipine, felodipine, nicardipine, isradipine, etc.) are L-type calcium antagonists.

The action of these drugs is focused on lowering blood pressure. Due to this, some of them act as sedatives and are drugs for optic nerve dysfunction (Fig. 4).



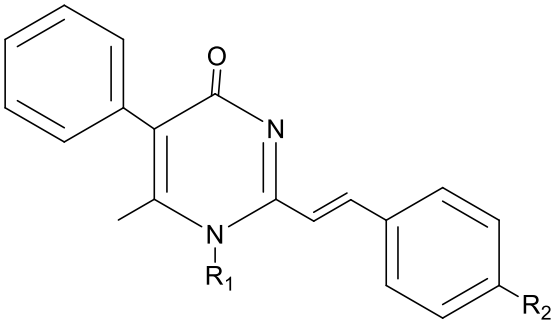
nimodipine amlodipine

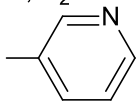
Fig. 4. Antihypertensive agents based on TGP (own reconstruction).

Derivatives of the 4-oxopyrimidine series containing heterocyclic substituents, namely: imidazole, pyridine, thiazole, which have antihistamine activity are known.

Derivatives of 4(3H)-pyrimidines have a tranquilizing effect. Salts of oxo-1,4-dihydropyrimidine exhibit antidepressant and tranquilizing effects.

The synthesis of oxo-1,4-dihydropyrimidine derivatives, which have immunotropic activity, has been described [23,24] (Fig. 5).



I R_1 = Ph, R_2 = OCH_3
II R_1 = Ph, R_2 = OH
III R_1=  R_2 = OCH_3

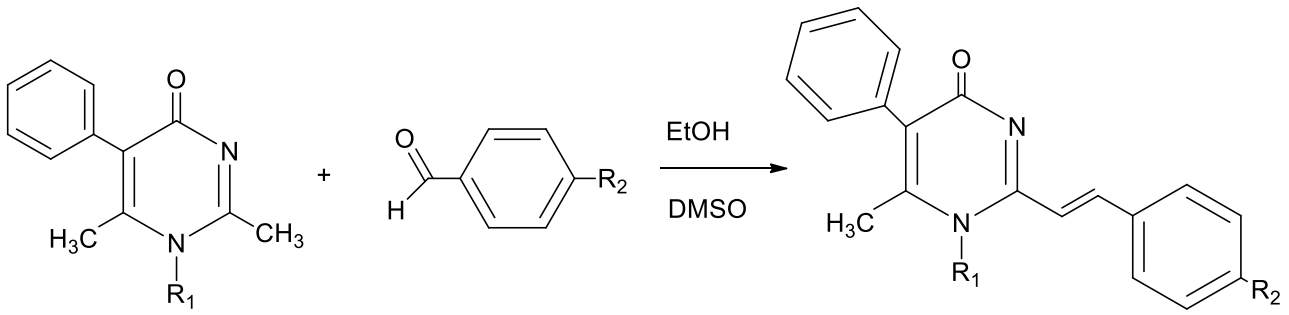


Fig. 5. Synthesis of 6-oxo-1,4-dihydropyrimidine derivatives [23,24].

Studies show that the described compounds have a pronounced antihistamine effect, which is two or more times higher than the activity of diazolin, while being practically non-toxic.

Pyruvic acid, whose formula is CH3C(O)COOH, is one of the key metabolites in the aerobic breakdown of glucose. One of the main roles of pyruvic acid in the body is participation in the synthesis of a number of intermediates of the Krebs cycle.

It is known that carbohydrates contribute to the absorption of fats. It has been proven that pyruvic acid is the active agent that activates lipolytic enzymes. In addition, it is able to convert into alanine. It is known that alanine serves as a raw material for obtaining glucose. Thus, pyruvate is an intermediate stage of glycogen accumulation. Work in this area has confirmed the ability of pyruvic acid and its salts to accelerate the "reduction" of fat.

A significant increase in lipolysis was found when taking pyruvates. Calcium and sodium salts of pyruvic acid are produced as food additives.

The value of pyruvic acid derivatives, as already known physiologically active substances, along with a large number of such substances among 1,2,3,6-tetrahydropyrimidin-2-ones and -2-thiones, justifies the need to search for potential pharmaceuticals among condensation products with pyruvic acid derivatives.

2.1.1.2.2. Use of different reagent variations in the synthesis of tetrahydropyrimidines

2.1.1.2.2.1. Acetoacetic acid esters and β-diketones

The involvement of esters of β-keto acids and β-diketones is the most common modification of the cyclocondensation reaction (Fig. 6).

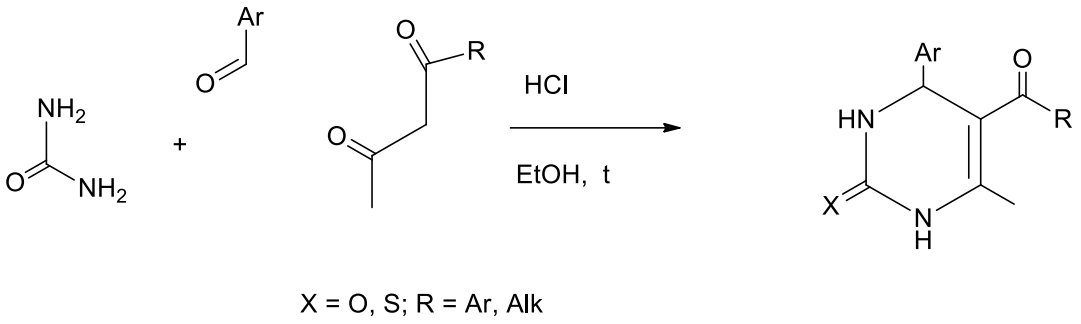


Fig. 6. Cyclocondensation involving esters of β-keto acids and β-diketones (own interpretation)

In this case, when R = Me, Et, Ph, OMe, OEt, the reaction has high yields even when carried out under standard conditions (HCl/EtOH) and requires special conditions only in the presence of electron-withdrawing substituents in the aldehyde component or when participating in the reaction of thioureas. In addition to condensation products with arylaldehydes, products based on heterocyclic aldehydes were obtained (the best yield is for 2-thiophenecarbaldehyde 52%, the lowest is for 8-quinolinecarbaldehyde 28.6%) [25] (Fig. 7):

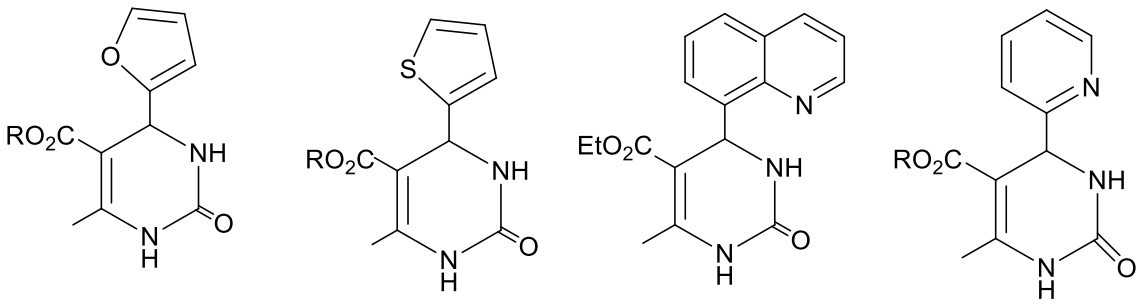


Fig. 7. Condensation products based on heterocyclic aldehydes [25].

For the reaction with aliphatic aldehydes, cyclocondensation products were obtained with yields significantly lower than for aryl and heteroaryl aldehydes [26] (Fig. 8):

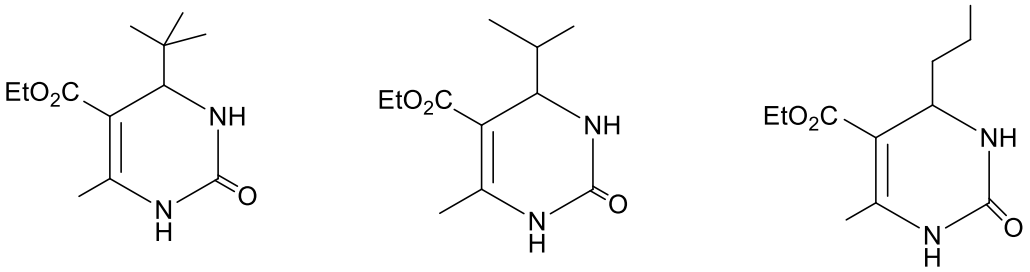


Fig. 8. Condensation products based on aliphatic aldehydes [26].

For this reason, modified methods have been developed. Two modifications of the cyclocondensation reaction are widespread: using "hidden carbonyl equivalents" and the Atwell modification [29].

The idea of using substances in the reaction that would give an aldehyde in the reaction medium, which would subsequently participate in the condensation, was implemented in [27, 28], where 2-substituted 1,3-oxazinanes were used (Fig. 9):

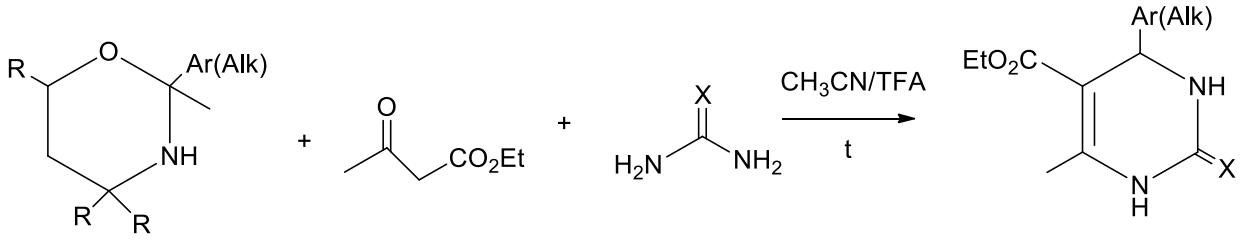


Fig. 9. Use of oxazines in the synthesis of THP [27, 28].

For the introduction of guanidines into the reaction, as well as for the purpose of obtaining O- or S-alkylated 1,4-dihydropyrimidines, it is convenient to use the modification proposed by Etwell [29]. In this method, the previously obtained benzylidene-β-ketoester is added by Michael to guanidine with subsequent cyclization to 1,4-dihydropyrimidine. It is proposed to use the method for electron-deficient

aldehydes, cyclohexylcarbaldehyde and some others. Instead of HCl, acetic or p-toluenesulfonic acid is used as a catalyst [30]. The best results were obtained in the presence of boron trifluoride [31], polyphosphoric ether [32], lanthanide compounds LaCl3 [33], Yb(OTf)3 [34], lithium bromide [35], under microwave irradiation [36] and so-called "solvent-free" reaction conditions (using a mixture of acidic or basic Yb(III)-modified polymers and a solid acid catalyst [37]) in the presence of ionic liquids, such as 1-n-butylmethylimidazole tetrafluoroborate or its hexafluorophosphate [38].

The choice of an effective catalyst allows to significantly increase the yields. For example, for 2-bromo-4-nitrobenzaldehyde the yield according to the standard method approaches 20%. The use of ytterbium triflate allows to increase it to 52% [34].

2.1.1.2.2.2. Synthesis of tetrahydropyrimidine-5-carboxylic acid amides

In [39], the synthesis of tetrahydropyrimidine-5-carboxylic acid amide by nitrile hydrogenation was reported Fig. 10):

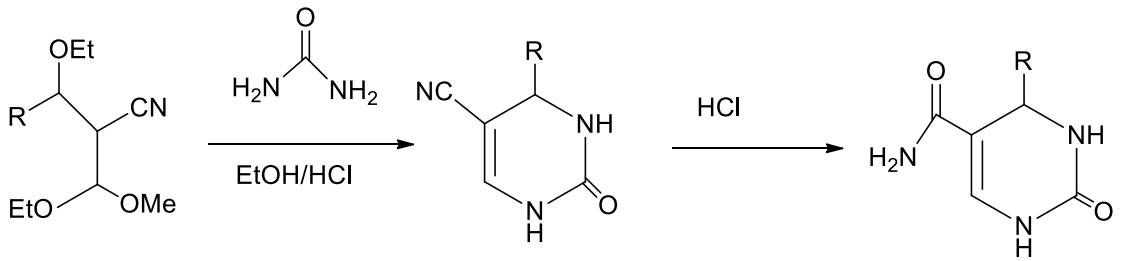


Fig. 10. Synthesis of tetrahydropyrimidine-5-carboxylic acid amide by hydrolysis of nitrile [39].

But already in work [40] examples of syntheses with amides of β-keto acids as methylenecarbonyl components are given (Fig. 11):

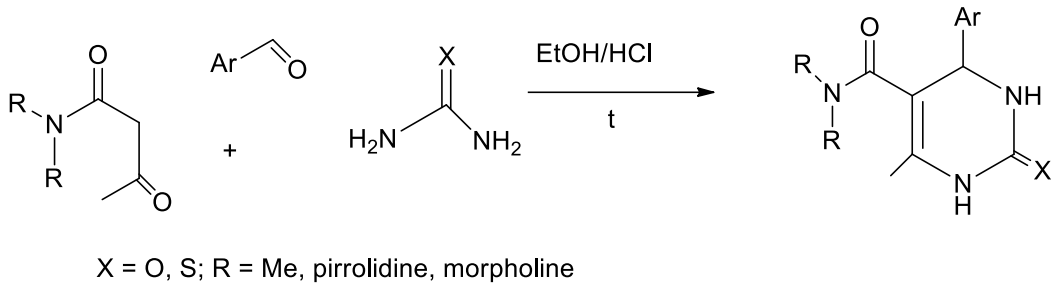


Fig. 11. Examples of syntheses with amides of β-keto acids as methylenecarbonyl components [40].

The yields of the acid derivatives are quite high.

The synthesis and physiological activity of tetrahydropyrimidine-5-carboxamides were studied in [41].

2.1.1.2.2.3. α-Aryl- and α-heterylcarbonyl compounds in cyclocondensation reactions

The possibility of using α-arylcarbonyl compounds in cyclocondensations was shown in an early work [42] using the example of acetophenone and phenylacetaldehyde (Fig. 12):

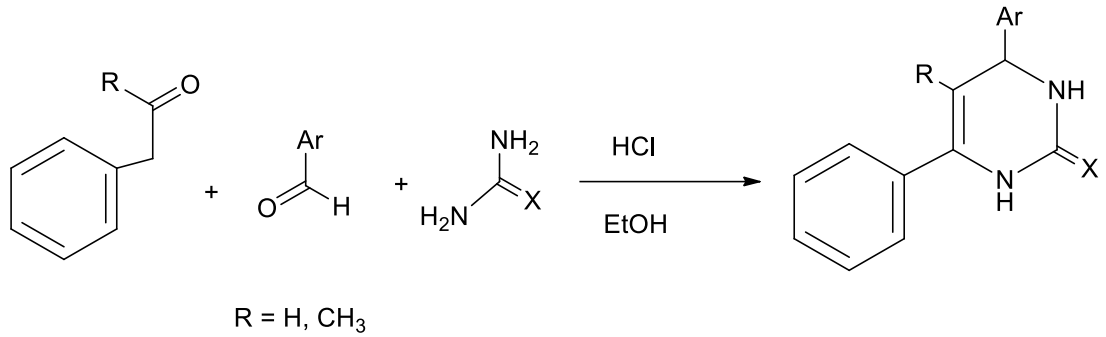


Fig. 12. Possibility of using α-arylcarbonyl compounds in cyclocondensations [42].

Variation of aromatic substituents logically led to the use of α-gererylcarbonyl compounds as methylenecarbonyl components. Thus, in [43] the reaction of 2-phenacylbenzothiazole with aldehydes and urea (thiourea) was investigated (Fig. 13):

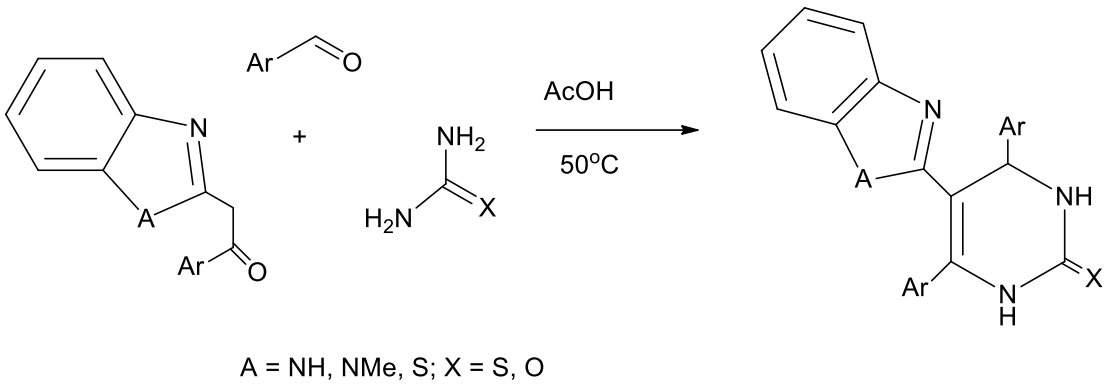


Fig. 13. Reaction of 2-phenacylbenzothiazole with aldehydes and urea (thiourea) [43].

Under the conditions of catalysis by alcoholic HCl, a mixture of products was obtained that could not be separated. After optimizing the reaction conditions, the solvent, temperature, and ratio of reagents were selected. Cyclocondensation was carried out in acetic acid at 50°C. The molar ratio of aldehyde, phenacylbenzothiazole, and urea was 1:1.1:3. Thus, a yield of 72-97% was achieved.

The cyclocondensation products formed are subjected to further functionalization. Thus, in [44], a convenient method for the synthesis of N(3)- ethoxycarbonyl-3,4-dihydropyrimidine-(1H)-2-one was developed, which consists in its acylation with a mixture of thionyl chloride and carboxylic acid.

In the thionyl chloride-carboxylic acid system (1:1 mol.), sufficient solubility of the starting compound is achieved due to an excess of acid. The optimal ratio of starting material, acid, and thionyl chloride for acylation is 1:10:10 (mol). Under these conditions, N(3)-acyl derivatives were obtained with yields of 47-70% (Fig. 14):

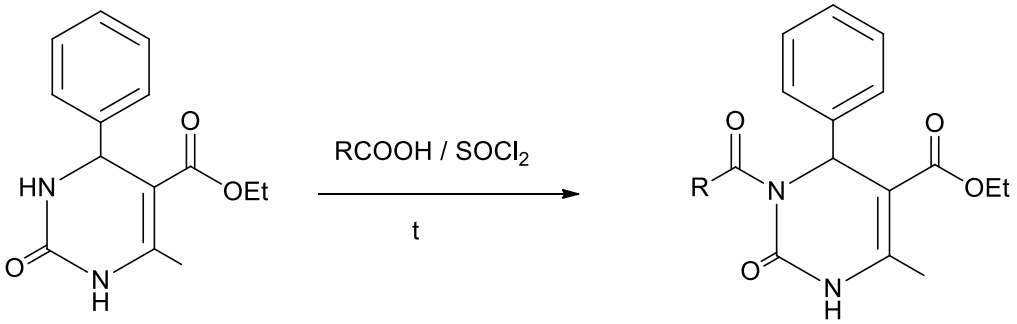


Fig. 14. Conditions for obtaining N(3)-acyl derivatives with yields of 47-70% (own interpretation).

Another example of successful N-acylation is the synthesis of 3-(2-chloroacetyl)-6-methyl-2-oxo-4-phenyl-1,2,3,4-tetrahydropyrimidine-5-carboxylate by the action of chloroacetic anhydride on 3,4-tetrahydrohydropyrimidin-2-one. When reacted with thiourea in ethanol, an S-substituted isothiourea derivative is formed (Fig. 15):

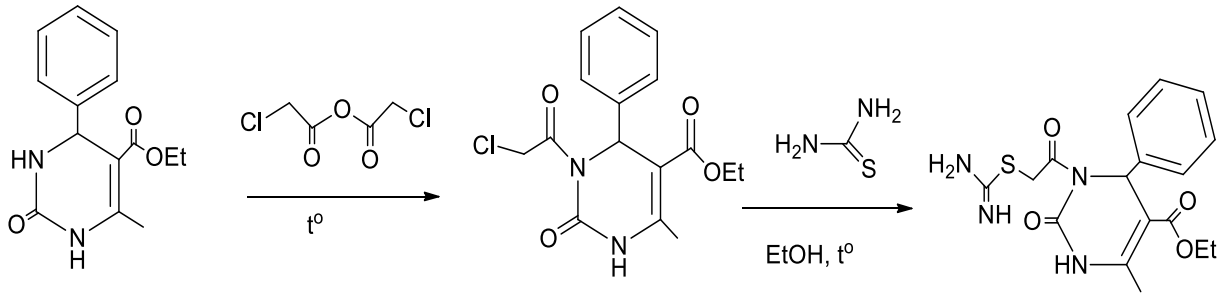


Fig. 15. N-acylation of 3,4-tetrahydrohydropyrimidin-2-one (own interpretation)

2.1.1.2.2.4. Use of other methylcarbonyl components

Use of functionalized acetophenones [29] (Fig. 16):

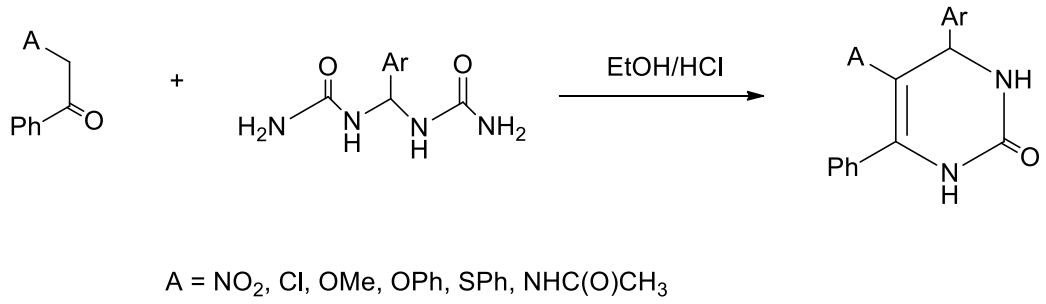


Fig. 16. Use of functionalized acetophenones for the synthesis of the TGP system [29].

In [45, 46] it was proposed to use nitroacetone. The reaction was carried out under standard conditions (HCl/EtOH). The product was obtained in 91% yield (Fig. 17):

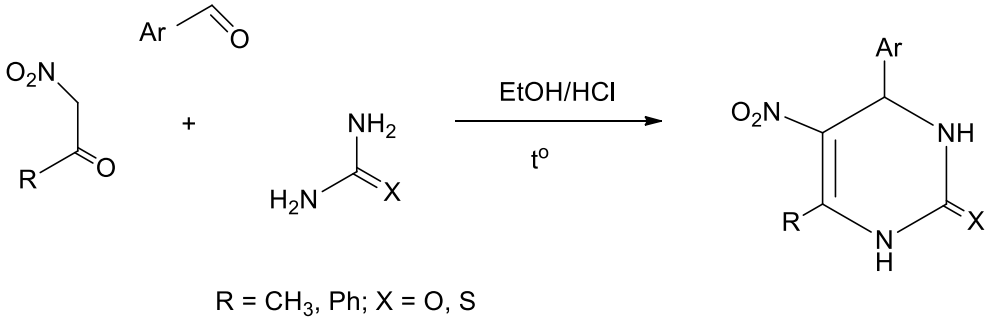


Fig. 17. Use of nitroacetone for the synthesis of the TGP system [45, 46].

2.1.1.2.2.5. Use of trimethylchlorosilane in cyclocondensation reactions

A significant expansion of the spectrum of methylene components and the selection of new reaction conditions led to improved yields for low-reactivity aldehydes. At the same time, the range of ureas is limited almost exclusively to unsubstituted urea and thiourea. In this context, the work [47] is interesting, which discussed the use of the Me3SiCl-DMF system for the condensation of amides with carbonyl compounds. For example, the reaction of benzamide with benzaldehyde produces a dicarboxamide (Fig. 18):

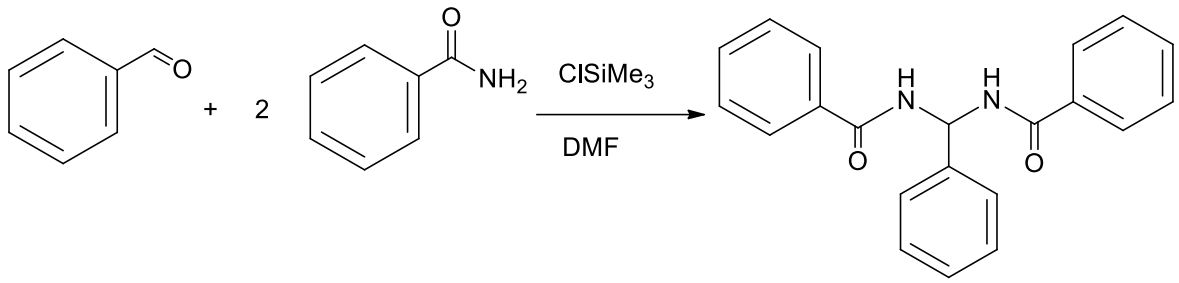


Fig. 18. Use of the Me3SiCl-DMF system for the condensation of amides with carbonyl compounds [47]

But a similar reaction (with the formation of aryl methane diureides) also occurs at one of the stages of the Biginelli reaction. In [48] it was shown that the TMSCl-DMF system allows the process to be carried out at room temperature and to obtain the target products with yields of 62-80% with aromatic aldehydes and 32-37% with aliphatic ones. The reaction was carried out in two stages: urea was added to the reaction mixture after the completion of the crotone condensation of β-dicarbonyl compounds with aldehydes in the presence of TMSCl-DMF and the formation of unsaturated ketones.

In [49] it was shown that high yields of 3,4-dihydropyrimidin-2-(1H)-ones (76-97%) can be obtained using TMSCl in a mixture of MeCN-DMF (2:1) starting from various aromatic, aliphatic and α,β-unsaturated aldehydes, ureas and thioureas, acetylacetone and acetoacetic ester.

Instead of 1,3-dicarbonyl compounds in cyclocondensation, cycloalkanones can be used [50]. When cyclic ketones interact with urea or thiourea and aromatic aldehydes in the TMSCl/MeCN/DMF system, depending on their ratio, three types of products

can be formed: condensed heterocyclic (A), benzylidene heterobicyclic (B) and spiroheterotricyclic (C) pyrimidines (Fig. 19):

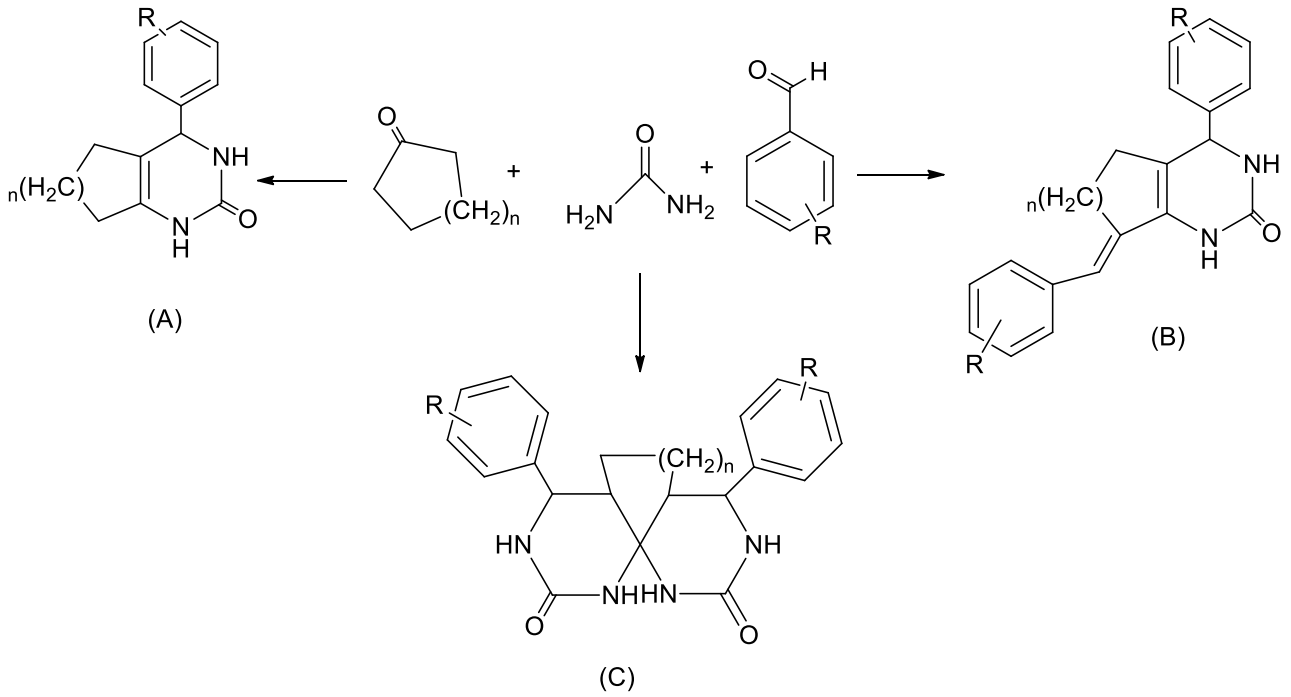


Fig. 19. Use of cycloalkanones for the synthesis of the THP system [50].

For example, the reaction of cyclopentanone with urea and aromatic aldehydes that do not contain an electron-withdrawing group in the para position in the presence of TMSCl/MeCN/DMF at room temperature with yields of 78-95% produces benzylidene heterobicyclic pyrimidines (B) (Fig. 20):

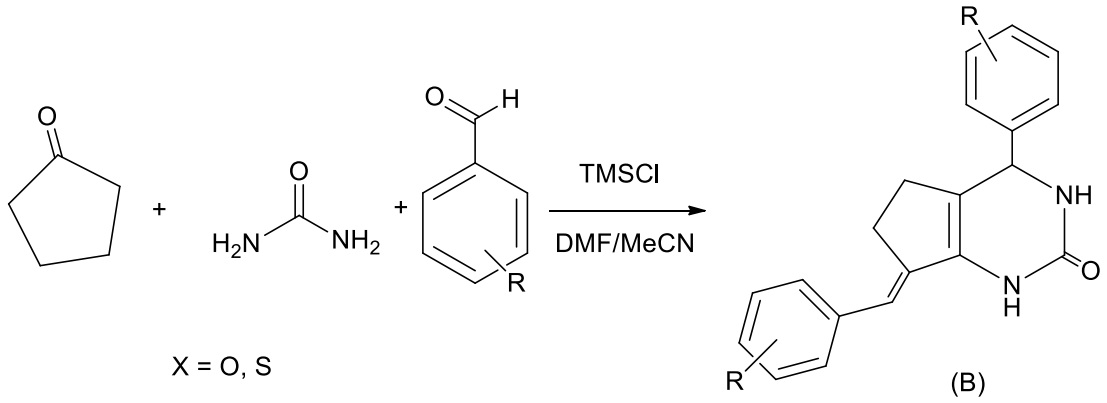


Fig. 20. Synthesis of benzylidene heterobicyclic pyrimidines (B) (own interpretation)

p-Fluorobenzaldehyde under similar conditions gives a mixture of products (B) and (C) in the ratio 87:13.

Aliphatic aldehydes are less reactive than aromatic ones and give good yields of condensation products only at boiling. Cycloalkanones with a ring size greater than 7 react with ureas or thioureas and aliphatic aldehydes to form spiro-fused heterotricyclic compounds (C) or fused heterobicyclic compounds (A) (Fig. 21):

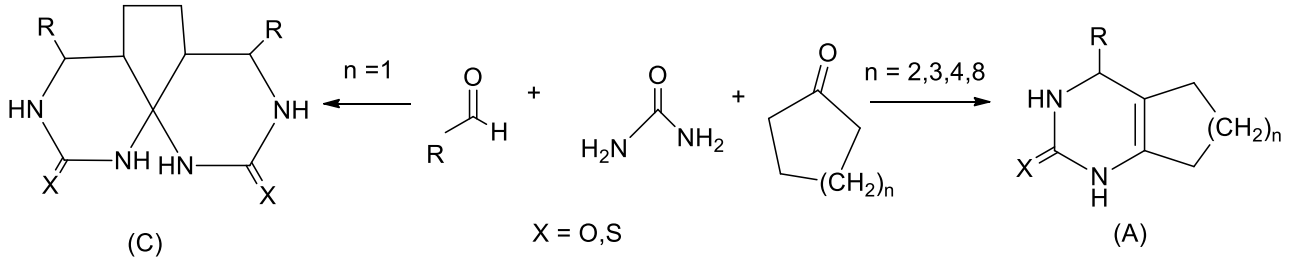


Fig. 21. Reactivity of cycloalkanones in reactions with aliphatic aldehydes and ureas or thioureas (own interpretation)

For example, the interaction of cyclooctanone and cyclodecanone with aliphatic aldehydes and thiourea gives condensed heterobicyclic pyrimidines (A) in 70-85% yields.

The condensation reactions of butyric and valeric aldehydes with urea under the action of TMSCl in a DMF/MeCN mixture lead to the formation of 5,6-dihydro-(1H)-pyrimidin-2-ones (D) in 53% and 62% yields, respectively (Fig. 22):

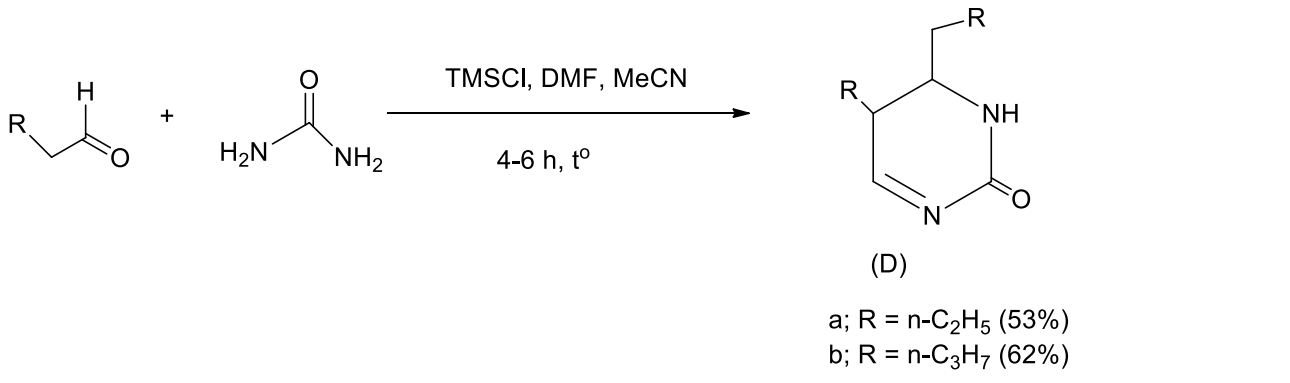


Fig. 22. Reactions of formation of 5,6-dihydro-(1H)-pyrimidin-2-ones (D) (own interpretation)

When isovaleric aldehyde reacts with urea or thiourea under similar conditions, 3,4-dihydro-(1H)-pyrimidin-2-ones (E) are formed, cyclohexanone with urea gives a spiroheterocyclic product (F) with a yield of 78% (Fig. 23):

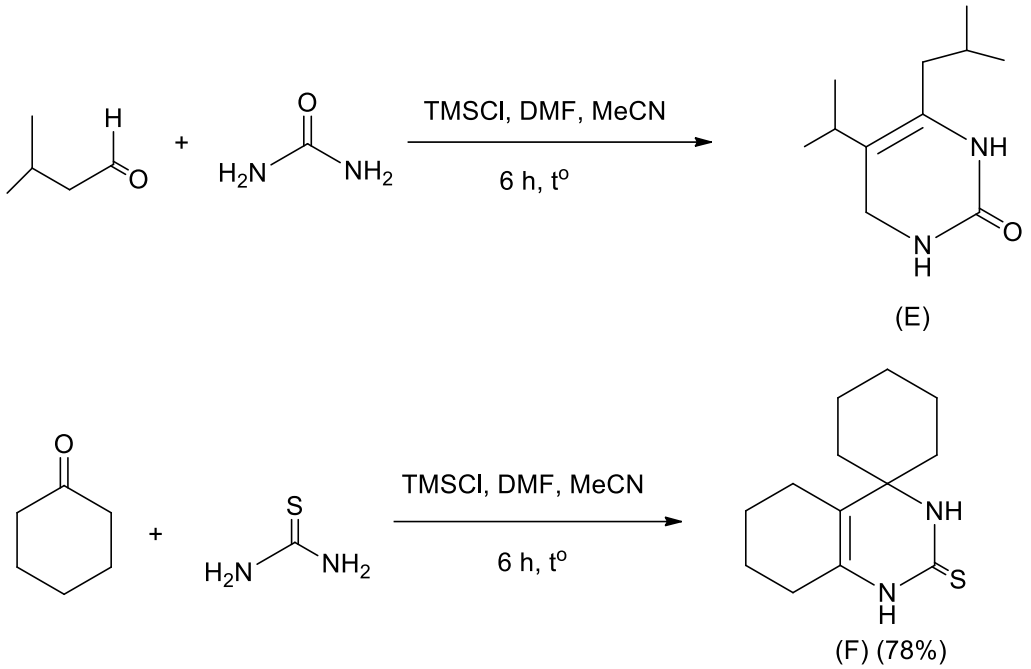


Fig. 23. Reactions of formation of 3,4-dihydro-(1H)-pyrimidin-2-ones (E) and spiroheterocyclic product (F) (own interpretation)

Condensation of 1,3-cyclohexanedione with urea or thiourea in the presence of TMSCl as a Lewis acid in a DMF/MtCN mixture (1:2) leads to the formation of the corresponding heterobicyclic (G) and spirofused (H) compounds in high yields [51] (Fig. 24):

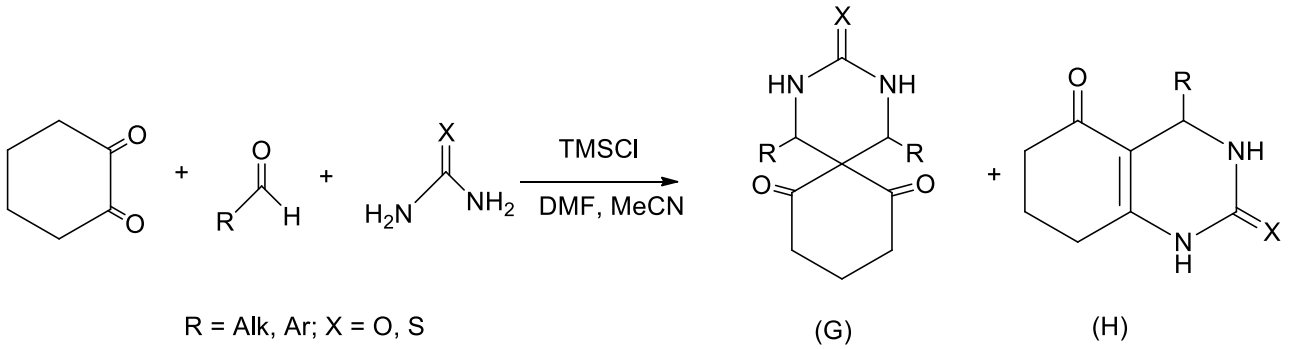


Fig. 24. Formation of corresponding heterobicyclic (G) and spirocondensed (H) [51]

In this case, benzaldehyde and para-substituted aromatic aldehydes give a mixture of two compounds with a predominant content of the spiro product, while ortho- and meta-substituted aromatic aldehydes and aliphatic aldehydes react under similar conditions with the selective formation of octahydroquinazolinones.

Similarly, a series of octahydroquinazolinones (H) were obtained as a result of a one-step three-component condensation starting from dimedone, aromatic aldehydes and ureas in the presence of TMSCl at reflux in a mixture of MeCN/DMF (1:4) [52].

Other silicon derivatives can also be used as condensing agents in the reaction. Thus, TMSI, generovin with TMSCl and NaI. has been successfully used for the cyclization of aromatic, aliphatic, heterocyclic and α,β-unsaturated aldehydes, ureas and β-dicarbonyl compounds (acetylacetone or acetoacetic ester) to dihydropyrimidin-2-(1H)-ones [49].

Finally, TMSOTf is an effective catalyst for the condensation reaction and leads to the formation of the corresponding products in 80-95% yields [53].

2.1.1.3. Discussion of results

The aim of this work was to use carboxy derivatives of pyruvic acid in cyclocondensation reactions for the synthesis of pyrimidines.

Tetrahydropyrimidine derivatives have a wide range of physiological activity and are considered important components of drugs. Cyclocondensation reactions are a powerful method for the synthesis of these drugs.

The literature provides data that substances synthesized on the basis of pyruvic acid derivatives have physiological activity [56]. This fact proves the logic of using carboxy derivatives of pyruvic acid as a mylenecarbonyl component in cyclocondensation reactions (Fig. 25):

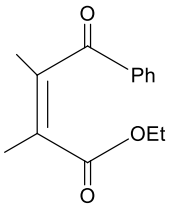


Fig. 25. Fragment of a tetrahydropyrimidine molecule, which belongs to the benzoyl derivative of pyruvic acid [56]

Previous work has been done to optimize the reaction between benzaldehyde (3e), acetoethyl acetate (4e), N-phenylurea (1e) or N-phenylthiourea (2e). The reaction conditions, solvents, reaction time and amount of trimethylchlorosilane were varied [54] (Fig. 26):

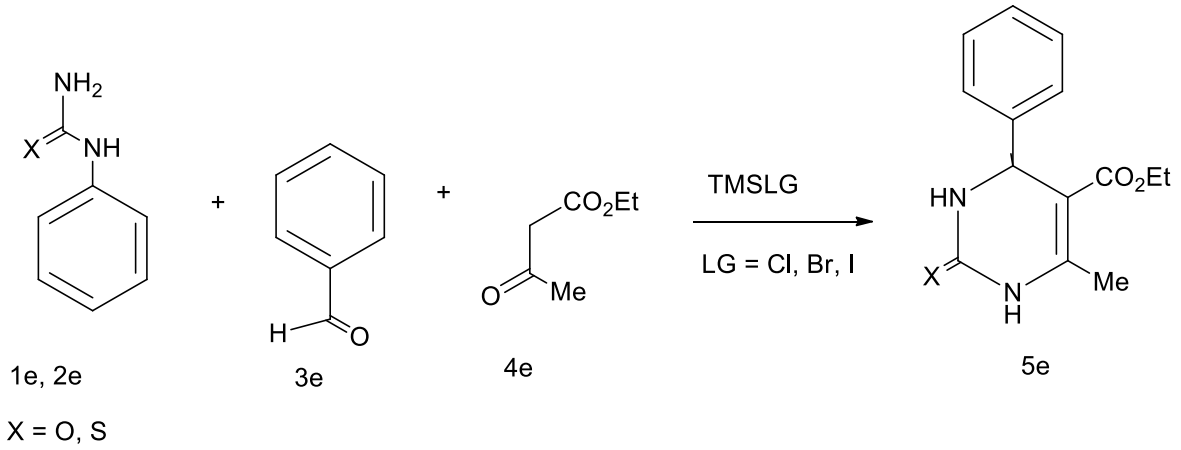


Fig. 26. Optimization of the reaction between benzaldehyde (3e), acetoethyl acetate (4e), N-phenylurea (1e) or N-phenylthiourea (2e) [54]

2.1.1.3.1. Use of trimethylhalosilanes in cyclocondensation reactions

Halogenosilanes with halogens such as chlorine, bromine, iodine were used in the reaction. Me_3SiI was synthesized in situ from Me_3SiCl and NaI in DMF (Fig. 27):

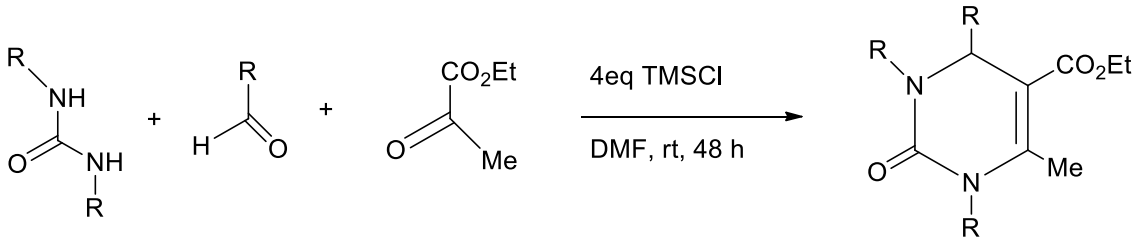


Fig. 27. Use of halosilanes for the synthesis of THP (own interpretation).

It was previously shown that Me3SiCl is an effective promoter and dehydrating agent in various condensations. It was decided to try it as a condensing reagent and in cyclocondensation reactions with various substituted ureas and thioureas. Benzaldehyde, acetoethyl acetate, phenylurea and phenylthiourea were used to develop the method. By varying the solvent, reagent ratios, temperature and reaction time,

100% conversion was achieved for model compounds. The use of Me3SiBr and Me3SiI does not give any advantages over Me3SiCl. The optimal reaction conditions were: reaction temperature 20°C, solvent dimethylformamide, reaction time 48 hours, presence of 4 equivalents of Me_3SiCl.

The use of Me3SiCl made it possible to introduce into the reaction a wide range of aromatic and heterocyclic aldehydes, mono- and disubstituted ureas and thioureas. It was also possible to use sterically hindered ureas and thioureas, aromatic aldehydes with donor and acceptor substituents in the 2 and 6 positions. At the same time, alkylaryl and diaryl ureas and thioureas were found to be unreactive (Fig. 28):

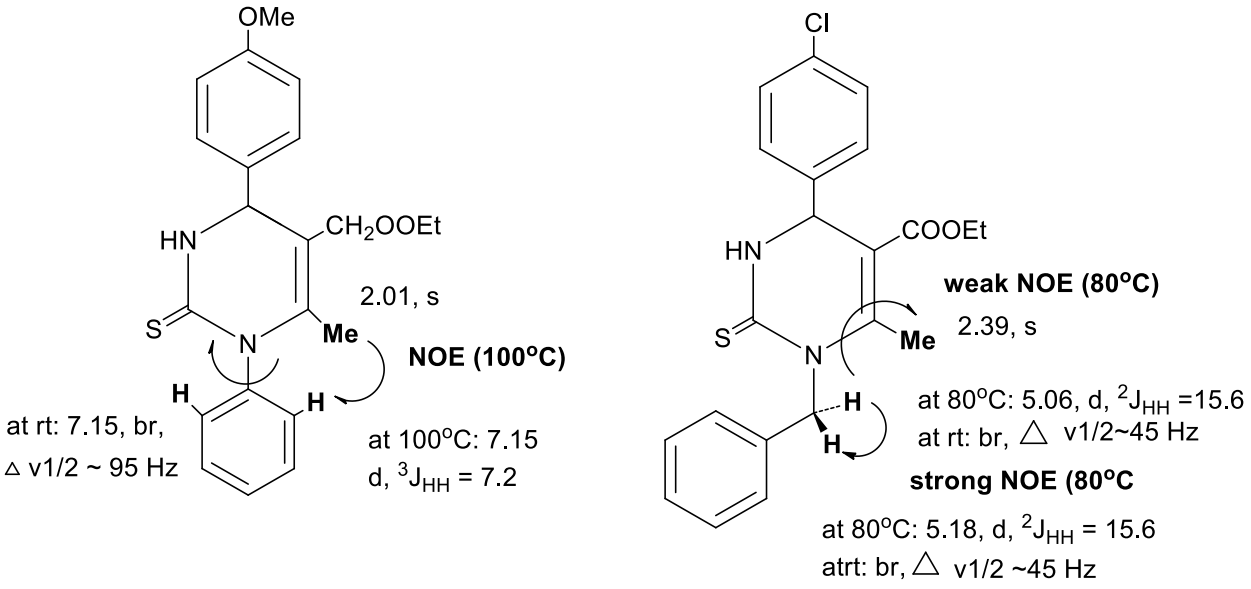
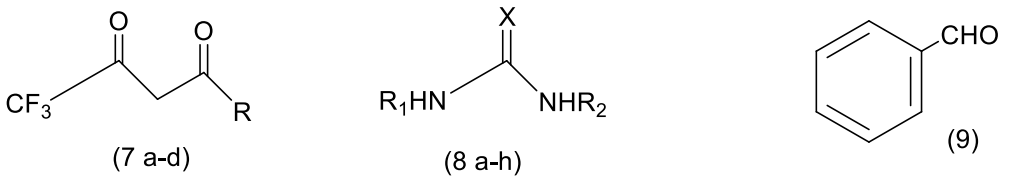


Fig. 28. ^{1}H NMR data (DMSO-d_6, 400 MHz) for 3,4-dihydropyrimidine-2(1H)-thiones (own interpretation)

2.1.1.3.2. CF_3-β-Diketones in cyclocondensation reactions

β-Diketones participate in cyclocondensation reactions as bifunctional reagents. At the same time, there is no information in the literature about the participation of CF3-β-diketones in such reactions, although the presence of a pharmacophore fluorine atom could give the reaction products new physiologically active properties.

The DMF/TMSCl system was used. CF3-β-diketones (7a-d), ureas and thioureas (8a-h), and benzaldehyde (9) were chosen as model compounds (Fig. 29):



7a: R = CF_3
7b: R = OEt
7c: R = Ph
7d: R = Me

8a: X = O, R_1 = R_2 = H
8b: X = O, R_1 = H, R_2 = Me
8c: X = O, R_1 = R_2 = Me
8d: X = O, R_1 = H, R_2 = *p*-Tol

8e: X = S, R_1 = R_2 = H
8f: X = S, R_1 = H, R_2 = Me
8g: X = S, R_1 = R_2 = Me
8h: X = S, R_1 = H, R_2 = Ph

Fig. 29. Starting compounds for synthesis with the DMF/TMSCl system (own interpretation)

Optimized conditions were used to carry out the reaction (Fig. 30):

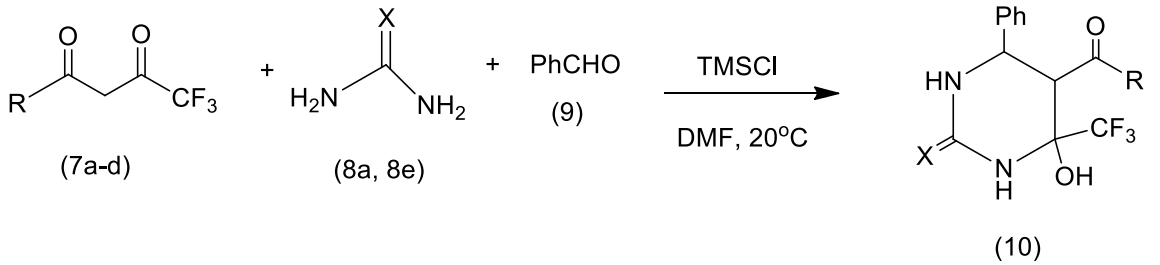


Fig. 30. Optimized reaction conditions (own interpretation)

First, unsubstituted ureas and thioureas (8a, 8e) were introduced into the reaction. As a result, hydroxy derivatives (10) were isolated.

When moving to substituted ureas and thioureas, a very interesting dependence of the behavior of diketones (7a-d) on the nature of the R substituents was observed.

In the case of R= Ph, OEt, CF3 (7a-e), the formation of compounds of type (11) was observed. However, when moving to R = Me (7d), a reversal of regioselectivity occurred with the formation of cyclization products (12) at another carbonyl group Fig. 31):

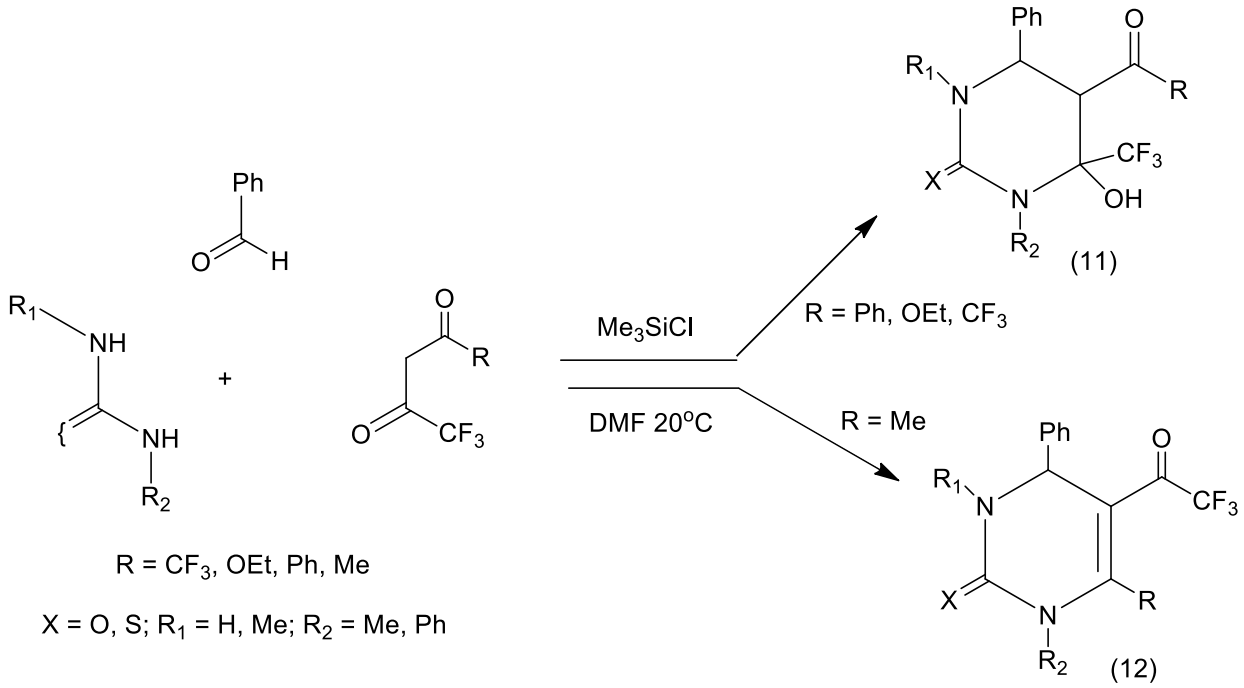


Fig. 31. Behavior of CF3-β-diketones in the heterocyclization reaction (own interpretation)

2.1.1.3.3. Carboxyderivatives of pyruvic acid (CPA) in cyclocondensation reactions

Carboxyderivatives of pyruvic acid, as well as CF3-β-diketones, contain 2 potential cyclization centers. The DMF/TMSCl system was used for the study. A number of derivatives (13a-d), ureas and thioureas (14a-h), the reactivity of which was studied in [54,55], and benzaldehyde (9) were selected as model compounds (Fig. 32):

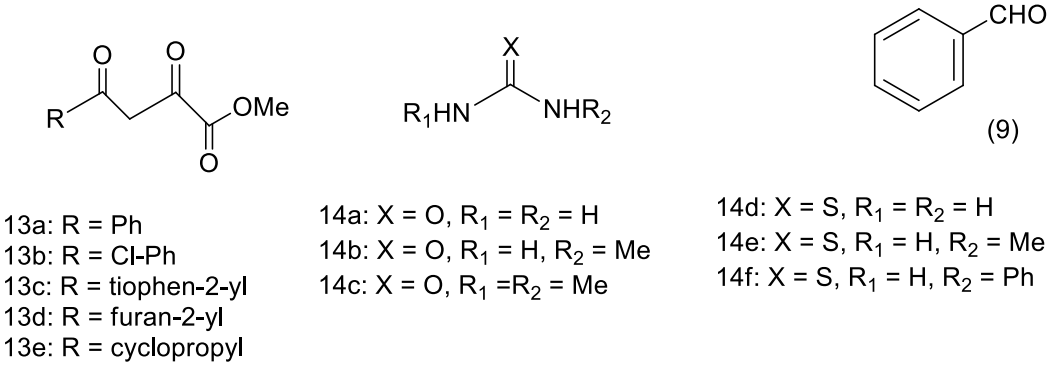


Fig. 32. Reactivity of the starting compounds [54, 55]

The synthesis of carboxy derivatives of pyruvic acid was carried out by Claisen using ketones and diethyl oxalate in the presence of sodium ethoxide (Fig. 33):

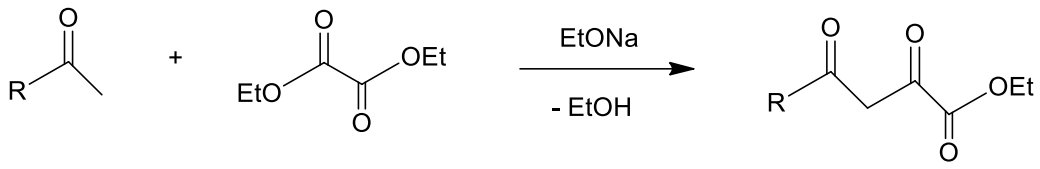
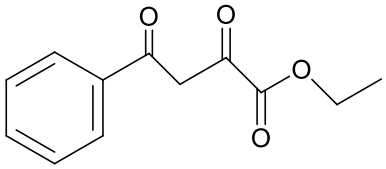


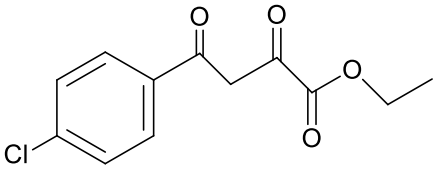
Fig. 33. Synthesis of carboxy derivatives of pyruvic acid (own interpretation)

A number of CPVKs were synthesized for further use in the heterocyclization reaction (Fig. 34):



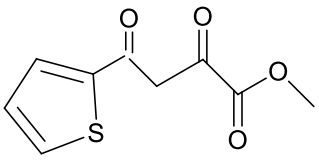
(13a)

2,4-Dioxo-4-phenylethylbutanoate



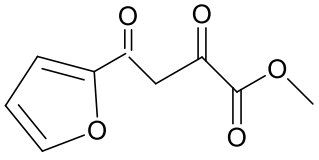
(13b)

4-(4-Chlorophenyl)-2,4-dioxo-ethylbutanoate



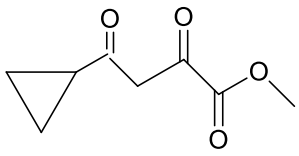
(13c)

2,4-Dioxo-4-(thiophen-2-yl)-methylbutanoate



(13d)

2,4-Dioxo-4-(furan-2-yl)-methylbutanoate



(13e)

2,4-Dioxo-4-cyclopropyl methylbutanoate

Fig. 34. Synthesized series of CPVK for further use in the heterocyclization reaction (own interpretation)

First, unsubstituted ureas (14a) and thioureas (14d) were introduced into the reaction. The reagents were taken in the following ratio: urea (thiourea) : aldehyde : KPPVK: Me3SiCl = 1 : 1 : 1 : 4. The reaction proceeded for 24-48 hours at room temperature (Fig. 35):

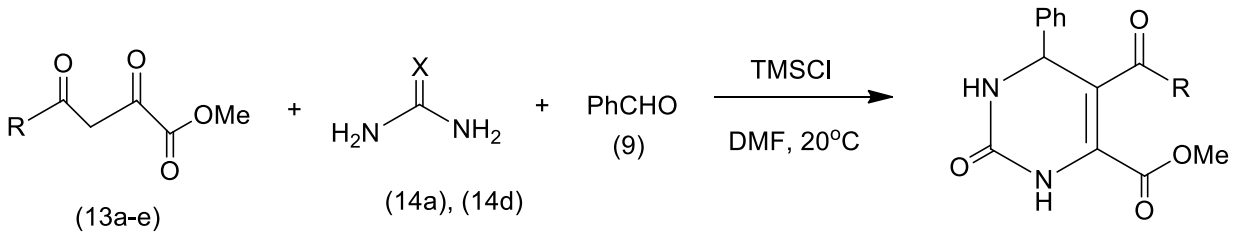


Fig. 35. Reaction scheme for the synthesis of TGP derivatives (own interpretation)

As a result, derivatives (15) were obtained.

The following experiments were carried out using substituted ureas and thioureas, which reacted well with CF3-β-diketones. When switching to monosubstituted ureas and thioureas, the dependence of the behavior of CPVK (13a-d) on which urea entered into the reaction was observed.

In the case of X = O (14b), the formation of analogues of compounds (16) was observed. And when X = S (14e, 14g) - the formation of compounds of the type (17), in which the hydroxy group remains in position 4 (Fig. 36):

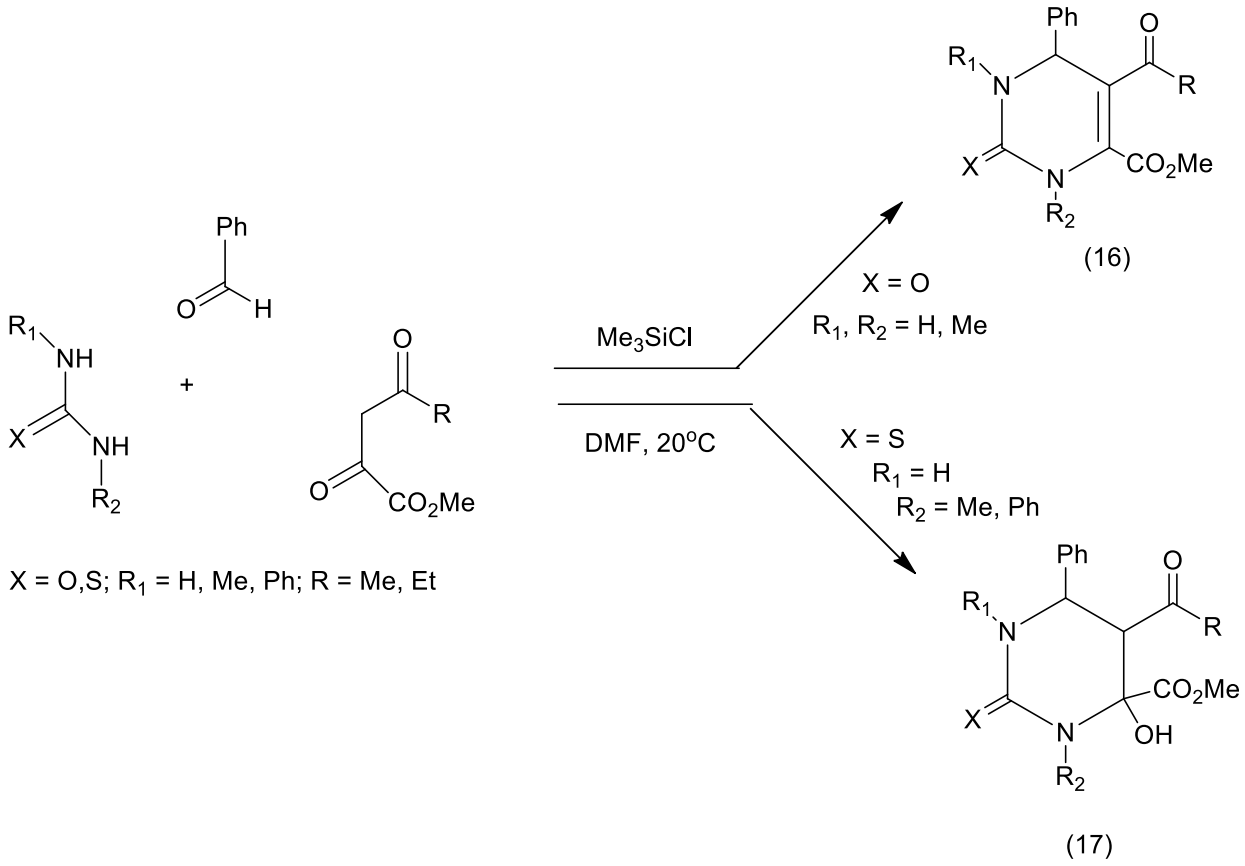


Fig. 36. Formation of compounds (16) and (17) depending on the type of urea (own interpretation)

As can be seen from the scheme, the obtained hydroxypyrimidines are analogues of compounds formed in the heterocyclization reaction with CF3-β-diketones. Compounds of type (16) are analogues of (12), and compounds of type (17) are analogues of (11).

The following reaction mechanism was proposed in the presence of Me_3SiCl (Fig. 37):

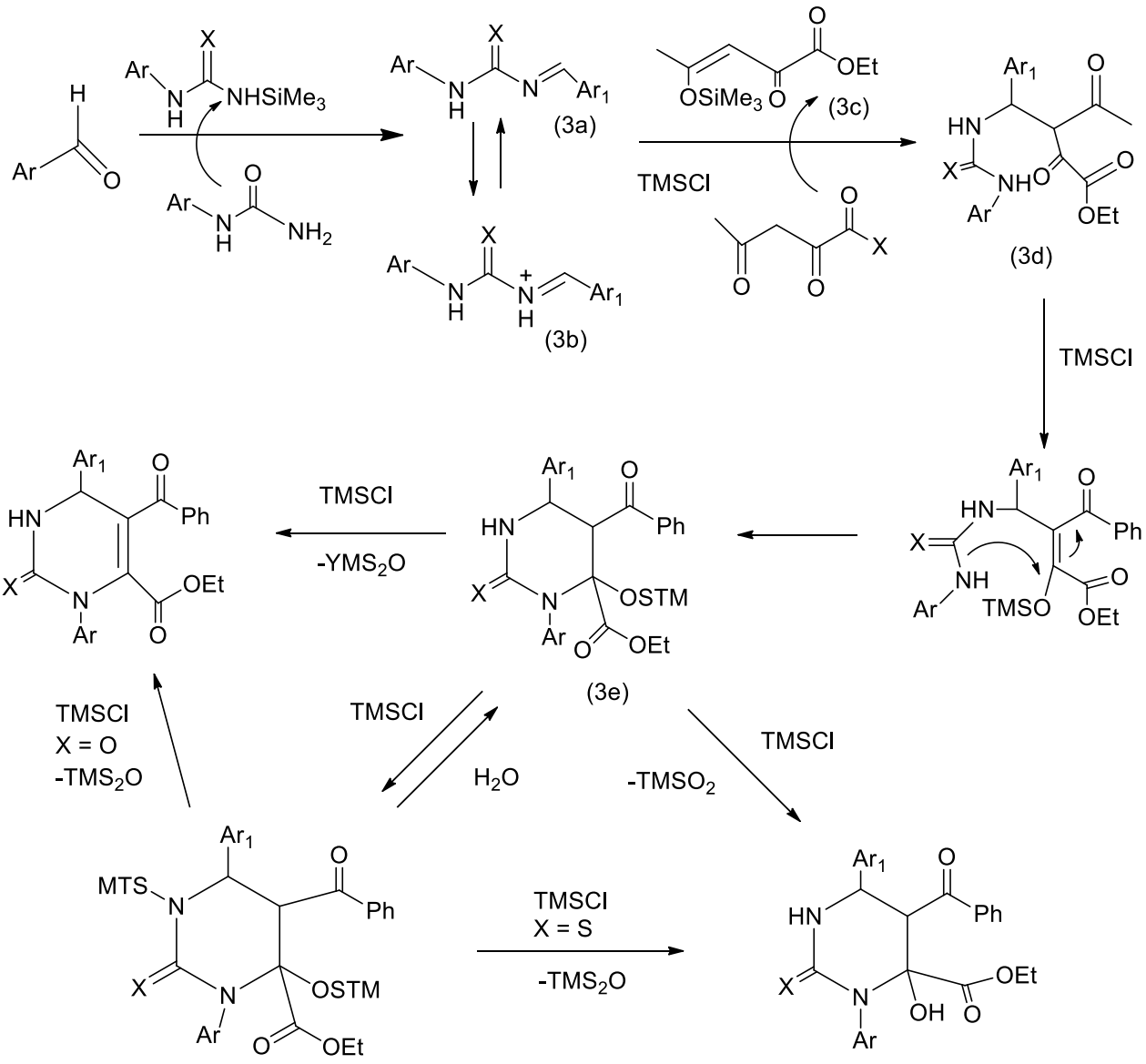
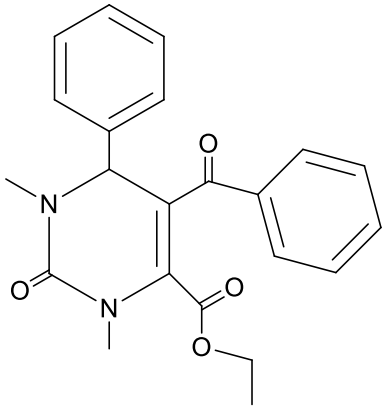


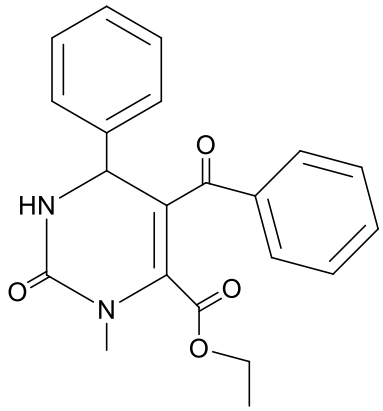
Fig. 37. Proposed reaction mechanism in the presence of MeSiCl (own interpretation)

The first step is the formation of the iminium intermediate (3a) in the protonated form (3b). The next step is the addition of silylated 2,4-dioxo-ethylpentanoate (3c) to the imine (3a) leading to the final 3,4-dihydropyrimidin-2-(1H)-ones or -thiones. The formation of products with a substituent specifically at position 1 was confirmed by NOE.

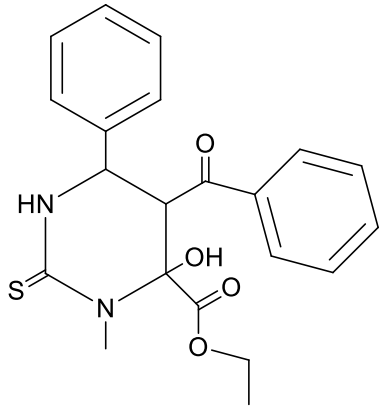
As a result, the following substances were obtained (Fig. 38):



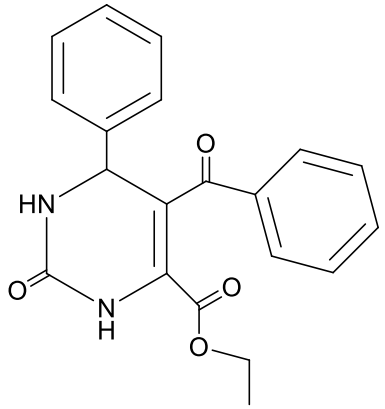
(2a) 5-Benzoyl-1,3-dimethyl-2-oxo-6-phenyl-1,2,3,6-tetrahydropyrimidine-4-ethylcarboxylate



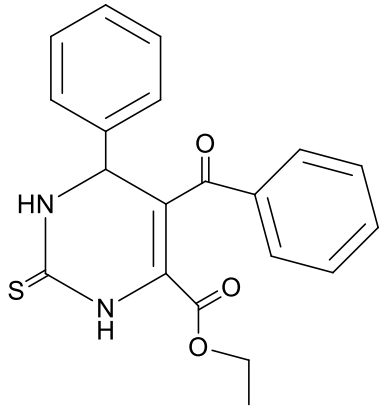
(2b) 5-Benzoyl-3-methyl-2-oxo-6-phenyl-1,2,3,6-tetrahydropyrimidine-4-ethylcarboxylate



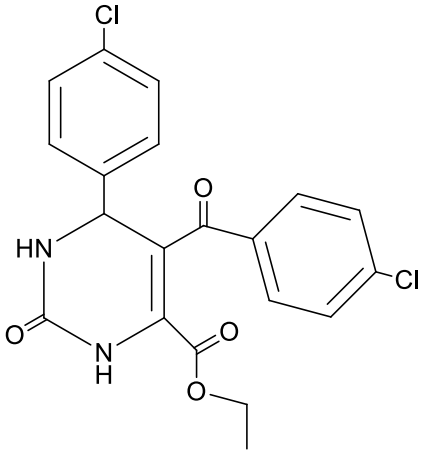
(2c) 5-Benzoyl-4-hydroxy-3-methyl-6-phenyl-2-thiooxo-hexahydropyrimidine-4-ethylcarboxylate



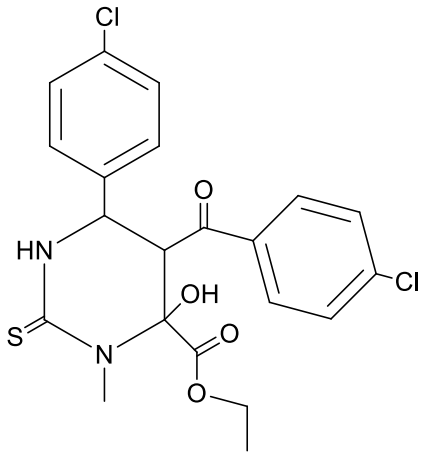
(2d) 5-Benzoyl-2-oxo-6-phenyl-1,2,3,6-tetrahydropyrimidine-4-ethylcarboxylate



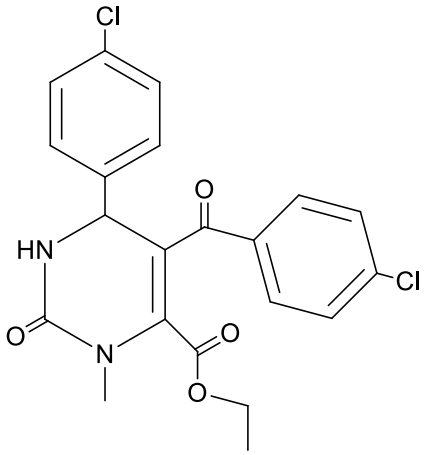
(2e) 5-Benzoyl-6-phenyl-2-thiooxo-tetrahydropyrimidine-4-ethylcarboxylate



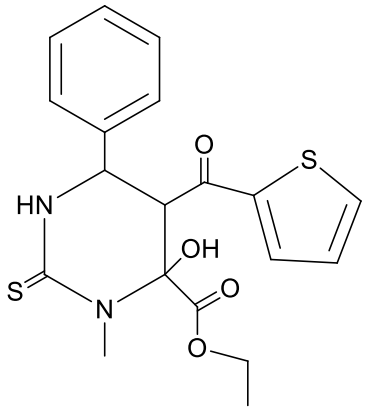
2f) 5-(4-Chlorobenzoyl)-6-(4-chlorophenyl)-2-oxo-1,2,3,6-tetrahydropyrimidine-4-ethylcarboxylate



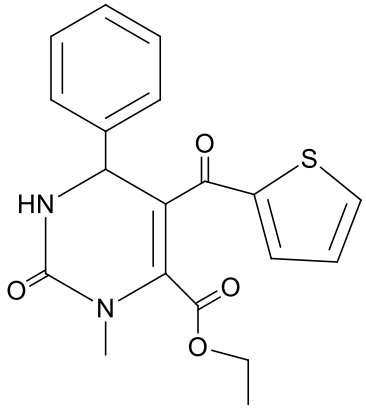
(2g) 5-(4-Chlorobenzoyl)-6-(4-chlorophenyl)-4-hydroxy-3-methyl-2-thiooxo-hexahydropyrimidine-4-ethylcarboxylate



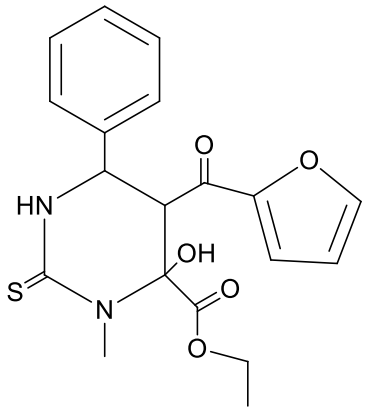
(2h) 5-(4-Chlorobenzoyl)-6-(4-chlorophenyl)-3-methyl-2-oxo-1,2,3,6-tetrahydropyrimidine-4-ethylcarboxylate



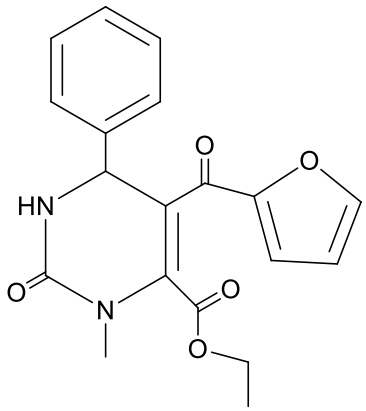
(2i) 4-Hydroxy-3-methyl-6-phenyl-5-(thiophene-2-carbonyl)-2-thiooxo-hexahydropyrimidine-4-ethylcarboxylate



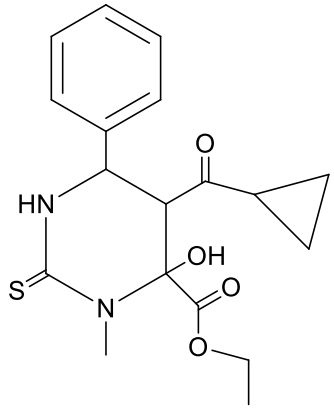
(2j) 3-Methyl-2-oxo-6-phenyl-5-(thiophene-2-carbonyl)-1,2,3,6-tetrahydropyrimidine-4-ethylcarboxylate



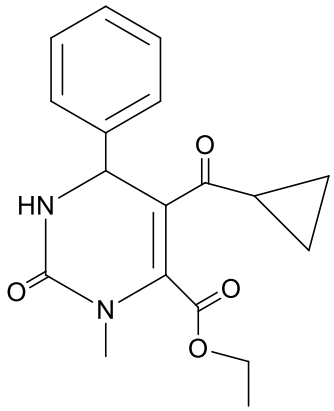
(2k) 5-(Furan-2-carbonyl)-3-methyl-2-thiooxo-6-phenyl-1,2,3,6-tetrahydropyrimidine-4-ethylcarboxylate



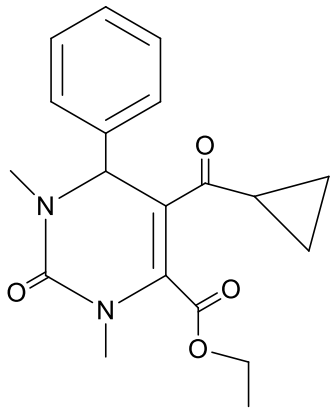
(2l) 5-(Furan-2-carbonyl)-3-methyl-2-oxo-6-phenyl-1,2,3,6-tetrahydropyrimidine-4-ethylcarboxylate



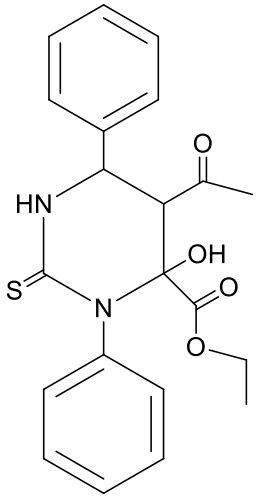
(2m) 5-(Cyclopropanecarbonyl)-4-hydroxy-3-methyl-6-phenyl-2-thiooxo-hexahydropyrimidine-4-ethylcarboxylate



(2n) 5-(Cyclopropanecarbonyl)-3-methyl-2-oxo-6-phenyl-1,2,3,6-tetrahydropyrimidine-4-ethylcarboxylate



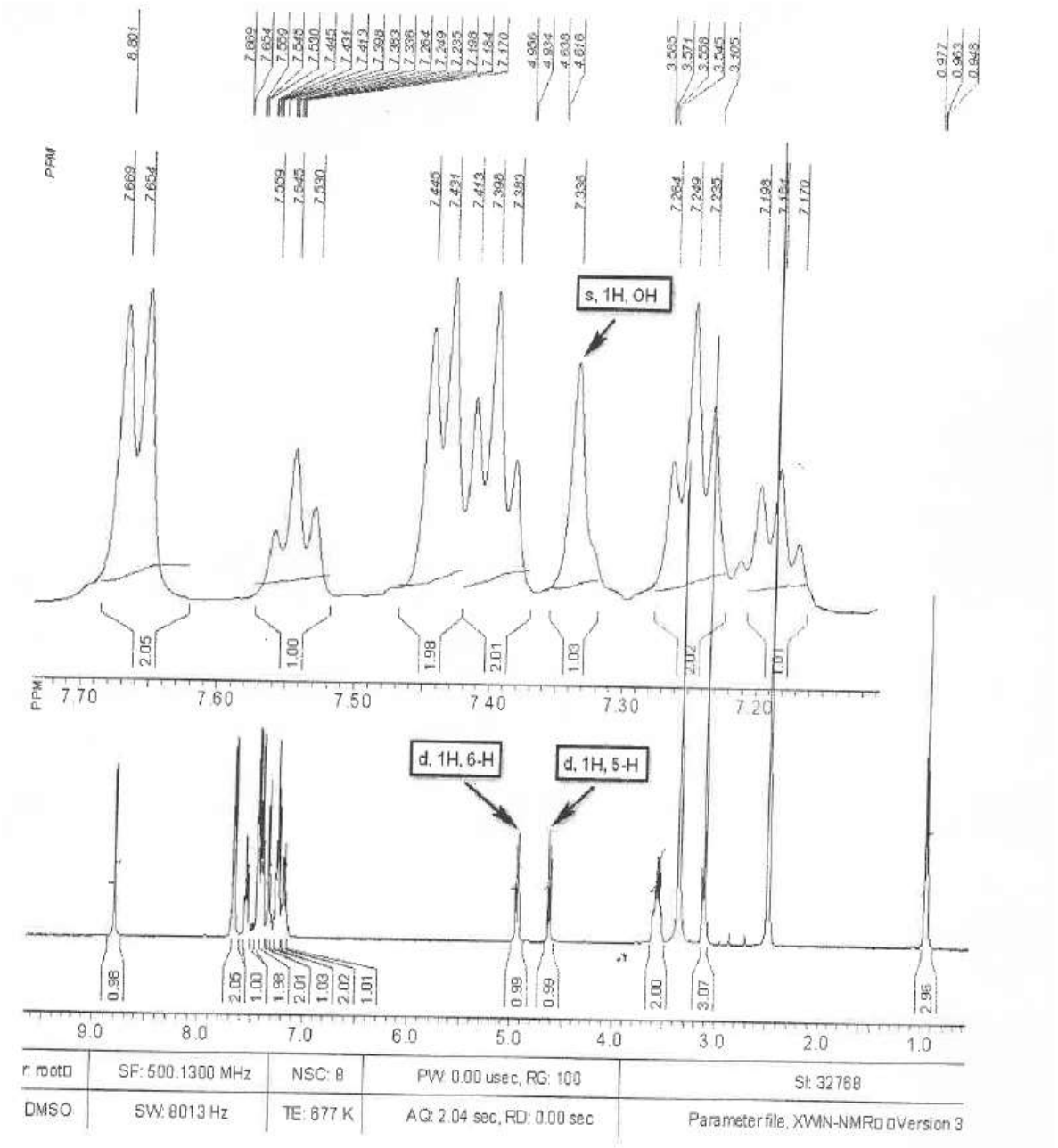
(2o) 5-(Cyclopropanecarbonyl)-1,3-dimethyl-2-oxo-6-phenyl-1,2,3,6-tetrahydropyrimidine-4-ethylcarboxylate



(2p) 5-Benzoyl-4-hydroxy-3,6-diphenyl-2-thiooxo-hexahydropyrimidine-4-ethylcarboxylate

Fig. 38. Formation of products with a substituent exactly in position 1 (own interpretation)

Analysis of 1H NMR spectra showed that in the case of monosubstituted thioureas, the water molecule was not eliminated and the hydroxy group remained in position 4. In cases of using monosubstituted ureas, such an effect was not observed. The structure of 5-benzoyl-4-hydroxy-3-methyl-6-phenyl-2-thiooxo-hexahydropyrimidine-4-ethylcarboxylate was reliably proven by 1H NMR spectrum (500 MHz, DMSO-d6) (Fig. 39):



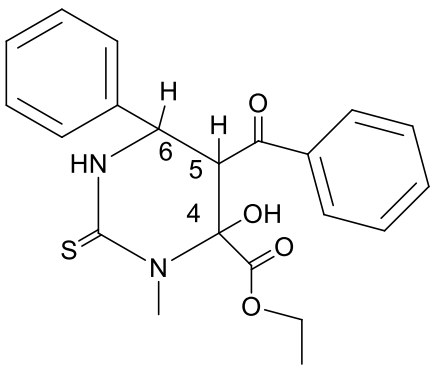
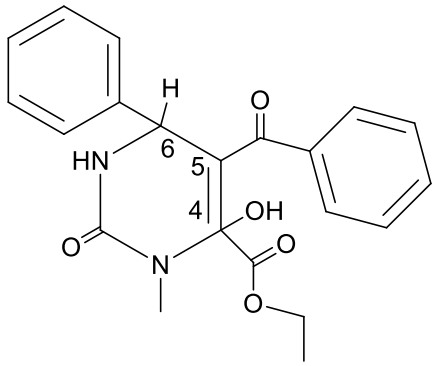


Fig. 39. [1]H PMR spectrum of 5-benzoyl-4-hydroxy-3-methyl-6,2-thiooxo-hexahydropyrimidine-4-ethylcarboxylate (2c) (own interpretation)

The presence of a hydroxy group in compound (2c) is evidenced by the presence of corresponding characteristic signals. Doublets of hydrogen atoms are observed at 4.63 ppm (H in position 5) and 4.95 ppm (H in position 6). This indicates the absence of a double bond in the pyrimidine ring.

In addition, a singlet of the hydrogen atom of the OH group is observed in the spectrum at 7.37 ppm. After washing with D_2O, this signal disappears. The hydrogen atom of the NH group was determined by the characteristic singlet at 8.80 ppm.
The given spectrum can be compared with the spectrum (2b) (Fig. 40):



(2b)

Fig. 40. 5-Benzoyl-3-methyl-2-oxo-6-phenyl-1,2,3,6-tetrahydropyrimidine-4-ethylcarboxylate (own interpretation)

A characteristic signal in the spectrum is a doublet at 5.30 ppm. This can only be the H atom at C 6. In position 4, the H atom signal is absent, which indicates a double bond between carbon atoms 4 and 5. The hydrogen atom of the OH group is also absent (Fig. 41):

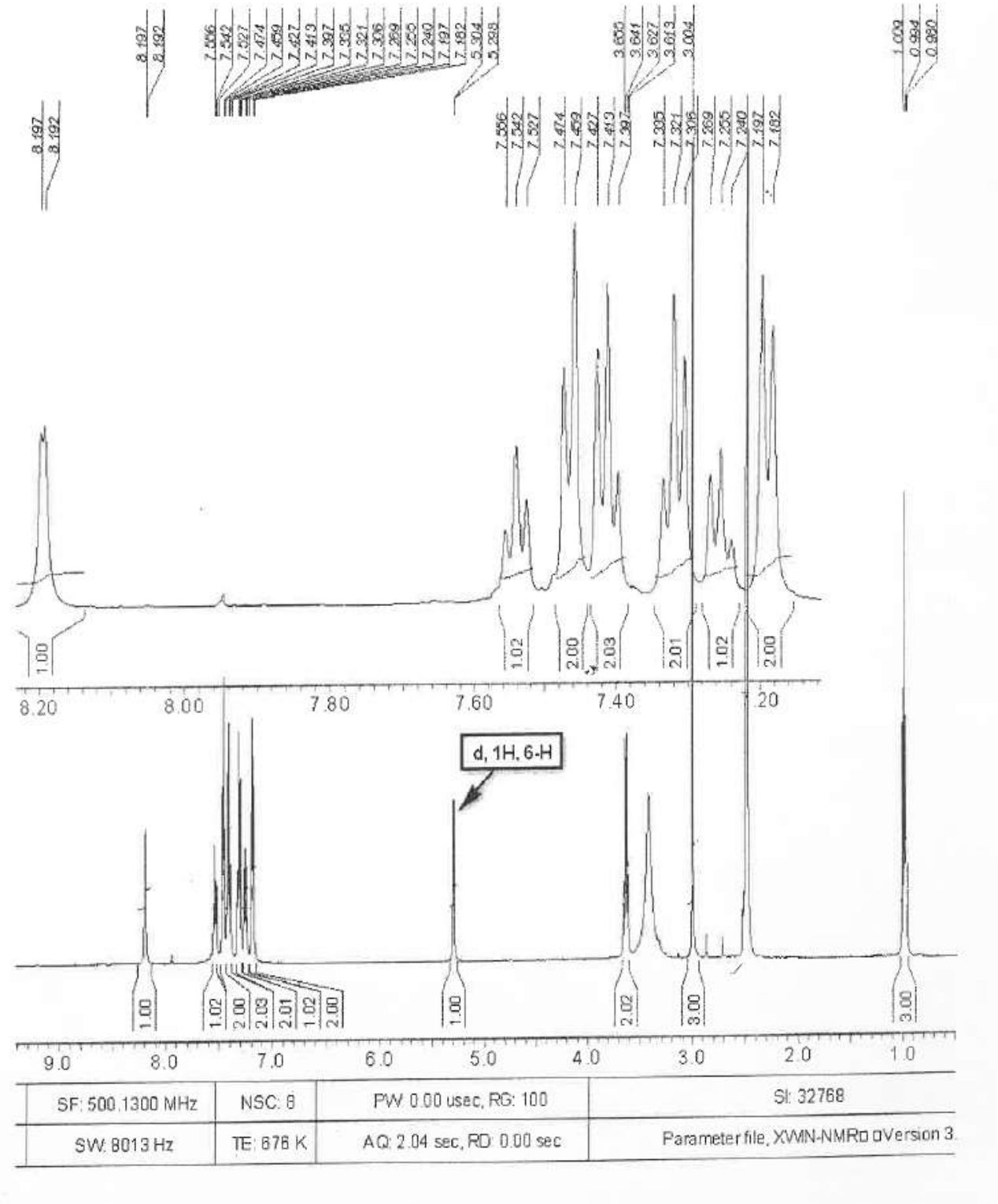


Fig. 41. 1H PMR spectrum of 5-benzoyl-3-methyl-2-oxo-6-phenyl-1,2,3,6-tetrahydropyrimidine-4-ethylcarboxylate (own interpretation)

2.1.1.4. Experimental part

Chromatograms and LC/MS spectra were obtained on an "Agilent 1100 Series" instrument equipped with an "Agilent LC/MSD SL" detector.

1H NMR spectra (400 MHz and 500 MHz) were recorded on Varian Mercury-400 and Bruker Avance DRX 500 NMR spectrometers with TMS as an internal standard.

All reagents were obtained from commercially available sources (Aldrich, Fluka) and used without additional purification. DMF was freshly distilled and dried by a standard method. The amount of water in the solvents (<0.05%) was controlled by the Fischer method using a Mettler Toledo DL31 KF Titrator. Melting points were measured on a Buchi instrument. Before determining the melting point, performing elemental analysis and spectral studies, all product samples were dried for 3-5 hours in a vacuum of 12-15 mm. Hg. at 80-100°C.

General procedure for the synthesis of tetrahydropyrimidinone and tetrahydropyrimidinethione derivatives from unsubstituted ureas and thioureas.

To a solution of 0.022 mmol of urea or thiourea in 20 ml of DMF, 0.01 mmol of aldehyde and 0.01 mmol of pyruvic acid carboxy derivative are added and stirred until dissolved. Then 15 ml (~ 0.12 mmol) of Me3SiCl are added and quickly stoppered. The flask with the reaction mixture is left for 48 hours at room temperature. After the reaction is complete (a sign is the stratification of the reaction mass), the reaction mass is poured with stirring into 50-60 ml of ice water. The precipitate that has formed is filtered, washed with water and 2-3 times with methanol in portions of 10 ml. The filtered precipitate is dried in air. Recrystallized from methanol. Yields of target products are 80-86%.

5-Benzoyl-2-oxo-6-phenyl-1,2,3,6-tetrahydropyrimidine-4-ethylcarboxylate (2d). Yield: 85%. M.p. 176 °C. ^{1}H NMR (δ, ppm): 0.85 (t, $3J_{HH}$ = 7.1 Hz, 3H, CH_2 CH_3), 3.50-3.72 (m, 2H, CH_2CH_3), 5. (s, 1H, 4-H), 7.23 (m, 3H, 2,4,6-HPh), 7.31 (t, $3J_{HH}$ = 7.2 Hz, 2H, 3,5-HPh), 7.38 (t, $3J_{HH}$ = 7.8 Hz, 2H, 3,5-HPh), 7.46-7.54 (d+t, $3J_{HH}$ = 7/8 Hz, 3H, 2,4,6-HPh), 7.86(s, 1H, NH), 9.16(s, 1H, NH). ^{13}C NMR (125 MHz, DMSO-d_6, δ ppm): 13.5b 56.8, 62.3, 115.0, 126.9, 128.4, 128.9,129.2, 133.1, 133.9,

138.6, 142.9, 152.3, 161.9, 193.6. MS (m/z): $M^{+\bullet}$ = 350. Calc. for $C_{20}H_{18}N_2O_4$: C 68.56, H 5.18, N 8.00, O 18.27. Found: C 68.42, H 5.30, N 8.08.

5-Benzoyl-6-phenyl-2-thiooxo-1,2,3,6-tetrahydropyrimidine-4-ethylcarboxylate (2e). Yield: 80%. M.p. 185 °C. ^{1}H NMR (δ, ppm): 0.88 (t, $3J_{HH}$ = 7.1 Hz, CH_2CH_3), 3.64 (m, 2H, CH_2CH_3), 5.32 (d, $3J_{HH}$ = 2.9 Hz, 1H, 4-H), 7.21 (d, $3J_{HH}$ = 7.6 Hz, 2, 6-HPh), 7.28 (t, $3J_{HH}$ = 7.6 Hz, 1H, 4-HPh), 7.35 (t, $3J_{HH}$ = 7.6 Hz, 2H, 3,5-HPh), 7.40 (t, $3J_{HH}$ = 7.8 Hz, 3,5-HPh), 7/50 (d, $3J_{HH}$ = 7.8 Hz, 2H, 2.6-HPh), 7.54 (t, $3J_{HH}$ = 7.8 Hz, 1H, 4-HPh), 9.79 (s, 1H, NH), 10.26 (s, 1H, NH). ^{13}C NMR (125 MHz, DMSO-d_6, δ ppm): 13.6, 56.4, 62.6, 115.5, 127.0, 128.5, 128.8, 129.0 129.3, 131.9, 133.4, 138.1, 141.9, 161.5, 174.9, 193.4. MS(m/z): $M^{+\bullet}$ = 366. Calc. for $C_{20}H_{18}N_2O_3S$: C 65.56, H 4.95, N 7.64, O 13.10, S 8.75. Found: C 65.39, H 5.07, N 7.72, S 8.68.

5-(4-Chlorobenzoyl)-6-(4-chlorophenyl)-2-oxo-1,2,3,6-tetrahydropyrimidine-4-ethylcarboxylate (2f). Yield: 86%. M.p. 140 °C. ^{1}H NMR (δ, ppm): 0.89 (t, $3J_{HH}$ =7.1 Hz, 3H, CH_2CH_3), 3.56 (m, 2H, CH_2CH_3), 5.43 (d, $3J_{HH}$ = 2.9 Hz, 1H, 4-H), 7.42 (d, $3J_{HH}$ = 7.6 Hz, 1H, 2,6-HPh), 7.32 (t, $3J_{HH}$ = 7.6 Hz, 1H, 4-HPh), 7.34 (t, $3J_{HH}$ = 7.6 Hz, 3,5-HPh), 7.31 (t, $3J_{HH}$ = 7.8 Hz, 2H, 3,5-HPh), 7.48 (d, $3J_{HH}$ = 7.8 Hz, 2H, 2,6-HPh), 7.64 (t, $3J_{HH}$ =7.8 Hz, 1H, 4-HPh), 9.69 (s, 1H, NH), 10.37 (s, 1H, NH). ^{13}C NMR (125 MHz, DMSO-d_6, δ ppm): 14.6, 57.7, 62.8, 114.5, 127.6, 128.5, 123.8, 139.0, 127.1, 132.8, 134.4, 138.1, 141.9, 162.5, 174.9, 193.4. MS (m/z): $M^{+\bullet}$ = 419. Calc. for $C_{22}H_{16}Cl_2N_2O_4$: C 57.30, H 3.85, Cl 16.91, N 6.68, O 15.26. Found: C 56.36, H 3.71, N 6.74.

General procedure for the synthesis of tetrahydropyrimidinone and tetrahydropyrimidinethione derivatives from monosubstituted ureas and thioureas.

To a solution of 0.022 mmol of urea or thiourea in 20 ml of DMF, 0.01 mmol of aldehyde and 0.01 mmol of carboxy derivative of pyruvic acid are added and stirred until dissolved. Then 15 ml (~0.12 mmol) of Me3SiCl are added and immediately sealed. The reactor with the reaction mixture is left for 4 days at room temperature.

After the reaction is complete (a sign is the stratification of the reaction mass), the reaction mass is poured with stirring into 50-60 ml of ice water. The precipitate that has formed is filtered, washed with water and 2-3 times with methanol in portions of 10 ml. The filtered precipitate is dried in air. Recrystallized from methanol. The yields of the target products are 82-90%.

5-Benzoyl-3-methyl-2-oxo-6-phenyl-1,2,3,6-tetrahydropyrimidine-4-ethylcarboxylate (2b). Yield: 89%. M.p. 168 °C. ^{1}H NMR (δ ppm): 0.99 (t, $3J_{HH}$ = 7.1. Hz, 3H, CH_2CH_3), 3.00 (s, 3H, NCH_3), 3.63 (q, $3J_{HH}$ = 7.1 Hz, 2H, CH_2CH_3), 5.30 (d, $3J_{HH}$ = 2.9 Hz, 4-H), 7.19 (d, $3J_{HH}$ = 7.5 Hz, 2H, 2,6-HPh), 7.26 (t, $3J_{HH}$ = 7.5 Hz, 1H, 4-HPh), 7.32 (t, $3J_{HH}$ = 7.5 Hz, 2H, 3,5-HPh), 7.41 (t, $3J_{HH}$ = 7/4 Hz, 2H, 3,5-HPh), 7.47 (d, $3J_{HH}$ =7.4 Hz, 2H, 2,6-HPh), 7.54 (t, $3J_{HH}$ = 7.4 Hz, 1H, 4-HPh), 8.20 (d, $3J_{HH}$ = 2.9 Hz, 1H, NH). ^{13}C NMR (125 MHz, DMSO-d_6, δ ppm): 13.6, 31.7, 55.1, 62.7, 114.4, 126.8, 128.4, 128.8, 129.2, 132.9, 138.4, 140.6, 142.6, 152.8, 162.5, 193.4. MS (m/z): $M^{+\bullet}$ = 364. Calc. for $C_{21}H_{20}N_2O_4$: C 69.22, H 5.53, N 7.69, O 17.56. Found: C 69.38, H 5.47, N 7.58.

5-Benzoyl-4-hydroxy-3-methyl-6-phenyl-2-thiooxo-hexahydropyrimidine-4-ethylcarboxylate (2c). Yield: 90%. M.p. 170 °C. ^{1}H NMR (δ ppm): 0.96 (t, $3J_{HH}$ =7.1 Hz, 3H, CH_2CH_3), 3.11. (s, 3H, NCH_3), 3.57 (m, 2H, CH_2CH_3), 4.63 (d, $3J_{HH}$ =11.2 Hz, 1H, 5-H), 4.95 (d, $3J_{HH}$ = 11.2 Hz, 1H, 4-H), 7.18 (t, $3J_{HH}$ = 7.4 Hz, 1H, 4-HPh), 7.25 (t, $3J_{HH}$ = 7.4 Hz, 2H, 3.5-HPh), 7.34 (s, 1H, OH, 7.40 (t, $3J_{HH}$ =8.0 Hz, 2H, 3.5-HPh), 7.44 (d, $3J_{HH}$ = 7.4 Hz, 2H, 2.6-HPh), 7.55 (t, $3J_{HH}$ = 8.0 Hz, 1H, 4-HPh), 7.66 (d, $3J_{HH}$ = 8.0 Hz, 2H, 2.6-HPh), 8.80 (s, 1H, NH). ^{13}C NMR (125 MHz, DMSO-d_6, δ ppm): 13.9, 37.0, 53.0, 54.2, 62.6, 85.6, 128.5, 128.6, 128.7, 128.9, 129.0, 133.9, 137.6, 138.7, 168.8, 178.8, 195.2. MS (m/z): $M^{+\bullet}$ = 398. Calc. for $C_{21}H_{22}N_2O_4S$: C 63.30, H 5.56, N 7.03, O 16.06, S 8.05. Found: C 63.48, H 5.44, N 6.92, S 8.2.

5-(4-Chlorobenzoyl)-6-(4-chlorophenyl)-3-methyl-2-oxo-1,2,3,6-tetrahydropyrimidine-4-ethylcarboxylate (2h). Yield: 85%. M.p. 12 °C. ^{1}H NMR (δ ppm): 0.88 (t, $3J_{HH}$ = 7.1 Hz, 3H, CH_2CH_3), 3.56 (m, 2H, CH_2CH_3), 5.43 (d, $3J_{HH}$ = 2.9 Hz, 1H, 4-H), 7.42 (d, $3J_{HH}$ =7.6 Hz, 2H,2,6-HPh), 7.32 (t, $3J_{HH}$ = 7.6 Hz, 1H, 4-HPh),

7.34 (t, $3J_{HH}$ = 7.6 Hz, 2H, 3.5-HPh), 7.31)t, $3J_{HH}$ = 7.8 Hz, 2H, 3.5-HPh), 7.48 (d, $3J_{HH}$ = 7.8 Hz, 2,6-HPh), 7.64 (t, $3J_{HH}$ =7.8 Hz, 1H, 4-HPh), 9.69 (s, 1H, NH), 10.36 (s, 1H, NH). ^{13}C NMR (125 MHz, DMSO-d_6, δ ppm): 14.6, 57.7, 62.8, 114.5, 127.6, 128.5, 123.8, 139.0, 125.1, 132.8, 134.4, 138.1, 141.9, 162.5, 174.9, 193.4. MC (m/z): $M^{+\bullet}$ = 433. Calc. for $C_{21}H_{18}Cl_2N_2O_4$: C 58.21, H 4.19, Cl 16.36, N 6.47, O 14.77. Found: C 58.36, H 4.11, N 6.74.

5-(4-Chlorobenzoyl)-6-(4-chlorophenyl)-4-hydroxy-3-methyl-2-thiooxo-hexahydropyrimidine-4-ethylcarboxylate (2g). Yield: 84%. M.p. 125°C. ^{1}H NMR (δ ppm): 0.85 (t, $3J_{HH}$ = 7.1 Hz, 3H, CH_2CH_3), 3.50-3.72 (m, 2H, CH_2CH_3), 5.33 (s, 1H, 4-H), 7.23 (m, 3H, 2,4,6,-HPh), 7.31 (t, $3J_{HH}$ = 7.2 Hz, 2H, 3,5-HPh), 7.38 (t, $3J_{HH}$ =7.8 Hz, 2H, 3,5-HPh), 7.41 (s, 1H, OH), 7.46-7.54 (d+t, $3J_{HH}$ = 7.8 Hz, 3H, 2,4,6-HPh), 7.86 (s, 1H, NH), 9.16 (s, 1H, NH). ^{13}C NMR (125 MHz, DMSO-d_6, δ ppm): 13.5, 56.8, 62.3, 115.0, 126.9, 128.4, 128.9, 129.2, 133.1, 138.6, 142.9, 152.3, 161.9, 193.6. MS (m/z): $M^{+\bullet}$ = 467. Calc. for $C_{21}H_{20}Cl_2N_2O_4S$: C 53.97, H 4.31, Cl 15.17, N 5.99, O 13.69, S 6.86. Found: C 56.36, H 4.21, N 5.76, S 8.12.

4-Hydroxy-3-methyl-6-phenyl-5-(thiophene-2-carbonyl)-2-thiooxo-hexahydropyrimidine-4-ethylcarboxylate (2i). Yield: 82%. M.p. 115 °C. ^{1}H NMR (δ ppm): 0.97 (t, $3J_{HH}$ = 7.1 Hz, 3H, CH_2CH_3), 3.00 (s, 3H, NCH_3), 3.53 (q, $3J_{HH}$ = 7.2 Hz, 2H, CH_2CH_3), 5.20 (d, $3J_{HH}$ = 2.9 Hz, 1H, 4-H), 7.19 (d, $3J_{HH}$ = 7.5 Hz, 2,6-HPh), 7.27 (t, $3J_{HH}$ = 7.5 Hz, 1H, 4-HPh), 7.32 (t, $3J_{HH}$ = 7.5 Hz, 2H, 3,5-HPh), 7.42 (t, $3J_{HH}$ = 7.4 Hz, 2H, 3,5-HPh), 7.54 (d, $3J_{HH}$ = 7.4 Hz, 2H, 2,6-HPh), 7.34 (t, $3J_{HH}$ =7.3 Hz, 1H, 4-HPh), 7.41 (s, 1H, OH), 8.30 (d, $3J_{HH}$ = 2.9 Hz, 1H, NH). ^{13}C NMR (125 MHz, DMSO-d_6, δ ppm): 13.6, 31.7, 55.1, 62.7, 114.4, 126.8, 128.4, 128.6, 128.8, 129.2, 132.9, 138.4, 140.6, 142.6, 152.7, 142.4, 193.7. MS (m/z): $M^{+\bullet}$ = 404. Calc. for $C_{19}H_{20}N_2O_4S_2$: C 56.42, H 4.98, N 6.93, O 15.82, S 15.85. Found: C 57.39, H 4.97, N 6.97, S 15.34.

3-Methyl-2-oxo-6-phenyl-5-(thiophene-2-carbonyl)-1,2,3,6-tetrahydropyrimidine-4-ethylcarboxylate (2j). Yield: 86%. M.p. 135 °C. ^{1}H NMR (δ ppm): 0.89 (t, $3J_{HH}$ = 7.1 Hz, 3H, CH_2CH_3), 3.00 (s, 3H, NCH_3), 3.53 (q, $3J_{HH}$ = 7.1

Hz, 2H, CH_2CH_3), 5.32 (d, $3J_{HH}$ =2.9 Hz, 1H, 4-H), 7.18 (d, $3J_{HH}$ =7.5 Hz, 2H, 2,6-HPh), 7.36 (t, $3J_{HH}$ = 7.5 Hz, 1H, 4-HPh), 7.33 (t, $3J_{HH}$ = 7.5 Hz, 2H, 3,5-HPh), 7.32 (t, $3J_{HH}$ = 7.4 Hz, 2H, 3,5-HPh), 7.48 (d, $3J_{HH}$ = 7.4 Hz, 2H, 2,6-HPh), 7.34 (t, $3J_{HH}$ = 7.4 Hz, 1H, 4-HPh), 8.10 (d, $3J_{HH}$ = 2.9 Hz, 1H, NH). ^{13}C NMR (125 MHz, DMSO-d_6, δ ppm): 12.5, 31.6, 55.3, 61.8, 124.1, 127.8, 129.1, 124.6, 124.8, 130.7, 131.9, 137.4, 141.5, 142.6, 162.9, 163.5, 192.4. MS (m/z): $M^{+\bullet}$ = 370. Calc. for $C_{19}H_{18}N_2O_4S$: C 61.61, H 4.90, N 7.56, O 17.28, S 8.66. Found: C 61.39, H 4.49, N 7.57, S 8.56.

5-(Furan-2-carbonyl)-3-methyl-2-oxo-6-phenyl-1,2,3,6-tetrahydropyrimidine-4-ethylcarboxylate (2k). Yield 85%. M.p. 150 °C, ^{1}H NMR (δ ppm): 0.96 (t, $3J_{HH}$ =7.1 Hz, 3H, CH_2CH_3), 3.00 (s, 3H, NCH_3), 3.53 (q, $3J_{HH}$ = 7.2 Hz, 2H, CH_2CH_3), 5.20 (d, $3J_{HH}$ = 2.9 Hz, 1H, 4-H), 7.19 (d, $3J_{HH}$ = 7.5 Hz, 2H, 2,6-HPh), 7.27 (t, $3J_{HH}$ = 7.5 Hz, 1H, 4-HPh), 7.32 (t, $3J_{HH}$ = 7.5 Hz, 2H, 3,5-HPh), 7.42 (T, $3J_{HH}$ = 7.4 Hz, 2H, 3,5-HPh), 7.54 (d, $3J_{HH}$ = 7.4 Hz, 2H, 2,6-HPh), 7.34 (t, $3J_{HH}$= 7.3 Hz, 1H, 4-HPh), 7.34 (s, 1H, OH), 8.30 (d, $3J_{HH}$ = 2.9 Hz, 1H, NH). ^{13}C NMR (125 MHz, DMSO-d_6, δ ppm): 13.6, 31.7, 55.1, 62.7, 114.4, 126.8, 128.4, 128.6, 128.8, 129.2, 132.9, 138.4, 140.6, 142.6, 152.7, 142.4, 193.6. MS (m/z): $M^{+\bullet}$ = 388. Calc. for $C_{19}H_{18}N_2O_5$: C 64.40, H 5.12, N 7.91, O 22.58. Found: C 65.39, H 5.15, N 7.17.

5-(Furan-2-carbonyl)-3-methyl-2-oxo-6-phenyl-1,2,3,6-tetrahydropyrimidine-4-ethylcarboxylate (2l). Yield 85%. M.p. 140 °C. ^{1}H NMR (δ ppm): 0.88 (t, $3J_{HH}$ = 7.2 Hz, 3H, CH_2CH_3), 3.02 (s, 3Y, NCH_3), 3.61 (q, $3J_{HH}$ = 7.2 Hz, 2H, CH_2CH_3), 5.11 (d, $3J_{HH}$ = 2.9 Hz, 1H, 4-H), 7.18 (d, $3J_{HH}$ = 7.6 Hz, 2H, 2,6-HPh), 7.34 (t, $3J_{HH}$ = 7.5 Hz, 1H, 4-HPh), 7.14 (t, $3J_{HH}$ = 7.5 Hz, 2H, 3,5-HPh), 7.29 (t, $3J_{HH}$ = 7.5, Hz, 2H, 3,5-HPh), 7.56 (d, $3J_{HH}$ =7.4 Hz, 2H, 2,6-HPh), 7.27 (t, $3J_{HH}$ = 7.3 Hz, 1H, 4-HPh), 7.17 (s, 1H, OH), 8.14 (d, $3J_{HH}$ = 2.9 Hz, 1H, NH). ^{13}C NMR (125 MHz, DMSO-d_6, δ ppm): 14.7, 32.3, 51.3, 62.7, 115.4, 127.9, 127.1, 129.7, 130.1, 133.7, 139.2, 141.7, 143.2, 153.6, 151.1, 180.6. MS (m/z): $M^{+\bullet}$ = 354. Calc. for $C_{19}H_{18}N_2O_5$: C 64.40, H 5.12, N 7.91, O 22.58. Found: C 65.42, H 5.17, N 7.71.

5-(Cyclopropane-carbonyl)-4-hydroxy-3-methyl-6-phenyl-2-thiooxo-hexahydropyrimidine-4-ethylcarboxylate (2m). Yield 89%. M.p. 155 °C. ^{1}H NMR

(δ ppm): 0.84 (t, $3J_{HH}$ = 7.3 Hz, 3H, CH_2CH_3), 3.45 (s, 3H, NCH_3), 3.57 (q, $3J_{HH}$ = 7.2 Hz, CH_2CH_3), 5.34 (d, $3J_{HH}$ = 2.9 Hz, 1H, 4-H), 7.21 (d, $3J_{HH}$ = 7.6 Hz, 2H, 2,6-HPh), 7.32 (t, $3J_{HH}$ =7.5 Hz, 1H, 4-HPh), 7.37 (t, $3J_{HH}$ = 7.4 Hz, 2H, 3,5-HPh), 7.43 (t, $3J_{HH}$ =7.4 Hz, 2H, 3,5-HPh), 7.59 (d, $3J_{HH}$ =7.4 Hz, 2H, 2,6-HPh), 7.41 (t, $3J_{HH}$ = 7.3 Hz, 1H, 4-HPh), 7.44 (s, 1H, OH), 8.41 (d, $3J_{HH}$ =2.9 Hz, 1H, NH). ^{13}C NMR (125 MHz, DMSO-d_6, δ ppm): 14.2, 31.3, 55.4, 61.8, 115.1, 127.9, 124.6, 123.6, 127.4, 130.1, 134.9, 139.4, 141.7, 144.6, 153.8, 141.1, 197.7. MS (m/z): $M^{+\bullet}$ = 362. Calc. for $C_{18}H_{22}N_2O_4S$: C 59.65, H 6.12, N 7.73, O 17.66, S 8.85. Found: C 5952, H 6.15, N 7.79, S 8.71.

5-(Cyclopropane-carbonyl)-3-methyl-2-oxo-6-phenyl-1,2,3,6-tetrahydropyrimidine-4-utilcarboxylate (2n). Yield 82%. M.p. 158 °C. ^{1}H NMR (δ ppm): 0.95 (t, $3J_{HH}$ =7.2 Hz, 3H, CH_2CH_3), 3.05 (s, 3H, NCH_3), 3.51 (q, $3J_{HH}$ = 7.0 Hz, 2H, CH_2CH_3), 5.11 (d, $3J_{HH}$ = 2.8 Hz, 1H, 4-H), 7.20 (d, $3J_{HH}$ =7.5 Hz, 2H, 2.6-HPh), 7.29 (t, $3J_{HH}$ = 7.5 Hz, 1H, 4-HPh), 7.12 (t, $3J_{HH}$ = 7.5 Hz, 2H, 3.5-HPh), 7.53 (t, $3J_{HH}$ = 7.4, Hz, 2H, 3,5-HPh), 7.64 (d, $3J_{HH}$ = 7.4 Hz, 2H, 2,6-HPh), 7.35 (t, $3J_{HH}$ = 7.3 Hz, 1H, 4-HPh), 7.44 (s, 1H, OH), 8.41 (d, $3J_{HH}$ = 2.9 Hz, 1H, NH). ^{13}C NMR (125 MHz, DMSO-d_6, δ ppm): 13.8, 31.4, 56.2, 63.7, 115.4, 128.9, 128.1, 128.2, 128.7, 133.7, 137.4, 141.5, 142.8, 152.2, 142.5, 193.7, MS (m/z): $M^{+\bullet}$ = 328. Calc. for $C_{18}H_{20}N_2O_4$: C 65.84, H 6.14, N 8.53, O 19.49. Found: C 66.05, H 6.12, N 8.71.

5-Benzoyl-4-hydroxy-3,6-diphenyl-2-thiooxo-hexahydropyrimidine-4-ethylcarboxylate (2p). Yield 85%. M.p. 156 °C. 1H NMR (δ ppm): 0.94 (t, $3J_{HH}$ =7.1 Hz, 3H, CH_2CH_3), 3.01 (s, 3H, NCH_3), 3.53 (q, $3J_{HH}$ = 7.2 Hz, 2H, CH_2CH_3), 5.20 (d, $3J_{HH}$ = 2.9 Hz, 4-H), 7.19 (d, $3J_{HH}$ = 7.5 Hz, 2H, 2.6-HPh), 7.27 (t, $3J_{HH}$ = 7.5 Hz, 1H, 4-HPh), 7.32 (t, $3J_{HH}$ = 7.5 Hz, 3.5-HPh), 7.42 (t, $3J_{HH}$ = 7.4 Hz, 2H, 3,5-HPh), 7.54 (d, $3J_{HH}$ = 7.4 Hz, 2H, 2,6-HPh), 7.34 (t, $3J_{HH}$ = 7.3 Hz, 1H, 4-HPh), 7.34 (s, 1H, OH), 8.36 (d, $3J_{HH}$ = 2.9 Hz, 1H, NH). ^{13}C NMR (125 MHz, DMSO-d_6, δ ppm): 13.6, 31.7, 55.1, 62.7, 114.4, 126.8, 127.6, 127.8, 128.4, 128.5, 128.8, 129.2, 132.9, 138.4, 140.6, 142.6, 152.7, 142.4, 193.6. MS (m/z): $M^{+\bullet}$ = 460. Calc. for $C_{26}H_{24}N_2O_4S$: C 67.81, H 5.25, N 6.08, O 13.90, S 6.96. Found: C 67.75, H 5.34, N 6.01, S 6.87.

General procedure for the synthesis of similar tetrahydropyrimidinones and terahydropyrimidinones from disubstituted compounds and thiosections.

Add 0.010 mmol of aldehyde and 0.010 mmol of carboxy-like pyruvic acid to 20 ml of DMF to dissolve 0.022 mmol of carboxylic pyruvic acid and mix until dissolved. Then add 15 ml (~0.12 mmol) Me_3SiCl and tightly cover it with a crust. Dissolve n 3 additives at room temperature. After the reaction is complete (which means the reaction mass has dissolved), pour the reaction mass into 50-60 ml of cold water while stirring. The precipitate that has been drained is filtered, washed with water and 2-3 times with methanol in portions of 10 ml. After filtering, dry the sediment in the air. Recrystallize with ethanol. The yield of whole products is 78-83%.

5-Benzoyl-1,3-dimethyl-2-oxo-6-phenyl-1,2,3,6-tetrahydropyrimidine-4-ethylcarboxylate (2a). Yield 78%. M.p. 180 °C. 1H NMR (δ ppm): 0.97 (t, $3J_{HH}$ = 7.0 Hz, 3H, CH_2CH_3), 2.81 (s, 3H, NCH_3), 3.07 (s, 3H, NCH_3), 3.58 (m, 2H, CH_2CH_3), 5.38 (s, 2H, 4-H), 7.21 (d, $3J_{HH}$ = 7.4 Hz, 2.6-HPh), 7.31 (t, $3J_{HH}$ = 7.4 Hz, 1H, 4-HPh), 7.36 (t, $3J_{HH}$ = 7.4 Hz, 2H, 3.5-HPh), 7.41 (t, $3J_{HH}$ = 7.5 Hz, 2H, 3.5-HPh), 7.45 (d, $3J_{HH}$ = 7.5 Hz, 2H, 2,6-HPh), 7.54 (t, $3J_{HH}$ = 7.5 Hz, 1H, 4-HPh). ^{13}C NMR (125 MHz, DMSO-d_6, δ ppm): 13.6, 32.7, 34.4, 61.8, 62.7, 114.2, 127.1, 128.6, 128.79, 128.82, 129.4, 132.9, 138.4, 139.8, 139.9, 152.9, 162.2, 193.1. MS (m/z): $M^{+\bullet}$ = 378. Calc. for C 69.83, H 5.86, N 7.40, O 16.91. Found: C 69.98, H 5.74, N 7.29.

5-(Cyclopropylcarbonyl)-1,3-dimethyl-2-oxo-6-phenyl-1,2,3,6-tetrahydropyrimidine-4-ethylcarboxylate (2o). Yield 83%. M.p. 192 °C. ^1H NMR (δ ppm): 0.97 (t, $3J_{HH}$ = 7.0 Hz, 3H, CH_2CH_3), 2.81 (s, 3H, NCH_3), 3.07 (s, 3H, NCH_3), 3.58 (m, 2H, CH_2CH_3), 5.38 (s, 1H, 4-H), 7.21 (d, $3J_{HH}$ = 7.4 Hz, 2H, 2.6-HPh), 7.31 (t, $3J_{HH}$ = 7.4 Hz, 1H, 4-HPh), 7.36 (t, $3J_{HH}$ = 7.4 Hz, 2H, 3.5-HPh), 7.41 (t, $3J_{HH}$ = 7.5 Hz, 2H, 3,5-HPh), 7.45 (d, $3J_{HH}$ = 7.5 Hz, 2H, 2,6-HPh), 7.54 (t, $3J_{HH}$ = 7.5 Hz, 1H, 4-HPh). ^{13}C NMR (125 MHz, DMSO-d_6, δ ppm): 13.6, 32.7, 34.4, 61.8, 62.7, 114.2, 127.1, 128.6, 128.79, 128.82, 129.4 132.9, 138.4, 139.8 139.9, 152.9, 162.2, 193.1. MC (m/z): M+• = 342. Calc. for $C_{19}H_{22}N_2O_4$: C 66.65, H 6.48, N 8.18, O 18.69. Found: C 66.67, H 6.47, N 8.31.

2.1.1.5. Conclusions

1. A method for the synthesis of new terahydropyrimidinones and terahydropyrimidinethiones using carboxy derivatives of pyruvic acid as a methylenecarbonyl component has been developed and optimized.

2. It is possible to use the developed method for the synthesis of combinatorial libraries of compounds that are promising physiologically active substances.

2.1.2. A NEW APPROACH TO THE SYNTHESIS OF ADAMANTYL-CONTAINING HETEROCYCLES

2.1.2.1. Introduction.

The chemistry of derivatives of nitrogenous heterocycles attracts the attention of chemists, since these compounds are of great scientific and practical importance. They are used in the production of polymer materials, dyes, medicines, insecticides, herbicides, and plant growth regulators.

Heterocyclic compounds occupy a significant place among physiologically active substances. A special place among them is occupied by compounds having an adamantyl radical as a substituent. The specific physiological activity of such heterocycles is known from many examples. However, their availability varies quite significantly, which is determined by the method of synthesis.

Among the fused heterocycles, the most famous are indoles, quinazolines, and benzodiazepines. Pharmacophores based on them are widely presented in the literature. Condensed systems with a seven-membered heterocyl are much less common.

Nevertheless, among them, compounds have been identified that exhibit antitumor and antiviral properties, are used as psychotropic drugs [57].

However, many heterocyclic compounds are difficult to prepare, which limits their scope of application. Therefore, the search for new regioselective heterocyclizations based on available reagents is very relevant. Such reagents currently include various adamantyl-containing compounds and amidoalkylating agents based on them.

Particular attention should be paid to the presence of an adamantyl fragment in the composition of amidoalkylating agents. Pharmacologists are well aware that the

presence of such a fragment can impart unique pharmacophoric properties to compounds.

2.1.2.2. Materials and methods

The reagents of the company Lankaster were used. IR spectra were obtained on a Specord 751R spectrometer for samples in KBr tablets containing 0.25% of the substance. Or in a thin film, layer thickness 0.6 mm. PMR spectra were taken on Bruker AVANCE III HD (400 MHz).GLC analysis was carried out on a Цвет-500 device, glass column 2000x3 mm, 15% Apiezon L on Inerton N-AW-HMDS carrier, temperature 150-260°C (10 deg/min), carrier gas – helium (40 ml/min). The mixtures were separated by column chromatography on Silicagel L 40/100 sorbent. Chromatomass spectra are measured on the Hewlett-Packard 5890-II device with a detector MSD 59771A (capillary 30 m, HP-1, 100-250 ^{o}C, 10^{o} / min).

The structure of intermediate and final compounds was proved by IR and ^{1}H, ^{13}C NMR spectrometry and mass spectroscopy.

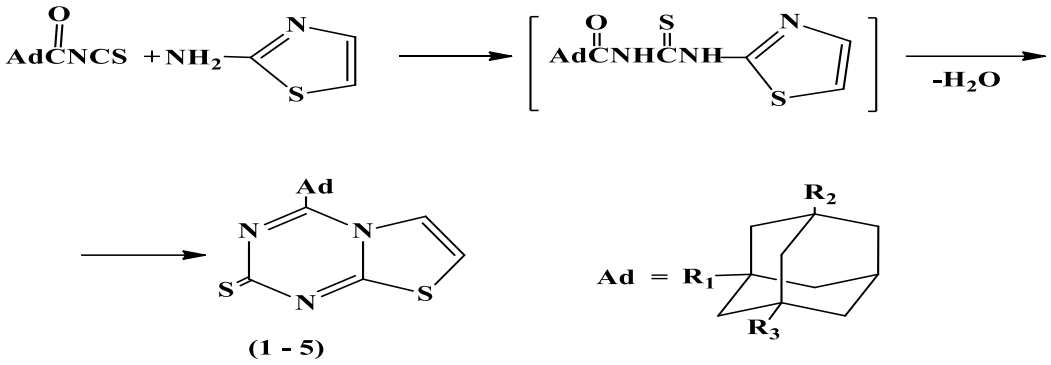
2.1.2.3. Results and discussion

2.1.2.3.1. Condensation of adamantoilizotiocyanate with 2-aminotiazol.

Thiazole derivatives show pharmacological activity: antimicrobial antiviral and antihistamines, diuretics and mitodepressants.

We have found that the interaction of adamantoylisothiocyanates with 2-aminothiazole in anhydrous acetone causes spontaneous condensation of intermediate N-acylthioureas into the corresponding alkyl-5-thioxo-3-thia-4,6,7a-triazaindene (1 - 5).

The yields of the reaction products ranged from 65 to 78%.

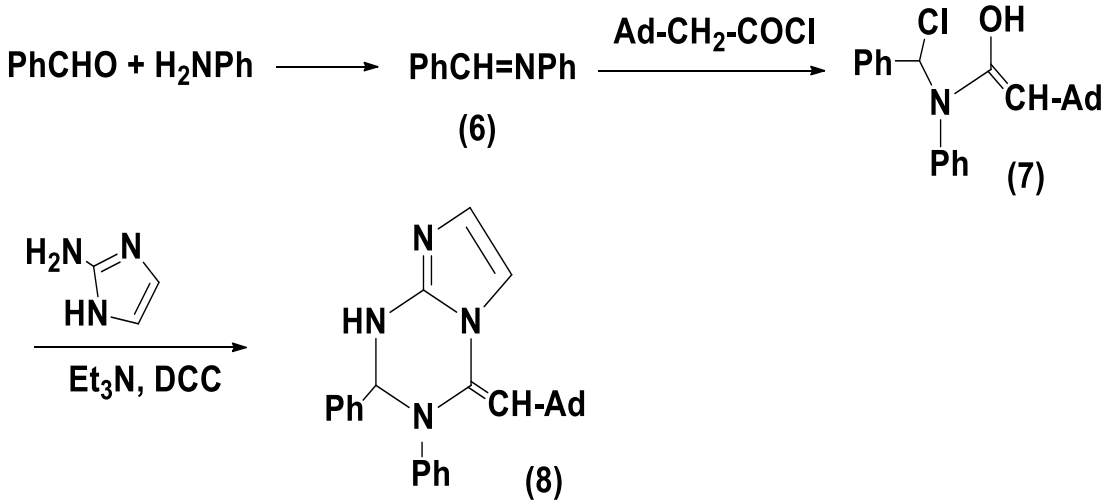


1: R_1=R_2=R_3=H; 2: R_1=R_2=H, R_3=CH_3; 3: R_1=H, R_1=R_3=CH_3; 4: R_1=R_2=R_3=CH_3; 5: R_1=R_2=H, R_3=CH_3, p-Ph

2.1.2.3.2. Example of synthesis of condensed 1,3,5-hexahydrotriazine system using adamantylcontaining iminoalkylating reagent.

1,3,5-Triazines are usually most readily prepared by reactions of 2,4,6-trichloro-1,3,5-triazine. However, the ring system can also be synthesized by condensation reactions.

The starting compound for the synthesis of the imidoalkylating reagent (7) was Schiff's base (6), which was obtained from benzaldehyde and aniline by a standard procedure. After isolation, imine (6) was treated with 1-adamantylacetic acid chloranhydride in dichloroethane. Equimolar amounts of 2-amino-imidazole as a condensation component, triethylamine and dicyclohexylcarbodiimide (DCC) were added to product (7) without isolation. The reaction took place at reflux for 2 hours. The yield of the condensation product (8) was 43%.



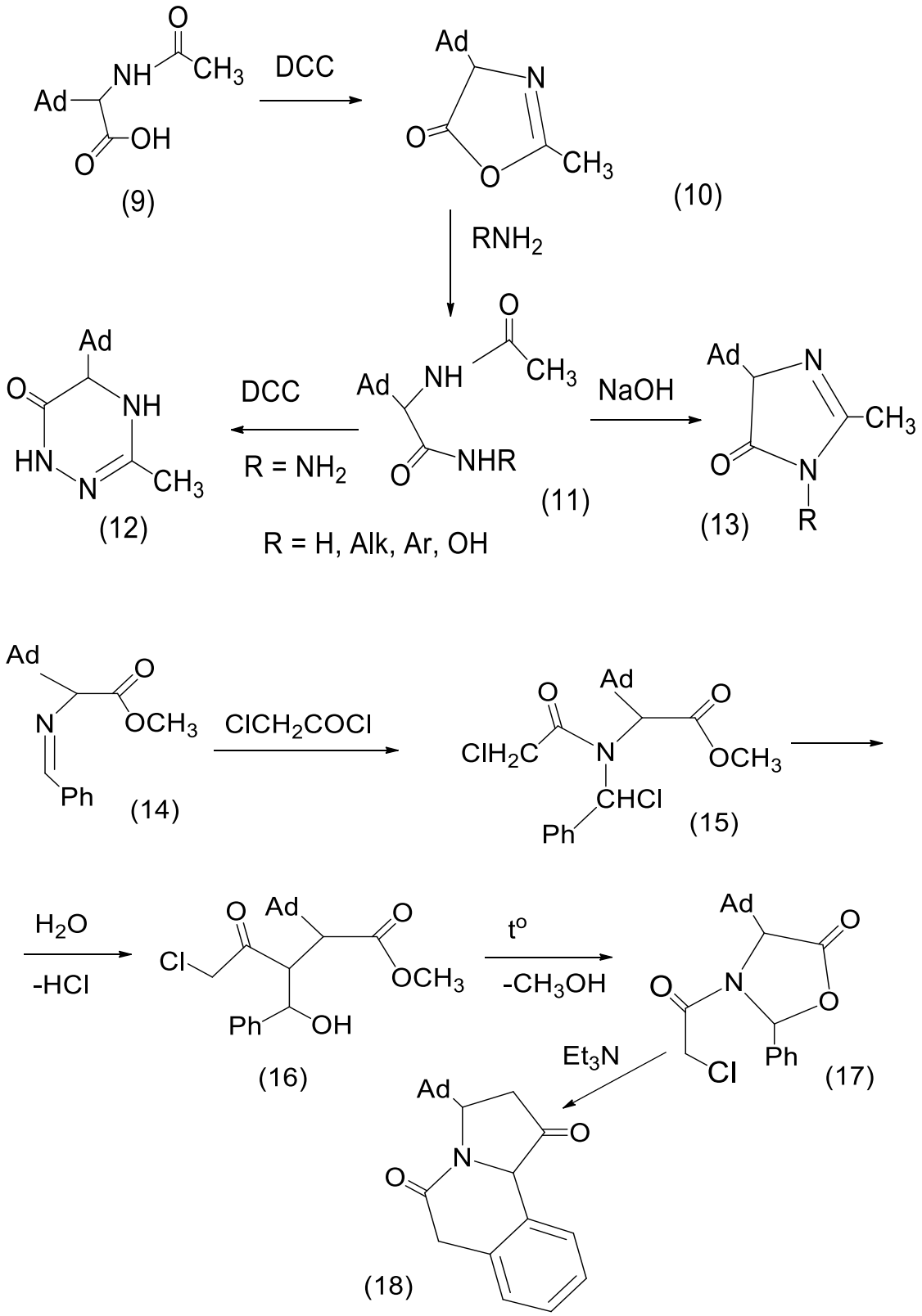
The method developed by us for the synthesis of compound (8) is a separate example of the synthesis of such systems. Wide possibilities for obtaining a family of similar compounds are opened by varying the substituents in the starting imide, adamantyl radical, and amine condensation component.

2.1.2.3.3. Cyclization of 1-adamantylglycine derivatives.

The intramolecular cycles discussed in this section necessarily involve a functional substituent in the α-position to the adamantium nucleus and proceed, in most cases, with the participation of the amide group.

As can be seen from the scheme, treatment of acylated 1-adamantylglycine (9) with dicyclohexylcarbodiimide (DCC) in dry chloroform leads to oxazolone (10). Cleavage of the latter with various nucleophiles: ammonia, primary and secondary amines, hydroxylamine, hydrazine and its organic derivatives gives derivatives of α-acylaminocarboxylic acid (11). Upon dehydration of synthons (11), depending on their structure and condensation conditions, derivatives of 2-imidazolin-5-one (13) and 1,2,4-triazine (12) are obtained. The yields of compounds (10), (12), (13) were 85%, 73%, 77%, respectively.

Another important synthon derived from 1-adamantylglycine is the Schiff base (14). The amidoalkylatin reagent (15) was obtained from it by treatment with monochloroacetic acid chloride in toluene. Without isolation, it was converted to an oxy derivative (16). Oxazolone (17) was obtained by azeotropic distillation of methanol in 84% yield. The addition of triethylamine to a solution of compound (17) in benzene, followed by reflux for 3 hours, resulted in heterocycle closure (18) in 69% yield [58].



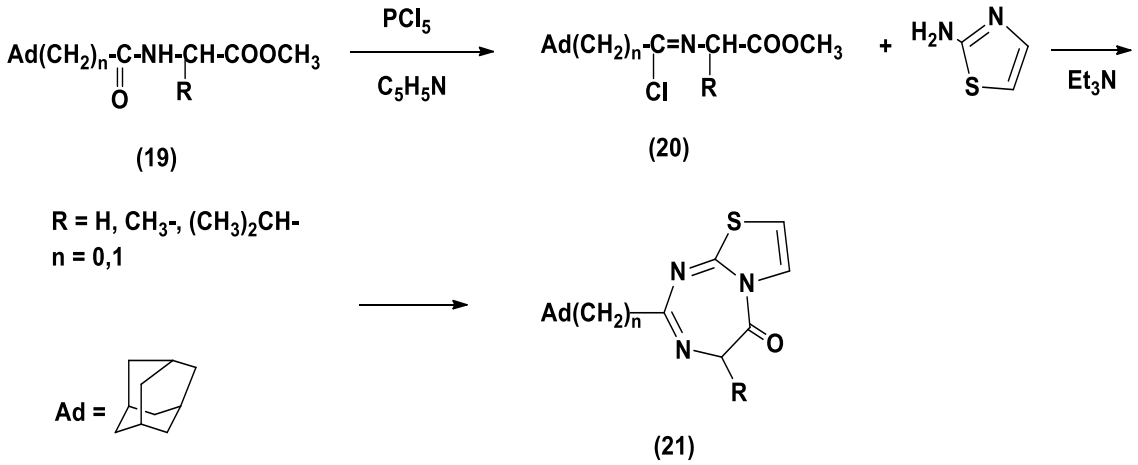
2.1.2.3.4. Synthesis of adamantylcontaining triazepinones.

This work describes the synthesis of adamantylcontaining triazepinones by condensation of natural amino acid derivatives with 2-aminothiazole.

Adamantyl-containing derivatives of natural glycine, L and D alanine, L and D valine (19) were obtained by the method [59] from methyl esters of the corresponding amino acids and acid chlorides of adamantyl-1-carboxylic and adamantyl-1-acetic acids. The esters of adamantylcontaining amino acids were hydrolyzed under alkaline conditions to N-acyl-α-amino acids. Which may be of interest as objects for biological research [60].

For the synthesis of imidoylchlorides (20) with retention of the ester group, a mixture of pyridine with phosphorus pentachloride was used [61].

Condensation of imidoyl chlorides (20) with 2-aminothiazole occurred in the presence of triethylamine with the formation of condensed heterocycle (21).



The yields of triazepinones depending on the adamantylcontaining amino acid fragment are shown in the table 1.

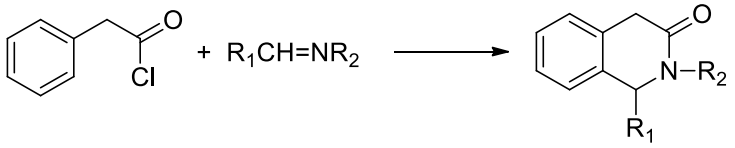
Table 1.

The yields of triazepinones depending on the adamantylcontaining amino acid fragment

Radical	Yield of products condensation , %		
	DL	L	D
1-Adamantoyl-N-glycin	51		
1-Adamantoyl-N-alanin		56	45
1-Adamantoyl-N-valin		58	47
1-Adamantoylmethyl-N-glycin	66		
1-Adamantoylmethyl-N-alanin		71	69
1-Adamantoylmethyl-N-valin		70	72

2.1.2.3.5. Synthesis of adamantylcontaining 3- oxotetrahydroisoquinolines.

The core of tetrahydrozoquinoline is part of such well-known alkaloids as coripulin, glauzin, pronunciferin and others. Many of them exhibit antimicrobial, antispasmithin, anti-inflammatory activity. On the other hand, it is known that the presence of volumetric frame substituents (adamantyl, diamantyl, etc.) in a molecule with pharmacophoric groups increases lipophilicity, reduces toxicity, in some cases significantly increases the activity of drugs.



(22), (23)

(22): R_1=Ph; R_2=Ad-, $AdCH_2$-, $AdCH_2CH_2$-

(23): R_1=$AdCH_2$-, R_2=Ph

The purpose of the work presented is to synthesize potential active drugs containing in positions 1 and 2 of the isochinolin nucleus various adamantyl-containing radicals.

The bases of Schiff was synthesized by method [62]. For the preparation of structures presented in the scheme, a method of amidoalkylating agents - the bases of Schiff [9] were used. The latter were synthesized on the basis of benzaldehyde and adamantyl-containing amines and 2- (1-adamantyl) of ethanal and aniline .

The reaction was carried out in a dichloroethane medium and the presence of excess triethylamine.

The outputs of the target products were: for R_2 = Ad - 78%, $AdCH_2$ - 84%, $AdCH_2CH_2$ - 87%, R_2 = $AdCH_2$ - 66%.

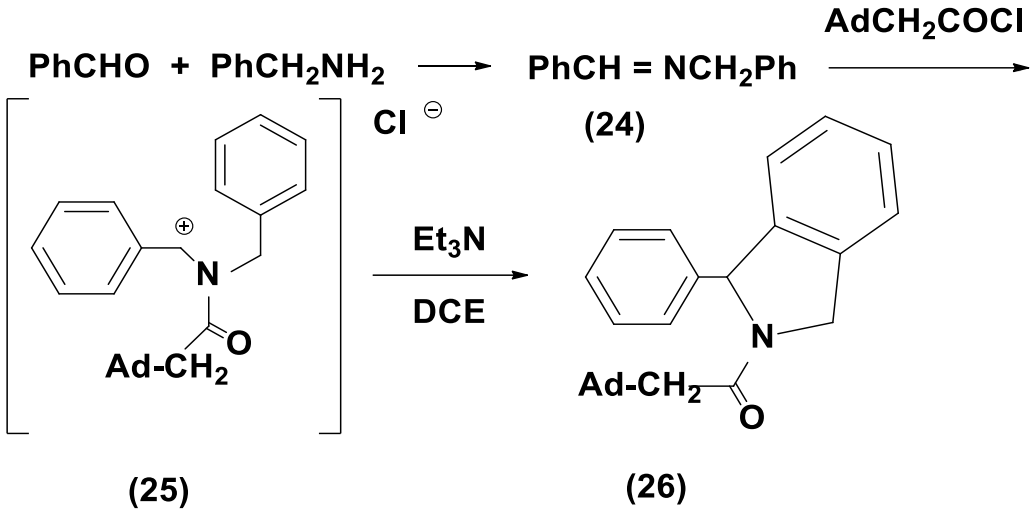
A convenient method of synthesis of potentially physiologically active adamantyl-containing 3-oxotetrahydroisoqinolins has been developed.

2.1.2.3.6. Synthesis of adamantanecontaining derivatives of dihydroisoindole.

Heterocyclic compounds occupy a significant place among physiologically active substances. Among the fused heterocycles, the most famous are indoles, quinazolines, benzodiazepines. Pharmacophores based on them are widely represented in the literature.

To obtain the structures presented in the scheme, the method of amidoalkylating agents - Schiff bases (24) was used [57]. The latter were synthesized on the basis of benzaldehyde and benzylamine. To obtain acyliminium salt (25), 1-adamantylacetic acid chloranhydride was used.

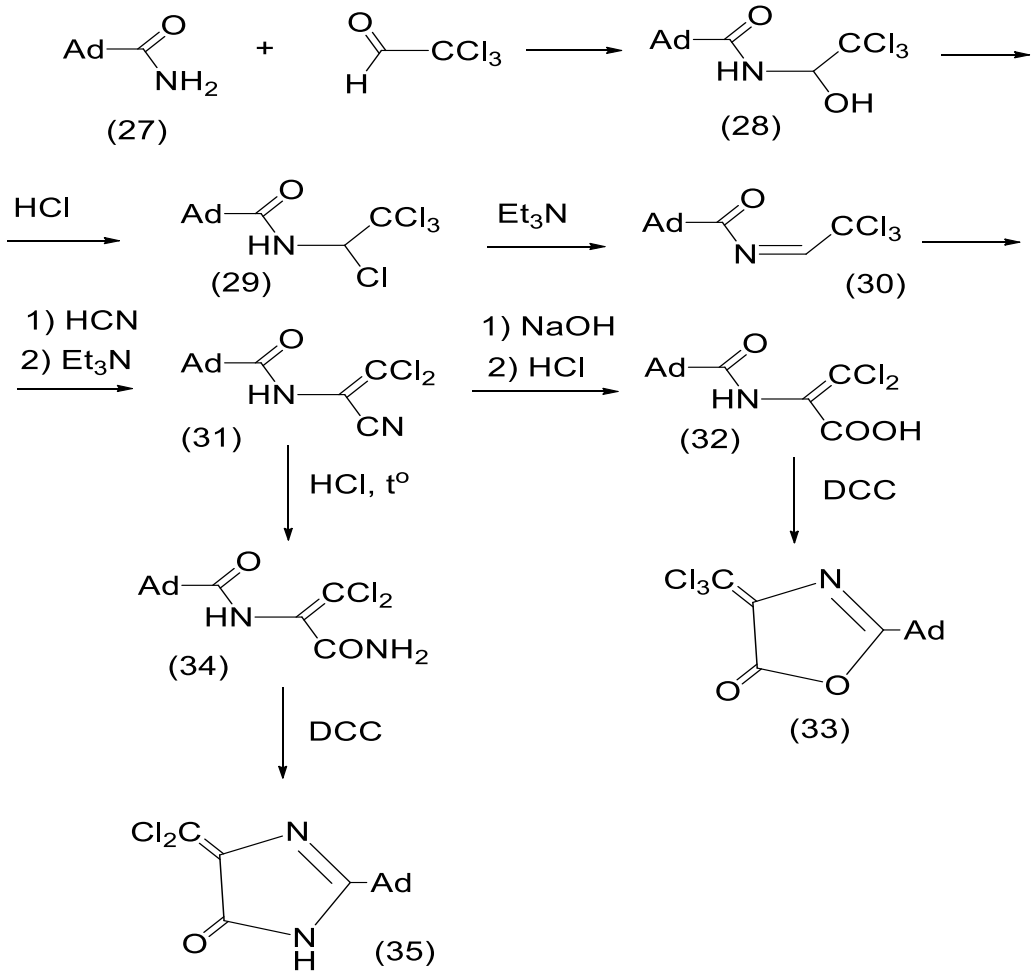
Heating a solution of an acyliminium salt in a solution of dichloroethane in the presence of triethylamine led with a yield of 58% to an isoindole derivative - N- [1-adamantylmethylcarboxy] -2-phenyldihydroisoindole (26).



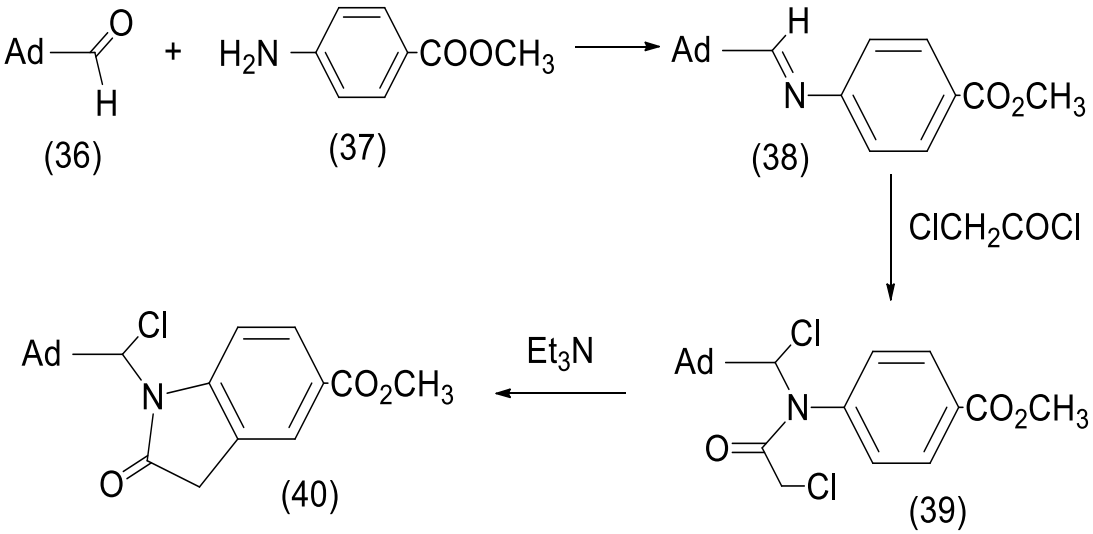
2.1.2.3.7. Examples of the synthesis of heterocycles based on adamanthyl-containing amidoalkylating reagents.

Syntheses were carried out according to standard procedures. Some of them are given in the monograph [58].

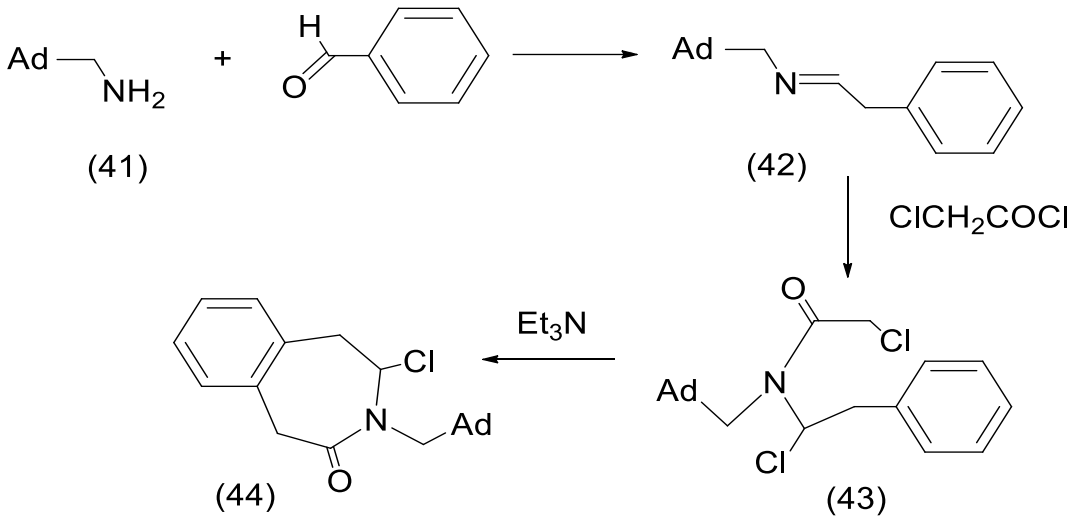
The scheme shows the scheme for the synthesis of imidoalkylating reagents (32) and (34) [57]. Treatment of (6) with dicyclohexylcarbodiimide (DCC) in dry chloroform gave oxazolone (33) in 87% yield. Similarly, heterocycle (35) was obtained from amide (34) in 85% yield.



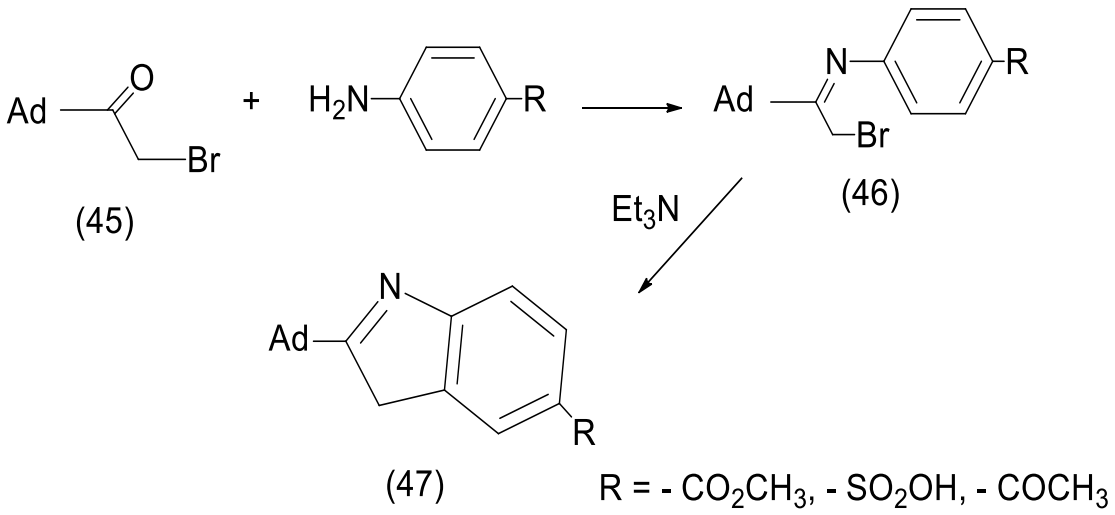
The following scheme shows the synthesis of heterocycle (40) from reagent (39) [57]. The concerted alkylation proceeds by refluxing in dry toluene in the presence of an equimolar amount of triethylamine. The yield of product (40) was 91%.



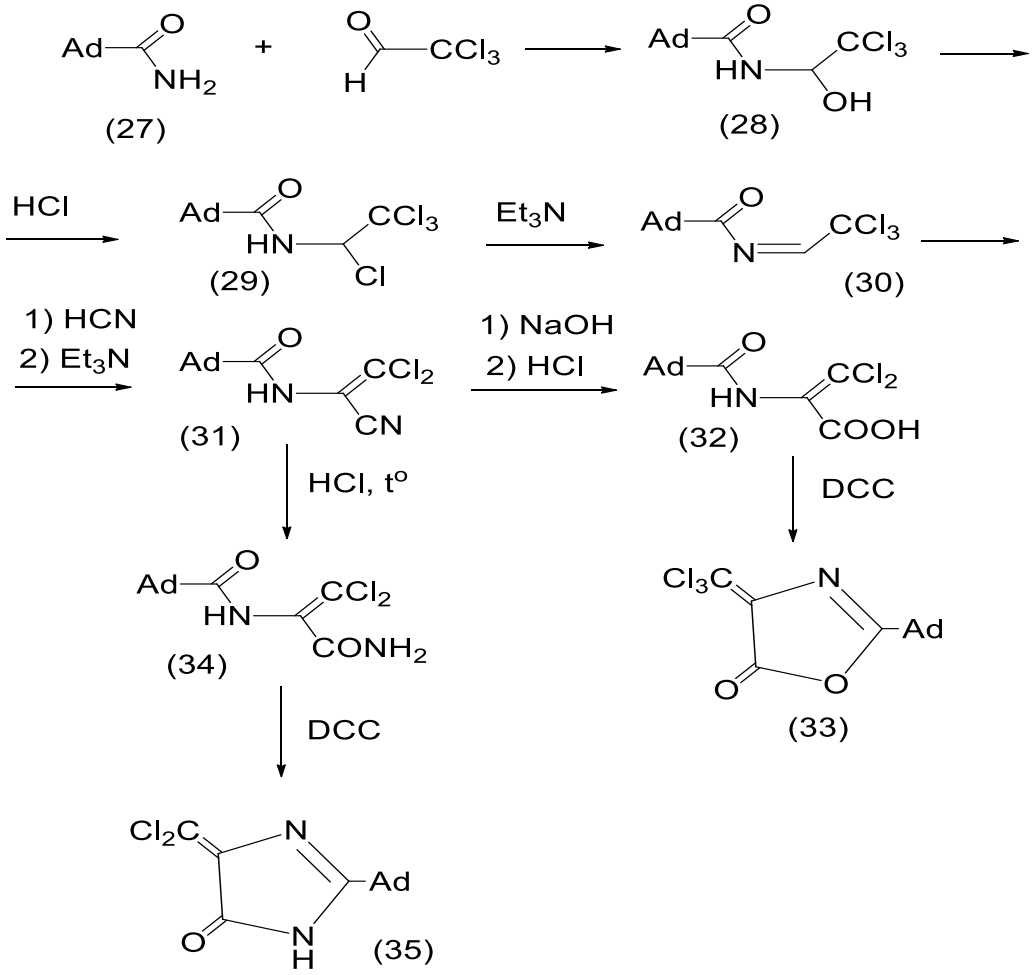
The use of amine (41) and its homologues as components for the preparation of Schiff bases (42) and then the N-acylated precursor (43) [57] made it possible to synthesize seven-membered condensed lactam (44) in 49% yield.



Of particular interest is the Schiff base (46), since it allows one to obtain hard-to-reach heterocycles (47) in one step. The substituents on the parent amine must be electron withdrawing groups to ensure consistent orientation during alkylation. The yields of heterocycles (47), depending on the substituent, were 57%, 63%, and 60%, respectively.



The following two examples show the introduction of the pharmacophore group of 1-adamantylglycine into heterocycles (51) and (55). Yields (51) and (55), however, were mediocre at 39% and 43%, respectively.



2.1.2.4. Conclusions

Methods for the synthesis of amidoalkating reagents containing an adamantane radical have been developed for the first time. On their basis, various nitrogen-containing heterocycles have been synthesized, which may be of interest as physiologically active substrates.

2.1.3. Synthesis of adamantyl-containing amid alkyling agents and nitrogen-containing heterocyles based on them

2.1.3.1. Introduction

The chemistry of nitrogen heterocyclic derivatives has attracted the attention of many researchers. They are finding increasing application in the production of polymeric materials, dyes, pharmaceuticals, insecticides, herbicides, and plant growth regulators. Therefore, the search for new regioselective heterocyclizations based on readily available reagents is highly relevant. Such promising reagents include various amidoalkylating agents suitable for a number of characteristic cyclizations that cannot be achieved with aminoalkylating agents.

Preparation of Reagents. Typical amidoalkylating agents with the characteristic >C(OH)NHCOR fragment are usually prepared by reacting carboxylic acid amides, alkyl carbamates, and ureas with aldehydes, ketones, or α-dicarbonyl compounds [63-70].

Most aliphatic and aromatic aldehydes do not form stable N-1-hydroxyalkyl derivatives with amides. The stability of the latter is significantly increased by the introduction of electron-withdrawing substituents into the alkyl residue. The most important of these are the products of the reaction of chloral with primary amides of the general formula RCONHCH(OH)CCl3, which are readily formed by heating equimolecular quantities of the reagents without a catalyst or in the presence of sulfuric or hydrochloric acid [65].

Most of these condensation products have proven suitable for the preparation of even more pronounced amidoalkylating agents containing an N-1-chloroalkyl fragment. The latter react particularly readily with various nucleophiles, which is widely used for the synthesis of a number of N-alkylamide derivatives containing various oxygen-, nitrogen-, sulfur-, or phosphorus-containing functional groups at the α-position of the N-alkyl residue.

When considering the reactivity of amidoalkylating agents, their electrophilic nature should be taken into account first [66, 67]. The lone electron pair of the nitrogen

atom, although conjugated with the carbonyl group, still has a significant effect on the C–X bond (X = OH, Hal, and N-, S-, P-containing groups) due to the α-effect.

Intramolecular condensations. Cyclizations without the participation of an electrophilic center at position 1 of the N-alkyl fragment have been successfully achieved when the amidoalkylating agents contain one or two halogen atoms at position 2.

Easily accessible N-substituted amides of carboxylic and thiocarboxylic acids with the general formula CHCl2CH(X)NHC(Y)R undergo dehydrochlorination (dehydration) when treated with alkalis, alcoholates, or triethylamine, and are converted into oxazole, 2-oxazoline, or thiazole derivatives. Dehydration of synthons of the RC(O)NH-C(>C=)C(O)NHR' type, depending on their structure and condensation conditions, yields 2-imidazolin-5-one derivatives, which have been studied in greatest detail and are a convenient preparative method for the synthesis of substituted imidazolin-5-ones [67-79]. One of the simplest cases of such cyclization was discovered back in 1900 by E. Erlenmeyer during the treatment of amide of α-benzoylaminocinnamic acid with sodium hydroxide. However, acetic acid in the presence of sodium acetate was more often used as the condensing agent [73, 75-77].

Aim of the work. It is widely known that the presence of a framework fragment in a heterocycle exhibiting pharmacophoric properties often enhances these properties. Therefore, the aim of this study was to introduce an adamantyl (framework) fragment into the heterocycle structure. At the initial stage of the study, as noted above, the use of adamantyl-1-carboxamide for the synthesis of the corresponding amidoacylating agent seemed the simplest.

2.1.3.2. Materials and methods

IR spectra were obtained on a Specord 75IR spectrometer for samples in KBr tablets containing 0.25% of the substance . ^{1}H NMR spectra (400 MHz and 500 MHz) were taken on Varian Mercury-400 and Bruker Avance DRX 500 NMR spectrometers with TMS in accordance with the internal standard.

Mass spectra were obtained on a GCMS-TQ8040 Shimadzu instrument.

GLC analysis was carried out on a Tsvet-500 M device, glass column 1000x3 mm, 5% Apiezon L on Inerton N-AW-HMDS carrier, temperature 150-260 °C (10 deg/min), carrier gas – helium (40 ml/min).

Adamantyl-1-carboxamide was obtained according to the method of [80].

Adamantyl-1-carboxy-N-(1-hydroxy-2,2,2-trichloroethyl)amide **(3)** [68]. A mixture of 0.2 mol of amide (1), 0.22 mol of chloral (2) and 1 ml of concentrated sulfuric acid is heated to boiling in 50 ml of chloroform and boiled for 6 hours. The formed precipitate after cooling the reaction mixture is filtered off, washed with benzene, water and dried in vacuo over P_2O_5. The yield of amide (3) is 87%. M.p. 154-155 °C (benzene). IR spectrum (KBr, cm^{-1}): 850 (C-Cl, ν), 1100 (C-O, ν), 1300 (OH, δ), 1570 (NH, δ), 1640 (C=O, ν), 2910 (CH, ν), 2840 (CH, ν), 3440 (NH, ν), 3625 (OH, ν). ^{1}H NMR (δ, ppm): 4.5 (OH, s, J=4.8 Hz), 7.3 NH, d, J=6.5 Hz), 7.6 (CH, m), 0-8-1.1 (15H, m). MS (m/z): 325 ($M^{\bullet+}$), 307, 289, 271, 135.

Adamantyl-1-carboxy-N-(1-chloro-2,2,2-trichloroethyl)amide **(4)** [81]. To a suspension of 0.05 mol of amide (3) in 50 ml of anhydrous CCl_4 is added 0.15 mol of $SOCl_2$ over 0.5 h. The mixture is stirred for another 1 h. The precipitate is separated, washed with CCl_4 and dried in vacuo. The yield of chloramide (4) is 89%. M.p. 171-172 °C (CCl_4). IR spectrum (KBr, cm^{-1}): 870 (C-Cl, ν), 970 (C-Cl, ν), 1130 (C-O, ν), 1290 (OH, δ), 1580 (NH, δ), 1650 (C=O, ν), 2830 (CH, ν), 2920 (CH, ν), 3450 (C-O, ν), 3640 (OH, ν). ^{1}H NMR (δ, ppm): 7.4 (NH, d, J=6.8 Hz), 6.2 (CH, d, J=6.8 Hz), 0.8-1.1 (15H). MS (m/z): 343 ($M^{\bullet+}$), 308, 307, 261, 135.

Adamantyl-1-carboxy-N-(2,2,2-trichloroethylidene)amide **(5)** [82]. A solution of 0.03 mol of triethylamine in 20 ml of benzene is added dropwise with stirring to a solution of 0.03 mol of amide (4) in 180 ml of benzene. After 30 min, the triethylamine salt is filtered off, and the benzene is removed in vacuo. The residue is crystallized from hexane-ethyl acetate (10:1). Yield of imine (5) 75%. M.p. 116-117 °C. IR spectrum (KBr, cm^{-1}): 990 (C-Cl, ν), 1710 (C=O, ν), 2850 (CH, ν), 2890 (CH, ν). ^{1}H NMR (δ, ppm): 9.2 (CH, s), 0.8-1.1 (15H). MS (m/z): 307 ($M^{\bullet+}$), 225, 190, 135.

Adamantyl-1-carboxy-N-(2,2-dichloro-1-cyanovinyl)amide **(6)** [64]. A solution of 0.02 mol of amide (5) in 70 ml of ether is added dropwise over 0.5 h with vigorous stirring and ice-cooling to a mixture of 0.042 mol of triethylamine and 0.04 mol of hydrocyanic acid in 50 ml of ether. The mixture is stirred for 1 h at room temperature. The precipitate is filtered off and suspended in 100 ml of water. The insoluble portion is filtered off, washed with water, dried in vacuo over P_2O_5 and recrystallized from benzene. The yield of amide (6) is 73%. M.p. 121-122 °C (with decomposition). IR spectrum (KBr, cm^{-1}): 950 (C-Cl, ν), 1570 (NH, δ), 1645 (=C-CN, ν), 1660 (C=O, ν), 2210 (>N-C=C-CN, ν), 2840 (CH, ν), 2910 (CH, ν), 3440 (NH, ν). ^{1}H NMR (δ, ppm): 9.6 (NH, s), 0.8-1.1 (15H). MS (m/z): 332 ($M^{\bullet+}$), 250, 135, 42.

2-(Adamantyl-1-carboxamido)-3,3-dichloroacrylamide **(7)** [84]. To a suspension of 0.5 mol of nitrile (6) in 250 ml of 80% aqueous acetic acid solution, 1 mol of activated zinc dust is added in small portions over 3 hours with vigorous stirring at a mixture temperature no higher than 40 °C. The mixture is kept under stirring for 5 hours, the zinc salts are filtered off and washed with acetic acid. The filtrate is evaporated in vacuo at 30-40 °C. The residue is triturated with water to obtain a crystalline mass. After filtration, the crystals are dried in vacuo over P_2O_5 and recrystallized from hexane-ethyl acetate (1:1). Yield 71%. M.p. 186-187 °C. IR spectrum (KBr, cm^{-1}): 780 (C=C-CCl_2), 835 (C-Cl, ν), 929 (C-Cl, ν), 1660 (C=O, ν), 1677 (C=O, ν), 2840 (CH, ν), 2910 (CH, ν), 3180 (NH, ν), 3350 (NH, ν), 3440 (NH, ν). ^{1}H NMR (δ, ppm): 8.3 (NH_2, m), 10.1 (NH, s), 0.8-1.1 (15H). MS (m/z): 352 ($M^{\bullet+}$), 270, 135, 44.

2-(Adamantyl-1-carboxamido)-3,3-dichloroacrylic acid **(8)** [85]. A suspension of 0.3 mol of nitrile (6) in 800 ml of concentrated hydrochloric acid is quickly heated until the precipitate dissolves and boiled for 15-20 min. Cooled with ice. The precipitate is filtered off, washed with water and added in small portions to 1.5 l of saturated sodium bicarbonate solution. The mixture is shaken until the evolution of carbon dioxide ceases. Insoluble amide of the acid (8) is filtered off. The filtrate is acidified with concentrated hydrochloric acid to pH ~ 2. The precipitate is filtered off, washed with

water and dried in vacuum over P_2O_5. The yield of acid (8) is 62%. M.p. 195-196 °C. IR spectrum (KBr, cm^{-1}): 950 (C-Cl, ν), 1635 (C=O, ν), 1640 (C=O, ν), 1715 (C=C-CO_2H, ν), 2840 (CH, ν), 2910 (CH, ν), 3300 (OH, ν). ^1H NMR (δ, ppm): 9.9 (NH, s), 12.8 (COOH, s), 0.8-1.1 (15H). MS (m/z): 353 ($M^{\bullet+}$), 336, 308, 271, 135, 45.

2-(Adamantan-1-yl)-4-(dichloromethylene)oxazol-5(4H)-one **(9).** a) To a solution of 0.01 mol of acid (8) in 50 ml of methylene chloride is added 0.015 mol of dicyclohexylcarbodiimide (DCC). The mixture is boiled for 5 hours. The mixture is cooled and filtered to remove the urea precipitate. The filtrate is evaporated in vacuo. The residue is crystallized from hexane – ethyl acetate (1:1). The yield of oxazole (9) is 76%. M.p. 147-148 °C. IR spectrum (KBr, cm^{-1}): 1240 (C-O, ν), 1700 (C=CCl_2, ν), 1820 (C=O, ν), 2840 (CH, ν), 2910 (CH, ν). ^1H NMR (δ, ppm): 0.8-1.1 (15H). MS (m/z): 299 ($M^{\bullet+}$), 217, 135, 44, 42.

b) [86]. A solution of 0.03 mol of sodium methoxide in 5 ml of methanol is added to a solution of 0.01 mol of acid (8) in 30 ml of methanol. The mixture is kept at 20-25 °C for 10-12 days. Sodium chloride is filtered off. Methanol is removed in vacuo. To the residue are added 30 ml of water and ether. The aqueous layer is additionally extracted twice with 50 ml of ether. The combined ethereal extracts are dried over sodium sulfate. The ether is removed in vacuo. The residue is crystallized from hexane – ethyl acetate (1:1). The yield of oxazole (9) is 53%. M.p. 148–149 °C. IR spectrum (KBr, cm^{-1}): 1240 (C-O, ν), 1700 (C=CCl_2, ν), 1820 (C=O, ν), 2840 (CH, ν), 2910 (CH, ν). ^1H NMR (δ, ppm): 0.8–1.1 (15H). MS (m/z): 299 ($M^{\bullet+}$), 217, 135, 42, 44.

2-(Adamantan-1-yl)-4-(dichloromethylene)-1H-imidazol-5(4H)-one **(10)** [73]. To a solution of 0.01 mol of amide in 30 ml of acetic acid is added 0.01 mol of sodium acetate. The mixture is heated at 60 °C for 7 hours. After cooling, the mixture is diluted with 100 ml of water and made alkaline with 10% NaOH solution. The solution is extracted with 3x50 ml of chloroform. Dry over anhydrous sodium sulfate. The extract is evaporated. The residue is triturated with water until a crystalline mass is formed. Filtered and dried in vacuo over P_2O_5. The yield of imidazole (10) is 73%. M.p. 183-184 °C. IR spectrum (KBr, cm^{-1}): 800 (NH, δ), 930 (C=CCl_2, ν), 1330 (C-N, ν), 1465

(NH, δ), 1715 (C=O, ν), 2840 (CH, ν), 2910 (CH, ν). ^{1}H NMR (δ, ppm): 8.5 (NH, s), 0.8-1.1 (15H). MS (m/z): 298 ($M^{\bullet+}$), 297, 216, 135, 42, 27.

2.1.3.3. Results and discussion.

2.1.3.3.1. Synthesis of reagents.

As can be seen from the scheme, to obtain the target heterocycles (9) and (10), it was necessary to go through several stages of synthesis of the starting reagents - acid (8) and amide (9), respectively. The first synthesis, common to both reagents, was the synthesis of adamantyl-containing amide (3). To obtain it, it was necessary to make changes to the original method [68], since amide (1) had limited solubility in benzene even when heated. The reaction was carried out in chloroform. The time was increased to 6 hours. Identification of product (3) was carried out based on the IR spectrum. The presence of characteristic deformation and stretching vibrations of NH, OH bonds, as well as stretching vibrations of C=O, C-Cl, CH bonds confirms the composition of amide (3). In addition, the PMR spectrum contains signals of NH and CHOH protons with characteristic shifts and splitting constants. The presence of the adamantyl fragment is confirmed by a multiplet integrating over 15 protons in the range of 0.8-1.1 ppm. The mass spectrum confirms the mass of the product and the presence of characteristic fragments formed by the elimination of water molecules, dichlorocarbene, and the adamantyl cation (m/z 135) [87]. The yield of amide (3) was 87%.

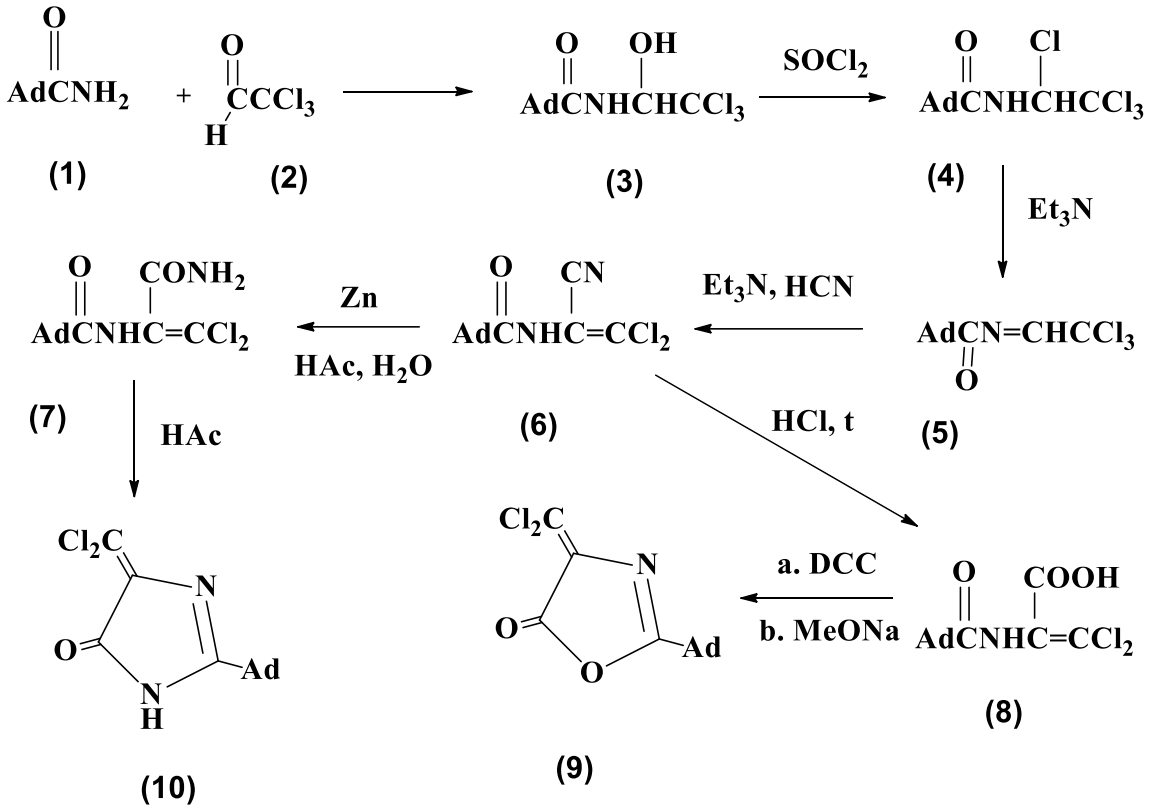


Fig. 1. Synthesis of heterocycles (9) and (10) (own interpretation).

The next step was the conversion of the amido alcohol (3) to the amido chloride (4) [81]. For this, a suspension of the amide (3) in CCl_4 was treated with thionyl chloride. The yield of amide (4) was 89%. The structure of chloride (4) is confirmed by the following spectra IR: 870 (C-Cl, ν), 970 (C-Cl, ν), 1130 (C-O, ν), 1290 (OH, δ), 1580 (NH, δ), 1650 (C=O, ν), 2830 (CH, ν), 2920 (CH, ν), 3450 (C-O, ν), 3640 (OH, ν), ^{1}H NMR (δ, ppm): 7.4 (NH, d, J=6.8 Hz), 6.2 (CH, d, J=6.8 Hz), 0.8-1.1 (15H), MS (m/z): 343 ($M^{\bullet+}$), 308, 307, 261, 135. Imine (5) was obtained by treating a solution of chloride (4) in benzene with triethylamine [82]. The reaction proceeded at room temperature for 30 minutes, as evidenced by the precipitation of triethylamine hydrochloride. The yield of the product was 75%. The product was identified by IR: 990 (C-Cl, ν), 1710 (C=O, ν), 2850 (CH, ν), 2890 (CH, ν), ^{1}H NMR (9.2 (CH, s), 0.8-1.1 (15H)) and MS spectra (307 ($M^{\bullet+}$), 225, 190, 135).

The next step was the synthesis of the key product, nitrile (6), from which the starting compounds for the synthesis of heterocycles, amide (7) and acid (8), were

obtained [83]. A solution of amide (5) in ether was added dropwise with cooling to a solution of triethylamine and HCN. The reaction mixture was kept at room temperature for 1 hour. As a result, nitrile (6) was formed in 76% yield. IR, PMR and mass spectrometry served as evidence of the structure. spectra. So, in the IR spectrum there are characteristic signals of bond vibrations: stretching C-Cl at 950 cm^{-1}, =C-CN at 1645 cm^{-1}, C=O at 1660 cm^{-1}, >N-C=C-CN at 2210 cm^{-1}, CH at 2840 and 2910 cm^{-1}. The next step was the conversion of the amido alcohol (3) to the amido chloride (4) [81]. For this, a suspension of the amide (3) in CCl_4 was treated with thionyl chloride. The yield of amide (4) was 89%. The structure of chloride (4) is confirmed by the following spectra: IR: 870 (C-Cl, ν), 970 (C-Cl, ν), 1130 (C-O, ν), 1290 (OH, δ), 1580 (NH, δ), 1650 (C=O, ν), 2830 (CH, ν), 2920 (CH, ν), 3450 (C-O, ν), 3640

(OH, ν), ^{1}H NMR (δ, ppm): 7.4 (NH, d, J=6.8 Hz), 6.2 (CH, d, J=6.8 Hz), 0.8-1.1 (15H), MS (m/z): 343 ($M^{\bullet+}$), 308, 307, 261, 135. Imine (5) was obtained by treating a solution of chloride (4) in benzene with triethylamine [28]. The reaction proceeded at room temperature for 30 minutes, as evidenced by the precipitation of triethylamine hydrochloride. The yield of the product was 75%. The product was identified by IR 990 (C-Cl, ν), 1710 (C=O, ν), 2850 (CH, ν), 2890 (CH, ν), ^{1}H NMR (9.2 (CH, s), 0.8-1.1 (15H)) and MS spectra (307 ($M^{\bullet+}$), 225, 190, 135).

The next step was the synthesis of the key product, nitrile (6), from which the starting compounds for the synthesis of heterocycles, amide (7) and acid (8), were obtained [83]. A solution of amide (5) in ether was added dropwise with cooling to a solution of triethylamine and HCN. The reaction mixture was kept at room temperature for 1 hour. As a result, nitrile (6) was formed in 76% yield. IR, PMR and mass spectrometry served as evidence of the structure. spectra. So, in the IR spectrum there are characteristic signals of bond vibrations: stretching C-Cl at 950 cm^{-1}, =C-CN at 1645 cm^{-1}, C=O at 1660 cm^{-1}, >N-C=C-CN at 2210 cm^{-1}, CH at 2840 and 2910 cm^{-1}, NH at 3440 cm^{-1}; deformation vibrations of NH at 1570 cm^{-1}. In the PMR spectrum, proton signals were observed: NH, a broad singlet at 9.6 ppm and 15 protons of the adamantane nucleus at 0.8-1.1. The mass spectrum showed a molecular ion mass of

298 m/z, which corresponds to the butto formula of compound (6), as well as signals of fragments with masses of 297 (-$H^{\bullet}$), 216 (-CCl_2), 135 (Ad^+), 42 (NCO^+), 27 (CN^+).

Nitrile (6) is reduced to amide (7) using the procedure described in [84]. As a result, amide (7) was obtained in 71% yield. The product was identified by IR, PMR, and mass spectra. IR spectrum: 780 (C=C-CCl_2), 835 (C-Cl, ν), 929 (C-Cl, ν), 1660 (C=O, ν), 1677 (C=O, ν), 2840 (CH, ν), 2910 (CH, ν), 3180 (NH, ν), 3350 (NH, ν), 3440 (NH, ν). ^{1}H NMR (δ, ppm): 8.3 (NH_2, m), 10.1 (NH, s), 0.8-1.1 (15H). MS (m/z): 352 ($M^{\bullet+}$), 270, 135, 44.

The procedure in [85] was used to convert nitrile (6) into acid (8). The yield of product (8) was 62%. The standard set of signals in the IR, PMR, and mass spectra of acid (8), proving its structure, is given in the experimental section.

2.1.3.3.2. Synthesis of heterocycles.

Two methods were used to synthesize oxazolone (9). The first of them was "traditional" and described in the article [86]. The synthesis consisted of treating acid (8) with sodium methylate in a methanol solution, followed by prolonged incubation of the reaction mixture at room temperature. After isolation and purification of the product, the yield of oxazolone (9) was 53%. The IR, PMR, and MS spectra contained all the signals necessary to prove the structure: IR spectrum: 1240 (C-O, ν), 1700 (C=CCl_2, ν), 1820 (C=O, ν), 2840 (CH, ν), 2910 (CH, ν). The latter parameters indicated the presence of an adamantane core in the product. This is also evidenced by the only proton signals in the ^{1}H NMR spectrum: 0.8-1.1 (15H). The mass spectrum shows the molecular weight of oxazolone (9), 299 D ($M^{\bullet+}$), a low-intensity molecular ion, which corresponds to the gross formula. As well as fragments corresponding to the departure of the CCl_2 (217 D), Ad (135 D), NCO (42 D), CO2 (44 D) groups.

The second method involved the use of dicyclohexylcarbodiimide (DCC) as a condensing agent in equimolar quantities. Product (9) was formed by boiling the

reagent mixture in methylene chloride. The yield of oxazolone (9) was significantly greater than in the first method and amounted to 76%. The product had spectra similar to those of the product obtained in the first method.

The synthesis of imidazole (10) consisted of heterocyclization by intramolecular condensation of amide (7) [73]. The reaction took place in acetic acid in the presence of sodium acetate at 60 °C for 7 hours. Such a long heating was required to achieve the maximum degree of conversion - 73%. Identification of product (10) was carried out using IR and PMR spectroscopy, mass spectrometry. Thus, the following characteristic bond signals were observed in the IR spectrum: 800 (NH, δ), 930 (C=CCl2, ν), 1330 (C-N, ν), 1465 (NH, δ), 1715 (C=O, ν), 2840 (CH, ν), 2910 (CH, ν). PMR spectroscopy shows the presence of a broad singlet at 8.5 ppm, indicating the presence of a proton at the nitrogen atom. The presence of a group of signals in the product at 0.8-1.1 ppm, integrating on 15H, indicates the presence of a damantan substituent. The mass spectrum proved to be quite informative. The mass of the product according to the MS spectrum was 298 D, which corresponded to the molecular formula $C_{14}H_{16}Cl_2N_2O_2$ and indicated the presence of two nitrogen atoms. The presence of fragments 297, 216, 135, 42, 27 D confirmed the structure of imidazole (10)., NH c at 3440; deformation vibrations of NH at 1570 cm^{-1}. In the PMR spectrum, proton signals were observed: NH, a broad singlet at 9.6 ppm and 15 protons of the adamantane nucleus at 0.8-1.1. The mass spectrum showed a molecular ion mass of 298 m/z, which corresponds to the butto formula of compound (6), as well as signals of fragments with masses of 297 ($-H^{\bullet}$), 216 ($-CCl_2$), 135 (Ad^+), 42 (NCO^+), 27 (CN^+).

Nitrile (6) is reduced to amide (7) using the procedure described in [84]. As a result, amide (7) was obtained in 71% yield. The product was identified by IR, PMR, and mass spectra. IR spectrum: 780 (C=C-CCl_2), 835 (C-Cl, ν), 929 (C-Cl, ν), 1660 (C=O, ν), 1677 (C=O, ν), 2840 (CH, ν), 2910 (CH, ν), 3180 (NH, ν), 3350 (NH, ν), 3440 (NH, ν). 1H NMR (δ, ppm): 8.3 (NH_2, m), 10.1 (NH, s), 0.8-1.1 (15H). MS (m/z): 352 ($M^{\bullet+}$), 270, 135, 44.

The procedure in [31] was used to convert nitrile (6) into acid (8). The yield of product (8) was 62%. The standard set of signals in the IR, PMR, and mass spectra of acid (8), proving its structure, is given in the experimental section.

Two methods were used to synthesize oxazolone (9). The first of them was "traditional" and described in the article [86]. The synthesis consisted of treating acid (8) with sodium methylate in a methanol solution, followed by prolonged incubation of the reaction mixture at room temperature. After isolation and purification of the product, the yield of oxazolone (9) was 53%. The IR, PMR, and MS spectra contained all the signals necessary to prove the structure: IR spectrum: 1240 (C-O, ν), 1700 (C=CCl2, ν), 1820 (C=O, ν), 2840 (CH, ν), 2910 (CH, ν). The latter parameters indicated the presence of an adamantane core in the product. This is also evidenced by the only proton signals in the ^{1}H NMR spectrum: 0.8-1.1 (15H). The mass spectrum shows the molecular weight of oxazolone (9), 299 D ($M^{\bullet+}$), a low-intensity molecular ion, which corresponds to the gross formula. As well as fragments corresponding to the departure of the CCl_2 (217 D), Ad (135 D), NCO (42 D), CO_2 (44 D) groups.

The second method involved the use of dicyclohexylcarbodiimide (DCC) as a condensing agent in equimolar quantities. Product (9) was formed by boiling the reagent mixture in methylene chloride. The yield of oxazolone (9) was significantly greater than in the first method and amounted to 76%. The product had spectra similar to those of the product obtained in the first method.

The synthesis of imidazole (10) consisted of heterocyclization by intramolecular condensation of amide (7) [73]. The reaction took place in acetic acid in the presence of sodium acetate at 60 °C for 7 hours. Such a long heating was required to achieve the maximum degree of conversion - 73%. Identification of product (10) was carried out using IR and PMR spectroscopy, mass spectrometry. Thus, the following characteristic bond signals were observed in the IR spectrum: 800 (NH, δ), 930 (C=CCl_2, ν), 1330 (C-N, ν), 1465 (NH, δ), 1715 (C=O, ν), 2840 (CH, ν), 2910 (CH, ν). PMR spectroscopy shows the presence of a broad singlet at 8.5 ppm, indicating the presence of a proton at the nitrogen atom. The presence of a group of signals in the product at 0.8-1.1 ppm, integrating on 15H, indicates the presence of a damantan substituent. The mass spectrum proved to be quite informative. The mass of the product according to the MS spectrum was 298 D, which corresponded to the molecular formula $C_{14}H_{16}Cl_2N_2O_2$ and

indicated the presence of two nitrogen atoms. The presence of fragments 297, 216, 135, 42, 27 D confirmed the structure of imidazole (10).

2.1.3.4. Conclusions

1. Methods for producing adamantyl-containing amidoadkylating reagents in high yields have been developed.

2. Adamantylimidazole and adamantyloxazolone have been synthesized using adamantyl-containing amidoadkylating reagents.

3. Approaches for the synthesis of a variety of framework-containing nitrogen heterocycles have been discovered.

2.1.4. Synthesis and antimicrobial activity of some adamantyl-containing hydrazones

2.1.4.1. Introduction

The shortage of new antibacterial drugs due to growing bacterial resistance to antimicrobial agents is a major challenge in the development of new drugs. Quaternary amine derivatives have previously been reported to exhibit antimicrobial properties [88–91]. Certain mono- and bis-quaternary ammonium compounds, including various alkyl chain lengths with various hydrophobic substituents, have been found to exhibit antimicrobial activity [92–94].

Pyridinium halides, like quaternary nitrogen salts, exhibit antimicrobial properties and adsorption properties on negatively charged solids. The antimicrobial activity of 1-alkylpyridinium salts depends on their adsorption activity on the surface of bacterial cells [95–103] and the pKa values of the corresponding pyridines [104]. Factors controlling their antimicrobial activity include molecular hydrophobicity [104,106], adsorbability [107], surface activity [106], and the electron density [108,109] of the quaternary nitrogen atom. These compounds possess one hydrophobic alkyl chain and one hydrophilic quaternary nitrogen ion group per molecule, which provides greater surface activity and more pronounced antimicrobial activity compared to conventional antimicrobial agents [110].

On the other hand, Schiff bases are important in medicine, and many studies have reported their biological activity [111,112]. Hydrazones, a special group of Schiff bases, are also known as one of the most important classes of organic compounds, some of which exhibit significant biological activities such as antimicrobial [113–117], antituberculosis [118–120], anticancer [121–123], analgesic [124], anti-inflammatory [124], antiplatelet [125], and antiviral [126, 127] activities. The data reported in these studies showed that the side chain attached to the pyridinium nitrogen significantly influenced the antimicrobial activity. Among them, compounds with 3-phenylpropyl chains showed remarkable activity [127]. Based on these results, ortho-methyl, -methoxyl, -hydroxyl benzylidenehydrazinylpyridinium salts with benzyl, 2,6-dichlorobenzyl, 2-phenylethyl, and 3-phenylpropyl groups on the pyridine nitrogen were prepared to study the effect of such structural modifications of quaternary pyridinium salts on the expected antimicrobial activity.

In addition to the above, the objective of this study was to introduce a bulky hydrocarbon radical, adamantane, into the Schiff base molecules. The latter is widely known to enhance the lipophilicity of the drug substance, which prolongs its therapeutic effect.

2.1.4.2. Results and Discussion

2.1.4.2.1.Chemistry

Benzylidenehydrazinylpyridinium salts were prepared in three steps according to the reported procedure [128] as shown in Scheme 1. In the first step, 4-chloropyridine was refluxed with hydrazine hydrate in 1-propanol to give 4-hydrazinylpyridine (1). This compound was then condensed with 4-(1-adamantyl)benzaldehyde (2) in ethanol at room temperature to give hydrazone (3). In the last step, the final compounds (4a–d) were obtained by quaternization of hydrazone derivatives (3) with the appropriate substituted alkyl halides in ethanol under reflux. All the key compounds are new. Except for compounds (3) and (4), compounds (1) and (2) were previously described [129,130].

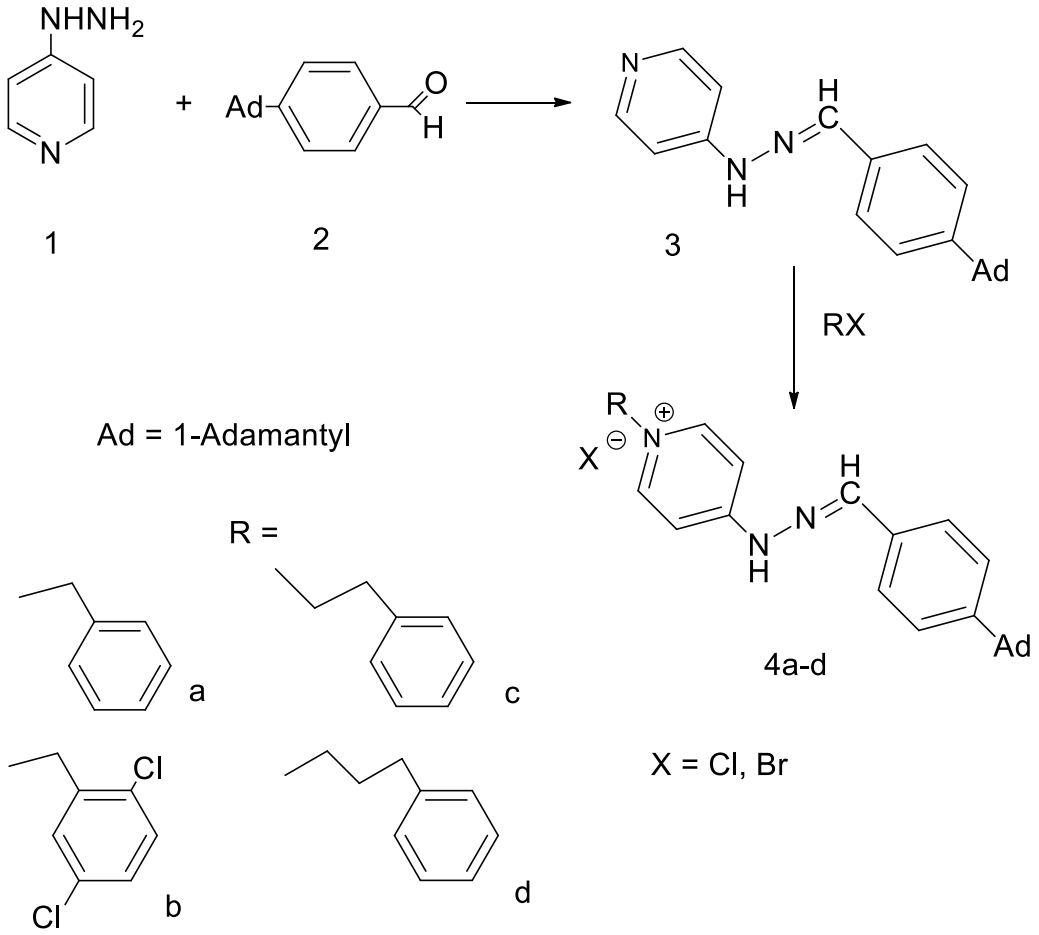


Fig.1. Synthesis of the title compounds.

The structures of the final compounds were determined by spectral methods. The IR spectra of the final compounds showed intense absorption bands in the range of 3315–3446 cm^{-1} and the range of 1436–1644 cm^{-1}, which were assigned to vibrations of the NH and C=N functions, respectively. In the ^{1}H NMR spectra, the signals of the NH group protons were recorded in the range of 12.26–13.00 ppm. The signals of the protons belonging to the N=CH group were observed as singlets in the range of 8.52–8.65 ppm. The IR and ^{1}H NMR data confirmed the condensation between the amino and carbonyl groups. As expected, while the pyridine hydrogens at positions 2 and 6 of compound (3) showed peaks in the 8.19–8.21 ppm range, the signals of the hydrogens at these positions were in the final compounds (4a–d) in the 8.30–8.55 ppm range [131]. The shifts of these peaks to higher frequency indicated that compounds

(4) were quaternized with an alkyl halide. All ^{13}C NMR results supported the proposed structures as stated in the experimental section. The mass spectra of the final compounds (4a–d) showed molecular ion peaks that were consistent with the proposed structures.

4.2.2. Antimicrobial Activity

A series of benzylidenehydrazinylpyridinium salts with an adamantyl substituent at the para-position of the benzene ring were evaluated for antimicrobial activity against Gram-positive and Gram-negative bacteria and fungi. The bacterial strains represented important Gram-positive and Gram-negative species, including Staphylococcus aureus, Escherichia coli, and Pseudomonas aeruginosa. Their antibacterial activity was assessed by measuring the minimum inhibitory concentration (MIC) using a standard broth dilution assay (Table 1).

Table 1.

Antimicrobial activity of compounds 4a-d.

Compound	Minimum Inhibitory Concentration (MIC) (μg/mL)			
	E. coli	P.aeruginosa	S. aureus	C. albicans
4a	35	512	20	66
4b	>2048	>2048	67	1030
4c	66	512	32	66
4d	131	1030	4	66
Ceftazidime	**<0.125 (0.06-0.5)***	1 (1–4)*	4 (4–16)*	
Fluconazole	–	–	–	(0.25–1.0)*

* Acceptable quality control ranges of minimum inhibitory concentrations (MICs) (μg/mL) for strains [132,133].

Based on the antimicrobial activity results, all compounds exhibited high antimicrobial activity against Staphylococcus aureus and low antimicrobial activity against Pseudomonas aeruginosa. Among the tested compounds, 4d was the most active derivative against Staphylococcus aureus, being as effective against this microorganism as the standard compound ceftazidime. The results showed that the longer the side chain of a compound, the greater its antimicrobial activity. In the series of adamantyl-substituted phenylpropyl derivatives, the antimicrobial activity of 4d was followed by 4c, 4a, and 4b, respectively. No significant difference in the antibacterial activity of compounds 4c and 4a was observed. Both compounds had identical MIC values against the test microorganisms, with the exception of Pseudomonas aeruginosa. According to the MIC values of the compounds, 4d had the lowest MIC values (4 μg/mL) compared to other pyridinium salts.

This bioisosteric substitution resulted in a slight increase in antimicrobial activity. On the other hand, compounds with a 2,6-dichlorobenzyl side chain on the pyridinium nitrogen showed no activity against Gram-negative bacteria. Our study showed that all compounds exhibited stronger antibacterial activity against Gram-positive bacteria than Gram-negative bacteria.

These data suggest that pyridinium salts act on cell membranes, and the surface activity of these compounds may be primarily responsible for their antibacterial properties. However, all tested compounds exhibited low antifungal activity against Candida albicans. The reason for the weaker antifungal activity compared to the antibacterial effect can be considered the difference in the mechanism of action of the compounds on the inhibition of the respiratory system of fungal cells, and not the destruction of the cell wall.

2.1.4.3. Materials and methods.

The melting points (mp) of the synthesized compounds were recorded on a Boetius bench. 1H and ^{13}C NMR spectra were recorded on a Bruker AM300 spectrometer (300 and 75 MHz, respectively) in DMSO-d6 and $CDCl_3$ at 25 °C. Chemical shifts were measured in DMSO-d_6 with TMS as an internal standard. IR spectra were recorded

using the thin film method and in KBr tablets on a Bruker Alpha spectrometer. Electrospray ionization (ESI) mass spectra were measured on an Agilent 1100 LC/MSD instrument. Reagents and solvents used for the synthesis were purchased from Aldrich. 4-(1-Adamantyl)benzaldehyde was provided by AKos GmbH. Thin-layer chromatography was performed on silica gel-coated 60 F254 plates (Merck). The spots were developed using UV light or iodine.

4-Hydrazinopyridine Hydrochloride (1). Compound (1) was obtained according to the method described in [134]. A solution of 4-chloropyridine (0.01 mol) and hydrazine monohydrate (0.15 mol) in 1-propanol (30 ml) was refluxed for 18 h. The solution was cooled to 0 °C, the precipitate was filtered off, washed with cold 1-propanol and crystallized from ethanol. M.p. 242–243 °C (ref. [134,135] 242–243 °C).

4-(2-(4-(1-Adamantyl)benzylidene)hydrazinyl)pyridine(3).

4-Hydrazinylpyridine (0.01 mol) and benzaldehyde derivative (2) (0.01 mol) were stirred in ethanol (30 ml) at room temperature for 4–9 h. The precipitate was filtered off, washed with cold ethanol, and crystallized from ethanol. Yield 73%. M.p. 232 °C. IR (ν, cm^{-1}): 1427, 1452, 1486, 1527, 1538 (Ar-C=C and N=C), 2886, 2948 (aliphatic C-H), 3014 (Ar-C-H), 3210 (N-H); ^{1}H-NMR (δ, mmp): 1.76 (6CH_2, Ad), 1.87 (3CH, Ad), 6.97 (2H, d, J = 6.2 Hz, Py-H), 7.23 (2H, d, J = 8.2 Hz, Ar-H), 7.83 (2H, d, J = 8.2 Hz, Ar-H), 8.19 (1H, s, N=CH), 8.21 (2H, d, J = 6.2 Hz, Py-H), 10.80 (1H, s, NH).

2.1.4.3.1.General Synthesis Method for Compounds (4a-d).

Hydrazone (3) (0.01 mol) and the corresponding alkyl halide (0.02 mol) were refluxed in ethanol (30 mL) for 10-40 h. The mixture was cooled to 0°C, and the resulting precipitate was filtered off and washed with cold ethanol. The crude products were crystallized from ethanol, yielding compounds (4a-d).

1-Benzyl-4-(2-(4-(1-adamantyl)benzylidene)hydrazinyl)pyridine chloride (4a). Yield 68%. M.p.= 267 °C. IR (ν, cm^{-1}): 1455, 1482, 1517, 1544, 1600, (Ar-C=C and N=C), 1644 (N^+=C), 2838, 2911, 2979 (aliphatic C-H), 3037 (Ar- C-H), 3397 (N-H). ^{1}H-NMR (δ, mmp.): 1.76 (6CH_2, Ad), 1.87 (3CH, Ad), 5.48 (2H, s, N^+-CH2-Ph), 7.16 (1H, dd, J = 7.0, 2.3 Hz, Py-H), 7.23 (2H, d, J = 8.2 Hz, Ar-H), 7.83 (2H, d, J = 8.2 Hz,

Ar-H), 7.36-7.42 (5H, m, Ar-H), 7.56 (1H, d, J = 7.4 Hz, Py-H), 8.47 (1H, d, J = 7.4 Hz, Py-H), 8.55 (1H, d, J = 7.4 Hz, Py-H), 8.62 (1H, s, N=CH), 13.00 (1H, s, NH). ^{13}C-NMR (δ, mmp.): 60.75 107.80, 109.64, 126.96, 127.47, 128.78, 129.46, 129.78, 130.9, 131.7, 132.18, 136.20, 137.92, 143.72, 144.89, 147.99, 154.38. MS (m/z): 458 ($M^{\bullet+}$), 91.135, 77.

1-(2,6-Dichlorobenzyl)-4-(4-(1-adamantyl)benzylidene)hydrazinyl)pyridinium chloride (4b). Yield 72%. M.p. 298 °C; IR (ν, cm^{-1}): 1436, 1513, 1581 (Ar-C=C and N=C), 1644 (N^+=C), 2694, 2886 (aliphatic C-H), 3052 (Ar-C-H), 3442 (N-H). ^{1}H-NMR (δ, mmp): 1.76 (6CH_2, Ad), 1.87 (3CH, Ad), 5.70 (2H, s, N+-CH2-Ph), 7.14 (1H, dd, J = 7.2, 2.8 Hz, Py-H), 7.26-7.30 (2H, m, Ar-H), 7.34 (1H, td, J = 7.4, 1.2 Hz, Ar-H), 7.52-7.56 (2H, m, Py -H), 7.23 (2H, d, J = 8.2 Hz, Ar-H), 7.83 (2H, d, J = 8.2 Hz, Ar-H), 8.22 (1H, dd, J = 7.0, 1.6 Hz, Py-H), 8.34 (1H, dd, J = 7.2, 1.6 Hz, Py-H), 8.60 (1H, s, N=CH), 13.00 (1H, s, NH). ^{13}C-NMR (δ, mmp): 56.44, 108.29, 110.28, 125.29, 128.30, 129.22, 129.72, 130.00, 131.74, 133.16, 134.16, 137.00, 143.50, 144.66, 144.74, 148.69, 154.80. MS (m/z): 527 ($M^{\bullet+}$), 135, 159, 145.

4-(4-(1-Adamantyl)benzylidene)hydrazinyl)-1-phenethylpyridinium bromide (4c). Yield 87%. M.p.190 °C. IR (ν, cm^{-1}): 1455, 1513, 1546, 1577 (Ar-C=C and N=C), 1644 (N^+=C), 2836, 2908 (aliphatic C-H), 3054 (Ar-C-H), 3415 (N-H); ^{1}H NMR (δ, mmp): 1.76 (6CH_2, Ad), 1.87 (3CH, Ad), 3.13 (2H, t, J = 7.2 Hz, N^+-CH_2-CH_2-Ph), 4.50 (2H, t, J = 7.2 Hz, N^+-CH_2-CH_2-Ph), 7.03 (1H, dd, J = 7.0, 2.3 Hz, Py-H), 7.19-7.36 (5H, m, Ar-H), 7.23 (2H, d, J = 8.2 Hz, Ar-H), 7.83 (2H, d, J = 8.2 Hz, Ar-H), 7.50 (1H, dd, J = 7.0, 2.3 Hz, Py-H), 8.30 (1H, d, J = 7.4 Hz, Py-H), 8.35 (1H, d, J = 7.0 Hz, Py-H), 8.53 (1H, s, N=CH), 12.38 (1H, s, NH). ^{13}C NMR (δ, mmp): 36.92, 59.03, 107.37, 108.99, 126.94, 127.36, 127.55, 129.23, 129.62, 130.96, 131.73, 132.12, 137.33, 137.89, 143.71, 144.84, 147.53, 154.10. MS (m/z): 513($M^{\bullet+}$), 77, 91, 135.

4-(4-(1-Adavantyl)benzylidene)hydrazinyl)-1-(3-phenylpropyl)pyridiniumbromide (4d).Yield 49%; M.p.160 °C; IR (ν, cm^{-1}): 1454, 1488, 1511, 1552, 1585, (Ar-C=C and N=C), 1644 (N^+=C), 2827, 2915 (aliphatic C-H), 3058 (Ar-C-H), 3424 (N-H); ^{1}H-NMR (δ, mmp): 1.76 (6CH_2, Ad), 1.87 (3CH, Ad),

2.12 (2H, quin, J = 7.6 Hz, N^+-CH_2-CH_2-CH_2-Ph), 2.60 (2H, t, J = 7.8 Hz, N^+-CH_2-CH_2-CH_2-Ph), 4.28 (2H, t, J = 7.2 Hz, N^+-CH_2-CH_2-CH_2-Ph), 7.06 (1H, dd, J = 7.2, 2.4 Hz, Py-H), 7.16-7.30 (5H, m, Ar-H), 77.56 (1H, dd, J = 6.8, 2.4 Hz, Py-H), 7.23 (2H, d, J = 8.2 Hz, Ar-H), 7.83 (2H, d, J = 8.2 Hz, Ar-H) 8.39 (1H, d, J = 6.8 Hz, Py-H), 8.46 (1H, d, J = 7.2 Hz, Py-H), 8.52 (1H, s, N=CH), 12.34 (1H, s, NH); ^{13}C-NMR (δ, mmp): 32.28, 52.50, 58.08, 107.50, 109.15, 126.76, 126.98, 127.50, 128.89, 129.12, 131.00, 131.80, 132.14, 137.33, 141.15, 143.79, 144.80, 147.64, 154.29. MS(m/z): 527 ($M^{\bullet+}$), 77, 91, 135.

2.1.4.3.2. Antimicrobial activity

The minimum inhibitory concentration (MIC) was determined by the broth microdilution method according to the Clinical and Laboratory Standards Institute (CLSI) [53,54]. The in vitro antimicrobial activity of the final compounds (4a–d) was assessed against the standard strains Staphylococcus aureus ATCC 29213, Escherichia coli ATCC 25922, Pseudomonas aeruginosa ATCC 27853, and Candida albicans ATCC 90028. Antibacterial and antifungal assays were performed in Mueller–Hinton broth and Sabouraud dextrose broth, respectively. All synthesized compounds were weighed (10 mg), dissolved in DMSO (250 μL), and diluted with water (750 μL) to prepare stock solutions of 10 mg/mL. Serial dilutions from 2048 to 1 μg/mL were performed in a 96-well plate. Fifty μL of bacterial suspension obtained from a 24-hour culture (~106 CFU/mL) was added to each well with a final DMSO concentration of 1:16. The plates were incubated at 35°C for 24 hours. We tested Ceftazidime as an antimicrobial agent for quality control of the method. Each experiment was repeated twice.

2.1.4.4. Conclusions

We described the synthesis of a series of adamantyl-containing benzylidenehydrazinylpyridinium salts (4a-d) with antimicrobial activity. The final synthesized compounds were characterized by spectral data (IR, 1H-NMR, 13C-NMR, MS). Both the synthesis and antimicrobial activity of the final compounds (4a-d) were reported for the first time. Compounds (4a-d) were found to possess moderate activity

against S. aureus. Notable activity was detected for compounds bearing a 3-phenylpropyl side chain on the nitrogen. The most active compound was 4-(4-(1-adamantylbenzylidene)hydrazinyl)-1-(3-phenylpropyl)pyridinium bromide (4d), with an MIC value of 4 μg/mL against S. aureus. The results showed that a longer side chain on the pyridinium nitrogen resulted in enhanced activity.

SECTION 3. ELECTRONICS, ELECTRONIC COMMUNICATIONS, INSTRUMENTATION AND RADIO ENGINEERING

DOI: 10.46299/ISG.2026.MONO.TECH.1.3.1

3.1 Конструювання силових елементів конструкцій РЕА

3.1.1. Аналіз сучасного стану теорії і практики процесів гнуття та способи інтенсифікації процесів листового штампування

Основними напрямками для вирішення завдань щодо переорієнтації економіки України в умовах військового стану на тлі російської агресії, підвищення продуктивності праці, якості продукції та її конкурентоспроможності є всебічна інтенсифікація виробництва, ресурсозбереження, прискорення науково-технічного прогресу та реконструкція машинобудування. Такий підхід дозволяє перейти у промисловості до інтенсивних методів розвитку.

Що стосується виробництва силових елементів конструкцій РЕА це означає використання найбільш прогресивних, економічних і високопродуктивних процесів, які повинні витіснити процеси, що не відповідають сучасним вимогам і умовам.

Для виготовлення силових елементів конструкцій РЕА широко застосовують згинання профільних заготовок. Профілі, які погано працюють на кручення, нерідко вигинають на кут, надаючи їм невелику спіральність, потім відрізають кінцеві припуски. Масивні кільцеві елементи зварюють із гнутих півкілець або кількох секторів.

Найбільш актуальною проблемою за такої технології є підвищення точності згинання та відповідне скорочення робіт з розмірного доведення вигнутих заготовок. Низька точність згинання пояснюється так званим пружинінням, яке завжди супроводжує згинання і пов'язане з розвантаженням – зняттям зовнішнього згинального навантаження. Застосовуючи згинання по оправках і штампах, необхідно заздалегідь – за виготовлення згинального

інструменту (оправок, пуансонів, матриць) – враховувати пружиніння заготовок.

Повне виключення необхідності доведення вигнутих заготовок по радіусу потребує вирішення ще однієї проблеми – різкого скорочення розкиду значень параметрів, що характеризують пружиніння. Різне пружиніння заготовок одного типорозміру, особливо за їх малого розміру, пояснюється анізотропністю матеріалу та розмірів у межах, що встановлюються стандартами на матеріал та сортамент. Наприклад, допуск на товщину стінок «профілів», що отримуються прокаткою, досягає 10% і більше.

Можливо значно зменшити пружиніння заготовок, поєднуючи вигин з поздовжнім розтягуванням, проте застосування даного способу згинання обмежене через складність і недостатню потужність обладнання.

Оптимальні радіуси згинального інструменту можуть бути визначені на основі адекватного математичного моделювання немонотонної формозміни заготовок.

Використання математичного моделювання дозволяє проводити розрахунок процесів згинання з урахуванням всіх основних факторів, що впливають на пружиніння: зміцнення матеріалу, пружних деформацій, пластичних деформацій розвантаження та ін.

Розробка та впровадження нових технологічних процесів можливі як при застосуванні новітнього, так і існуючого обладнання, причому другий шлях у поточних умовах сучасної України є кращим, оскільки зводить до мінімуму капітальні вкладення і в багатьох випадках веде до помітного зниження собівартості продукції. Однак у деяких випадках використання нових технологічних процесів неможливе без застосування новітнього устаткування. В обох випадках пошук шляхів інтенсифікації повинен базуватися на знаннях про процеси, що протікають в матеріалі, що деформується, під дією різного роду фізико-механічних впливів (теплових, електричних і електромагнітних полів, різного роду навантажень, сил контактного тертя та ін.).

В останні роки сформувалися основні напрямки вдосконалення процесів

обробки металів тиском, спрямовані на подолання факторів, що обмежують формозміну (руйнування та втрата стійкості заготівлі, локалізація деформації, зміна розмірів зерен та інші структурні зміни, точність деталей), розроблено та впроваджено нові способи та обладнання, що дозволяють значно підняти технічний рівень виробництва.

Для розширення технологічних можливостей операцій листового штампування зазвичай потрібно зробити будь-які додаткові дії над заготівлею до початку або в процесі деформування. Ці дії повинні бути спрямовані на усунення дефектів, що виникають при виконанні даної конкретної операції, що характеризується певними напругами, деформаціями, умовами докладання зовнішнього деформуючого навантаження, температурою і швидкістю здійснення процесу, якістю, і станом матеріалу заготівлі та ін. Характер додаткових дій може бути визначений тільки за умови, що відомі механізми форм. Питаннями розробки нових технологічних процесів листового штампування та вдосконалення існуючих займалося багато вчених, а саме: В.П. Романовський, В.Г. Мещерін, Д.А. Войнтрауб, М.Є. Зубцов, М.І. Лисов, С.М. Поляк., Є.І. Ісаченков, А.П. Груднєв, А.Т. Леванов, А.Л. Тарновський, Л.А. Шофман, А.К. Чертавських, А.Г. Овчинніков, Ю.П. Давидов, Є.А. Попов, С.З. Юдович, І.С. Алієв, В.А. Євстратов, В.А. Огороднiков, В.К. Борисович та ін.

Таким чином, для розширення можливостей операцій холодного штампування потрібно встановити вид обмежуючого чинника та вжити додаткових заходів щодо зменшення його впливу. Характер цих заходів можна визначити з фізичних закономірностей пластичної деформації.

Розрахунок параметрів зовнішнього навантаження, напруженого та деформованого стану матеріалу вимагає правильного обліку великої кількості факторів, що супроводжують процес холодної пластичної деформації. Найважливішим досягненням у розвитку теорії та практики процесів листового штампування на сучасному етапі є зниження роботи пластичної деформації при використанні вібропластичного ефекту, керування силами контактного тертя,

накладення додаткового впливу на вогнище деформації, локальне нагрівання, високошвидкісне штампування, деформування в режимі надпластування.

В даний час відома та використовується в практиці велика кількість формозмінювальних операцій штампування листових, профільних та трубчастих заготовок. Метою кожної з цих операцій є зміщення одних частин напівфабрикату щодо інших перетворення форми заготівлі у форму деталі. Зміщення, яке здійснюється пластичним деформуванням, може відбуватися в різній послідовності під дією різноманітних зовнішніх навантажень. У зв'язку з цим, параметри силового впливу, схема напружено-деформованого стану та технологічні можливості операцій будуть різними залежно від конкретної реалізації процесу та тісно пов'язані з металоємністю обладнання та оснащення, що застосовується.

3.1.1.1 Сучасний стан технології виготовлення деталей методом згинання з профільних та листових заготовок

У штампах згинання виконується переважно з напівфабрикатів, попередньо заготовлених у розділових штампах чи ножицях. Крім того, широко поширені заготівлі із сортового прокату, труб та дроту. Деталі, одержувані гнучкою, можна класифікувати за формою вигину і розташування заготовки в штампі при виконанні операції.

Методи згинання є найбільш поширеними процесами отримання деталей різної форми та розмірів, ці методи значно дешевше менш трудомісткі порівняно з іншими операціями листового штампування. Деталі, які отримують гнучкою характеризуються: конструктивною формою, якістю поверхонь, механічними та фізичними якостями матеріалу заготівлі. Так як механічні і фізико-хімічні якості матеріалу, а також якість поверхні деталі визначаються вихідним напівфабрикатом (заготівлею) і спеціальними методами обробки (термічними, хімічними, електромеханічними і т. д.), то конструктивна форма деталі набуває вирішального значення при виборі технологічного процесу і способів інтенсифікації існуючих способів виробництва необхідних переходів), вибір

обладнання (його тип, робоче зусилля тощо), вид та конструкцію інструменту, оснащення, форму та розміри робочих деталей штампів. Як вважають провідні фахівці в галузі листового штампування, принципове значення для аналізу існуючих технологічних процесів та пошуку нових напрямків розвитку технології згинання в виготовленні силових елементів конструкцій РЕА є класифікація за загальними технологічними, конструктивно-технологічними ознаками та класифікація за матеріалами деталей.

Гнуття широко використовується для отримання різноманітних деталей з листового металу, профільного прокату, труб та дроту. У процесі згинання метал піддається одночасної дії зусиль, що розтягують і стискають: на зовнішній стороні згинання волокна металу розтягуються і подовжуються, а на внутрішній стороні згинання – стискуються і коротшають. І лише центральний шар, або нейтральна лінія, в момент згинання не відчуває стискування та розтягування. Довжина нейтральної лінії після вигину заготовки не змінюється. Якщо напруги вигину не перевищують межі пружності матеріалу, деформації заготовки будуть пружними, і після зняття напружень заготівля набуде свого первісного вигляду.

Існує й інший вид згинання – згинання з розтягуванням, при якому забезпечується отримання точних кутів і радіусів вигину. Заготівля при такому згині піддається дії додаткової сили, що розтягує, при цьому всі волокна металу відчувають розтягування. Спостерігається лише деяке скорочення площі поперечного перерізу, тоді як кут і радіус згинання не змінюються.

При виготовленні деталей з дуже малими радіусами вигину, що дуже часто зустрічається в силових конструкціях РЕА, виникає небезпека розриву зовнішнього шару заготівлі в місці вигину внаслідок надмірного для даного матеріалу відносного подовження шару. Небезпека розриву збільшується за наявності дефектів поверхні заготівлі (тріщин, виривів). Величина мінімально допустимого радіусу згину залежить від механічних властивостей матеріалу заготівлі, якості її поверхні і від технології згинання, що застосовується. Деталі з дуже малими радіусами заокруглення слід виготовляти із пластичних

матеріалів або попередньо піддавати вихідний матеріал термічній обробці – відпалу. При виготовленні деталей з мало пластичних матеріалів із відносно малими радіусами закруглень необхідно застосовувати процеси згинання, при яких виникають незначні сили, що розтягують. Останні зменшуються внаслідок тертя заготівлі про згинальний пристрій або штамп, радіус згинання деталі не слід приймати близьким до мінімально допустимого, якщо це не викликано конструктивними вимогами. З технологічних міркувань навіть найбільш пластичних матеріалів недоцільно допускати радіус згину менше товщини заготовки. Мінімальні внутрішні радіуси згинання наведені в таблиці 1.

Слід брати до уваги, що в попередній операції, наприклад при вирубуванні, матеріал заготівлі поблизу лінії зрізу наклепується (ущільнюється) та його пластичність знижується; це викликає необхідність збільшення мінімально допустимого радіусу згинання. Зі збільшенням товщини листового прокату його пластичні властивості знижуються, внаслідок чого величина мінімально допустимого радіусу значно підвищується. Недотримання основних положень при виборі радіусу згинання заготовок або деталей призводить до появи тріщин та інших дефектів на металі.

Різновиди згинання обумовлені вимогами до властивостей готових деталей та формою вихідних заготовок, скоб, петель, кронштейнів, кілець та інших виробів з листового, круглого та профільного металу. Заготовки можна згинати під кутом, по радіусу та фасонним кривим. Залежно від розмірів та форми деталі, профілю вихідної заготівки та характеру виробництва гнуття здійснюється:

– у штампах, з прив’язкою на ексцентрикових, кривошипних, фрикційних та гідравлічних пресах;

– на спеціальних ручних або механізованих пристроях;

– на згинальних та профільувальних верстатах.

Як правило, довжина заготівлі (розгортка) вказана на кресленні. Якщо цього розміру немає, профіль заготовки слід розбити на ділянки, визначити довжину кожного з них і, підсумовуючи, знайти загальну довжину розгортки.

Таблиця 1.

Мінімальні радіуси згинання

Товщина заготовки, мм	Радіус гнуття деталі з:				
	сталі	дюралюмінію	алюмінію	міді	латуні
0,2	-	-	-	0,2	0,2
0,3	0,5	1,0	0,5	0,3	0,4
0,4	0,5	1,5	0,5	0,4	0,5
0,5	0,6	1,5	0,5	0,5	0,5
0,6	0,8	1,8	0,6	0,6	0,6
0,8	1,0	2,4	1,0	0,8	0,8
1,0	1,2	3,0	1,0	1,0	1,0
1,2	1,5	3,6	1,2	1,0	1,2
1,5	1,8	4,5	1,5	1,5	1,5
2,0	2,5	6,5	2,0	1,5	2,0
2,5	3,5	9,0	2,5	2,0	2,5
3,0	5,5	11,0	3,0	2,5	3,5
4,0	9,0	16,0	4,0	3,5	4,5
5,0	13,0	19,5	5,5	4,0	5,5
6,0	15,5	22,0	6,5	5,0	6,5

Схеми штампів для V-подібного згинання подані на рис. 1. Перша схема (рис. 1.1, а) без притиску заготовки що штампується, застосовується з відносно малою умовною глибиною робочої порожнини матриці.

$$h_{\text{усл}} \leq 0.7\ (Rn + 5\ S) \qquad (1)$$

Радіус заокруглення матриці приймають *Rм = (1.5 – 2)S*. Якщо радіус

закруглення на пуансоні $Rn = S$,то $h_{усл} \approx (4\text{-}5)S$. Дані рекомендації ґрунтуються виходячи з наявності мінімально необхідної величини прямокутної ділянки $x \approx 3S$, що є основою для побудови робочої порожнини матриці за будь-яких інших радіусів Rn і $R_м$. Радіус на підставі робочої порожнини матриці Ro повинен відповідати зовнішньому радіусу виробу тільки у випадку, якщо $R_{Нвир} > 2S$. При менших значеннях $R_{Нвир}$ допускається Ro виконувати меншим ніж $R_{Нвир}$. Загальна висота матриці Н повинна становити орієнтовно $2h_{усл}$. За важких умов роботи доцільно проводити врізання матриці в плиту штампу. Кут вигину деталі, що штампується, можна виконувати в значних межах (від кута γ кілька меншого $180°$ до кута $\gamma \approx 15 - 20^0$). Мала величина γ залежить від вигину матеріалу, що допускається, і стійкості пуансона.

Вільне гнуття без притиску рекомендується застосовувати при відносно довгих заготовках, коли їх загальна довжина до вигину перевищує «розтвір» матриці L на $(2 \div 4)S$. Заготівлі при вільному згинанні можуть зміщуватися від центру вигину. Абсолютна величина цього усунення тим менше, чим менше розмір L і глибина $h_{усл}$ матриці. Крім того, на відносно неглибоких матрицях неможливо здійснити редагування всієї полиці деталі. Тому даний метод згинання застосовують для деталей, що не потребують високої точності.

Друга схема згинання (рис. 1, б) більш досконала. Створенням необхідного притискного зусилля можна забезпечити отримання полиць однакової висоти А з достатньою точністю. Функції притисків виконують переважно круглі стрижні. Для вузьких деталей достатньо одного стрижня в центрі матриці, а для широких – не менше двох. Притиск допускає виконання матриці зі значною глибиною $h_{усл}$ (у межах величини ходу тарілки буфера). Можливе ведення процесу з правкою полиць деталі і, отже, із забезпеченням їхньої площинності. У аналізованих схемах рекомендується дотримуватися умова, щоб ширина пуансона C не виходила за межі прямолінійних ділянок матриці дотримуючись розміру X (рис. 1, а).

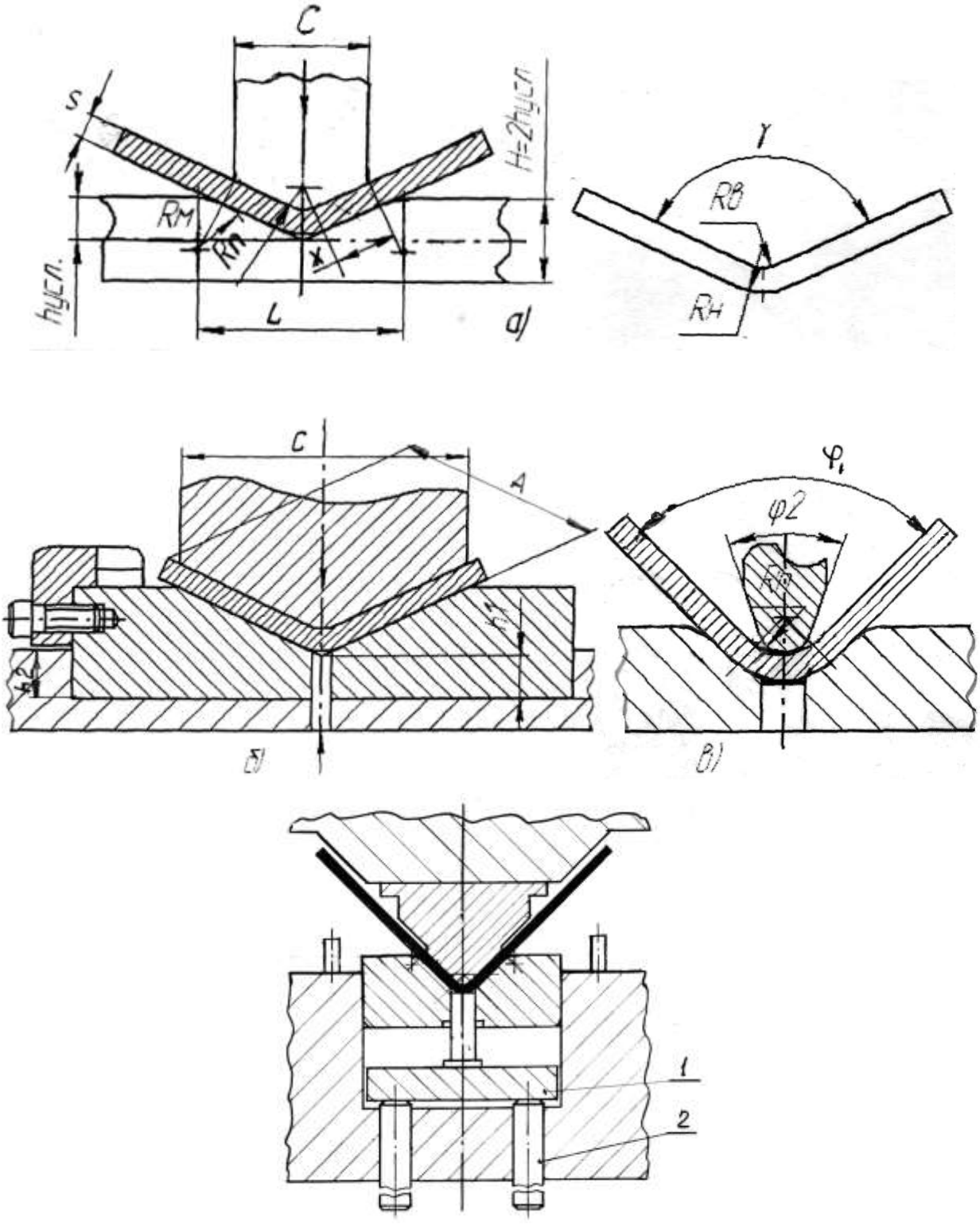


Рисунок 1. Схеми V-образного гнуття

Якщо тиск на буфер преса передається через отвори підштампової плити, можна застосовувати місцеві траверси *1* з проміжними шпильками *2* (рис. 1, г).

Матрицю з малою глибиною $h_{усл}$ (рис. 1, а) зазвичай виготовляють цільною, а з великою глибиною – секційною із застосуванням врізання (рис. 1, б). При легких роботах можна використовувати врізні шпонки. Розмір $h1$ секції не повинен бути меншим за 0,5 $h_{усл}$ при глибині врізання $h2 \geq h1$. Секційний інструмент по жорсткості не повинен поступатися цільному. Кут між полицями V-подібної деталі утворюється по матриці (якщо не враховувати пружиніння), тому процес формування можливий при пуансоні з кутом робочої частини $\varphi 2$ меншим, відповідного кута деталі. Наприклад, при вугіллі деталі $\varphi 1 = 90°$ можна застосовувати пуансон із кутом $\varphi 2 = 60°$ (рис. 1, в). Будь-яка, навіть незначна, різниця між кутами $\varphi 1$ і $\varphi 2$ виключає можливість процесу згинання з правкою сторін деталі.

Листові деталі V-подібної форми можна отримувати в штампах з еластичною матрицею (рис. 2), наприклад, гнучкою в поліуретановому середовищі.

Твердість поліуретану по Шору 90–95. Обов’язковою умовою є встановлення контейнера. Як еластичну масу можливо використовувати і деякі сорти твердої гуми. Еластичне середовище сприяє збереженню чистої поверхні деталей без слідів найменших пошкоджень, що важливо для деталей з різними захисними, декоративними покриттями, нанесеними на вихідний матеріал, а також для м’яких деталей.

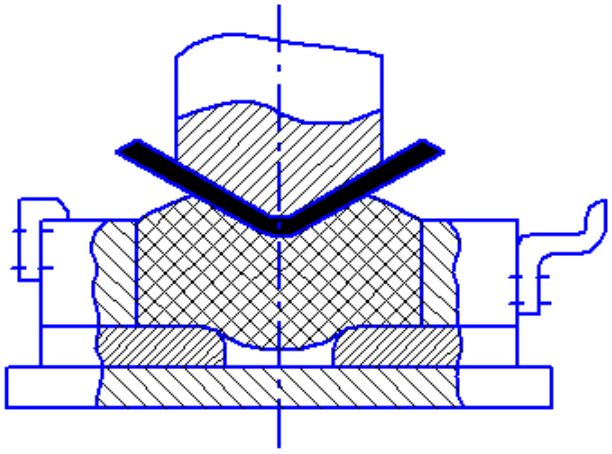


Рисунок 2. Еластична матриця (з поліуретану) у штампах для V-подібного згинання

Потрібне зусилля для V-подібного згинання в штампах визначають, розглядаючи заготівку як балку, що вільно лежить на двох опорах. Ковзаючи полицями по робочих ребрах матриці, заготівля при згинанні під дією реактивної (розпираючої) сили *R* і сили тертя *T* (рис. 3) піддається зовнішньому згинаючому моменту. Максимальна деформація спостерігається у тангенціальному напрямку (вздовж осі заготівки). Зовнішня зона заготівки (стосовно центру кривизни) відчуває деформацію розтягування, а внутрішня – деформацію стискування. Одночасно пластична деформація спостерігається в одному або двох інших взаємно перпендикулярних напрямках – радіальному та поперечному.

Формули для розрахунку зусиль згинання заготівок:

1) прямокутних:

а) за любого кута α:

$$P_{\square} = \frac{BS^2\ (1{,}5+\varepsilon_{\text{в}})\sigma_{\text{в}}\ (\cos\alpha+\mu\sin\alpha\ )}{\frac{1{,}5\ L}{cos\alpha}-\ 3\ tg\ \alpha\ (r_n+S+r_{\text{м}}\ )+\ 1{,}5\mu S} +\ Q_{\text{буф}},$$

б) за α= 30° і середнім значенні $\varepsilon_в$ = *0,2*:

$$P_{max} = \frac{1{,}7BS^2\ \sigma_{\text{в}}\ (0{,}866+0{,}5\mu)}{1{,}73\ (\text{L}-r_n-S-r_{\text{м}}\ )+\ 1{,}5\mu S} +\ Q_{\text{буф}}.$$

2) круглих:

а) за любого кута α:

$$P_o = \frac{0{,}2d^3\ (1{,}7+\varepsilon_{\text{в}})\ (\cos\alpha+\mu\sin\alpha\ )\sigma_{\text{в}}}{\frac{L}{2cos\alpha}-\ tg\ \alpha\ (r_n+d+r_{\text{м}}\ )+\ \mu\frac{d}{2}} +\ Q_{\text{буф}},$$

б) за α= 30° і середнім значенні $\varepsilon_в$ = *0,2*:

$$P_{omax} = \frac{0{,}66\, d^3 \sigma_{\text{в}}\, (0{,}866 + 0{,}5\mu)}{L - (r_n + d + r_{\text{м}}) + 0{,}865 \mu d} + Q_{\text{буф}}.$$

Допуски на кут згинання у залежності від показника співвідношення *R/s* (радіуса згинання до товщини листа) подані в табл. 2.

Таблиця 2.

Допуски на кут згинання

Матеріал	Допуск на кут α за R/s		
	до 1	від 1 до 2	від 2 до 4
Сталь м'яка, латунь м'яка, $\sigma_{\text{ср}}$ до 220 МПа, алюміній	±15'	±30'	±1°
Сталь середньої твердості $\sigma_{\text{ср}} = 400$ МПа, латунь напівтверда, $\sigma_{\text{ср}} = 350$ МПа	±30'	±1°30'	±3°
Сталь тверда, $\sigma_{\text{ср}} = 600$ МПа, бронза БрОФ	-	±3°	±5°

Найменша можлива висота полки що відгинається $H > 2s + R$, де s – товщина матеріалу, R – радіус згинання.

Гнуття зі защемленням (притиском) заготовки що штампується, виконується за кількома схемами, з яких основні три: при нерухомій горизонтальній заготовці (рис. 4, а), з горизонтальною заготовкою (рис. 4, б) і з похилим розташуванням заготовки.

Перші дві схеми ідентичні. В одному випадку напівфабрикат укладається горизонтально на нерухомий пуансон *1* (рис. 4, а) і після защемлення притиском *2* відгинається верхнім інструментом *3*. В іншому випадку процес починається з укладання напівфабрикату на притиск *2* (рис. 4, б). Зі схем видно, що кут вигину

деталі γ не може бути меншим за 90^0.

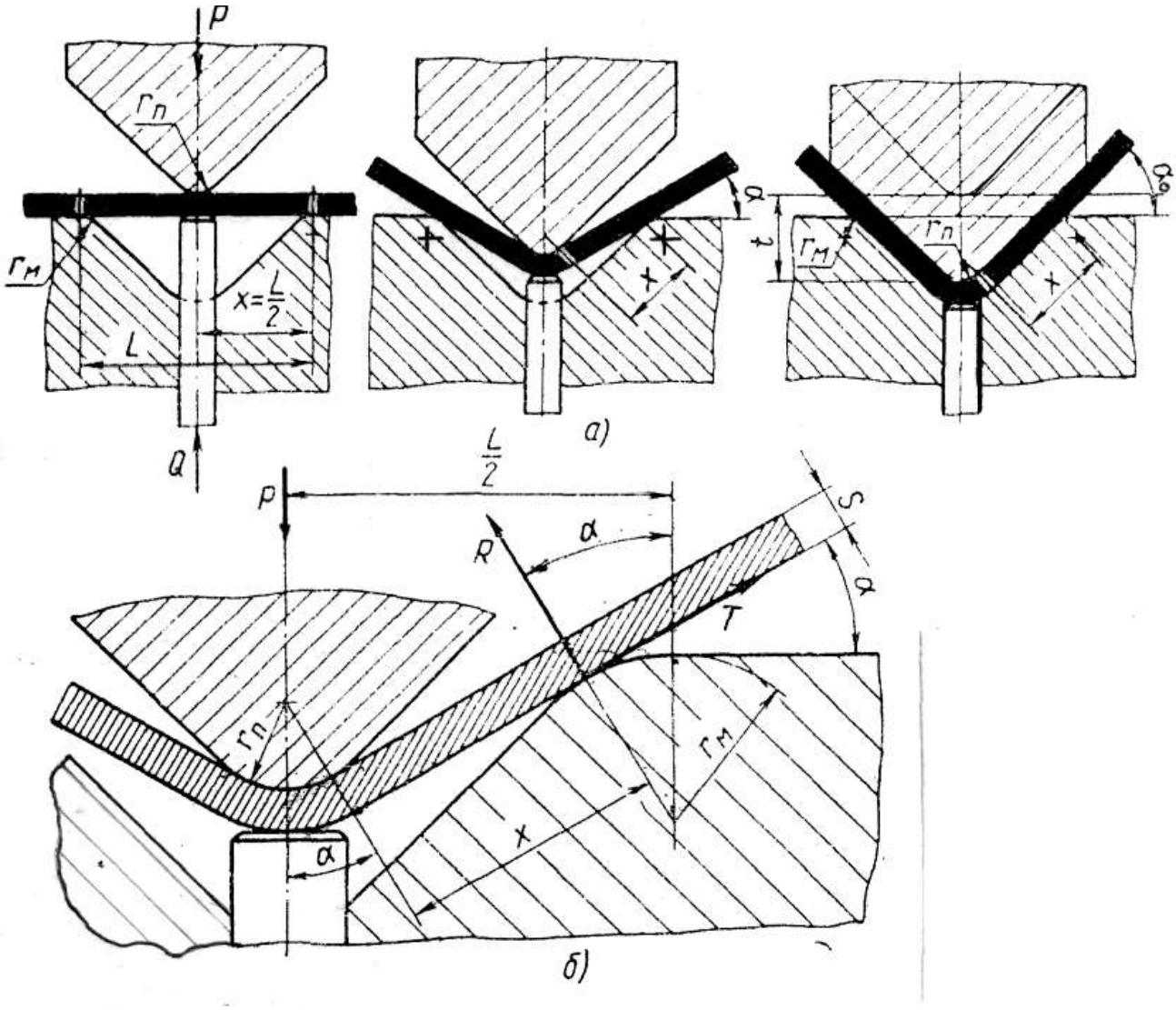


Рисунок 3. До визначення зусиль за V-образного гнуття: *а* – проміжні положення заготовки у процесі згинання; *б* – розрахункова схема

Третя схема (рис. 4, в) забезпечує отримання деталей із різним кутом вигину. Крім того, з'являється можливість для коригування кута вигину γ з урахуванням пружиніння матеріалу що штампується. Подібні конструкції дозволяють робити правку одночасно двох полиць деталей, що неможливо виконати при вертикальному розташуванні однієї полиці деталей. Ця схема раціональніша порівняно з першими двома.

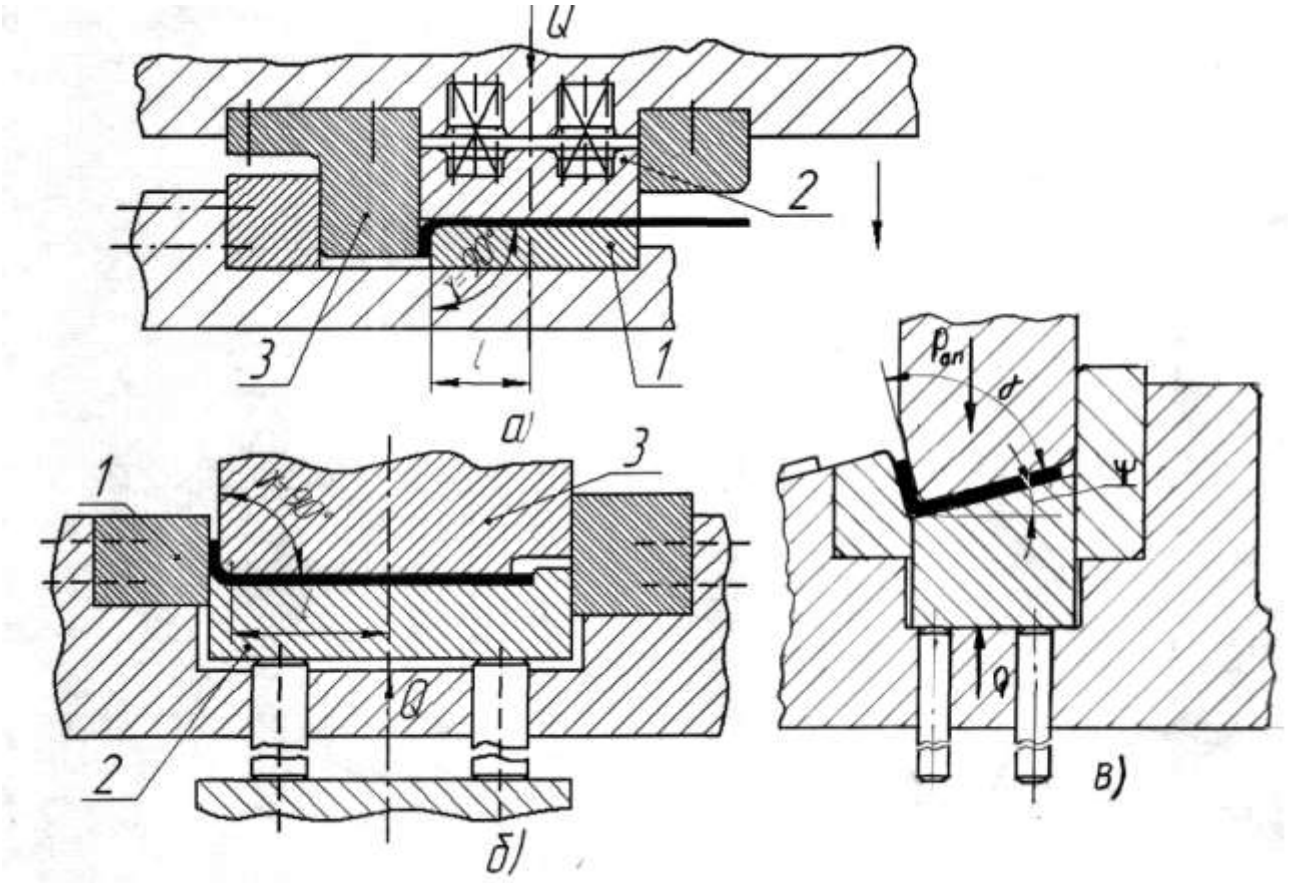
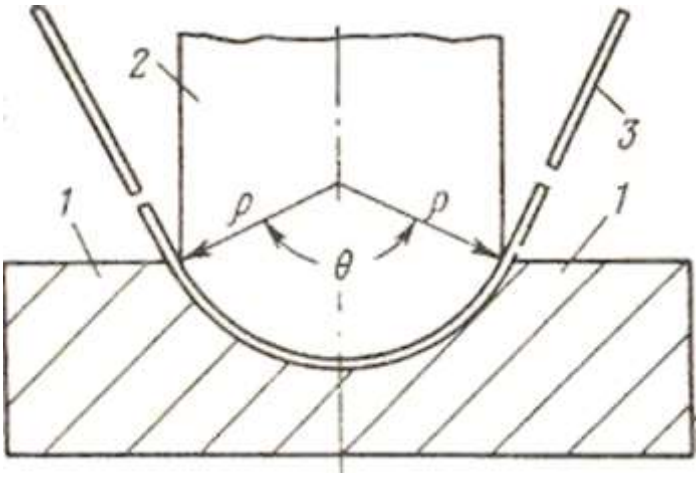


Рисунок 4. Однокутове (Г-образне) гнуття зі защемленням (притиском) вихідної заготівки в горизонтальному положенні: *а* – за нерухомого пуансона; *б* – за нерухомої матриці; *в* – з можливістю коригування кута вигину γ

У штампах з пов’язаною формою пуансона і матриці виготовляються деталі із заданою кривизною вигнутого контуру. Відмінною особливістю порівняно з вільним гнуттям в цьому способі є те, що заготовка яка деформується, в кінці навантаження приймає форму деформуючого інструменту (рис. 5). Тому форма пуансона і матриці повинні бути скориговані на пружиніння, щоб після розвантаження деталь мала заданий кут загину θ і радіус кривизни контуру ϱ_0.



1 – матриця, 2 – пуансон, 3 – деталь

Рисунок 5. Схема гнуття в інструментальному штампі:

Зусилля *Pn* з яким пуансон деформує заготівлю до необхідної кривизни χ_0, дорівнює величині рівнодіючої реакцій $P_м$ з боку матриці з урахуванням сил тертя заготовки про матрицю (рис. 6):

$$P\text{п} = 2P\text{м}cos\alpha\ (\ 1 + ftg\alpha),$$

де f – коефіцієнт тертя заготовки по матриці.

За невільного гнуття у міру утворення кривизни вигину, що дорівнює кривизні пуансона, відповідна ділянка заготовки прилягає до останнього і вимикається з подальшої деформації. Кордони відформованої ділянки – точки *b* – у міру занурення пуансону в матрицю переміщаються з його контуру. Їх становище, у загальному випадку, характеризується кутами α (рис. 6), які становлять з віссю пуансона нормалі до його контуру в зазначених точках.

Плече Δl сили $P_м$ щодо граничної точки *b* відповідно до міри переміщення останньої за контуром пуансона зменшуватиметься. Отже, сила реакції матриці $P_м$ для створення необхідного згинального моменту в процесі гнуття зростатиме.

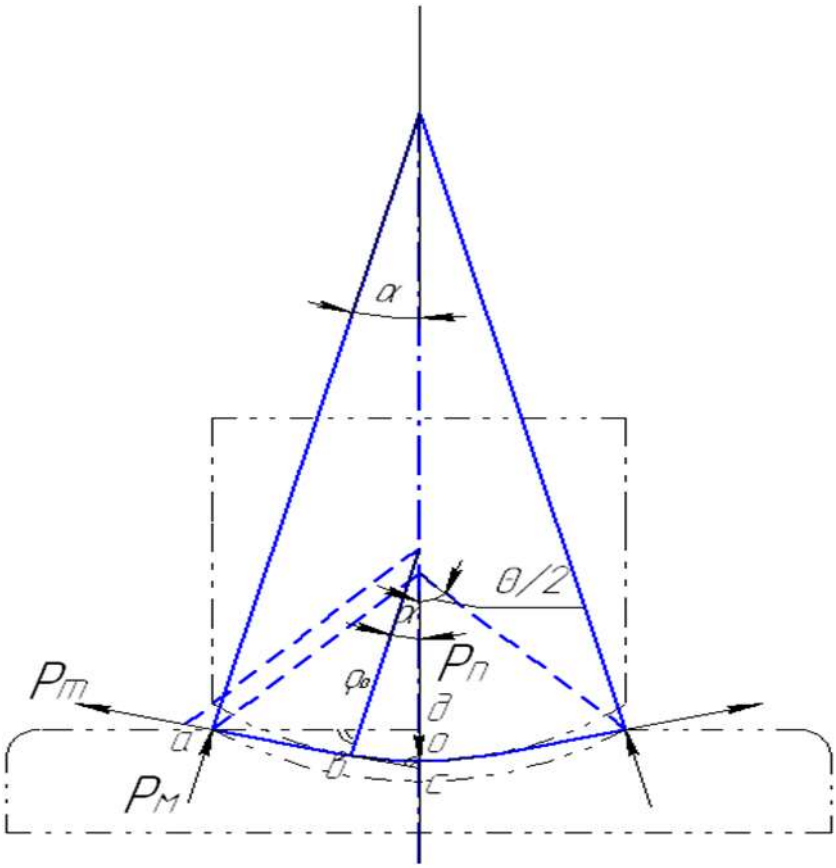


Рисунок 6. Розрахункова схема для визначення зусиль штамповки за невільного гнуття

Якщо нехтувати впливом на кривизну і прогин різальних сил і вважати, що вигин заготовки до сполучення по всьому контуру матриці – пуансона відбувається тільки за рахунок моменту, то потрібне зусилля штампування P_n (за $\Delta l = 0$ або $\alpha = \frac{\theta}{2}$) відповідно до формули є нескінченним. Насправді зусилля P_n, як показує практика, є кінцевим. Це свідчить про те, що в даному випадку не можна нехтувати впливом на кривизну і прогин сили, що перерізує. У процесі вигину настає момент, за якого не відформована ділянка заготовки Δl (між точками контакту з пуансоном і матрицею) стає рівним товщині h. За таких умов взаємні зсуви поперечних перерізів, що викликаються силою перерізу $P_м$, створюють вигин і переміщення ділянки заготівки в кілька разів більші, ніж від дії моменту. За рахунок цього і відбудеться прилягання заготовки по всьому контуру пуансона – матриці при кінцевому значенні штампування зусилля P_n.

Гнуття сполучених профілів у заготовках малих та середніх розмірів здійснюють у складних згинальних штампах. Штамп (рис. 7, а) має сталеву плиту *1* із закріпленою на ній матрицею *5*. Формоутворююча поверхня матриці має опукло-ввігнутий пов'язаний профіль. Встановлені на її передніх сторонах упорні планки *4* призначені для укладання заготовок *6*. Робоча поверхня вставки пуансона *3* має такий же профіль, як профіль матриці, різниця лише в тому, що сполучення радіуса опукло-ввігнутого профілю виконані з урахуванням товщини заготовки. Вставка пуансона розташовується в паз пуансоноутримувача *2* і з двох сторін кріпиться контрольними штифтами.

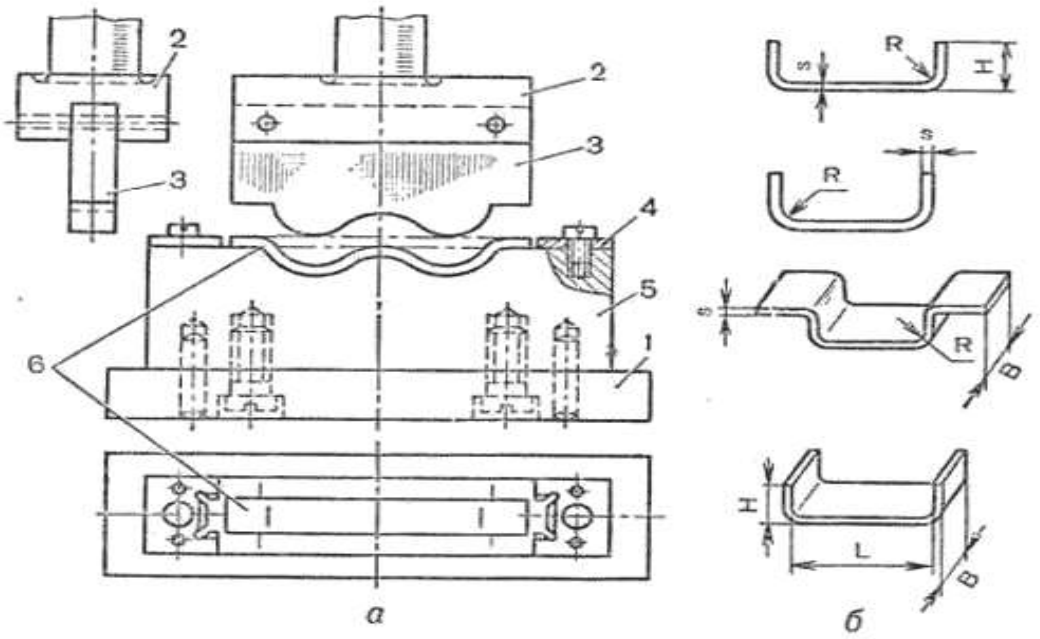


Рисунок 7. Гнуття складних опукло-ввігнутих профілів деталей: а – найпростіший штамп для згинання петлі; б – типи отриманих деталей

Джерело рисунка [154]

Для забезпечення достатньої точності висота *H* прямої частини стін що відгинаються (поличок) деталі повинна бути більше подвійної товщини, тобто *H-R>= =2s* (за умови, що *s* < *5* мм). Мінімально допустимий внутрішній радіус вигину залежить від товщини та пластичних властивостей вихідного матеріалу, а також від напрямку прокатки.

Таблиця 3.

Значення мінімальних радіусів вигину для складних деталей

Матеріал	Відпалений чи нормалізований		Наклепаний	
	Лінія гнуття			
	поперек волокон	вздовж волокон	поперек волокон	вздовж волокон
1	2	3	4	5
Сталь: Ст.08, Ст.05	-	0.3	0.2	0.5
08; Ст.2; 10	-	0.4	0.4	0.8
Ст.3, 15, 20	0.1	0.5	0.5	1.0
Ст.4, 25, 80	0.2	0.6	0.6	1.2
Ст.5, 35, 40	0.3	0.8	1.0	1.5
Ст.6, 45, 50	0.5	1.0	1.0	1.7
Ст.7, 55, 60	0.7	1.3	1.3	2.0
корозійна	-	-	2.5	6.5
1	2	3	4	5
Мідь М1, М2, М3	-	0.3-0.5	1.0	2.0
Латунь: Л62, Л68	-	0.3-0.4	0.5	0.8
ЛС59-1	0.2	0.5	0.8	1.4
Мельхіор, нейзильбер	0.3-0.6	0.5-1.0	-	-
Бронза БрОФ 6,5-0,15	0.5	1.2	-	-
БрКМц 3-1; БрА5	0.5	1.2	-	-
БрОЦС 4-4-2,5; БрБ2	1.0	2.5	-	-
БрАМЦ 9-2	1.5	3.0	-	-
Алюміній	-	0.3-0.4	0.5	0.8
Алюмінієвий сплав Д1	0.5	1.0	1.5	2.2
Д16М	1.0	1.5	1.5	2.5
Д16Т	2.0	3.0	3.0	4.0

Якщо деталь має форму скоби з горизонтальними полицями і виходить в одному штампі, радіус R, звернений у бік матриці, повинен бути більше s. Якщо $R < s$, то в процесі згинання на бічних полицях деталі можлива поява вм'ятин і дефектів, що особливо небезпечно для металів, що мають плакувальне покриття. За малого радіуса процес слід проводити в дві операції: згинання в матриці $R > s$ і гнуття до отримання заданого радіусу. Радіуси заокруглення у скоб мають бути рівними, якщо ця умова нездійсненна, отримати деталь з однаковою висотою полиць важко. Для точності фіксування заготовок у штампах та запобігання їх зсуву в момент згинання бажано передбачати в деталях технологічні отвори. З наведених на рис. 7, б прикладів випливає:

а) радіус згинання тим більше: чим менше подовження металу;

б) зі зменшенням кута вигину, особливо у металів з малим відносним подовженням, радіус R повинен бути збільшений;

в) найменше значення, за інших рівних умов, радіус має у разі, коли лінія вигину розташована впоперек напрямку прокатки. За розташування ліній вигину під кутом $45°$ або за напрямом прокатки радіус має бути збільшений;

г) якщо при згинанні задирки на кромці заготовки розташовані назовні, тобто у бік матриці, то необхідно значне збільшення R.

Значення мінімально допустимих радіусів вигину R для захищених від задирок заготовок або заготовок з задирками, зверненими в бік пуансона, наведені в табл. 3.

3.1.1.2 Проблеми, що виникають у процесах згинання різних заготовок та інтенсифікація процесів згинання

За практичного використання процесу гнуття, який є одним із найпоширеніших, постійно виникають деякі проблеми, основні з них перераховані нижче.

1. Запобігання руйнуванню заготівлі при її вигині за надмірно малим радіусом.

Руйнування зазвичай відбувається по бісектрисі кута внаслідок великих

деформацій розтягування на опуклій поверхні радіусу. Часто буває необхідно виготовити деталь, зігнуту за мінімально можливим радіусом у межах що близькі до нуля. Таким способом можна отримати з листового матеріалу профільні деталі (куточки, швелери та ін.), переріз яких наближається формою до перерізу пресованих профілів. Так як міцність листового напівфабрикату зазвичай вища, ніж пресованого з матеріалу тієї ж марки, а допуск на товщину жорсткіший, то при рівній масі гнутий з листа профіль буде міцнішим, ніж пресований.

Іноді зменшення гранично допустимого радіусу вигину диктується необхідністю зниження матеріаломісткості виробу, умовами монтажу та ін., внаслідок чого ця проблема є актуальною.

2. Зменшення витончення заготовки у зоні вигину. Чим менший радіус вигину, тим більшою мірою зменшується товщина заготовки в процесі деформування. Витончення призводить до зниження міцності деталі. Крім того, воно є додатковою причиною концентрації напруги та втомного руйнування. Зазвичай допустиме витончення обмежується деяким значенням (близько 20%). Усунення витончення, а ще краще – збільшення товщини в зоні вигину дозволило б підвищити жорсткість та міцність деталі.

3. Запобігання зміні форми поперечного перерізу при згинанні труб та профілів. Наприклад, сплющування труб при гнутті веде до зменшення площі прохідного перерізу, що неприпустимо, так як знижуються пропускна здатність трубопроводу, міцність і жорсткість трубчастого елемента.

4. Підвищення точності вигнутих деталей. При згинанні частина матеріальних волокон, що розташовані поблизу опуклої поверхні, розтягується в окружному напрямку (зона тангенціального розтягування), а решта поблизу увігнутої поверхні стискається в тому ж напрямку (зона тангенціального стиснення). Ці зони розділяє шар матеріалу радіусу r_n, в даний момент не змінює своїх розмірів і називається нейтральною поверхнею. Напруги розтягування і стискання в окружному напрямку, що виникають при гнутті, створюють відносно нейтральної поверхні момент внутрішніх сил, який врівноважується

зовнішніми навантаженнями, що додаються. Після зняття останніх після закінчення згинання відбувається пружна віддача (пружиніння), за якого деталь прагне розпрямитися у бік, протилежному попередньому вигину. При цьому змінюються радіус і кут вигину, тому розміри під навантаженням і після його зняття різняться.

Для виготовлення деталі з необхідною точністю, потрібно згинати заготовку по радіусу на кут, скоригований з урахуванням пружиніння, тобто розміри інструменту (наприклад, кут пуансона) повинні відрізнятися від розмірів деталі. Це відхилення визначають розрахунковим чи досвідним шляхом. Але з урахуванням відхилень виготовити точну деталь складно, так як навіть у межах однієї партії матеріалу його механічні характеристики (межа пропорційності, тимчасовий опір, подовження, анізотропність та ін.), а також геометричні розміри перерізу (товщини листа і полиць профілю, діаметр і товщина стінки труби та ін.) досить істотно розрізняються, внаслідок чого виготовлені деталі необхідно обробляти додатково, найчастіше вручну. Це трудомісткий і шкідливий для здоров'я процес, особливо при доведенні великогабаритних, масивних деталей, вимагає високої кваліфікації виконавця, тому зменшення або усунення пружиніння є важливим завданням як з технічної, так і з економічної та соціальної точок зору.

Наведені дефекти обмежують мінімально допустимі радіуси вигину. Наприклад, відносний радіус вигину *R/S* для листових титанових сплавів має такі значення:

1) ВТ1-1 – 2,5;

2) ОТ4 – 3,7;

3) ВТ6 – 7;

4) Д16Т – 2;

5) 01420 – 3,5.

При згинанні профілів відношення радіуса вигину до висоті профілю повинно мати певне значення, наприклад, для профілів з алюмінієвих сплавів –

не менше 5...6, а з титанових сплавів – не менше 7...8.

Усі розглянуті вище проблеми виникають через специфіку напружено-деформованого стану заготівлі при згинанні, тому найбільш раціональним способом їх вирішення є зміна поля напружень та деформацій у процесі формоутворення.

Гнуття із зональним нагріванням. його використовують як спосіб зменшення спотворення форми поперечного перерізу. При згинанні труби *1* (рис. 9, а) згинальним роликом *5* заготовка піддається вузькозональному нагріванню індуктором *3*. Ширина зони обмежується за допомогою спрейєрів (розбризкувачів) *2* і *4*, через які струмені води подаються на заготовку, охолоджуючи її стінку. Розподіл температури (рис. 9, б) визначає відповідний розподіл властивостей міцності по довжині труби – у вузькій нагрітій зоні, ширина якої не перевищує декількох товщин стінки заготовки, міцність матеріалу різко зменшується. Ділянка яка деформується межує з обох сторін з більш міцнішими частинами заготовки, які перешкоджають сплющуванню перерізу в осередку деформації.

Позитивний вплив на процес згинання надає нерівномірність нагріву за перерізом заготовки. Якщо більш нагрітою, отже, менш міцною, виявиться увігнута поверхню заготівлі, то це веде до усунення нейтральної поверхні убік опуклої і відповідного зменшує деформацій розтягування в окружному напрямі. За такого способу нагрівання можливо запобігти руйнуванню за гнуття по малому радіусу. Якщо більш нагрітим буде матеріал у зоні розтягування, то нейтральна поверхня зміститься у напрямі увігнутої і буде зменшено абсолютне значення окружних стискаючих напружень. Це дозволить запобігти гофроутворенню при згинанні труб і профілів і тим самим зменшити гранично допустимий радіус вигину. Нерівномірність нагрівання по перерізу легко забезпечити, змінюючи відносне положення індуктора, спрейєрів і труби.

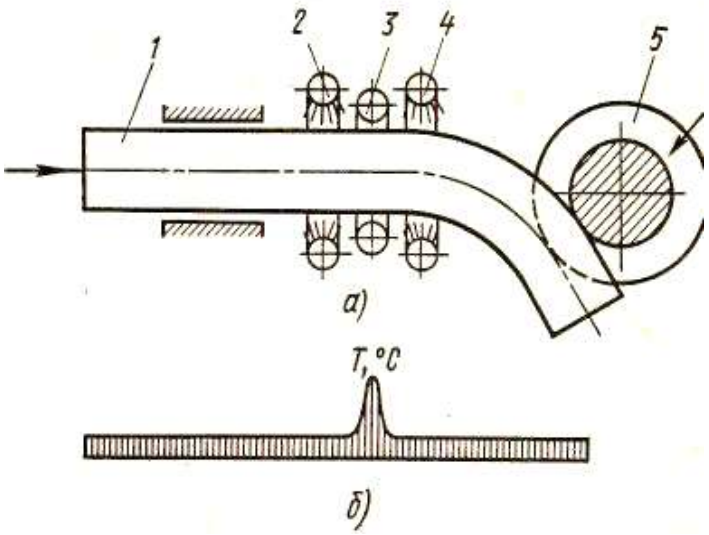


Рисунок 8. Схеми згинання труби з зональним нагріванням (а) та розподілу температури вздовж осі труби (б)

Гнуття з додатковим навантаженням. Все більшого поширення набуває згинання з додатковим навантаженням. Заготівка зображена на рис. 9, а згинається тільки під дією моменту сил. Навантаження заготівлі можливе відбуватися у трьох напрямках (рис. 9):

– у радіальному – стискаючому навантаженні *f* (рис. 9, б);

– в окружному – навантаженням *q*, яке може працювати на стискання або розтягування (рис. 9, в);

– в осьовому, що стискає або розтягує навантаження *p* (рис. 9, г).

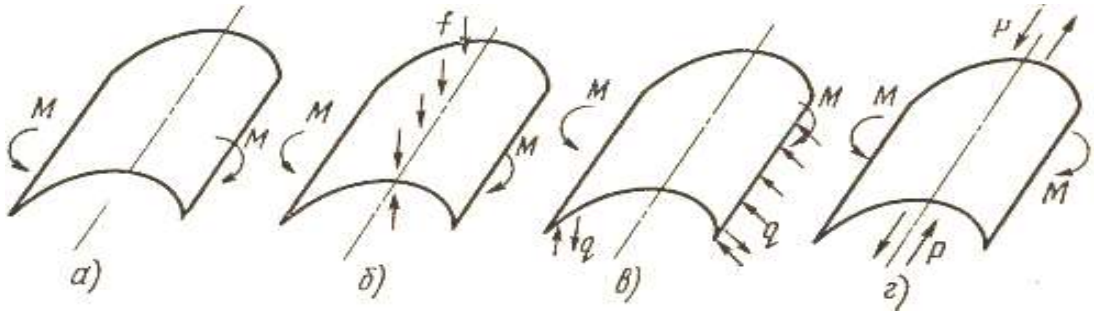


Рисунок 9. Схеми гнуття заготовки без додаткового навантаження (а) та з додатковим навантаженням у радіальному (б), окружному (в) та осьовому (г) напрямках

Можливі також поєднання додаткових навантажень у двох чи трьох напрямках. Кожен варіант навантаження дозволяє вирішувати одну або кілька розглянутих проблем відповідно до зміни напружень і деформацій, що залежать від положення нейтральної поверхні, і зміною коефіцієнта жорсткості схеми напруженого стану.

Гнуття з радіальним стиском (1 варіант). Гнуття з радіальним стисненням може здійснюватися в декількох варіантах: додаткове навантаження прикладається до або під час згинання (рис. 10, а) або після нього (рис. 10, б).

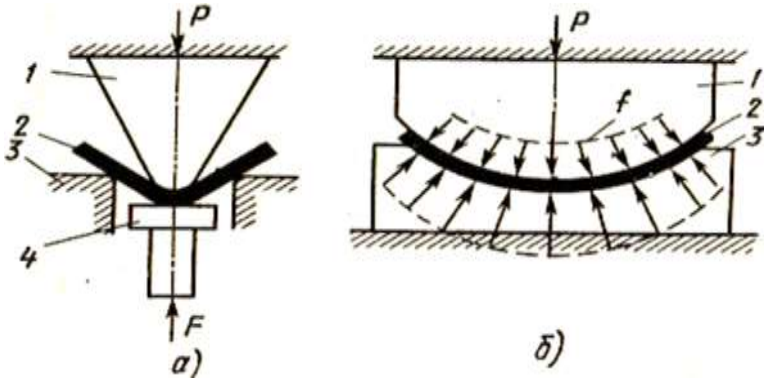


Рисунок 10. Схеми гнуття зі стиском в радіальному напрямку із застосуванням додаткового навантаження протягом всього процесу згинання (а) і після нього (б)

У першому випадку пласка листова заготовка *2* затискається між пуансоном *1* і притиском *4*, до якого прикладається додаткове зусилля *P* (постійного значення або збільшується в ході процесу). Це зусилля створюється з допомогою гідро- або пневмоциліндра, маркерного пристрою, пружини та ін. Потім під дією сили *P*, прикладеної до пуансона ($P>F$), відбувається вигин заготівлі в матриці *3*.

При цьому способі гнуття є можливість стиснути матеріал в осередку деформації великою силою *F* і тим самим зробити схему напруженого стану м’якою. Це веде до суттєвого зменшення мінімально допустимого радіусу згину. Цьому ж сприяють сили контактного тертя, що діють на опуклій поверхні

заготовки, які перешкоджають переміщенню матеріалу в окружному напрямку і як би стискають його, ще більше зменшуючи коефіцієнт жорсткості напруженого стану.

Результатом є зменшення відносного радіусу вигину листових матеріалів порівняно із звичайним гнуттям:

– для Д16АТ (товщина листа 2,5 мм) – з 3 до 1,2 мм;

– для ОТ4 (товщина листа 2 мм) – з 3,7 до 2 мм (кут вигину дорівнює 90 °).

Пружиніння слабо залежить від радіального навантаження, яке прикладається не у всій зоні вигину, а лише поблизу бісектриси кута. Розвантаження заготовки слід проводити спочатку від згинального моменту, а потім – від сили *F*, щоб уникнути руйнування готової деталі.

Недоліком цього способу є збільшене витончення, яке може досягати 6 ... 8%.

Гнуття з радіальним стиском (2 варіант). Другий варіант навантаження називають гнуттям з наступним калібруванням радіальним стисненням. Так як додаткове навантаження прикладається після завершення гнуття, то воно не може зменшити гранично допустимий радіус деталі. По закінченні гнуття заготовку затискається між пуансоном і матрицею. На її контактних поверхнях діють сили тертя, спрямовані в бік бісектриси кута і стискають заготовку в окружному напрямку. Отже, в кінці деформування матеріал знаходиться в умовах, близьких до всебічного стиснення, що сприяє перерозподілу напруги і зміщення нейтральної поверхні в напрямку центру кривизни. Це зменшує момент внутрішніх сил та пружиніння після розвантаження.

Якщо стиснути заготовку так, щоб значення тиску *F* приблизно дорівнювало подвоєному значенню напруги плинності, то пружиніння буде відсутнє. При більш сильному стиску пружиніння змінює знак, тобто після зняття навантаження радіус вигину заготовки стане менше радіусу інструменту. Отже, калібрування значно підвищує точність деталей. Змінюючи навантаження

F, можна не тільки компенсувати шкідливий вплив розкиду механічних властивостей і розмірів заготовки, але навіть використовувати один і той же штамп для виготовлення деталей таких різних сплавів, як, наприклад, алюмінієві, титанові і сталі. При цьому відпадає необхідність коригувати розміри інструменту з урахуванням пружної віддачі.

Гнучка з радіальним стиском (3 варіант). Гнуття з радіальним стисненням може бути здійснено у звичайному, навіть універсальному штамповому оснащенні шляхом одночасного згинання декількох заготовок (рис. 11).

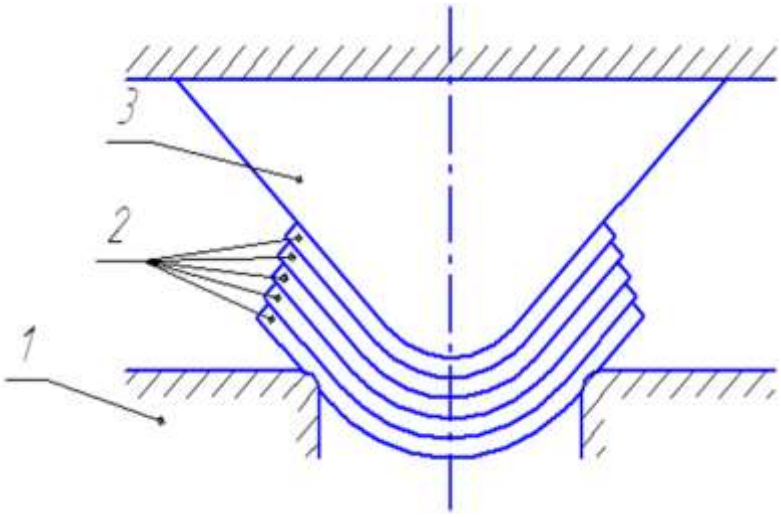


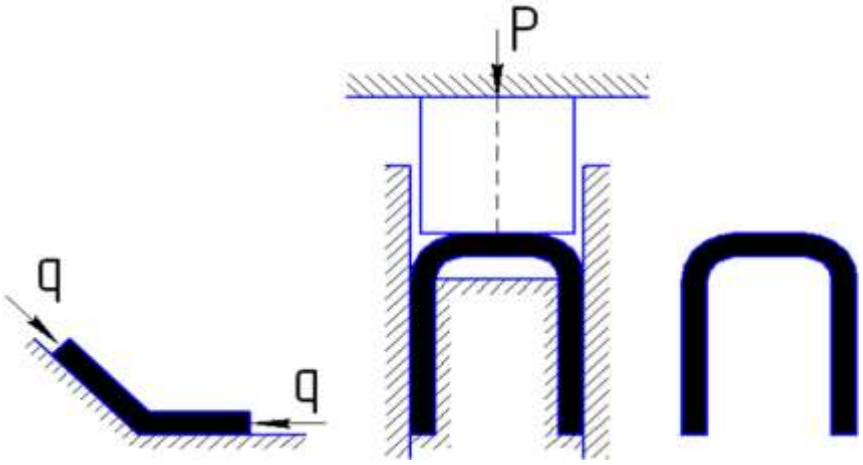
Рисунок 11. Схема одночасного гнуття декількох заготовок

На поверхню матриці *1* укладають пакет з 2...5 і більше заготовок *2*, які одночасно згинаються пуансоном *3*. Заготовка, що контактує з пуансоном, згинається по радіусу, заданому кресленням, а всі інші – по великих радіусах (радіус вигину самої нижньої заготовки більше мінімально допустимого). На опуклій поверхні кожної заготівлі діє зусилля, необхідне для вигину частини пакету розташованого нижче та створює радіальний стиск цієї заготовки. Максимальному стиску піддається заготовка, що згинається за найменшим радіусом. Після того, як пакет зігнутий, деталь, що торкається пуансона, видаляється, а з боку матриці додається плоска заготовка. При черговому ході пуансона по заданому радіусу буде зігнута заготовка, яка була другою та т. д.

За одночасного гнуття п’яти заготовок зі сплаву ОТ4 (товщина листа 2 мм) відносний радіус вигину зменшується з 3,7 до 1,5. Завдяки великим поверхням дотику заготовок на них діють значні сили тертя, що перешкоджають переміщенню матеріалу в окружному напрямку та зменшенню товщини, яке навіть за малих радіусів вигину не перевищує 3...4%.

Гнуття з окружним стиском. Гнуття з окружним (тангенціальним) стиском здійснюється під дією навантаження *q* (рис. 12, а), яке заштовхує попередньо вигнуту по великому радіусу заготовку в кутову зону інструменту (рис. 12, б), внаслідок чого кривизна цієї частини збільшується. Нейтральна поверхня при цьому зміщується в напрямку опуклої поверхні заготовки, що призводить до зменшення деформації розтягування в окружному напрямку та зменшення допустимого вигину радіуса. Товщина заготовки у кутовій зоні збільшується на 15...20 % при суттєвому зменшенні щодо радіусу вигину. Процес супроводжується значним негативним пружинінням.

Найчастіше окружний стиск забезпечується завдяки тому, що ширина заготовки (рис. 12, б) більше довжини тієї частини периметра деталі, формоутворення якої здійснюється гнуттям (рис. 12, в). За таких умов за переміщення пуансона відбувається вигин і потовщення переважно кутових зон заготовки.



а) б) в)

Рисунок 12. Схема навантаження заготовки (а), її згинання зі стисненням (б) і переріз готової деталі (в)

Найчастіше окружний стиск забезпечується завдяки тому, що ширина заготовки (рис. 12, б) більше довжини тієї частини периметра деталі, формоутворення якої здійснюється гнуттям (рис. 12, в), тому при переміщенні пуансона відбувається вигин і потовщення переважно кутових зон заготовки.

Ще більше зменшити радіус вигину та збільшити товщину у вигнутій зоні дозволяє комбіноване додаткове навантаження у радіальному та окружному напрямках. Заготовку *1* (рис. 13, а), вигнуту по великому радіусу, встановлюють у пази повзунів *2* і *3*, що переміщаються в корпусі *4*. Під дією сили *P* вигнута частина, що стикається з корпусом, випрямляється, а потім осідає зі збільшенням товщини в зоні вигину. Наприкінці ходу (рис. 13, б) отримують деталь, переріз якої відповідає перерізу пресованого профілю.

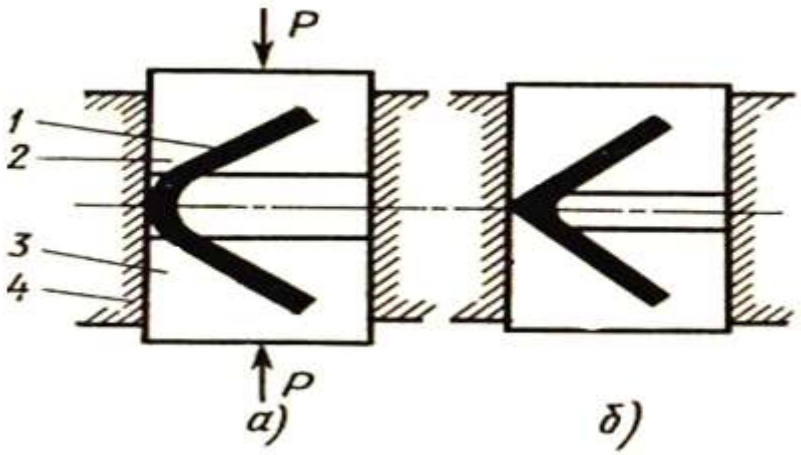


Рисунок 13. Вихідне (а) та кінцеве (б) положення заготівки при згинанні зі стисненням в окружному та радіальному напрямках

Джерело рисунка [155]

Гнуття з осьовим розтягуванням. Гнуття з осьовим розтягуванням (рис. 9, г) також дозволяє виготовляти деталі з меншим, ніж при звичайній згинанні, радіусом вигину. Наприклад, за звичайного згинання мінімальний відносний радіус вигину листової заготовки товщиною 1,2 мм зі сплаву ОТ4-1 дорівнює 2,1 мм. Якщо заготовку розтягнути в осьовому напрямку, створити в її матеріалі напругу порядку напруги плинності, то радіус може бути зменшений

до 1,4...1,5 мм, що пояснюється усуненням нейтральної поверхні від центру кривизни.

Поєднання осьового розтягування з окружним стиском у багатьох випадках дає можливість згинати заготовки по радіусу, що дорівнює нулю.

Локальне деформування. Порівняно новим є способи локального деформування – згинання – прокатка у валках і згинання – розкочування в двохроликовій машині. При згинанні – прокатці у валках (рис. 14, а) листова або профільна заготовка *1* пропускається між жорстким валком *2* і валком *3*, фанерованим шаром поліуретану *4*. Якщо відстані між центрами обертання роликів менше суми їх радіусів, то заготовка під дією верхнього валка впроваджується в еластичне покриття, на підставі чого виникає навантаження *f,* яке згинає заготовку. При зміні відносного положення валків змінюватиметься радіус вигину заготовки. Ця схема гнуття має велику універсальність, тому що дає можливість виготовляти деталі з різною шириною, товщиною та кривизною з різних матеріалів.

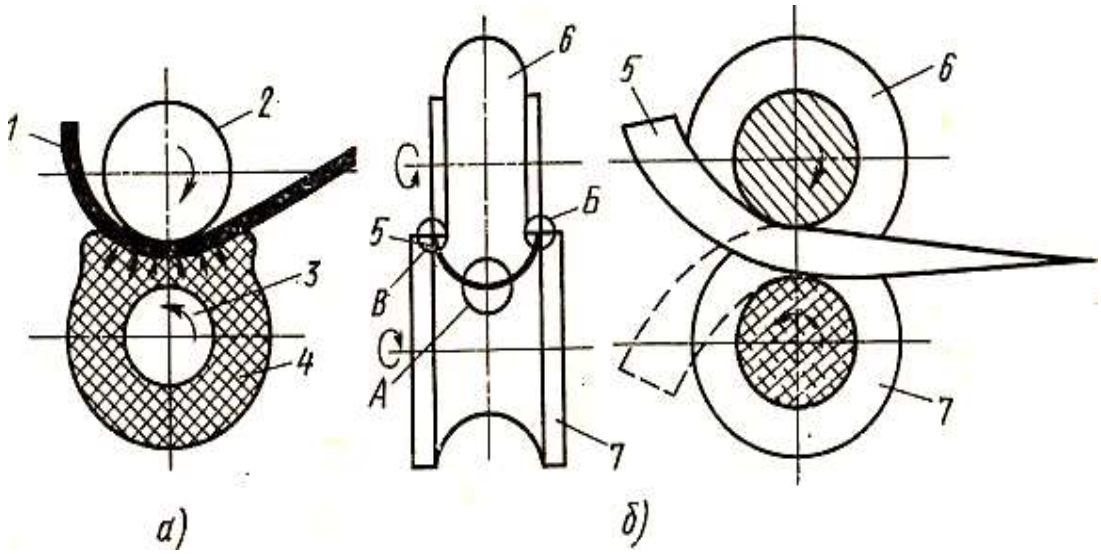


Рисунок 14. Схеми гнуття – прокатки у валках (а) та гнуття – розкочування у двороликовій машині (б)

Гнуття–розкочування у двохроликовій машині (рис. 14, б) використовується для виготовлення деталей одинарної та подвійної кривизни з

різною формою поперечного перерізу. Сутність способу полягає в тому, що плоска листова заготовка *5*, що пропускається між профільованими жорсткими роликами *6* і *7*, згинається в поперечному напрямку і одночасно (завдяки змінності зазору між роликами) – в поздовжньому. Якщо зазор між роликами менше товщини листа в зоні *А*, довжина заготовки в цьому місці збільшується, а заготовка згинається в напрямку опуклого ролика *6*. Якщо ж зазор між роликами менше товщини листа в зонах *Б* і *В*, то заготовка згинається в напрямку увігнутого ролика, як показано пунктиром. Зближуючи або видаляючи ролики, можна змінювати поздовжню кривизну деталі.

Перевагами цього процесу є простота і дешевизна оснастки в порівнянні з штампами, що традиційно використовуються, а також можливість виготовлення деталей необмеженої довжини. Продуктивність двохроликової машини значно вища за продуктивність преса.

3.1.1.3 Перспективні технологічні процеси формозміни листових заготовок

Одним із прогресивних методів, що дозволяє вирішити завдання зниження металоємності обладнання та енерговитрат, що є основним пріоритетом розвитку виробництва силових елементів конструкцій РЕА під час військового стану у нашій країні, є методи імпульсного листового штампування. Штампування вибухом пріоритетне перед іншими методами листового штампування, такими як викочування на оправці з нагріванням і виготовлення елементів розчленованої деталі на пресах з наступним зварюванням. В даний час освоєно виробництво кількох сотень найменувань листових деталей для всіх типів та модифікацій силових елементів РЕА застосованих в авіаційних двигунах, літальних апаратах, некерованих суднах, квадрокоптерах тощо. Однак багато підприємств відмовляються від запровадження імпульсних технологій, які можуть виконати практично будь-який вид обробки. При цьому обладнання дешевше за традиційне в десятки разів і також наявна колосальна економія ресурсів. Організація вибухової обробки, пов’язана з вирішенням багатьох

бюрократичних перешкод, не завжди екологічно безпечна та лякає багатьох керівників підприємств.

На сьогодні з'явилася ціла низка процесів обробки металів тиском, у яких відбувається мимовільна формозміна заготовки за незначного силового впливу або без нього. Тому виникла потреба у класифікації цих процесів, їх подальшому удосконаленні та розробці нових.

Для зниження деформуючих зусиль, енергоємності та підвищення екологічності можливо рекомендувати до використання такі пристрої, способи, технічні прийоми та фізичні процеси:

1. Використання резонансних явищ, що виникають при формозміні заготовки.

2. Формозміна заготовки за виникнення локалізації деформацій при розтягуванні та стисканні.

3. Концентрація та накопичення енергії в імпульсно-деформованій заготовці.

4. Використання ефекту відколу під час імпульсної формозміни заготовки.

5. Використання та облік внутрішніх напружень, що виникли в деформованій заготовці у технологічних операціях, що передують формозмінювальним операціям (технологічна спадковість), для зниження деформуючих зусиль у формозмінювальних та розділових операціях листового штампування.

6. Використання реактивних складових деформуючих зусиль для інтенсифікації процесу формозміни.

7. Використання зворотного ходу преса та його пружного розвантаження для виконання технологічних операцій та операцій, що інтенсифікують процес формозміни.

8. Розробка пристроїв для штампування листових заготовок рідиною, що кристалізується, «розбухаючими» металами та використання процесу епітаксії для створення високих тисків.

9. Використання ефектів електро- та надпластичності.

10. Використання локального навантаження для формозміни.

Коротко зупинимося на низці згаданих заходів.

Резонансні явища виникають у заготовці що деформується, як за вібраційної обробки, так і за імпульсного штампування за умови самозбудження коливань в заготовці спеціально виготовленим інструментом в умовах статичного навантаження. Особливо це проявляється в умовах резонансу. Останній виникає за умов вібропластичного ефекту (за збігу частот навантаження інструменту з частотою коливання дислокацій), за автоколивань (частота навантаження відповідає частоті власних коливань заготовки) та за впорядкованого навантаження заготовки відповідно переміщення пластичного шарніру в заготовці, узгодженого з загальним переміщенням. І якщо за віброобробки відбувається зниження зусиль, що деформують на 15–20 %, то на резонансних частотах на 35-40 %. Найбільш ефективно збуджувати автоколивання в заготовці спеціально виготовленим деформуючим інструментом без додаткових механічних, електричних, гідравлічних та інших віброзбудників.

При імпульсній формозміні є цілий арсенал засобів, які дозволяють накопичувати енергію в заготовці, що деформується. Це кумулятивні порожнини, газонасичені накладки, приєднані маси та пакетне штампування в обкладках. При достатній тривалості імпульсного навантаження відбувається багаторазове відображення ударної хвилі між верхньою та нижньою обкладками. Якщо в нижній обкладці виконати концентратор контуру формозміни, то в певний момент відбудеться руйнування по контуру концентратора нижньої обкладки. Остання відлітає, захоплюючи за собою заготовку, що деформується, з накопиченою в ній енергією.

Значне зниження деформуючих зусиль у 3–4 рази можливе за умови заміни операцій формування гнуттям. Так за виготовлення деталей з гофрами попереднє підгинання полиць і подальше їх розпрямлення призводить до мимовільного

оформлення поверхні гофру. Деформуюче зусилля при цьому знижується вчетверо. За організації процесу описаним способом можливий перехід від потужних гідравлічних пресів до механічних кромкогибів, які більш екологічні та менш енергоємні.

Зменшити витрати на виконання технологічних операцій формозміни можливо шляхом використання кристалогідратного способу одержання холоду або систем гідридного охолодження. Такі системи не тільки економічні, екологічно чисті і мають високу надійність (немає жодної механічно рухомої частини). Такі системи працюють безпосередньо на сонячному теплі та не вимагають додаткових джерел тепла.

Методи обробки заготовок з використанням ефектів над- та електропластичності, а також при локалізації деформацій досить повно висвітлені в літературі та не розглядаються у даній роботі.

Відомі величезні переваги методів локального деформування заготовок, зокрема, сфероруховогo штампування, торцевого розкочування, профілювання та ін. У цих процесах зусилля деформування знижується в 8–12 разів. Подальшим розвитком методу локальної деформації може знайти спосіб згинання вдавлювання жорсткого інструменту в плоску заготовку, що знаходиться на жорсткій основі. При вдавлюванні пуансону відбувається мимовільний вигин заготовки. Провівши послідовні натискання пуансоном на заготовку отримуємо деталь заданої форми. Розроблено спеціальний пуансон, який здійснює поступальний та обертальний рух для отримання деталі типу «жолоб» (рис. 15).

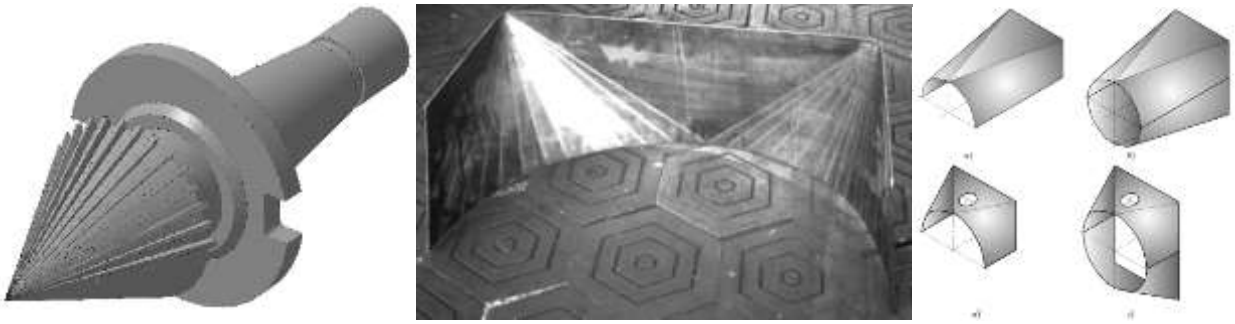


Рисунок 15. Пуансон та деталі отримані вдавлюванням жорсткого інструменту в заготовку

Зниження зусиль деформації можливе при навантаженні, як вогнища деформацій, так і недеформованих елементів заготовки деякими додатковими видами зовнішніх активних та пасивних навантажень, наявність яких не є обов'язковою для здійснення заданої формозміни. Це можливо за використання комбінованих та поєднаних процесів обробки тиском та за послідовного навантаження. Варіювання параметрами силового впливу дозволяє вирішити такі завдання:

– розширити технологічні можливості штампування шляхом зменшення лімітуючого та діючого напруження або деформацій або збільшення пластичності матеріалу;

– виготовити деталі раціональної конструкції при мінімальних зусиллях штампування та забезпечення мимовільної течії металу.

Раніше відомі поєднані операції можливо доповнити:

– поєднанням згинання з формуванням;

– згинанням з витяжкою та торцевим підпором;

– згинанням з підпором у кромку та розпором у стінки і т. д.

Великі можливості для поєднання операцій відкривають процеси профілювання коліс. В основу базових схем профілювання з центральним струмком покладено суміщені процеси згинання-формування та згинання-відбортування.

При згинанні-формуванні елементи полиці формуються роздаванням, а елементи струмка обтисканням вихідної заготовки. При згинанні–відбортовці спостерігається переважне підгинання полиць без помітного зміщення елементів струмка. За гнуття-формування реактивний момент, який виникає за умови дії зусиль, що розтискають і обтискають, сприяє течії металу в порожнину струмка. Організація при роздачі та підпорі кромки дозволить при значно менших зусиллях оформити бічну країну. За гнуття-відбортовки реактивні моменти протидіють формозміни заготовки.

За суміщення операцій роздачі та обтиску на попередньому переході формуванню вдається отримувати складніший профіль формової частини готового обода. Це призводить до зменшення деформації на наступних переходах та зменшення витончення матеріалу в радіусних переходах. Не менш ефективні схеми профілювання та формування з обтисненням та циклічним підпором заготівлі.

У найбільш поширеному процесі листового штампування – витяжці вдале поєднання досягається за витяжки без притискання на малу глибину за великого ступеня деформації або все одно що при наступній витяжці з притиском і підпором кромки. І тут зусилля штампування знижується на 20–25 %.

Таким чином, виявлено та систематизовано основні методи формоутворення силових елементів конструкцій РЕА, спрямовані на зниження енергоємності процесу та зниження деформуючих зусиль. Найбільш ефективно це досягається за:

– штампування рідиною, що кристалізується;

– заміни операцій формування гнуттям з мимовільною формозміною та гнуттям із вдавлюванням жорсткого інструменту.

Одним з основних напрямків розвитку листоштампувального виробництва є синтез та розвиток поєднаних процесів обробки тиском.

Висновки:

1. У результаті викладеного аналізу науково-технічної інформації

встановлено, що на даний час добре розроблено загальну теорію процесів гнуття заготовок силових елементів конструкцій РЕА у холодному стані. Отримано обґрунтовані дані про напружено-деформований стан та силові параметри різних методів гнуття, запропоновано класифікації способів та схем гнуття, виявлено вплив геометричних розмірів деформованої заготовки на напружено-деформований стан та залишкових (пластичних) напружень на форму готового виробу.

2. Розглянуто нові можливості вдосконалення процесів гнуття та формування силових елементів конструкцій РЕА, що веде до отримання деталей з кращими механічними характеристиками, економії матеріалів, зниження потрібних зусиль, підвищення стійкості оснастки, зниження собівартості продукції.

3. З усього вищевикладеного, слід зазначити, що одним із перспективних завдань удосконалення процесів листового штампування, у тому числі операцій гнуття є розробка та дослідження нових ефективних схем вигину листових заготовок, що забезпечують зниження втрат металу та витрат на обладнання, інструмент та технологічне оснащення.

4. Найбільш ефективними та раціональними, з погляду економії матеріальних витрат, прийомами, є зміна схеми напруженого стану та локалізація вогнища пластичної деформації.

SECTION 4. ENERGY PRODUCTION

DOI: 10.46299/ISG.2026.MONO.TECH.1.4.1

4.1 The radioactive materials management at the nuclear power plants of Ukraine

In most cases, the radiation-hazardous materials contain radioactive isotopes with the long half-lives, making such materials hazardous for millennia. The long half-lives of radionuclides may exceed the time required for the protective barriers to retain the necessary properties. At the same time, the interaction of radioactive isotopes with other substances during the storage and treatment can lead to unpredictable chemical reactions, which complicates the radiation-hazardous materials management. For example, the effect of oxygen on some irradiated materials can cause the release of radioactive gases.

For storage the large amount of hazardous radioactive materials, the construction of high-capacity repositories is accompanied by a significant financial burden even for the most developed countries. Therefore, the development of methods for effective treatment of radioactive materials with a reduction in the total volume does not lose the relevance.

All this together requires the active scientific research and development of innovative technologies to ensure the long-term safety.

Over the years of nuclear energy usage, the numerous methods for treatment and decontamination of radioactive materials have been proposed. However, the attempts to find a solution based on the experience gained show that a long-term strategy for the safe management of spent nuclear fuel and radioactive waste is more complex than it seemed before, and that this problem has not only a technological, but also a socio-ecological, economic and moral direction.

Some methods of hazardous radioactive materials management involve the direct geological disposal (near-surface sites or deep geological repositories). However, the large accumulated quantities of radioactive materials require the high-capacity

repositories. Direct geological disposal is well studied by scientists, but has not attracted public enthusiasm. Doubts about disposal usually focus on the release of long-lived isotopes ^{36}Cl and ^{14}C through the groundwater. Since 1949, some hazardous radioactive materials were also dumped into the ocean in the form of packaged waste. But now, the sea disposal of radioactive materials is prohibited by the «Convention for the Protection of the Marine Environment and Coastal Area of the North-East Atlantic».

Preliminary preparation for disposal (conditioning) of radiation-hazardous material includes operations for the manufacture of material packaging, the ultimate goal of which is to convert the nuclear material into a form suitable for transportation, storage and disposal. Conditioning includes, in particular, the radioactive material processing. Conditioning methods depend on the characteristics of nuclear material, the manufacturability and cost-effectiveness of the selected processing method, the conditions and duration of temporary storage of containers, and the conditions of transportation and disposal. Other things being equal, the preference is given to the method that ensures the minimum risk of exposure to personal at all subsequent stages of radioactive material management.

As a result of conditioning, the volume of radioactive material should be reduced to the required minimum (which is especially important for solidifying the high activity level waste, when the permissible volume is limited by the specific heat release, heat removal conditions and other storage and/or disposal conditions). The radioactive waste must be in the solid aggregate state, have the necessary resistance to the mechanical factors and temperature effects in accordance with the state standards regulating the requirements for solidified radioactive waste.

At the final stage of conditioning, the containerization of processed radioactive material is required for:

temporary storage of waste in the above-based engineering structure;

transportation of waste within the enterprise or beyond boundaries of the enterprise, in or without a transport packaging kit;

long-term storage in engineering structures or waste disposal.

The conditioned radioactive material for disposal must meet acceptance criteria taking into account a number of characteristics, including the restrictions on the total activity of radiation-hazardous material package, the specific activity, the structural stability and water resistance of the solidified form of radioactive waste, the content of corrosive substances, and heat release.

When storing in the above-ground structures, the service life of container is determined by the time until the final disposal of radioactive material in the geological formation and should be at least 50 years. For reduce the radioactive material volume and immobilization of radioactive material, the various technologies are used.

At the same time, the projects of today operating Ukrainian nuclear power plants are characterized by the lack of modern high-tech approaches to radioactive materials management, and the resolution of these issues has been postponed indefinitely. However, the current legislation provides for the construction and commissioning of Complex for the Processing of Solid Radioactive Waste at the Ukrainian nuclear power plants. Therefore, the issue of choosing and optimizing the most modern and effective methods for the radioactive materials management is more relevant than ever.

It is obvious that the development of methods for the radioactive materials management for the specific requirements must comply with the Ukrainian legislation, where the main law is the Law of Ukraine «On the Use of Nuclear Energy and Radiation Safety» [156]. All current laws on the nuclear safety are developed taking into account the international agreements ratified by Ukraine. Such as the Convention on the Assistance in the Case of a Nuclear Accident or Radiation Emergency (1987), the Convention on the Physical Protection of Nuclear Materials and Nuclear Facilities (1993), the Convention on the Nuclear Safety (1997) and the Joint Convention on the Safety of Spent Nuclear Fuel Management (2000). In addition, the Association Agreement between Ukraine and the European Union (2014) also included an agreement with the Euratom. Accordingly, the agreement stipulates Ukraine’s obligation to implement the several Council of Europe/Euratom directives. For

example, the Council Directive №2011/70/Euratom of establishing a Community framework for the responsible and safe management of spent nuclear fuel and radioactive waste. As an active member of the International Atomic Energy Agency, Ukraine must comply with the relevant documents of this organization. In addition, there are various norms and rules in the field of nuclear energy usage and sanitary rules in the field of radiation safety ensuring, which were developed by the relevant supervisory authorities.

The radioactive materials management in Ukraine is a complex, multilayered process based on the detailed legislative and institutional framework. This system functions as a coordinated mechanism, where each element performs its unique role, from strategic planning at the state level to daily operations. The basis is not just a set of separate documents, but a holistic, hierarchically built architecture aimed at ensuring the long-term safety.

In terms of the radioactive waste volume, Ukraine ranks 2-nd in Europe and 4-th in the world (3.500.000 m^3).

The state entrusts the State Agency of Ukraine on Exclusion Zone Management with the important function of radioactive waste long-term storage and disposal. In accordance with this function, the activities of the State Environmental Inspectorate of Ukraine in this field are realized in the following directions:

management of spent sources of ionizing radiation and radioactive waste, coming from the medical, scientific, educational and industrial institutions;

management of radioactive waste, resulting from the Chornobyl disaster;

elimination of radiation accidents with the radioactive materials in illegal circulation.

Ukraine signed the Joint Convention on the Safety of Spent Nuclear Fuel Management and on the Safety of Radioactive Waste Management September 29, 1997 and was one of the first to ratify it by the Law of Ukraine of April 20, 2000. In accordance with the aforementioned convention, Ukraine has Radioactive Waste Management Strategy, which was adopted in 2009 and is designed for 50 years.

According to the Radioactive Waste Management Strategy, the radioactive waste generated during the use of nuclear energy must be transported to the Exclusion Zone at the Production Complex «Vector» for further long-term storage or disposal.

For implementing the tasks defined by the Radioactive Waste Management Strategy, the State Specialized Enterprise «Radon Association» has been created, which includes the special plants, the project organization State Enterprise «Scientific and Technical Center of Decontamination and Complex of Radioactive Waste Management, Substances and Ionizing Radiation Sources», an educational institution for training the personnel in the field of radioactive waste management, and the State Specialized Enterprise «Central Enterprise for the Management of Radioactive Waste», which is the only enterprise in Ukraine that has the right to radioactive waste disposal.

Special plants were established in 1960–1962, and the service areas were assigned to each special plant by the resolution of the Council of Ministers of the Ukrainian SSR №377 dated December 21, 1990.

The State Specialized Enterprise «Radon Association» is also entrusted with the functions of maintaining the State Register of Radioactive Waste and the State Cadastre of Radioactive Waste Storage Facilities and Temporary Storage Sites.

For identify radioactive waste, ensure the control over their accumulation and movement, transfer to the special enterprises for disposal, use existing storage capacities, and ensure the constant updating and timely amendments to the State Register of Radioactive Waste and the State Cadastre of Radioactive Waste Storage Facilities and Temporary Storage Sites, the regular state inventories of radioactive waste and radioactive waste storages are realized. The state inventories of radioactive waste are realized every three years.

The main enterprise of the State Specialized Enterprise «Radon Association» is the State Specialized Enterprise «Central Enterprise for the Management of Radioactive Waste», which by the order of the Minister of Emergency Situations of Ukraine №1086 dated December 9, 2010 «On Reforming the State Enterprises of the Exclusion Zone»,

was determined as the only national operating organization for radioactive waste management at the stage of long-term storage and disposal [157].

The State Specialized Enterprise «Central Enterprise for the Management of Radioactive Waste» is an operating organization (operator) at all stages of life cycle of Radioactive Waste Disposal Sites: «Buryakivka», «Pidlisnyi», «Chornobyl nuclear power plant Stage III» and 9 Radioactive Waste Interim Confinement Sites in the Exclusion Zone, which were formed in 1986–1987 when using the measures to decontaminate the Chornobyl nuclear power plant industrial site and the territory of the near Exclusion Zone [158].

The key task of the State Specialized Enterprise «Central Enterprise for the Management of Radioactive Waste» is to create the industrial complex for the decontamination, transportation, processing and disposal of radioactive waste (the Production Complex «Vector»).

The foundation of modern Radioactive Waste Management Strategy is a new radioactive waste classification system that meets the international safety standards [159]. It provides the division of waste into four main categories according to the level of activity: very low activity level waste, low activity level waste, intermediate activity level waste and high activity level waste. This approach is not just a technical update, but the key step in optimizing the entire system. It allows the application of differentiated methods of management and disposal, depending on the real level of danger. For example, the short-lived radioactive waste can be placed in the near-surface or surface repositories, while the long-lived radioactive waste requires disposal in the stable deep geological sites.

The low activity level waste and intermediate activity level waste – are the largest category of radioactive waste in terms of volume, which is generated during the operation and repair of nuclear power plants, in industry and medicine. The period of danger is relatively short. The sources of low activity level waste and intermediate activity level waste are diverse, but the main volume is generated by nuclear power. The effective processing allows significantly reducing the final volume for disposal.

The long-lived high activity level waste contains a large number of radionuclides with the long half-lives. This radioactive waste include spent nuclear fuel and processing products of spent nuclear fuel. The high activity level waste require the most reliable isolation from the biosphere for thousands of years, which is a major challenge for the long-term strategy.

Introduction of this classification has a significant economic effect, as allows significantly reducing the total cost of radioactive waste management. In the past, less hazardous waste could be stored according to the criteria for high activity level waste, which led to the unjustified costs. The improved classification makes it possible to place low activity level waste in the less expensive near-surface repositories, which according to the explanatory note to the relevant draft law, can reduce the cost of disposal by a factor of 10 without reducing the level of safety [159]. This rationalization is critically important in the long-term. Thus, this technical step is the basis for the economic efficiency of the entire Radioactive Waste Management Strategy.

The choice of disposal method depends on the activity level and half-life period of radionuclides, in particular the long-lived isotope ^{14}C.

Near-surface disposal. This method is suitable for low activity level waste and intermediate activity level waste. After proper conditioning and packaging, the radiation-hazardous materials are placed in the special engineering structures at a depth of up to several tens of meters. In Ukraine, the Production Complex «Vector» is operating in the Exclusion Zone for such materials.

Geological disposal. This is an internationally accepted standard for the long-lived high activity level radioactive materials. This method involves the locating of radiation-hazardous material in the stable geological formations at a depths ranging from hundreds of meters to several kilometers. A multibarrier system (engineered barriers and a natural geological barrier) ensures the reliable isolation of radioactive material from the biosphere for thousands of years. Ukraine is conducting the research on constructing its own geological repository, which in the long-term could become the final disposal site for high activity level radioactive materials. This project is extremely capital-intensive

and time-consuming – its implementation could take decades. However, while the Centralized Storage Facility for Spent Nuclear Fuel solves the problem for 100 years, the deep geological repository is a solution for millennia.

Borehole disposal. This innovative approach considered as an alternative to traditional geological disposal. The radiation-hazardous materials are placed in the special capsules in deep (up to 5 km) vertical or inclined boreholes. The great depth and stability of the geological layers provide an extremely high level of isolation. This method can be cost-effective for small volumes of long-lived radioactive materials.

In countries with the developed nuclear energy (taking into account the safety requirements), the most common methods of radioactive materials processing are the following [160]:

1. The pressing of solid radioactive waste with the high-pressure hydraulic presses (force 15.000–20.000 tons). For such processing, the metal shavings, thermal insulation materials, fire-resistant braiding of electrical cables, etc. are suitable. Depending on the radioactive waste type, this makes it possible to reduce the initial volume up to 5 times. Pressed solid radioactive waste can subsequently be immobilized and sent for disposal [161, 162, 163].

2. The incineration of flammable solid radioactive waste and liquid radioactive waste. Organic waste and other flammable radioactive waste are the subject to incineration. The purpose of incineration is to convert the radioactive waste into an inert state (ash residue), which improves the safety conditions of temporary storage and subsequent disposal, and also significantly reduces the initial volume of radioactive waste (up to 50 times). As a rule, the ash residue is sent for pressing and immobilization. For the most part, due to the financial and technological factors, as an immobilizing substance, the cement mortar is used [161, 163].

3. The conversion of liquid radioactive waste into a solid state by incorporating them into an immobilizing matrix. For obtain the final cementation product with the specified radiological and physicochemical characteristics, the radioactive waste (cube residue, ion-exchange resins, perlite-wash filters) are mixed in certain proportions with

the cement mortar and special additives. After solidification, the resulting compound can be sent for temporary storage or disposal [164]. For converting the liquid radioactive waste into a solid state, another common method is bituminization. In this case, the radioactive waste is evaporated to a dry residue (powder substance) at the high temperature on the walls of the bituminizer and mixed with the molten bitumen mass. Other liquid radioactive waste types can also be immobilized (ion-exchange resins and perlite-wash filters). The certain characteristics of bitumen compound, in particular resistance to the leaching of radionuclides, are the higher than those of cement compound. On the other hand, in terms of manufacturability and economic costs, the cementation is more acceptable.

The implementation of comprehensive solid radioactive waste processing at the nuclear power plants before the start of decommissioning stage is a cardinal solution for problem of overfilling the solid radioactive waste storage facilities. As a result, it is possible not only to reduce the initial volume of solid radioactive waste, but also to obtain the final processing product with characteristics that enable for the final disposal. The projects of today operating Ukrainian nuclear power plants do not include the comprehensive approach to radioactive materials management. However, the current legislation provides for the construction and commissioning of Complex for the Processing of Solid Radioactive Waste at the Ukrainian nuclear power plants [165, 166].

The Complex for the Processing of Solid Radioactive Waste at the Zaporizhzhia nuclear power plant is designed for processing low activity level waste and partially intermediate activity level waste (up to 300 μGy/h), and this is justified, since these waste categories include the largest amount of accumulated solid radioactive waste [161]. The Complex for the Processing of Solid Radioactive Waste was commissioned in 2017 and consists of the following main technological units:

burning of solid radioactive waste and flammable liquid radioactive waste (spent radioactively contaminated oil) with a capacity of 30 kg/h for solid radioactive waste and 12 kg/h for liquid radioactive waste; after burning of radioactive waste, an ash residue is obtained;

super-compactors for pressing solid radioactive waste, which are suitable for pressing by structure and composition (in particular, ash residue); the time of pressing process is the regulated, the maximum pressing force is 1500 t/s, the capacity is 8 barrels/h, the efficiency of volume reduction depends on the solid radioactive waste type; after pressing the barrels, the briquettes of appropriate height are obtained;

fragmentation of bulky and long-length solid radioactive waste with the possibility of redirection (if necessary) on the decontamination;

removing the solid radioactive waste from storage compartments.

The Complex for the Processing of Solid Radioactive Waste also includes a system of radiation and chemical monitoring of emissions for control the content of radioactivity and chemically harmful substances in exhaust gases. The briquettes (pressed and placed in secondary packages) are the product of solid radioactive waste processing on the technological units of Complex for the Processing of Solid Radioactive Waste at the Zaporizhzhya nuclear power plant. It is advisable to provide the technological unit for cementing. It is necessary to analyze the compliance of final processing product with the acceptance criteria for disposal in the repository of the Production Complex «Vector».

The Complex for the Processing of Solid Radioactive Waste at the Rivne nuclear power plant is also designed for processing low activity level waste and partially intermediate activity level waste (up to 300 μGy/h) [162]. The project envisages equipping the Complex for the Processing of Solid Radioactive Waste with the following technological units:

removing the solid radioactive waste from storage compartments;

sorting and fragmentation of solid radioactive waste;

super-compression of solid radioactive waste (due to the absence of technological unit for incineration, the flammable radioactive waste of organic origin will also be compressed);

processing of spent oil;

cementing of pressed briquettes;

metal decontamination.

The Complex for the Processing of Solid Radioactive Waste was commissioned in 2019. For obtain the final processing product, the technological unit for incineration is necessary, since cementing the organic (flammable) solid radioactive waste can create certain difficulties in disposal.

Construction of Complex for the Processing of Solid Radioactive Waste at the Khmelnytskyi nuclear power plant [167] and the South Ukraine nuclear power plant [168] is provided by the Law of Ukraine «On the National Targeted Environmental Program for Radioactive Waste Management» [166]. The design documentation for the construction of Complex for the Processing of Solid Radioactive Waste at the Khmelnytskyi nuclear power plant has undergone the comprehensive state examination, and as of 2026, the construction of complex is ongoing. The Complex for the Processing of Solid Radioactive Waste includes the following technological units and systems:

removing the solid radioactive waste from storage compartments;

sorting and fragmentation of solid radioactive waste;

incineration;

pressing;

cementing;

activity measurement;

metal decontamination;

control and accounting of solid radioactive waste.

The project is planned to be implemented in two stages: the first is the commissioning of technological units for sorting and fragmentation, incineration, pressing and activity measurement; the second is the commissioning of technological unit for removing, cementing and metal decontamination.

The design documentation for the construction of Complex for the Processing of Solid Radioactive Waste at the South Ukraine nuclear power plant has undergone the comprehensive state examination and is being sent to finalization taking into account

the expert comments. As of 2025, the decision to the start project implementation has not yet been made. The project is also planned to be implemented in two stages: the first is the commissioning of technological units and systems for sorting, pressing, drying, characterization (barrel measurement system); the second is the commissioning of technological units for incineration, ash residue melting, and emission control systems.

Today, radioactive waste management activities are crucial in terms of safe decommissioning of the Chornobyl nuclear power plant and the transformation of the Shelter object in accordance with the National Decommissioning Program (Figure 1.).

Figure 1. Confinement at the Chornobyl nuclear power plant [169]

All radioactive waste from the Chornobyl nuclear power plant is divided into 2 types:

normal operational radioactive waste, which are generated as a result of the operational processes of power units;

emergency radioactive waste, formed as a result of 1986 accident and its liquidation (including waste from the Shelter object).

According to the origin of radioactive waste, it is classified as follows:

liquid radioactive waste and solid radioactive waste accumulated to date, which are located in the storage facilities available on the site;

operational liquid radioactive waste and solid radioactive waste, which are generated during the maintenance of equipment that remaining in operation at the Chornobyl nuclear power plant units in the safe condition;

liquid radioactive waste and solid radioactive waste of the Shelter object;

liquid radioactive waste and solid radioactive waste, which are generated during the decommissioning work (in particular during the operation of radioactive waste management facilities);

solid radioactive waste, which are generated during the work on the transformation of the Shelter object into an environmentally safe system.

At the Chornobyl nuclear power plant, all types of radioactive waste are present by activity: low activity level waste, intermediate activity level waste, and high activity level waste. This significantly complicates the waste management, as the entire management infrastructure must be able to characterize the radioactive waste by activity level and be adapted to work with high activity level waste. The projected volume of radioactive waste during the decommissioning of the Chornobyl nuclear power plant units and the transformation of the Shelter object into an environmentally safe system is 177.255 m^3, which is approximately equal in volume to 70 Olympic swimming pools. The share of liquid radioactive waste is 36.148 m^3, and solid radioactive waste is 141.107 m^3.

In radioactive waste management activities, the Chornobyl nuclear power plant is guided by the principle of minimizing the amount of radioactive materials and radioactively contaminated territories. For realization this principle, the practice of maximum reuse of materials and their decontamination is used.

One of the urgent tasks facing the enterprise today is to create an integrated radioactive waste management system that would meet the conditions of the Chornobyl nuclear power plant.

At the Chornobyl nuclear power plant, there was the radioactive waste management system that was intended for the operating nuclear power plant. It is currently being transformed into the radioactive waste management system for the decommissioned nuclear power plant. For the first time, the strategy for creating an integrated radioactive waste management system at the Chornobyl nuclear power plant site was outlined in the Chornobyl nuclear power plant Decommissioning Plan, developed within the framework of the «TACIS» program in 1996. For ensure the process of power units decommissioning and radioactive waste management, the document defines the list and main characteristics of facilities that need to be built at the station site: the facility for collecting, transporting, cementing the liquid radioactive waste; the facility for collecting and processing the solid radioactive waste; a place for their disposal.

At the Chornobyl nuclear power plant site, the following main radioactive waste management facilities have been constructed and nowadays they are being commissioned:

Plant for the Processing of Liquid Radioactive Waste;

Industrial Complex for the Solid Radioactive Waste Management;

Complex for Manufacturing Metal Barrels and Reinforced Concrete Containers for radioactive waste storage of the State Specialized Enterprise «Chornobyl nuclear power plant» [170].

The Plant for the Processing of Liquid Radioactive Waste is designed for the processing of liquid radioactive substances accumulated at the Chornobyl nuclear power plant, as well as waste that will be generated during the decommissioning of power units №1, 2 and 3 [163]. The Plant for the Processing of Liquid Radioactive Waste is responsible for the following functions:

removing the accumulated waste from storage tanks using the special systems;

transferring the extracted waste through pipelines to the technological units for processing;

pretreatment of waste to meet the requirements of subsequent stages of the technological process;

reduction of liquid radioactive waste volume by the concentration (evaporation) method;

producing the final processing product by the solidification (immobilization) of the pretreated waste with the help of cementation in the 200-liter metal barrels;

curing the barrels with the final product and placing them into the special transport packaging kits;

radiological monitoring of barrels and transport packaging kits;

control and return secondary liquid waste, purified technological environment and products of supply systems to the Chornobyl nuclear power plant facilities, subject to their compliance with the established standards.

The Plant for the Processing of Liquid Radioactive Waste processes three main output streams: evaporative concentrates; perlite-wash filter pulp; ion-exchange resins. The final product of liquid radioactive waste processing at the Plant for the Processing of Liquid Radioactive Waste is the cement compound, which consists of previously obtained waste (concentrated cube residue, dewatered resins and perlite pulp) and dry components (cement, lime, sand, additives). After mixing, the product is poured into the 200-liter barrels, which are hermetically sealed after curing. The final product must comply with the certain requirements regarding the radionuclide composition, partial and total activity, chemical and mechanical properties. The 200-liter barrels with the cement mixture are packed at 4 pieces into the reinforced concrete container (Figure 2). The container with the processed liquid radioactive waste is sent for disposal to the specially equipped solid radioactive waste near-surface storage of the Production Complex «Vector».

Figure 2. Metal containers with radioactive waste [169]

The Industrial Complex for the Solid Radioactive Waste Management is designed for the processing and conditioning of short-lived low activity level waste and intermediate activity level waste, accumulated in the solid radioactive waste storage during the operation of Chornobyl nuclear power plant units, as well as waste that will be generated during the decommissioning of power units №1, 2, and 3. The Industrial Complex for the Solid Radioactive Waste Management design includes three plants:

Solid Radioactive Waste Removal Facility for solid radioactive waste all categories from the solid radioactive waste storage compartments; all operations for accessing to the compartments, removing, fragmenting, and loading the solid radioactive waste into containers are performed without direct personnel involvement, using the remotely controlled equipment; solid radioactive waste in sealed transport containers is delivered to the Plant for the Sorting and Processing of Solid Radioactive Waste;

Plant for the Sorting and Processing of Solid Radioactive Waste – plant for sorting of solid radioactive waste all categories and processing of low activity level waste and intermediate activity level waste; the Plant for the Sorting and Processing of Solid Radioactive Waste is provided with the systems and equipment for sorting, fragmenting, pressing, and packaging the waste, as well as the technological units for incineration and cementation; technical maintenance areas, technological units for decontamination, sanitary checkpoints, and other auxiliary systems will be established;

Specially Engineered Near-Surface Disposal Facility for Solid Radioactive Waste – plant for processing and packaging of short-lived low activity level waste and intermediate activity level waste for the subsequent disposal; the long-lived low activity level waste, intermediate activity level waste and high activity level waste will be packaged and directed for the interim storage in the specially modified compartments of storage facility for liquid radioactive waste and solid radioactive waste at the Chornobyl nuclear power plant; a significant part of accumulated at the Chornobyl nuclear power plant waste originates from accidents, that is contains uranium and transuranic isotopes (alpha-active long-lived radionuclides), the permissible content of which for disposal in the near-surface repositories is strictly limited [171, 172].

With the object of obtaining the final processing product suitable for disposal in the Specially Engineered Near-Surface Disposal Facility, the special attention in the technological chain of solid radioactive waste management is given to the process of sorting based on the radiological characteristics. The project includes radiation monitoring of waste at the sorting tray and at the subsequent stages of radioactive waste management.

After processing, the waste is stored in the interim storage sites or transported to the Radioactive Waste Disposal Site «Buryakivka». Currently, 22.645 m^3 of radioactive waste has accumulated in the Chornobyl nuclear power plant storage facilities, which is approximately equal in volume to 9 Olympic swimming pools. The share of liquid radioactive waste is 20 133 m^3. The solid radioactive waste is located in:

solid radioactive waste storage – 2.502 m^3;

high activity level waste open storage – 8 m^3;

storage for liquid radioactive waste and solid radioactive waste – 2 m^3.

The military aggression of the Russian Federation created unprecedented challenges for the nuclear and radiation safety in Ukraine [173]. Now, the physical protection of nuclear facilities and radioactive materials management infrastructure is a critical factor that must be integrated into all plans. Joint statements with the

international partners and reports to the International Atomic Energy Agency now include an analysis of risks associated with the military actions. Thus, due to the occupation of Exclusion Zone by Russian forces, the State Nuclear Regulatory Inspectorate of Ukraine suspended License №ОВ001096 for the activity «processing and storage of Radioactive Waste» on April 26, 2022. However, after the deoccupation of industrial site, the license was reinstated (August 2022). Before resuming the full operation of the radioactive waste processing infrastructure, a number of measures were taken to ensure the safe and proper operation of equipment and systems involved in the radioactive waste processing technological process. The personnel successfully completed the final stage of physical work during the third stage of comprehensive «hot» tests for the Solid Radioactive Waste Removal Facility and Plant for the Sorting and Processing of Solid Radioactive Waste.

In the coming years, the following issues of national importance are planned to be addressed in the field of radioactive materials management:

construction of centralized storages for the disposal or long-term storage of radioactive waste at the Production Complex «Vector»;

continuation of the operation for near-surface storages at the Radioactive Waste Disposal Site «Buryakivka»;

commissioning of the Centralized Storage for Long-Term Storage of Spent Ionizing Radiation Sources;

completion of the construction for two near-surface storages for radioactive waste disposal: SRW-1, SRW-2 of the Production Complex «Vector»;

continuation of the design and construction of storage facility for vitrified high activity level waste from the spent nuclear fuel processing of the Ukrainian nuclear power plants;

implementation of projects for modernize and improve the safety of storage facilities, where radioactive waste was stored in the first years of the Chornobyl accident liquidation – the Radioactive Waste Disposal Site «Pidlisnyi» and the Radioactive Waste Disposal Site «Chornobyl nuclear power plant Stage III»;

continuation of the inspection for Radioactive Waste Interim Confinement Sites, substantiating their safety, as well removing the radioactive waste from the most dangerous locations;

implementation of measures for repurpose of Radioactive Waste Disposal Sites at the special enterprises of State Specialized Enterprise «Radon Association» and re-equip them into the Radioactive Waste Collection and Temporary Localization Points;

continuation of the maintenance, radiological examination and rendering the safe for Decontamination Waste Disposal Points and Special Transport Treatment Points that were formed during the work to eliminate the consequences of the accident outside the Exclusion Zone;

modernization of organizational and legal framework, as well completion of the creation for centralized infrastructure of radioactive waste management, namely

– establishment of the special industrial use zone on the territory of the Exclusion Zone and definition of its boundaries;

– establishment of the acceptance criteria for radioactive waste disposal in the storage facilities of the appropriate type;

– continuation of the development of storage facilities system for the disposal of radioactive waste from the operating Ukrainian nuclear power plants and the geological repository for the disposal of vitrified high activity level waste at the Production Complex «Vector».

A typical radioactive materials management pathway (based on the data of the International Atomic Energy Agency [174]) includes pretreatment, treatment, conditioning, storage, transportation and disposal.

Pretreatment includes waste collection, segregation, characterization, drying and separation of high activity level waste from the low activity level waste. The main objectives of waste treatment are:

reduction of the radionuclide content in radiation-hazardous material, especially for long-lived radionuclides such as ^{14}C and ^{36}Cl;

reduction of the radiation-hazardous material volume, including the crushing, compression or gasification.

The purpose of conditioning is to limit the leaching rate of radionuclides to meet the acceptance criteria for storage repositories. The storage for decay or interim storage means the temporary storage of radiation-hazardous material before the final disposal in order to reduce the radioactive heat and radioactivity. The transportation of radiation-hazardous materials to the final disposal site is very complex; maximum radiation protection must be provided. The disposal sites include the near-surface repositories, where radiation-hazardous material with the low activity is stored, and deep geological repositories (at the depths of more than 500 m), where radiation-hazardous material with the high activity is stored. The development and construction of deep geological repositories requires the significant financial costs, stimulating the development of methods for decontamination of hazardous radioactive materials.

The world community proposed the various methods for treatment and decontamination of radioactive materials, such as:

incineration (high-temperature oxidation of radioactive material in the air);

thermal decontamination (heating the radioactive material in a micro-oxidation or inert atmosphere to remove the specific isotopes);

chemical treatment (exposure of radiation-hazardous material to chemical reagents for dissolve it or remove radioactive nuclides);

electrochemical treatment (exfoliation of material outer layers from the main matrix under the action of electrochemical potential; material acts as an anode);

immobilization in an inert matrix (cementation, vitrification, bituminization, geopolymerization);

plasma treatment (converting the flammable ingredients into synthesis gas and simultaneously vitrifying the non-flammable ingredients into dense, inert and leach-resistant vitrified slags);

oxidation in molten salts (technology of flameless material oxidation, developed on the basis of incineration);

self-propagating high-temperature synthesis (conversion of radionuclides into a solid state with simultaneous immobilization into ceramic matrix).

Each of these methods has its advantages and disadvantages, in particular the release of hazardous gases and radionuclides that require additional processing.

It is worth paying special attention to the brief descriptions of main methods for treatment and decontamination of radioactive materials.

According to the detailed analysis of known literature, the most common method for management of some radioactive materials is the incineration. This method can be used for the large and small volumes, and also has the significant advantages. First of all, the volume of waste that requires storage is significantly reduced. For the conventional incineration process, it was found that the ratio of radioactive waste to ash is ~160; therefore, the total volume of radioactive waste to be disposed will be significantly smaller compared to the original radioactive waste, although the ash will belong to the higher category of waste. Due to the presence of isotope ^{14}C in some radioactive waste, the incineration with release of carbon dioxide CO_2 into the atmosphere encounters political resistance and regulatory restrictions. In addition to the release of radioactive CO_2, there are other problems: for incineration, the solid radioactive waste must be crushed. Disposal of radioactive materials in the containers, like incineration, will require performing the work in the difficult radiation environment, as well as the significant costs for the creation of storages facilities and transportation of containers. Technical and economic risks may arise during the conditioning of radioactive materials.

In most cases, the prospect of some radioactive waste burning for the final disposal faces the following problems:

the complexity of radioactive waste burning due to the specific properties;

the release of radioactive gases, in particular ^{14}C, ^{36}Cl, ^{3}H and the need to capture them for conversion into a solid fraction; processing and immobilization of ash, in which radionuclides are concentrated;

the need to grind solid radioactive waste into sufficiently small fragments before burning and simultaneously prevent the dust from escaping into the environment.

Often, when analyzing the possible ways of radioactive materials management, the disposal and incineration are considered as the mutually exclusive solutions. However, considering that even within the same reactor, the level of radioactive materials contamination can vary by more than an order of magnitude, a more effective approach to solving the problem is a comprehensive approach: after proper preparation and packaging, the most active part of radioactive material is the subject to disposal, and the low activity level radioactive material is the subject to incineration. Such an approach would reduce the costs for construction and operation of storage facilities, and accelerate the solution of problem.

The chemical treatment is based on the decontamination of radiation-hazardous materials with chemical reagents, aimed at the removal of long-lived radionuclides and metal radionuclides from the surface layers of radiation-hazardous material, and also effectively removes the corrosion products, surface contamination and surface-bound organics. This reduces the volume and radiation hazard of radioactive material. As compared with incineration, the chemical treatment requires simpler equipment. Ultrasonic technology can be used to accelerate the decontamination process. From the perspective of using this method as a pretreatment, the industrial and financial feasibility of the process needs to be assessed in more detail, taking into account the characteristics of radioactive material. For example, part of radionuclides, which are chemically bound in the matrix of some irradiated materials, remains the potentially resistant even to prolonged leaching. In this case, the incineration method (with $^{14}CO_2/^{14}CO$ exhaust gases capture) is better suited for their removal. In addition, any chemical method generates the secondary radioactive waste (spent solutions, exhaust gases, sludge), which themselves require the treatment and conditioning.

Options for the radioactive material immobilization in the various inert matrices are being considered in addition to its direct disposal. There are various matrix materials: cement, geopolymers, resins, bitumen, glass and ceramics. Among the

potential matrix materials, the cement/geopolymers and mineral matrices have been studied in the most detail.

The inclusion in cement is one of the main methods for the solidification of both homogeneous and heterogeneous materials. The properties of cement such as non-flammability, lack of plasticity in the solidified product and simplicity of the mixing process with the waste led to the widespread use of this method. For example, the cement mortar is prepared from three parts of blast furnace slag and one part of Portland cement. The crushed solid radioactive waste is mixed with the cement mortar. The resulting compound is then assessed for potential use in the final disposal, namely the following properties are measured: mechanical strength, impact resistance, geometric dimensions, chemical and corrosion properties, thermal stability, and radiation resistance. The resulting cement matrices must comply with the acceptance criteria for radioactive waste disposal. The disadvantages of cementation include an increase in the volume of stored waste, the possibility for leaching of components that included in the cement, and the presence of significant amount of water in the solidified product.

Sometimes instead of cement, the geopolymer is used. The geopolymer is an analogue of cement, and, like cement, is used for conditioning the nuclear waste [175, 176, 177]. It is a two-component system consisting of the actual geopolymer powder based on the silicon oxide and aluminosilicates, mixed in the certain proportions, and a liquid solidifier based on the alkaline components.

When manufacturing geopolymer, the first geopolymer and solidifier are mixed, and then filler is added. The traditional filler for geopolymers is coarse sand. Solidification occurs at the room temperature. As a result, the amorphous inorganic polymer hydrates are formed. The resulting composite (geopolymer with filler) has the following properties:

the high strength;

resistance to acids and sulfates;

the high mechanical stability;

the high structural integrity;

resistance to thermal action;

the low density: 1,5–1,6 g/cm^3 (cement – 2,2 g/cm^3);

increased fluidity during the vibration.

Bitumen is a product of oil and coal distillation. Bitumen, unlike cement, has the high waterproofing properties and the low rate of salt leaching (10^{-4}–10^{-5} g/cm^2 per day). The main disadvantage of this material is the flammability. Bitumen blocks are resistant only to the temperature of 350 °C. In addition, when mixed with waste, the properties of bitumen are changed. Thus, an increase in the salt content in the bitumen mixture can cause it exfoliation in the heated state during the transportation or at the initial stage of storage; and the presence of ion-exchange resins and crystal hydrates in radioactive material leads to an increase in the volume and swelling of mixture, which ultimately reduces the hydrostability of the final product. In addition, the bitumen mixture can be a food product for bacteria living in the soil at the storage area, which will lead to the destruction of bitumen blocks and the release of stored radionuclides.

Epoxy compounds include a wide class of substances containing an epoxy group in their chains [178]. Solid compositions based on the epoxy resins have the high chemical resistance and mechanical strength, the increased radiation and heat resistance. The solidification of resins can be carried out both at the elevated and room temperatures. The use of acrylic acid as an additive made it possible to create a composition that solidifies in air at the room temperature and is suitable for the vitrification. This process of transforming a substance into the glassy matrix has a number of important advantages compared to other technologies for radioactive materials management:

the stability (strength) of substance immobilization in the glass;

the possibility of immobilization in the glass of various materials;

the applicability of this method for both inorganic and organic materials;

the possibility of volume reduction.

Other original methods of immobilization are also possible. Interesting simple method for the immobilization of radioactive material, contaminated with uranium and

actinides, is proposed. After grinding, the solid radioactive waste is mixed in the stoichiometric proportions with Al powders and Y, Ce, Ti oxides. The next stage, after heating, is the high-temperature synthesis in the sealed steel containers or hot pressing. The resulting compound has a density of ~4 g/cm^3. During such synthesis, Y, Ce atoms can be replaced by uranium or actinide atoms. In such structure, for example, it is possible to block ^{14}C and all significant isotopes. Thus, it is possible to obtain a stably inert composite material ready for disposal by means of synthesis methods.

There are possibilities of using the geopolymer as a matrix for the conservation of radioactive material with the low activity. The development of this approach requires optimization for the production formulation of geopolymer with solid radioactive waste, research of geopolymer properties to determine the optimal degree of solid radioactive waste grinding and the waste/geopolymer ratio to ensure the strength of at least 10 MPa. The properties of geopolymer make it possible to achieve the necessary standards with a fairly simple technology of preparation and management.

Thermal stability is the most important factor in radioactive waste disposal. According to [179, 180], the criterion «fire at 800 °C for 1 h and subsequent cooling for 24 h should not result in the release of radioactive waste from the container» is mandatory. Therefore, the radioactive waste filled with bitumen must be additionally placed in the fire-resistant packages, while geopolymers meet the requirements of this criterion without the additional packaging.

Resistance to acids and sulfates is also an important factor. Immobilizing material serves as a matrix that holds the radioactive waste, and the dissolution/destruction of which can lead to the release of radionuclides into the environment. The aluminosilicate lattice of geopolymer has a significantly higher chemical resistance than even organic polymers. A comparison with other immobilizing materials clearly demonstrates the advantage of geopolymer. Dissolving the three most commonly used types of cement and the geopolymer in a 5 % sulfuric acid solution showed that cement dissolves almost completely after 28 days, and the geopolymer dissolves only by 10 % [176].

The corrosion processes of metals poured in the geopolymer were also studied [177]. Experiments were conducted with zinc, aluminum, copper, steel, and stainless steel. It turned out that only zinc and aluminum noticeably corrode in the alkaline environment of geopolymer [176]. Thus, according to a number of physicochemical characteristics, the geopolymer is the best for pouring/fixing radioactive waste in containers [176, 177, 181, 182]. A key objective in the development of technology is identifying the optimal proportion of waste (coarse/fine grinding)/geopolymer [182].

The purpose of coating and impregnation is the immobilization of radioactive waste and protection of radioactive waste from the effects of oxidizing gases or moisture. Epoxy resin is considered superior to other materials due to the rapid curing, which occurs within a few days at the room temperature, eliminating the need for heat treatment. This method is able to effectively immobilize the vast majority of available radionuclides, as well as to ensure the environmental protection from possible damage of radioactive waste containers during the storage.

Each of main methods for treatment and decontamination of radioactive materials contains a substantiated scientific component and each of them has its own characteristic features. Thus, the need to determine the physical and chemical properties of hazardous radioactive material for a specific nuclear power plant is due to the difference in the isotopic and chemical composition of radioactive materials depending on the operating conditions and operating periods of power units. The determination of criteria according to which a particular technology for radioactive materials management will be evaluated is based on a comprehensive analysis of operations under normal conditions and possible accident situations, with a focus on organization, regulation, social protection and control over the work of operating and maintenance personnel, while simultaneously ensuring the radiation safety for personnel and the environment, even in cases that are not regulated by the current norms and standards. Performing the work under particularly hazardous conditions at the facilities with limited access and using the ionizing radiation sources requires special permits and passes, specialized licensed equipment, personal protective outfits,

and periodic medical examinations. On the other hand, this involves the approval of permitting and organizational documentation, as well as relevant licenses. An important component of overall process is an appropriate strategy for selecting the employees to solve the main tasks and focus on the effective use of personnel potential. It is necessary to ensure the availability of qualified staff that undergoes periodic knowledge testing in accordance with the established requirements, as well as to develop the individual training programs using the appropriate models, simulators, and training equipment. At the same time, the training programs must be reviewed and approved. Under any circumstances, measures remain focused on the protection and implementation of professional, intellectual, legal, social and household interests and rights of personnel. The selection of technical solutions, which planned for application in the management of radiation-hazardous materials, is based on the strategy that emphasizes the use of information technologies, the continuous maintenance of existing databases, the modernization of equipment, personnel workplaces, and software updates. To investigate the radiation conditions, as well as to provide the physical and biological protection, the availability of a number of licensed specialized equipment must be ensured. In order to minimize personnel exposure and optimize design solutions, as well as to develop the alternative radiation safety technologies, it is necessary to establish the integrated information systems for monitoring the condition of premises and site. For controlling the radiation level and the presence of radioactive dust in the radiation-hazardous premises, it is advisable to develop or purchase the remotely controlled self-propelled units.

When selecting and optimizing the methods for radioactive materials management, it should be taken into account that radioactive materials from the different parts of reactor may have the different levels of contamination. In this case, the radioactive materials disposal will require the different technologies and preliminary sorting with the help of non-destructive measurement and control methods. So, it is impossible to recommend only one method for the processing of hazardous radioactive materials,

due to the varying levels of radioactive materials contamination in the different parts of reactors.

From the data above, it is clear that the choice of technology for treatment and decontamination of radioactive materials is influenced by a number of factors, including the level of radioactive contamination and available radionuclides. And the need for scientific substantiation of methods for radioactive materials management becomes obvious.

The following properties and characteristics of radiation-hazardous materials can be distinguished, which must be investigated and controlled during the radioactive materials management:

radioactivity level – by measuring the radiation level of radioactive material and the activity of radionuclides, which helps to determine safe storage and disposal methods;

chemical composition – to identify hazardous impurities, such as fluorine or heavy metals, which affect the choice of treatment or storage methods;

physical properties – density, porosity, mechanical strength and other characteristics that may affect the choice of treatment or storage methods;

geochemical parameters – assessment of radioactive material interaction with the environment, including the ability to dissolve in water and the mobility of radioactive elements;

gas release – study of combustion products such as CO_2, CO, radon, as well as other gases that may be released during the incineration of radioactive material, which helps to determine filtration and waste treatment methods.

For this purpose, it is advisable to use the following methods for determining the properties of radiation-hazardous materials:

1. Radiometric measurements – using the different types of detectors to assess radiation levels and identify radionuclides in the radioactive material samples, which helps to determine the hazard and control radiation levels. The gas-discharge detectors use the ionizing radiation to generate electrical pulses in a gaseous medium, for

example, Geiger-Muller type detectors, which reveal α- and β-particles. Such detectors are easy to operate and have the high sensitivity to β-radiation. Scintillation detectors use the special crystals (for example, sodium iodide) that emit light when interacting with the ionizing radiation, which is then transformed to electrical signal. Such detectors have the high sensitivity to γ-radiation and can be used for spectroscopy. The γ-rays detectors, usually scintillation-type detectors or detectors with the highly sensitive crystals, such as lutetium orthophosphate or gallium arsenide, are used to measure the level of γ-rays and identify the types of radionuclides using the spectrometry.

2. Chemical analysis – is important for detecting the hazardous impurities and determining the chemical composition. Spectroscopy is used to the study of atomic and molecular spectra; atomic absorption spectroscopy allows the determination of element concentrations by measuring the absorption of light in the atomic state. Chromatography separates the components of a sample using the mobile phase; Gas Chromatography can be used to analyze the organic impurities; and High-Performance Liquid Chromatography – to analyze the soluble compounds.

3. Physical testing – measuring the mechanical properties of hazardous radioactive material, which is important for understanding the behavior of radioactive material during the storage and treatment. Density is measured using the water displacement or pycnometry methods, which allows determining the mass and volume of sample for assess the porosity and compaction degree. Fracture, tensile, impact strength or compression testing are performed to determine the mechanical strength of radioactive material.

4. Gas Chromatography analyzes the gaseous components of radioactive material combustion products and allows the separation of gases mixture into individual components, as well as determining their concentration. Detectors such as a thermal conduction detector or a field ionization detector are used to measure the concentration of gases – the mobile phase (gas) carries a sample through a column containing the stationary phase (usually a liquid or solid adsorbent), the components of sample

interact with the stationary phase in the different ways that allows them to be separated and identified.

5. Neutron activation – using the neutrons to activate atoms in the hazardous radioactive material samples, and then measuring the γ-radiation. The sample is irradiated with neutrons, which leads to the formation of radioactive isotopes, and measuring the γ-radiation from these isotopes allows the determination of element concentrations in the sample.

6. Scanning Tunneling Microscopy allows the surface of samples to be examined at the atomic level for detect the defects and structural characteristics of hazardous radioactive material (cracks, contamination, etc.). Scanning Tunneling Microscope uses a thin probe to scan the surface of sample, the tunneling current between the probe and sample varies with the distance, allowing the atomic images of surface to be obtained.

7. Fourier Transform Infrared Spectroscopy is used to determine the chemical bonds and functional groups in the radioactive material samples. The sample is exposed to infrared radiation while the absorption at the different wavelengths is measured, which depends on the presence of certain chemical groups.

8. X-ray diffraction allows analyze the crystal structure and phase composition of sample, as well as determine the stress state and the presence of microstructural defects both in the initial and irradiated state.

9. Electron Paramagnetic Resonance Spectroscopy – for the detection of paramagnetic centers in the hazardous radioactive material, formed as a result of irradiation. Method helps to investigate the structural changes and defects that occur in nuclear material under radiation conditions. The sample is irradiated with an electron magnetic field, the interaction of paramagnetic centers with this field is observed, which allows to determine the types and concentrations of paramagnetic centers.

10. Thermogravimetric Analysis – for analyze the thermal stability and chemical changes in hazardous radioactive material during the heating. The sample is heated in a controlled atmosphere and the mass changes are measured as a function of

temperature, allowing to determine at what temperature the chemical reactions or decompositions occur.

11. Mass Spectrometry is used to determine the mass and quantitative composition of molecules in samples, including the combustion products. The sample is ionized for generation of ions, which are then separated by the mass and measured in a mass-spectrometer, allowing the masses and concentrations of different molecules to be investigated.

The overall analysis indicates a significant prospect in the implementation of radioactive materials management in Ukraine. The key achievements include:

regulatory improvement: the adoption of a new classification of radioactive waste and constant updating of the legislative framework that meets international standards [159];

financial stability: the introduction of a sustainable financing mechanism through the State Fund for Radioactive Waste Management, ensuring the long-term viability of the program [183];

operational self-sufficiency: the successful launch of the Centralized Storage Facility for Spent Nuclear Fuel, which not only ensured energy independence from Russia, but also generates a significant economic effect that supports the further projects [184];

specialized expertize: the presence of specialized operators the National Nuclear Energy Generating Company «Energoatom» and the State Specialized Enterprise «Central Enterprise for the Management of Radioactive Waste» with clearly defined functions, which allows the effective management of waste various types [185].

However, there are some gaps in the radioactive materials management in Ukraine that need to be addressed immediately:

lack of final disposal: the biggest gap is the conceptual status of deep geological repository project for the final disposal of high activity level waste [186], long-term storage at the Centralized Storage Facility for Spent Nuclear Fuel is only a temporary solution;

uncertainty of retained radioactive waste: although there is a technological proposal from «Holtec», the issue for the final management of vitrified high activity level waste to be returned from Russia remains open [187];

impact of military operations: Russian aggression created a new, critical risk to nuclear security that requires the additional steps and international cooperation [188].

Based on the conducted analysis, to ensure the further successful development of radioactive materials management, it is recommended:

1. Political and technical level. Immediately intensify the process of developing and financing the deep geological repository project. This is a key strategic objective that cannot be postponed. It is also necessary to actively consider the possibility of adaptation for existing and licensed technologies to address the new, unforeseen challenges, such as the temporary storage of returned high activity level waste.

2. Financial level. Ensure the absolute transparency and efficiency in the usage of funds from the State Fund for Radioactive Waste Management, which will strengthen the trust of public and international partners.

3. Communication level. Integrate communication strategies and public dialogue as a mandatory element at all stages of planning and implementation, especially in the context of upcoming the deep geological repository project, which will require broad public support.

4. Safety level. Actively cooperate with the international partners and International Atomic Energy Agency to strengthen the physical protection of nuclear infrastructure objects and jointly counter military threats.

Conclusions

In Ukraine, the radioactive waste and spent nuclear fuel management is regulated by the Ukrainian legislation, including the Law of Ukraine «On the Use of Nuclear Energy and Radiation Safety». All current nuclear safety laws are implemented taking into account the international agreements ratified by Ukraine, as well International Atomic Energy Agency recommendations. Compliance with the international obligations is key aspect to ensure the highest safety standards and receiving the

international support. Ukraine regularly submits the national reports to the International Atomic Energy Agency, demonstrating the transparency and readiness for international verification.

Thus, the «Radioactive Waste Management Strategy in Ukraine» together with the «National Targeted Environmental Program for Radioactive Waste Management» defines the key principles:

safety priority: ensuring the protection of personnel, the population and the environment at all stages of radioactive waste management;

phased implementation: radioactive waste management is being considered as the part of long-term decommissioning process of the Chornobyl nuclear power plant units, which is planned for decades;

conditioning and storage: before final disposal, the radioactive waste must be converted into a safe and stable form; this includes collection, sorting, fragmentation and packaging in the special containers;

interim storage: the current strategy for high-level and long-lived radioactive materials involves the long-term interim storage (50–100 years); this allows to reduce the levels of radioactivity and heat release through the natural decay of short-lived radionuclides, which simplifies and reduces the cost of subsequent operations.

The projects of today operating Ukrainian nuclear power plants are characterized by the lack of modern high-tech approaches to spent nuclear fuel and radioactive waste management, and the resolution of these issues has been postponed indefinitely. This leads to the significant filling of storage facilities and risks for insufficient of storage capacities. However, the current legislation provides for the construction and commissioning of modern infrastructure. This would enable the production of finally treated product acceptable for the ultimate disposal in the near-surface repositories and ensure the processing of the bulk accumulated hazardous radioactive materials at the nuclear power plants sites before their decommissioning.

In general, the radiation-hazardous materials management at the Ukrainian nuclear power plants covers necessary activities related to the collection, transportation,

processing, temporary storage and preparation for transfer to the special enterprises for long-term storage/disposal. The liquid radioactive waste and solid radioactive waste, generated during the operation of nuclear power plants, are processed at the existing technological units and retained in the special storage facilities. At the same time, some radioactive materials from the Chornobyl nuclear power plant today remain in the reactor facilities undergoing the final decommissioning and conservation. Dismantling and management of graphite stacks is one of the most difficult tasks of the upcoming decommissioning phases. Scientific understanding of the properties and characteristics of hazardous radioactive materials is a prerequisite for the development of innovative technologies for the waste processing.

In Ukrainian nuclear power, the main technical measures as the following:

construction and commissioning of Complex for the Processing of Solid Radioactive Waste at the Khmelnytskyi nuclear power plant and South Ukraine nuclear power plant;

improvement of operating modes of radioactive materials processing facilities;

modernization of technological units for collection, transportation and storage of hazardous radioactive materials;

improvement of the radioactive materials accounting and control system;

decontamination of contaminated materials and their recycling;

application of modern technologies and means for decontamination.

Priority issues regarding the improvement of radioactive materials management system at the Ukrainian nuclear power plants are:

implementation of technologies for liquid radioactive waste processing in order to obtain a product acceptable for disposal;

continuation of works on constructing the temporary light-type storage facility for storing containers with the conditioned radioactive waste at the Zaporizhzhya nuclear power plant (after its deoccupation);

implementation of measures on the transport and technological scheme for transfer radiation-hazardous materials from nuclear power plants to the specialized enterprises.

Acknowledgments: this scientific study is related to the project «7121» (Science and Technology Center in Ukraine) fulfilled thanks to Lobach Kostiantyn, Simeiko Kostiantyn, Bondarkov Mykhailo, Khovavko Oleksandr, Kolodiy Ihor.

SECTION 5. INFORMATION AND MEASUREMENT TECHNOLOGIES

DOI: 10.46299/ISG.2026.MONO.TECH.1.5.1

5.1 Імплементація вимог ISO/IEC 17024 у системи управління якістю організацій

У контексті модернізації національної системи технічного регулювання та інтеграції України до європейського й міжнародного простору оцінки відповідності особливого значення набуває впровадження міжнародних стандартів у сфері сертифікації персоналу. Забезпечення довіри до результатів оцінювання компетентності фахівців є важливим чинником розвитку ринку послуг, підвищення мобільності робочої сили та посилення конкурентоспроможності українських організацій. У цьому контексті стандарт ISO/IEC 17024 [189] виступає нормативною основою формування прозорих, неупереджених і методологічно обґрунтованих процедур сертифікації персоналу.

Поняття «імплементація» походить від лат. implementatio (від impleo – наповнювати, здійснювати, приводити у виконання) та в сучасному науково-правовому дискурсі трактується як процес практичного впровадження нормативних положень у національну систему регулювання або в організаційні механізми управління [190, с. 218]. У сфері технічного регулювання імплементація означає не лише формальне прийняття нормативного акта, а й інтеграцію його вимог у правову, інституційну та процедурну архітектуру відповідної системи [191]. Таким чином, імплементація міжнародного стандарту передбачає адаптацію його положень до національного законодавства, створення механізмів контролю їх дотримання та забезпечення функціональної узгодженості з чинною інфраструктурою оцінки відповідності.

В Україні імплементація вимог ISO/IEC 17024 здійснюється шляхом прийняття ідентичного національного стандарту та акредитації органів із сертифікації персоналу в межах чинного законодавства у сфері технічного

регулювання. Інституційне забезпечення цього процесу покладено на Національне агентство з акредитації України, яке функціонує відповідно до положень національного законодавства та є учасником міжнародних угод про взаємне визнання результатів акредитації. Зазначений підхід забезпечує правову визначеність процедур сертифікації персоналу та їх узгодженість із міжнародними вимогами, водночас формуючи передумови для міжнародного визнання українських сертифікатів і повноцінної інтеграції національної системи сертифікації персоналу до глобальної інфраструктури оцінки відповідності.

Разом із тим практична реалізація вимог стандарту в діяльності організацій потребує системної інтеграції його положень у структуру систем управління якістю (СУЯ), гармонізації з процесним підходом і ризик-орієнтованим управлінням. У зв’язку з цим актуальним є формування узагальненої моделі імплементації ISO/IEC 17024 в українських організаціях, яка забезпечує методологічну цілісність, структурну узгодженість і результативність процесів сертифікації персоналу відповідно до міжнародних вимог та національних особливостей правового й інституційного середовища.

Аналіз сучасних наукових і нормативно-методичних джерел засвідчує зростання уваги до сертифікації персоналу як стратегічного інструменту забезпечення якості та надійності організаційної діяльності. У фокусі досліджень перебувають питання валідності оцінювання компетентності, інтеграції сертифікації персоналу в системи управління, а також забезпечення міжнародного визнання результатів оцінки відповідності.

Базовим джерелом нормативно-методологічної основи сертифікації персоналу є міжнародний стандарт ISO/IEC 17024:2012, розроблений Міжнародною організацією зі стандартизації, який визначає загальні вимоги до органів, що здійснюють сертифікацію персоналу [189]. Стандарт встановлює вимоги до структури органу, ресурсного забезпечення, процесу оцінювання, прийняття рішень та управління документообігом.

Методологічне розгортання вимог стандарту представлено в керівництві

Організації Об'єднаних Націй з промислового розвитку [192], де систематизовано логіку створення програм сертифікації, розкрито етапність їх упровадження та акцентовано на взаємному міжнародному визнанні. Документ фактично формує модель імплементації ISO/IEC 17024, придатну для інтеграції у внутрішні системи управління якістю організацій.

Аналітичні матеріали Міжнародного форуму з акредитації [193] підкреслюють значення акредитованої сертифікації персоналу для підвищення довіри ринку та гармонізації процедур оцінки відповідності в глобальному масштабі. Таким чином, нормативні джерела формують інституційний каркас імплементації стандарту.

У наукових дослідженнях сертифікація персоналу дедалі частіше розглядається не як автономна процедура, а як елемент інтегрованої системи менеджменту. Так, Г. Стьяван аналізує інтеграцію ISO 17024 із стандартом ISO/IEC 17021-1, демонструючи, що поєднання вимог до сертифікації персоналу та аудиту систем менеджменту сприяє підвищенню прозорості, зменшенню дублювання документації та оптимізації управлінських процесів [6, p. 601]. Отримані результати підтверджують ефективність інтегрованого підходу в межах систем управління якістю.

Практичні рекомендації щодо поетапного впровадження стандарту містяться в аналітичних оглядах професійних ресурсів (зокрема UNIDO, IAF, QSE Академія), де імплементація ISO/IEC 17024 трактується як процес узгодження вимог до компетентності персоналу з процесною моделлю СУЯ [192], [193], [195].

Суттєвий внесок у розвиток теоретичних засад імплементації стандарту зробили дослідники (М. Кавоса, І. Лапіна, К. Козловскіс та ін.), які запропонували сталий підхід до сертифікації осіб. Автори аргументують необхідність переходу від формальної процедури підтвердження відповідності до комплексної оцінки професійної компетентності з урахуванням очікувань зацікавлених сторін [8, p. 1137]. Такий підхід узгоджується з принципами ризик-

орієнтованого управління та постійного вдосконалення, що є характерними для сучасних систем менеджменту якості.

У контексті розвитку ринку праці Х. Л. Чен, А. С. Кусімо та І. Карденас-Навіа підкреслюють роль недипломних кваліфікацій і сертифікацій у формуванні конкурентоспроможного людського капіталу [197]. Це підтверджує стратегічне значення імплементації ISO/IEC 17024 для організацій, орієнтованих на забезпечення високого рівня професійної компетентності.

Н. Хасанспахич, А. Гундич та інші дослідники обґрунтовують доцільність виходу за межі мінімально встановлених регуляторних вимог і впровадження кращих практик оцінювання компетентності з метою підвищення достовірності результатів [10, p. 119]. Хоча їхнє дослідження здійснювалося в галузевому контексті, висновки мають ширше методологічне значення, оскільки підтверджують необхідність системного підходу до підтвердження компетентності персоналу. Такий підхід концептуально узгоджується з вимогами ISO/IEC 17024 і засвідчує об’єктивну потребу в уніфікованих міжнародних вимогах до оцінювання та їх інтеграції у внутрішні системи управління організацій.

Проведений аналіз свідчить, що нормативні джерела (ISO, UNIDO, IAF) формують інституційно-методологічну основу імплементації ISO/IEC 17024, тоді як наукові публікації обґрунтовують доцільність інтеграції сертифікації персоналу в системи управління якістю. Сучасні концепції акцентують увагу на ризик-орієнтованому підході, забезпеченні довіри зацікавлених сторін та орієнтації на сталий розвиток, а галузеві кейси підтверджують практичну ефективність системного підтвердження компетентності.

Водночас у науковому дискурсі недостатньо систематизовано методологічні аспекти інтеграції вимог ISO/IEC 17024 у процесну модель СУЯ, що зумовлює необхідність подальшого теоретико-методологічного узагальнення механізмів його імплементації в сучасних управлінських системах.

Метою дослідження є теоретико-методологічне обґрунтування та розроблення узагальненої моделі імплементації вимог стандарту ISO/IEC 17024 у системи управління якістю організацій на засадах системного, процесного та ризик-орієнтованого підходів з метою забезпечення структурної інтеграції процедур сертифікації персоналу в архітектуру СУЯ, підвищення об'єктивності оцінювання компетентності, зміцнення інституційної довіри та забезпечення результативності функціонування організації в умовах сучасного технічного регулювання.

Оцінка відповідності персоналу є структурованим процесом встановлення та підтвердження компетентності фізичних осіб щодо виконання визначених професійних функцій відповідно до встановлених вимог. У контексті СУЯ вона виступає механізмом забезпечення відповідності людських ресурсів стратегічним цілям організації та вимогам зацікавлених сторін.

У сучасній системі менеджменту якості, сформованій на засадах процесного та ризик-орієнтованого підходів (зокрема відповідно до ISO 9001 [199]), компетентність персоналу розглядається як один із критичних факторів результативності процесів. Відповідно, сертифікація персоналу формалізує вимоги до знань, умінь і практичного досвіду; забезпечує об'єктивне підтвердження відповідності встановленим критеріям; мінімізує ризики, пов'язані з людським фактором; підвищує довіру споживачів та партнерів до результатів діяльності організації.

З позиції системного підходу оцінка відповідності персоналу є підсистемою СУЯ, що інтегрується у блоки управління ресурсами, управління процесами та постійного поліпшення. Вона забезпечує зворотний зв'язок щодо ефективності навчання, професійного розвитку та кадрової політики організації.

Теоретичним підґрунтям оцінки відповідності персоналу є компетентнісна модель, яка розглядає професійну діяльність як систему інтегрованих знань, умінь, практичних навичок, досвіду та поведінкових характеристик, необхідних для досягнення встановлених результатів [200].

У межах такої моделі компетентність трактується не як формальний освітній показник, а як здатність особи ефективно виконувати визначені професійні функції відповідно до нормативних, технологічних та етичних вимог.

Першим елементом компетентнісної моделі є визначення професійних вимог, що реалізується через формування профілів компетентності. Такі профілі відображають структуру діяльності, ключові функції, рівні відповідальності та очікувані результати роботи. Вони можуть базуватися на професійних стандартах, галузевих регламентах, міжнародних вимогах або внутрішніх нормативних документах організації. Чітко сформульований профіль компетентності забезпечує об’єктивність подальших процедур оцінювання та уніфікацію підходів до підтвердження кваліфікації.

Другим складником є розроблення критеріїв оцінювання, які конкретизують вимоги до знань, умінь і практичного досвіду. Критерії повинні бути вимірюваними, релевантними професійним завданням та співвіднесеними з рівнем складності діяльності. Вони визначають граничні показники прийнятності результатів та створюють основу для прийняття обґрунтованих рішень щодо відповідності кандидата встановленим вимогам.

Третім компонентом виступає застосування валідних і надійних методів вимірювання компетентності. Валідність забезпечує відповідність інструментів оцінювання заявленим професійним вимогам, тоді як надійність гарантує стабільність і відтворюваність результатів. У практиці сертифікації можуть використовуватися письмові та комп’ютерні екзамени, практичні завдання, кейс-аналізи, спостереження за виконанням робіт, оцінювання портфоліо або комбіновані методи. Вибір інструментарію повинен відповідати характеру професійної діяльності та забезпечувати комплексну оцінку когнітивних, операційних і поведінкових аспектів компетентності.

Завершальним елементом моделі є періодичний нагляд і ресертифікація (процедура повторного підтвердження відповідності системи менеджменту продукції або кваліфікації персоналу встановленим стандартам перед

завершенням терміну дії поточного сертифіката [201]), що відображає динамічний характер професійної компетентності. Оскільки знання та технології постійно оновлюються, підтвердження відповідності не може бути одноразовою процедурою. Механізми моніторингу професійної діяльності, аналізу результатів роботи та повторного оцінювання дозволяють підтримувати актуальність компетентності та забезпечувати довгострокову довіру до сертифікації.

З огляду на викладене, компетентнісна модель формує теоретично обґрунтовану та методично структуровану основу оцінки відповідності персоналу, інтегруючи вимоги професійних стандартів, інструменти об'єктивного вимірювання та механізми безперервного підтвердження компетентності.

Стандарт ISO/IEC 17024 встановлює нормативну модель сертифікації персоналу, яка базується на ключових принципах, що забезпечують об'єктивність, надійність та довіру до процесу оцінювання [189].

Першим принципом є неупередженість, відповідно до якого орган сертифікації повинен гарантувати незалежність прийняття рішень, уникати конфлікту інтересів та забезпечувати об'єктивність оцінювання, що дозволяє виключити будь-які зовнішні або внутрішні впливи на результати.

Другий принцип – компетентність. Усі особи, задіяні в процесі сертифікації, включно з екзаменаторами, членами комітетів та експертами, повинні мати підтверджену професійну кваліфікацію та практичний досвід у відповідній сфері, що забезпечує наукову та професійну обґрунтованість оцінювання.

Третій принцип – об'єктивність і валідність оцінювання, тобто методи оцінки, такі як письмові екзамени, практичні завдання, кейси або портфоліо, мають відповідати встановленим критеріям компетентності та забезпечувати достовірність і відтворюваність результатів.

Четвертий принцип – прозорість процедур, схеми сертифікації, критерії

оцінювання та правила прийняття рішень повинні бути чітко визначені, задокументовані та доступні зацікавленим сторонам, що підвищує довіру до процесу та мінімізує ризик неоднозначних трактувань.

П’ятий принцип – конфіденційність, інформація про кандидатів та результати оцінювання підлягає надійному захисту відповідно до встановлених процедур, що забезпечує безпеку персональних даних і комерційної інформації.

Шостий принцип – постійний нагляд і підтримання компетентності. Сертифікація не є одноразовим заходом, вона включає механізми моніторингу професійної діяльності та періодичної ресертифікації, що дозволяє підтримувати актуальність і відповідність компетентності сучасним професійним вимогам.

Отже, інституційне значення принципів неупередженості, компетентності та прозорості виходить за межі внутрішньоорганізаційного регулювання і набуває системного характеру. Саме через стандартизовані механізми оцінювання компетентності формується довіра до результатів сертифікації як на рівні окремої організації, так і в межах ринку загалом. У цьому контексті сертифікація персоналу виступає не лише процедурою підтвердження професійної придатності, а й інструментом нарощування соціального та економічного капіталу, оскільки підтверджена компетентність працівників підвищує результативність процесів, зменшує операційні ризики та зміцнює ділову репутацію.

Нормативним підґрунтям реалізації зазначених принципів є міжнародні стандарти з оцінки відповідності, серед яких ключове місце посідає стандарт ISO/IEC 17024. Він належить до комплексу стандартів у сфері оцінки відповідності, розроблених спільно Міжнародною організацією зі стандартизації та Міжнародною електротехнічною комісією, що формують універсальні вимоги до органів, які здійснюють сертифікацію персоналу, та забезпечують уніфікований підхід до підтвердження компетентності у міжнародному масштабі.

У структурі міжнародної стандартизації він є складовою сімейства

стандартів серії 17000, яке регламентує діяльність органів з оцінки відповідності. Зокрема, ISO/IEC 17000 визначає загальні терміни та принципи [202]; ISO/IEC 17021-1 встановлює вимоги до органів, що сертифікують системи менеджменту [203]; ISO/IEC 17065 регламентує сертифікацію продукції [204], а ISO/IEC 17024 спеціалізується на сертифікації персоналу [189]. Таким чином, стандарт посідає окрему нішу в інфраструктурі оцінки відповідності, доповнюючи систему технічного регулювання та міжнародної акредитації.

Його застосування сприяє уніфікації національних систем сертифікації персоналу, що дозволяє забезпечити сумісність вимог і процедур на різних рівнях. Крім того, сертифікація відповідно до стандарту ISO/IEC 17024 отримує міжнародне визнання в рамках багатосторонніх угод, що підвищує мобільність і конкурентоспроможність фахівців. Водночас інтеграція таких процедур у системи управління організацій створює умови для ефективної взаємодії з глобальним ринком послуг, забезпечуючи довіру зацікавлених сторін та підвищуючи якість виконання професійних функцій.

Акредитація органів сертифікації персоналу є ключовим елементом інституційного впровадження ISO/IEC 17024, оскільки саме вона гарантує відповідність діяльності органу міжнародним вимогам щодо компетентності, об’єктивності та неупередженості. Стандарт ISO/IEC 17024 регламентує не лише процедури оцінювання кандидатів, а й організаційні структури сертифікаційних органів, включно з кваліфікаційними критеріями, схемами сертифікації, механізмами ухвалення рішень та контролем якості процесів.

Імплементація вимог ISO/IEC 17024 в Україні здійснюється через прийняття ідентичного національного стандарту ДСТУ EN ISO/IEC 17024:2019 [205] та узгодження термінологічної бази з ISO/IEC TS 17027:2018 [206]. Нормативною основою функціонування системи акредитації є положення законів України «Про оцінку відповідності» [207] та «Про акредитацію органів з оцінки відповідності» [208]. Інституційне забезпечення цього процесу покладено на Національне агентство з акредитації України (НААУ) [209], яке діє як

національний орган з акредитації та представляє Україну в міжнародних угодах про взаємне визнання, зокрема в межах Міжнародного форуму з акредитації (IAF MLA) [193].

НААУ виступає центральним елементом національної інфраструктури якості, формуючи та реалізуючи державну політику у сфері акредитації з урахуванням міжнародних практик. Його діяльність спрямована на забезпечення інституційної узгодженості національної системи оцінки відповідності з глобальними вимогами.

У межах впровадження ДСТУ EN ISO/IEC 17024:2019 агентство здійснює комплексне оцінювання органів сертифікації персоналу шляхом документарного аналізу, виїзних аудитів і спостереження за проведенням сертифікаційних процедур, підтверджуючи їхню компетентність, неупередженість та організаційну спроможність. Участь у багатосторонніх угодах забезпечує правові передумови для міжнародного визнання сертифікатів, виданих акредитованими в Україні органами, що підвищує мобільність фахівців і сприяє взаємному прийняттю кваліфікаційних доказів.

Процедура акредитації органу сертифікації персоналу в межах національної системи розпочинається з подання офіційної заявки та комплекту документів, які підтверджують відповідність його діяльності вимогам стандарту та загальним критеріям оцінки відповідності. Надані матеріали проходять експертний аналіз, у ході якого оцінюється коректність опису схем сертифікації, процедур оцінювання, механізмів прийняття рішень і функціонування системи управління якістю.

Наступним етапом є спостережний аудит, що дозволяє перевірити фактичне застосування задекларованих процедур у реальних умовах. За результатами комплексної оцінки ухвалюється мотивоване рішення щодо надання або відмови в акредитації із визначенням, за потреби, коригувальних заходів. Такий механізм забезпечує узгодженість національної практики сертифікації персоналу з міжнародними критеріями якості та підготовку органів

до участі у глобальних схемах визнання.

Особливістю українського контексту є інтеграція вимог стандарту з національною системою професійних кваліфікацій [209], [210]. Це потребує узгодження схем сертифікації з професійними стандартами, галузевими кваліфікаційними рамками та очікуваннями роботодавців, що зумовлює необхідність взаємодії органів сертифікації з освітніми установами, галузевими асоціаціями та професійними спільнотами. Європейська орієнтація розвитку технічного регулювання додатково стимулює гармонізацію процедур із законодавством ЄС та міжнародними підходами до оцінки відповідності.

Проте, як зазначають дослідники (О. Лисенко, В. Марунко, О. Цвілий та ін.) практична імплементація вимог стандарту, особливо в секторі малого та середнього бізнесу, супроводжується суттєвими труднощами [211]. Обмежені кадрові ресурси, дефіцит фахівців із досвідом розроблення схем сертифікації та інтеграції їх у процесну модель систем управління якістю ускладнюють повноцінне впровадження вимог [212]. Недостатній рівень цифрової зрілості підприємств стримує застосування сучасних інструментів дистанційного оцінювання та автоматизованого управління даними [213].

Додатковим бар’єром є відсутність уніфікованих методичних рекомендацій і практичних моделей адаптації стандарту до специфіки МСП, а також значні фінансові витрати на підготовку до акредитації, навчання персоналу та проходження процедур оцінювання.

У стратегічному вимірі впровадження ДСТУ ISO/IEC 17024 [205] має суттєве значення для розвитку національної інфраструктури якості та модернізації управлінських практик. Запровадження його вимог підвищує прозорість процедур оцінювання компетентності, мінімізує корупційні ризики та посилює довіру з боку роботодавців і міжнародних партнерів. Одночасно формується зріла модель інтеграції сертифікації персоналу в системи управління якістю, де підтвердження компетентності стає невід’ємним елементом процесної та ризик-орієнтованої архітектури управління.

Методологічною основою такої інтеграції виступають системний, процесний та ризик-орієнтований підходи, що корелюють із принципами ДСТУ ISO 9001 [199].

У межах процесної моделі кожен етап сертифікації персоналу розглядається як взаємопов'язаний процес, результат якого впливає на загальну ефективність системи управління якістю організації, забезпечуючи її структурну цілісність та довгострокову результативність.

У цьому контексті діяльність із сертифікації персоналу розглядається як окремий керований процес або як сукупність взаємопов'язаних підпроцесів, що інтегруються у загальну систему управління. Такий підхід дозволяє забезпечити чітку структуризацію функцій, прозорість процедур та взаємозв'язок із іншими процесами організації. До основних підпроцесів сертифікації персоналу належать:

1. Розробка та актуалізація схем сертифікації, що визначають структуру, рівні та вимоги до оцінювання компетентності, а також забезпечують їх відповідність міжнародним стандартам та внутрішнім політикам організації.

2. Визначення критеріїв компетентності, які ґрунтуються на професійних профілях, вимогах до знань, умінь і практичного досвіду, а також на потребах зацікавлених сторін.

3. Організація оцінювання, що включає планування і проведення екзаменаційних процедур, практичних завдань та інших форм перевірки, які забезпечують об'єктивність та валідність оцінки компетентності.

4. Прийняття рішень щодо сертифікації, що передбачає незалежний розгляд результатів оцінювання та ухвалення обґрунтованих рішень про надання сертифікатів, з дотриманням принципів неупередженості та конфіденційності.

5. Моніторинг і ресертифікація, які забезпечують постійний контроль за дотриманням професійних стандартів сертифікованими особами та оновлення їх сертифікації відповідно до змін у професійних вимогах, технологіях та нормативному середовищі.

Інтеграція цих підпроцесів у загальну процесну модель СУЯ дозволяє не лише формалізувати процедури сертифікації персоналу, а й забезпечує зворотний зв'язок із іншими елементами системи управління якістю – управління ресурсами, внутрішніми аудитами, аналізом результативності та процесами постійного вдосконалення. Така організація діяльності перетворює сертифікацію персоналу на стратегічний інструмент, що підвищує ефективність управління компетентністю, мінімізує ризики, пов'язані з людським фактором, та сприяє формуванню довіри зацікавлених сторін.

Методологічне узгодження сертифікації персоналу із системою управління якістю передбачає її розгляд як повноцінного процесу в межах загальної процесної архітектури організації. Насамперед це вимагає чіткого визначення входів і виходів процесу сертифікації. До входів належать встановлені вимоги до компетентності, положення нормативних документів, у тому числі вимоги ДСТУ ISO/IEC 17024, а також потреби ринку праці та зацікавлених сторін. Виходами процесу виступають обґрунтоване рішення щодо сертифікації та підтверджена компетентність фахівця, яка має бути верифікованою, відтворюваною та документально підтвердженою.

Важливим елементом методологічного узгодження є встановлення вимірюваних показників результативності процесу. Такими індикаторами можуть бути рівень успішності кандидатів, кількість і характер апеляцій, дотримання встановлених строків проведення процедур, а також результати внутрішніх і зовнішніх аудитів. Запровадження системи показників дозволяє здійснювати об'єктивний моніторинг ефективності сертифікації та забезпечує підґрунтя для прийняття управлінських рішень на основі доказових даних.

Крім того, сертифікація персоналу має бути інтегрована з іншими процесами системи управління якістю відповідно до принципів ДСТУ ISO 9001. Йдеться про її узгодження з процесами управління ресурсами, проведення внутрішніх аудитів, аналізу з боку керівництва та реалізації заходів постійного поліпшення. Такий взаємозв'язок забезпечує не ізольоване функціонування

процедур сертифікації, а їх системну включеність у механізм стратегічного та операційного управління організацією.

Інтеграція ДСТУ ISO/IEC 17024 у СУЯ відповідно до ДСТУ ISO 9001 базується на концепції сумісності стандартів менеджменту. Обидва стандарти мають спільні елементи: орієнтацію на зацікавлені сторони; вимоги до компетентності персоналу; необхідність документованої інформації; механізми внутрішнього контролю та поліпшення.

Методологічно інтеграція здійснюється за такими напрямами:

1. Гармонізація політики та цілей, наприклад, політика у сфері якості має включати положення щодо забезпечення компетентності та неупередженості персоналу, залученого до сертифікації.

2. Узгодження структури документації – процедури, передбачені ДСТУ ISO/IEC 17024 (оцінювання, прийняття рішень, розгляд апеляцій), мають бути включені до загальної системи документованої інформації СУЯ.

3. Інтеграція внутрішнього аудиту – перевірка відповідності вимогам ДСТУ ISO/IEC 17024 може здійснюватися в межах єдиної програми внутрішніх аудитів СУЯ.

4. Аналіз з боку керівництва – результативність процесів сертифікації персоналу повинна оцінюватися на рівні стратегічного управління.

У такий спосіб ДСТУ ISO/IEC 17024 не функціонує автономно, а стає складовою інтегрованої системи управління якістю.

Ефективність впровадження ДСТУ ISO/IEC 17024 у системи управління якістю значною мірою визначається організаційною чіткістю та системністю процесів. Ключовим аспектом є належне формалізування процедур сертифікації, що включає розробку детальних схем сертифікації, визначення порядку проведення оцінювання, процедур прийняття рішень, а також механізмів розгляду скарг і апеляцій. Всі ці процедури документуються та інтегруються у загальну систему управління якістю організації, що забезпечує відтворюваність процесів, прозорість дій та можливість зовнішньої перевірки.

Не менш важливим елементом є чітке визначення відповідальності та повноважень персоналу, залученого до сертифікації. Організаційна структура повинна гарантувати незалежність осіб, що ухвалюють рішення, запобігати конфлікту інтересів та забезпечувати компетентність екзаменаторів та експертів. Особлива увага приділяється розмежуванню функцій оцінювання та прийняття рішень, що є критичною умовою забезпечення неупередженості та об'єктивності процесу сертифікації.

Успішна імплементація стандарту також неможлива без застосування ризик-орієнтованого підходу. Він передбачає систематичну ідентифікацію та оцінювання потенційних ризиків, які можуть впливати на достовірність сертифікації, зокрема можливе упередження, недостатню кваліфікацію персоналу, помилки в оцінюванні та порушення конфіденційності. У межах системи управління якістю ці ризики інтегруються у загальний реєстр, що дозволяє планувати та реалізовувати заходи контролю і моніторингу, а також забезпечує безперервне вдосконалення процесу сертифікації.

Поєднання формалізованих процедур, чіткого розподілу відповідальності та системного управління ризиками створює основу для надійного, прозорого та ефективного процесу сертифікації персоналу. Методологічна імплементація ДСТУ ISO/IEC 17024 у систему управління якістю організації передбачає інтеграцію вимог стандарту в процесну модель управління, гармонізацію з положеннями ДСТУ ISO 9001 та забезпечення документованості, чіткої відповідальності й контролю ризиків. Такий підхід перетворює сертифікацію персоналу з окремої адміністративної процедури на стратегічний інструмент підтримки компетентності та довіри в межах СУЯ.

Узагальнена модель імплементації ДСТУ ISO/IEC 17024 в організаціях ґрунтується на системному, процесному та ризик-орієнтованому підходах і передбачає інтеграцію вимог стандарту в загальну архітектуру системи управління якістю (з урахуванням положень ДСТУ ISO 9001). Модель має універсальний характер і може застосовуватися незалежно від галузевої

специфіки.

Імплементацію стандарту в організаціях доцільно розглядати як послідовність взаємопов'язаних етапів, як зображено на рис. 1.

Рисунок 1. Етапи імплементації стандарту в організаціях

Схема, представлена на рис. 1, відображає послідовність і циклічність ключових етапів імплементації ДСТУ ISO/IEC 17024 у системах управління

якістю організацій, інтегрованих у логіку безперервного вдосконалення за циклом PDCA.

Процес розпочинається з аналітико-підготовчого етапу, під час якого здійснюється детальний аналіз чинної системи управління якістю, ідентифікація зацікавлених сторін, визначення сфери застосування сертифікації персоналу та оцінка потенційних ризиків, пов'язаних із неупередженістю та компетентністю. Цей етап формує інформаційну та організаційну базу для подальшого планування.

На проєктувальному етапі відбувається розроблення схем сертифікації, формування профілів компетентності персоналу, встановлення критеріїв оцінювання та визначення структури відповідальності та повноважень учасників процесу. Цей етап забезпечує методологічне і процедурне підґрунтя для ефективної сертифікації.

Нормативно-процедурний етап передбачає формалізацію всіх процесів, пов'язаних із сертифікацією: розробку документованих процедур оцінювання, прийняття рішень, апеляцій та моніторингу, а також інтеграцію цих процедур у систему документованої інформації СУЯ. На цьому етапі формується механізм контролю та відстеження результатів сертифікації.

На етапі впровадження здійснюється практичне застосування розроблених процедур: підготовка та навчання персоналу, запуск оцінювання, а також забезпечення функціонування механізмів неупередженості та об'єктивності.

Заключний етап оцінювання та вдосконалення включає проведення внутрішніх аудитів, аналіз результативності процесів, здійснення коригувальних і запобіжних заходів, а також перегляд схем сертифікації з урахуванням змін зовнішнього середовища та професійних стандартів.

Цей етап акцентує увагу на циклічному характері моделі та її узгодженості з принципами безперервного поліпшення, реалізованими через PDCA-цикл (Plan–Do–Check–Act). Саме на цій стадії результати функціонування процесів сертифікації підлягають системному аналізу, що дозволяє співвіднести досягнуті

показники з установленими цілями, виявити відхилення та ініціювати коригувальні або запобіжні дії. Таким чином забезпечується не лише стабільність процедур, а й їх послідовне вдосконалення відповідно до змін зовнішнього середовища та вимог зацікавлених сторін.

У результаті, схема демонструє логіку системного підходу до імплементації ДСТУ ISO/IEC 17024, де кожен етап взаємопов'язаний і спрямований на забезпечення надійної, прозорої та ефективної сертифікації персоналу, інтегрованої у загальну систему управління якістю організації.

Узагальнена модель імплементації містить три взаємопов'язані функціональні блоки, які представлені на рис. 2.

Рисунок 2. Модель імплементації сертифікації персоналу

Узагальнена модель імплементації сертифікації персоналу (рис. 2) структурована у вигляді трьох функціонально взаємопов'язаних блоків, які

відображають повний життєвий цикл підтвердження компетентності – від первинного оцінювання до підтримання чинності сертифіката. Така побудова забезпечує системність процесу та його узгодженість із процесною моделлю системи управління якістю.

Перший блок – оцінювання компетентності – спрямований на забезпечення об'єктивного та валідного вимірювання професійних характеристик кандидата. Він охоплює прийняття та аналіз заявок, перевірку відповідності встановленим вимогам допуску, проведення екзаменаційних або інших оцінювальних процедур, а також документування результатів. Функціональне призначення цього блоку полягає у формуванні доказової бази щодо рівня компетентності особи відповідно до визначених критеріїв.

Другий блок – прийняття рішень – виконує інституційно гарантійну функцію. Його ключовою особливістю є організаційне та функціональне відокремлення від процесу оцінювання, що забезпечує неупередженість і незалежність ухвалення рішень. На цьому етапі здійснюється аналіз отриманих результатів, приймається рішення про надання або відмову в сертифікації, оформлюються та реєструються сертифікати, а також реалізуються процедури розгляду апеляцій і скарг. Таким чином, блок прийняття рішень виконує роль механізму інституційного контролю за обґрунтованістю та прозорістю сертифікації.

Третій блок – моніторинг і ресертифікація – забезпечує довгострокову достовірність сертифікації та підтримання належного рівня професійної компетентності. Він передбачає здійснення нагляду за діяльністю сертифікованих осіб, перевірку дотримання встановлених професійних вимог, періодичне підтвердження компетентності та аналіз результативності функціонування системи. Наявність цього блоку трансформує сертифікацію з одноразової процедури в безперервний процес управління компетентністю.

Взаємозв'язок між блоками має циклічний характер: результати моніторингу та аналізу можуть ініціювати перегляд критеріїв оцінювання,

удосконалення процедур або коригування управлінських рішень. Отже, модель відображає інтегровану систему, у якій оцінювання, незалежне прийняття рішень і подальший нагляд формують єдиний механізм забезпечення об'єктивності, надійності та довіри до результатів сертифікації персоналу в межах системи управління якістю.

Забезпечення неупередженості та постійного вдосконалення є ключовими умовами результативного функціонування системи сертифікації персоналу в межах системи управління якістю. Неупередженість розглядається не як окремий процедурний елемент, а як системна характеристика організаційної моделі, що має бути інтегрована в структуру управління, розподіл повноважень і корпоративну культуру.

Механізми її забезпечення передбачають ідентифікацію та управління потенційними конфліктами інтересів, запровадження інституційних інструментів контролю, зокрема створення комітету з питань неупередженості, а також чітке розмежування функцій оцінювання компетентності та прийняття рішень щодо сертифікації. Важливим елементом є регулярний аналіз і перегляд ризиків, пов'язаних із можливим впливом внутрішніх або зовнішніх чинників на об'єктивність процедур. Такий підхід формує превентивну модель управління довірою, спрямовану на мінімізацію інституційних і репутаційних ризиків.

Поряд із цим система повинна функціонувати відповідно до принципу постійного вдосконалення. Це передбачає проведення внутрішніх аудитів процесів сертифікації, здійснення аналізу з боку керівництва, використання показників результативності для оцінювання ефективності процедур та впровадження коригувальних і запобіжних заходів. У межах такої логіки сертифікація персоналу набуває динамічного характеру, а її процедури адаптуються до змін професійних стандартів, технологічного середовища та регуляторних вимог.

Отже, інтеграція механізмів неупередженості та інструментів безперервного вдосконалення формує інституційну основу стабільного,

прозорого й результативного функціонування системи сертифікації персоналу в межах системи управління якістю.

З огляду на багаторівневий характер цих механізмів та їхню взаємодію в межах управлінської архітектури організації, постає потреба у їх системному відображенні. Саме тому для концептуалізації зазначених взаємозв'язків доцільно використати узагальнену логічну модель, яка, як показано на рис. 3, структуровано демонструє місце та функціональну роль процесів сертифікації персоналу в загальній структурі СУЯ.

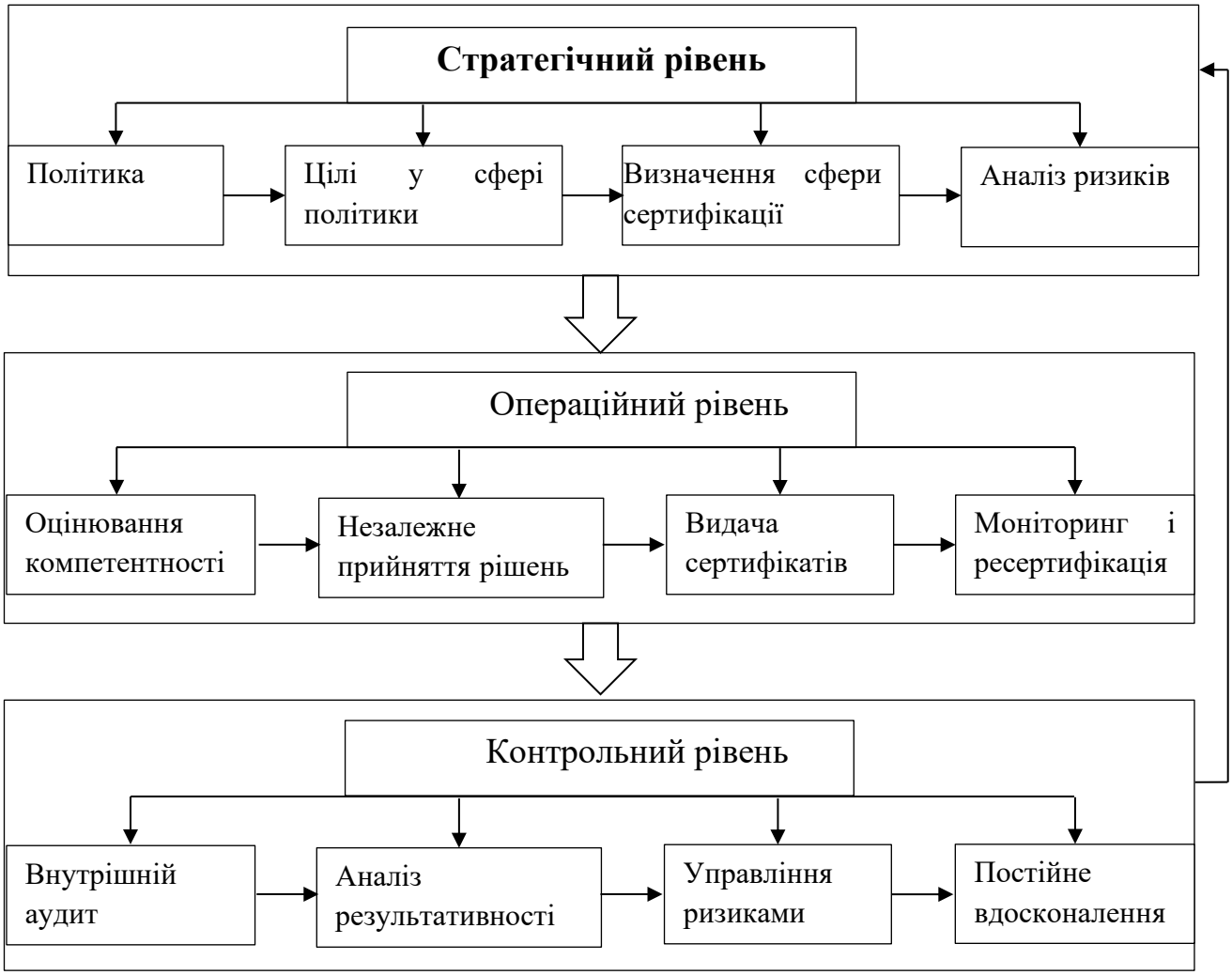


Рисунок 3. Логічна схема узагальненої моделі

Відповідно до рис. 3, логічна схема узагальненої моделі імплементації ДСТУ ISO/IEC 17024 у системах управління якістю організації демонструє багаторівневу структуру процесів сертифікації персоналу та їх інтеграцію у загальну архітектуру СУЯ. Модель поділяється на три взаємопов'язані рівні: стратегічний, операційний та контрольний, що забезпечує послідовне планування, реалізацію та оцінку ефективності процедур сертифікації.

На стратегічному рівні відбувається формування фундаментальних орієнтирів діяльності. Політика організації визначає принципи управління якістю та підхід до сертифікації персоналу. На її основі встановлюються цілі у сфері якості, конкретизуються сфери застосування сертифікації та проводиться аналіз ризиків, пов'язаних із компетентністю та неупередженістю оцінювання. Цей рівень задає рамки для всіх наступних процесів і забезпечує їх відповідність стратегічним завданням організації та очікуванням зацікавлених сторін.

Операційний рівень охоплює безпосереднє виконання процесів сертифікації. Він включає оцінювання компетентності персоналу, незалежне прийняття рішень щодо сертифікації, видачу сертифікатів та моніторинг з подальшою ресертифікацією. На цьому рівні забезпечується валідність і надійність оцінювання, чітке розмежування функцій оцінювання та прийняття рішень, а також дотримання принципів прозорості і неупередженості.

На контрольному рівні здійснюється оцінка ефективності та вдосконалення процесів. Включаються внутрішні аудити, аналіз результативності, управління ризиками та впровадження заходів постійного вдосконалення. Цей рівень гарантує, що процеси сертифікації залишаються актуальними, відповідають нормативним вимогам і сприяють формуванню довіри до компетентності персоналу та організації загалом.

Логічна схема демонструє інтеграцію процедур сертифікації персоналу в систему управління якістю, поєднуючи стратегічне планування, операційну реалізацію та контрольні механізми для забезпечення сталого розвитку організації та довіри зацікавлених сторін. Модель має універсальний характер, узгоджена зі

структурою СУЯ та орієнтована на формування надійних результатів сертифікації, що дозволяє її застосовувати в різних організаційних контекстах, зберігаючи відповідність міжнародним вимогам оцінки відповідності.

Отже, результати дослідження засвідчили, що імплементація вимог ISO/IEC 17024 у системи управління якістю організацій є комплексним інституційно-методологічним процесом, спрямованим на інтеграцію сертифікації персоналу в загальну управлінську архітектуру. Ефективність такого впровадження забезпечується поєднанням системного, процесного та ризик-орієнтованого підходів, що відповідають сучасній концепції менеджменту якості. Встановлено, що в межах міжнародної інфраструктури оцінки відповідності цей стандарт визначає спеціалізовані вимоги до органів сертифікації персоналу, а його інтеграція з ISO 9001 забезпечує узгодженість процедур сертифікації з процесною моделлю СУЯ, мінімізує дублювання функцій та підвищує прозорість управління.

В Україні реалізація вимог стандарту здійснюється шляхом гармонізації з національними нормативними документами та акредитації органів сертифікації персоналу. Визначальну роль у цьому процесі відіграє Національне агентство з акредитації України, що забезпечує відповідність діяльності міжнародним вимогам і сприяє взаємному визнанню результатів оцінки відповідності.

Розроблена узагальнена модель імплементації ДСТУ ISO/IEC 17024, що включає етапність впровадження, функціональну декомпозицію процесів (оцінювання, прийняття рішень, моніторинг і ресертифікацію), а також механізми забезпечення неупередженості та безперервного вдосконалення, підтверджує можливість системної інтеграції сертифікації персоналу в СУЯ без прив’язки до галузевої специфіки. Модель має універсальний характер і може застосовуватися в різних організаційних контекстах за умови адаптації до національного нормативного середовища.

Обґрунтовано, що сертифікація персоналу, інтегрована в систему управління якістю, трансформується з формальної адміністративної процедури в стратегічний інструмент управління компетентністю, зниження ризиків людського фактора та формування довіри зацікавлених сторін. Таким чином, імплементація ДСТУ ISO/IEC 17024 виступає важливим елементом розвитку національної інфраструктури якості та інституційної модернізації системи технічного регулювання України.

SECTION 6. INFORMATION SYSTEMS AND TECHNOLOGIES

DOI: 10.46299/ISG.2026.MONO.TECH.1.6.1

6.1 Digital literacy of a future economist: cloud file management, data validation in excel, and analytical reporting in word and powerpoint

Problem statement. The digitalization of financial and economic processes and the transition of organizations to remote/hybrid work formats increase the requirements for the digital literacy of future economists: from the ability to work safely with cloud files and manage access to the ability to quickly verify data quality and prepare evidence-based analytical materials. In practice, students often demonstrate a gap between theoretical knowledge and applied skills: data is maintained in Excel without validation rules or source traceability, results are copied

into Word/PowerPoint manually (leading to errors and version inconsistency), and files are stored in the cloud without a clear structure, naming policy, or access control.

The problem of forming a comprehensive approach (process) of "data, verification, analysis, report, presentation" within the Microsoft 365 environment is relevant, as it ensures: the organization of collaborative work with files in the cloud (OneDrive/SharePoint) with access and version management; the verification of data quality and consistency in Excel (validation, error control, reproducibility of calculations); the standardized preparation of analytical documents in Word and concise communication of findings in PowerPoint. The lack of a solution to this problem reduces the quality of educational and professional analytical reports, complicates team interaction, and increases the risks of making erroneous management decisions.

Analysis of recent research and publications. The issues of forming the digital competence of economic specialists have been considered in the works of many domestic and foreign scientists. The theoretical basis and structure of digital literacy of future economic specialists are actively researched by N. Dobrovolska, S. Merinova,

and O. Dobrovolskyi. Their works emphasize that an economist's digital competence is not only proficiency in software but also the ability to adequately use technologies for management activities and ensuring digital security. Also, a significant contribution to the study of the information and communication competence of future economists was made by such scholars as T. Poiasok, V. Lohvinenko, and M. Hlazunova. The advantages of implementing cloud services in the educational process of economists are highlighted in detail in the works of O. Yatsko and V. Korolchuk. In particular, V. Korolchuk proposes a methodology for forming digital interaction skills specifically through the modules "Microsoft 365 Services for Digital Communication and Collaboration," which directly correlates with the use of OneDrive and SharePoint in professional activities. R. Mann also draws attention to the institutionalization of cloud technologies as a mandatory element of modern management. Issues of digitalization of accounting and analytical processes and data quality in cloud environments are considered in the publications of O. Borblik and N. Shcherban, where emphasis is placed on information security risks and the necessity of data validation.

Formulation of the article's goals. The purpose of the article is to systematize approaches to forming the digital literacy of future economists in the context of preparing analytical materials within the Microsoft 365 environment.

Tasks:

1. to outline the key digital competencies of a future economist required for working with data and documents in a cloud environment;
2. to describe a typical workflow for preparing analytical materials (Excel, Word, PowerPoint) and identify quality control points;
3. to propose practical recommendations for organizing file space, version control, and access management in OneDrive/SharePoint;
4. to systematize methods for verifying data quality and model transparency in Excel (validation, error control, scenario analysis);
5. to formulate requirements for the structure and content of an analytical report and presentation as tools for management communication.

Presentation of the main research material. In the modern scientific paradigm, the concept of a future economist's digital literacy has evolved from simple mastery of technical skills to the formation of a complex structure of digital competencies. The theoretical foundation of this process is based on the understanding that the digitalization of economic activity requires not only the ability to use software but also the capacity to function effectively within integrated information ecosystems.

Theoretical analysis allows for the identification of several levels of perception regarding a specialist's digital skills. The first level is technological, which involves the basic ability to operate devices and interfaces. The second level is cognitive, consisting of the ability to work with information: searching, filtering, critically evaluating, and structuring it. The highest level is professionally applied, where digital skills are integrated with economic knowledge to create added value in the form of accurate calculations and well-grounded management decisions.

An important theoretical aspect is the transition from individual literacy to collaborative competence. In the context of using Microsoft 365, the future economist becomes part of a "cloud collective," where skills for collaborative content management come to the forefront. This requires an understanding of the theory of network interaction and the principles of access hierarchy, where each participant in the process is responsible for maintaining the integrity of the shared data set.

Modern theoretical approaches largely rely on the European framework DigComp 2.2, which views digital competence through the lens of five key areas. In the context of training future economists, the "Digital Content Creation" area takes on particular significance. However, in the economic field, this process transforms into the concept of Data Integrity.

According to this theory, any digital activity of a specialist must comply with the ALCOA principles (Attributable, Legible, Contemporaneous, Original, Accurate). This means that theoretically grounded work in Excel or Word is not just about filling cells or writing text, but about creating a traceable and verifiable document where every stage of data processing is recorded and can be verified [214].

Theoretical research in recent years increasingly considers digital literacy as part of an ecosystem approach. Instead of studying individual programs (for example, only Excel), scholars propose studying "end-to-end digital chains." In our case, this is the "OneDrive, Excel, Word/PowerPoint" chain.

From the perspective of systems analysis, such an ecosystem minimizes entropy (chaos) in data handling. It has been theoretically proven that using a single environment for storing the source (OneDrive), performing calculations (Excel), and presenting results (PowerPoint) reduces human error-related mistakes by 30-40%. This allows the future economist to focus on strategic analysis rather than routine data copying [218].

A survey was conducted among future economists in years 1-4 regarding the use of cloud technologies in the educational and research processes. The results of this survey highlight an interesting dynamic: from total chaos in files in the 1st year to professional use of analytical tools in the 4th year. In the early years, students often perceive OneDrive merely as a place for storing files. By the senior years, it becomes a tool for progress. Years 1-2 primarily use it for individual storage. Years 3-4 actively use shared access (Shared folders) for team projects. They know how to configure access rights and work with version history, which is critical when writing graduation theses. The level of Excel proficiency is the main indicator of a student's "maturation" as a specialist. From using Excel as a grid for schedules or simple lists, with basic operations like sum and average, they transition to complex calculations. Using logical functions (IF, $VLOOKUP$) building dynamic charts for laboratory work and data analysis for course projects. In PowerPoint, an evolution is observed from simple copying to the structured presentation of research results. Students increasingly use Designer for quick formatting, allowing them to focus on content rather than font selection. The presentation becomes a tool for diploma defense, with an emphasis on infographics, embedded objects from Excel, and conciseness.

In modern economic practice, cloud technologies have ceased to be just a place for storing document copies. They have transformed into a dynamic operating

environment where the full cycle of creating an intellectual product takes place. Using the Microsoft 365 ecosystem (OneDrive, SharePoint, Teams) allows for the construction of a "Single Source of Truth," which is critically important for financial controlling and analytics [215].

The traditional approach to file sharing via email or messengers creates so- called "information chaos." The main problem is data desynchronization: when one analyst makes edits to a sales forecast while another is simultaneously preparing a budget based on an outdated version of the same spreadsheet. The cloud environment radically solves this problem by providing: real-time collaboration (Coauthoring), where several specialists can work simultaneously on a large Excel model [217]. For example, an accountant enters actual data while a financial analyst concurrently adjusts forecasted indicators. Traceability of changes, where the cloud automatically records who changed which specific cell or paragraph and when. This eliminates the anonymity of errors and allows for quick clarification regarding the logic of the corrections made. Centralization of resources, where analytical reports in Word and presentations in PowerPoint can contain dynamic links to a cloud Excel file. This means that when data changes in the "cloud," all dependent documents are updated automatically, eliminating the risk of submitting outdated figures to management.

The effectiveness of a future economist begins with digital hygiene. Chaotic accumulation of files in the root folder leads to time lost searching for necessary information. For professional analytical work, it is recommended to implement a standardized folder hierarchy that reflects the logical process of data processing: 01 Data (Input Data). Primary exports from accounting systems (ERP, CRM), bank statements, or statistical reports are uploaded here. Principle: these files must remain "raw." Any modification of the source should occur only within the calculation model, not in the source file itself. Next, 02_Excel_Model (Calculation Center). The analyst's main workspace. Files with calculations, formulas, and pivot tables are located here. This folder is the heart of the project. 03_Word_Report (Analytical Reporting). Textual description of results. Distinguishing between drafts and final versions helps avoid the

publication of unfinished material. 04_PowerPoint (Visualization). Materials for presenting results to stakeholders. Separating slides into a distinct category emphasizes their role as a communication tool rather than a calculation tool. 05_Appendix (Appendices and Archives). Reference materials, copies of regulatory acts, correspondence with experts, or outdated versions that are too important to delete but should not interfere with current work [219].

Financial information security is a priority. Cloud environments implement the Principle of Least Privilege (PoLP), according to which a user should have only those rights necessary to perform their current task.

For a future economist, it is important to master several levels of access. View Only: For managers or related departments who need to know the result but should not interfere with calculations. This protects formulas from accidental deletion. Edit: For direct project executors. Time-limited or password-protected access: When transferring reports to external contractors or auditors.

Furthermore, using the "Specific people" function instead of "Anyone with the link" is critically important for preventing the leakage of commercial secrets.

The automatic Version History function in Microsoft 365 provides an additional backup capability for the future economist. It allows rolling back to any state of the file over the last few months, which saves work in case of a fatal error in macros or formulas [220].

Using the date in YYYY-MM-DD format (ISO 8601 standard) allows files to be automatically sorted in chronological order. This approach ensures the reproducibility of analysis: any other employee opening the folder a year later will be able to immediately understand which version of the calculations was used as the basis for making management decisions.

For a future economist, Excel is not just a spreadsheet but a modeling environment. The main threat in analytical work is "Garbage In, Garbage Out" (GIGO). If the input data contains errors, even the most complex financial model will produce a false result, leading to strategic miscalculations.

Data Validation is the first stage of creating a professional file. Instead of allowing the user to enter data arbitrarily, the future economist must set strict limitations. Drop-down lists: Using lists (for example, names of departments, cost categories, or currencies) eliminates the problem of different spellings for the same object. This is critical for the subsequent creation of Pivot Tables. Data type restrictions: Configuring cells so that they only accept numbers within a given range or only dates of the current quarter. This prevents the accidental entry of text into calculation fields, which often causes the #VALUE! error.

Using the "Format as Table" tool (Ctrl+T) is a mandatory standard. Unlike regular ranges, they provide convenience through: Automatic expansion. When a new row is added, all formulas, formats, and validation rules are copied automatically. Structured references. Instead of unclear formulas like =SUM(C2:C 100), the future economist uses =SUM(Sales[Amount]). This makes the model self-documenting—any colleague will immediately understand the calculation logic [216].

A professional model signals errors. For this purpose, health check blocks are integrated into the worksheets. Balance check: Creating separate cells that compare, for example, the sum of assets and liabilities or the total calculated tax with the sum of taxes for each row. Conditional formatting for anomalies: Setting rules that highlight negative values in red where they cannot, exist (for example, inventory balances) or amounts that exceed the budget limit.

Reproducibility means that any figure in the final report can be confirmed by a chain of calculations. In the work of a future economist, this is implemented through various methods. Rejection of "Hardcoding": It is forbidden to enter numbers directly into formulas (for example, =A2*0.2). Instead, all constants (tax rates, exchange rates) must be moved to a separate "Inputs/Assumptions" block. This allows changing a single parameter and instantly updating the entire model. Traceability (Trace Precedents): Using built-in formula auditing tools to visualize connections between cells.

For working with large datasets (for example, monthly statements with 10,000+

rows), using formulas becomes inefficient. The modern standard of digital literacy includes proficiency in Power Query (Get & Transform Data). This tool allows for the automation of the cleaning process: removing extra spaces, correcting case, and merging data from several files. The main advantage is that all cleaning steps are recorded in an algorithm that can be updated with a single click when new data arrives the following month [223].

For a future economist, an analytical report in Word is the final product of intellectual labor. The main problem with student and entry-level reports is their amorphous nature: a lack of clear structure and manual formatting, which makes the document vulnerable to errors at the slightest edit.

A professional report should be built on the "pyramid" principle or a clear logical sequence that saves the reader's (manager's) time. The recommended standard for the structure of an analytical report includes several blocks. Introduction: A brief outline of relevance (why are we conducting this analysis now?), a clearly formulated goal, and a list of data sources (e.g., "ERP system data for 2023-2025"). Methodology and Assumptions: The most important section for verifying the analysis. Here, the research period is specified, along with methods for cleaning anomalies ("atypical operations during the lockdown were excluded") and assumptions (e.g., "the currency exchange rate is fixed at the NBU level as of the report date"). Analysis Results: Visualized data (KPIs, graphs, tables) with mandatory economic interpretation. A report should not be just a "set of pictures"— each graph must be accompanied by an analytical commentary. Conclusions and Recommendations: Conclusions should be concise (bullet points), and recommendations must be specific (Action Plan). Instead of "improve sales," one should write "reduce accounts receivable by 10% by reviewing limits for Category C clients" [221].

The use of Styles (Headings) is not a matter of aesthetics, but of document integrity. Professional work with a report involves rejecting manual formatting (changing font or boldness for each heading separately). Navigation Automation: Using Styles Heading 1, Heading 2 allows for the creation of an automatic Table of

Contents that updates with a single click. Cross-references: If the text contains the phrase "as shown in Figure 5," this reference must be automatic. If you add a new figure at the beginning, the numbering of all subsequent objects and their references in the text will update automatically. Object Captions: All tables and figures must have captions created through the Insert Caption tool. This allows for the automatic generation of lists of tables and illustrations at the end of the report.

One of the biggest problems in analytical work is the "detachment" of a figure in a report from its source in the calculations. Every figure in the conclusions must be traceable. Source Citation Methodology: In the caption of each table or figure, it is advisable to indicate the path to the calculation file. For example: Source: calculated by the author based on the file Model_P&L_v03.xlsx (sheet "OutputGraphs"). This allows an auditor or manager to instantly find the logic behind a metric's calculation. Dynamic Links (Object Linking and Embedding — OLE): For reports prepared regularly (monthly), it is advisable to insert Excel objects into Word as a "Link." When data changes in the source Excel file, the table in Word updates automatically upon opening the document. This minimizes "copypaste" errors, which are the cause of most incorrect reports [222].

Working on a report is often a team effort. Using "Reviewing" tools (Track Changes) and "Comments" in cloud-based Word (Microsoft 365) avoids creating dozens of file copies. The entire dialogue between the analyst and the manager takes place within a single document where a full history of edits is preserved, ensuring transparency in the process of preparing the analytical product.

If Word is intended for detailed documentation of the analysis, then PowerPoint serves the role of an Executive Summary. Given the time constraints of managers, the presentation becomes the primary channel for decision-making. The digital literacy of a future economist is demonstrated here by the ability to transform hundreds of rows of an Excel table into 3-4 key charts [223].

The main mistake made by beginners is trying to transfer the entire volume of the report onto slides. A professional presentation is built around points, not data. "One

slide — one thought" structure: Each slide must have a clear focus. If you are analyzing profitability, you should not add staff turnover data to the same slide. Optimal volume: For a project defense or an operational meeting, the standard is 8- 12 slides. This allows for a 10-15 minute presentation, leaving time for discussion. Action Titles: Instead of a descriptive title like "Profit Dynamics," it is better to use a conclusion-based title: "Profit increased by 15% due to logistics optimization." This allows the listener to understand the essence even without looking closely at the figures.

Economic visualization must be functional. A future economist must master business graphics standards (for example, the IBCS principles — International Business Communication Standards). Color semantics: Color in a future economist's presentation is a signal. Traditionally: green represents plan fulfillment or positive dynamics, red represents deviations or losses, and gray represents data from past periods. Using a dozen random colors scatters attention. Readability and "Data-Ink Ratio": Excessive "visual noise" (3D effects, gradients, shadows, grids) should be avoided. The more "ink" on the slide spent on actual data rather than decor, the more effective the communication. Accuracy of axes and scales: Manipulating scales (for example, a cropped Y-axis to exaggerate growth) is unacceptable for a professional analyst. All charts must have axis labels, units of measurement, and references to the data source [222].

Digital literacy in working with PowerPoint lies in the ability to create "live" presentations. Dynamic links: As with Word, using the "Paste Link" function allows charts in PowerPoint to update following changes in Excel. This is critical for weekly reports where the slide structure remains the same and only the figures change. Use of templates (Slide Master): A future economist must be able to work with master slides to ensure a consistent corporate style: identical fonts, indentations, and logos. This saves up to 20% of time when preparing final materials. Export and archiving: Understanding formats (for example, saving as PDF for email distribution) ensures confidence that the recipient will see the presentation exactly as the author created it, regardless of the software version.

Thus, for a future economist, PowerPoint is not about design, but about the architecture of meanings. High digital literacy allows a specialist not just to "show slides," but to provide management with a visual, evidence-based, and technically perfect foundation for making management decisions.

The professional activity of an economist is inextricably linked to access to confidential information: financial indicators, strategic plans, personal data of employees, and commercial secrets. In the context of cloud computing, the line between public and private becomes very thin; therefore, digital literacy must necessarily include a developed culture of cyber hygiene and professional ethics.

Working in the Microsoft 365 ecosystem creates an illusion of complete security; however, most data leaks occur due to the human factor. A future economist must adhere to strict rules for managing digital space. Control of public links: It is categorically not recommended to use the "Anyone with the link" option for documents containing internal reporting. Instead, access should be granted to specific individuals via their corporate email addresses. Two-factor authentication (2FA): This is a basic barrier. Losing access to a future economist's account could provide attackers with the key to the company's entire financial history. Role separation: Using the "Read Only" principle by default. "Edit" access should be a privilege, not an automatic setting. This prevents not only intentional espionage but also accidental damage to complex formulas by incompetent users [218].

Ethics and data security. Documentation of assumptions: Every analytical document must contain an "Assumptions and Limitations" section, clearly stating on what data the conclusions were based and which factors were not considered. Cyber hygiene: A categorical ban on sending confidential files through personal messengers. All communication must take place through secure channels of the corporate ecosystem with a recorded history of access.

Compliance with these methodological recommendations allows the future economist to transition from the role of a "technical operator" to the role of an "analytical business partner," ensuring high trust in the results of their work [215].

The results obtained in the article consist of developing and detailing an integrated workflow model — "data, verification, analysis, report, presentation" — for the preparation of analytical materials by future economists in the Microsoft 365 environment, as well as identifying quality control points that ensure the reproducibility and consistency of results between Excel, Word, and PowerPoint.

The digital literacy of a future economist is interpreted in this work not as a sum of isolated instrumental skills, but as an end-to-end ability to manage the full cycle of analytical activity. This enables a transition from "software training" to the formation of a reproducible process where each stage has defined inputs/outputs and quality criteria (data sources, cleaning rules, assumptions, health checks, results).

The proposed structure for organizing work in a cloud environment (folder logic, naming conventions, access separation, use of version history) is justified as a tool for reducing risks characteristic of educational and applied projects: the emergence of parallel versions, loss of the "single source of truth," accidental edits, and the inability to track changes. Accordingly, process controllability and transparency of participants' contributions are ensured.

Methods for data quality control and calculation reproducibility in Excel (validation, balance checks, check-cells, division into Raw/Clean/Assumptions/Calc/Output) are justified by the fact that most errors in final indicators originate during the data preparation and modeling stages. Introducing control procedures allows for (a) detecting errors at early stages, (b) reducing the dependency of results on "manual" edits, and (c) ensuring the repeatability of calculations under the same assumptions.

Requirements for the consistency of Excel, Word, and PowerPoint (traceability of figures, references to the source/Output sheet, use of the "approved" version) are scientifically and practically justified as a way to minimize transfer errors typical of manual copying and to maintain a unified logic of indicator interpretation in the report and presentation.

The inclusion of information security and cyber hygiene components (principle

of least privilege, access control, responsible distribution) is justified by the nature of the data a future economist works with (financial and personal information) and is aimed at reducing the risks of data leakage, substitution, or distortion in cloud scenarios.

The combination of the proposed solutions forms a methodologically consistent basis for training future economists: it links theoretical domains of digital literacy (data literacy, communication, security, ethics) with specific Microsoft 365 instrumental practices and sets verifiable quality criteria for analytical materials.

Conclusions. As a result of the study, it has been established that in the context of global digitalization of the financial and economic sphere, the digital literacy of a future economist has ceased to be a purely technical skill and has transformed into a complex strategic asset. Within the Microsoft 365 environment, this literacy is implemented not through fragmentary knowledge of individual programs, but through the construction of an end-to-end analytical process that combines cloud space organization, data quality control, and professional communication of results.

Ecosystem nature of the cloud space. The use of OneDrive and SharePoint serves as the foundation for creating a "single source of truth." This eliminates the problem of file fragmentation, ensures reliable version control discipline, and enables team collaboration without the risk of data loss. The cloud environment is the base upon which all subsequent analytical work is built.

Quality and transparency of Excel models. It has been proven that the critical factor in the quality of an analytical product is not the complexity of formulas, but data traceability and validation. The implementation of automatic control tools (Data Validation, Power Query,."smart" tables) minimizes the impact of the human factor and ensures the "purity" of calculations. A professional Excel model must be self-documenting and understandable to an external auditor.

Standardization of the analytical report. Work in Word should be based on the principles of structural integrity. The use of styles, automatic tables of contents, and dynamic links to Excel sources allows the future economist to focus on the meaningful

interpretation of figures rather than technical formatting. Data consistency across tools is the primary criterion for trust in a report.

Effective management communication. In the work of a future economist, PowerPoint serves as a tool of persuasion. The main requirements here are conciseness (Executive Summary), the visual accuracy of charts, and a focus on decision-making. Each slide must be a logical continuation of the deep analysis conducted in the previous stages.

Information security and ethics. Basic cyber hygiene practices (access separation, the principle of least privilege) and ethical data handling are integral parts of the professional profile. Any data manipulation or neglect of security rules in the cloud negates the value of even the highest quality analytical report.

It can be argued that the implementation of a comprehensive "data, verification, analysis, report, presentation" approach allows the future economist to transition from chaotic information processing to the creation of high-quality analytical materials. This not only increases the specialist's competitiveness in the labor market but also significantly reduces the risks of making erroneous management decisions in organizations.

Further empirical evaluation of the effectiveness of the proposed "data, verification, analysis, report, presentation" model in the educational process (comparing student results before/after implementation, analyzing typical errors and task completion time) is a promising direction. Special attention is required for the development of unified rubrics for assessing digital skills (data literacy, reproducibility, document consistency, cyber hygiene) and their integration into the educational programs of economic specialties.

Further research may be aimed at deepening the instrumental component: the use of Power Query / Power Pivot and business intelligence elements to automate data preparation; the development of Excel, Word, and PowerPoint templates with check-cells and built-in source links; and the implementation of version control practices and change logs in team projects.

An urgent direction is also the expansion of the information security and ethics theme: modeling risks of data leakage/substitution in the cloud, forming access management skills, and familiarization with data retention policies and principles of responsible use of analytical tools. Additionally, researching the possibilities of integrating artificial intelligence tools into the preparation of analytical materials, provided that academic integrity is maintained and confidential information is protected, is a promising prospect.

DOI: 10.46299/ISG.2026.MONO.TECH.1.6.2

6.2 Модель рангового підходу до рішення задачі цілочисельного лінійного програмування з булевими змінними при оптимізації структури розподілених баз даних

Вступ. У сучасних умовах стрімкого розвитку інформаційних технологій практично у всіх сфер діяльності суттєво зростають об’єми даних, що зберігаються та обробляються в інформаційних системах. Централізовані архітектури баз даних дедалі частіше виявляються неспроможними забезпечити необхідний рівень продуктивності, масштабованості та надійності, що зумовлює широке впровадження розподілених баз даних.

Виклад основного матеріалу. Проведемо аналіз тенденцій розвитку баз даних [224]:

1. Розподілені бази даних. На сьогодні розподілені бази даних (РБД) є однією з ключових технологій обробки та зберігання інформації в умовах зростаючих об’ємів даних, що генеруються у глобальних, динамічних та географічно розподілених інформаційних системах. Еволюція РБД зумовлена потребами у підвищенні масштабованості, доступності, стійкості до відмов та зменшенні затримок при обробці запитів.

Сучасні РБД підтримують як горизонтальне масштабування, так і автоматизоване балансування навантаження між вузлами. Удосконалюються механізми реплікації, фрагментації даних та забезпечення цілісності в умовах паралельного доступу. Зокрема, реалізуються підходи до узгодженості за моделлю CAP-теореми, яка визначає компроміси між узгодженістю (Consistency), доступністю (Availability) та стійкістю до розбиття (Partition Tolerance).

На практиці спостерігається широке розповсюдження NoSQL-архітектур (Apache Cassandra, MongoDB, Amazon DynamoDB), які забезпечують гнучке управління нереляційними структурами даних та добре масштабуються у хмарних середовищах. Водночас активно розвиваються NewSQL-системи

(CockroachDB, Google Spanner), що поєднують переваги класичних реляційних баз із можливостями горизонтального масштабування.

Особливу увагу дослідники та розробники приділяють: оптимізації механізмів узгодженості даних при високих навантаженнях; реалізації транзакцій із гарантіями ACID у розподіленому середовищі; підвищенню ефективності запитів шляхом інтелектуального розміщення даних; впровадженню механізмів самовідновлення та безперервної доступності.

Крім того, стрімке впровадження розподілених обчислень та моделей обробки потокових даних у реальному часі (Apache Kafka, Apache Flink) стимулює інтеграцію РБД із системами аналізу об’ємних даних.

Таким чином, сучасний стан розвитку РБД характеризується переходом від централізованих до гнучких, масштабованих, інтелектуально керованих систем, які здатні ефективно функціонувати в умовах розподіленого середовища, високої інтенсивності транзакцій та вимог до реального часу.

2. Хмарні технології та гібридні системи. Хмарні технології (cloud computing) упродовж останнього десятиліття перетворилися на ключову інфраструктурну платформу для зберігання, обробки та аналізу великих об’ємів даних у режимі реального часу. Вони забезпечують масштабованість, еластичність, високу доступність і оптимізацію витрат на IT-ресурси. Розвиток моделей Software-as-a-Service (SaaS), Platform-as-a-Service (PaaS) та Infrastructure-as-a-Service (IaaS) дозволив ефективно адаптуватися до цифрової трансформації та швидко реагувати на зміни у зовнішньому середовищі.

Паралельно із розвитком публічних хмар набувають поширення гібридні хмарні архітектури (hybrid cloud), які об'єднують переваги приватних та публічних хмар для гнучкого управління навантаженням, конфіденційними даними та критичною інфраструктурою. Такі системи дозволяють зберігати дані або виконувати завдання в оптимальному середовищі з урахуванням вимог до безпеки, продуктивності та вартості.

Значну увагу в сучасних дослідженнях приділяють оркестрації гібридних

середовищ, побудові cloud-native застосунків, впровадженню контейнеризації (Docker, Kubernetes), а також забезпеченню кіберстійкості. У військовій, оборонній та критичній інфраструктурі гібридні хмарні моделі розглядаються як стратегічно важливі рішення для розподіленого обчислення, резервного копіювання, синхронізації даних та розгортання адаптивних інтелектуальних систем.

Поява концепцій Multi-Cloud і Edge-Cloud додатково розширює функціональні можливості хмарних середовищ, дозволяючи реалізовувати обчислення ближче до джерел даних, що критично важливо для задач з низькою затримкою обробки та високими вимогами до автономності.

Таким чином, хмарні та гібридні технології формують основу сучасних інформаційно-аналітичних платформ, сприяючи підвищенню ефективності систем підтримки прийняття рішень у сфері безпеки, оборони, логістики, охорони здоров'я, промисловості та державного управління.

3. Інтеграція з ШІ та Big Data. Узагальнення досвіду зарубіжних країн засвідчує, що швидке, ефективне та адаптивне задоволення потреб суспільства у сфері воєнної безпеки та забезпечення обороноздатності держави досягається шляхом інтеграції інноваційних технологій. Одним із ключових напрямів такого розвитку є впровадження систем штучного інтелекту (ШІ) та технологій обробки великих масивів даних (Big Data), що розглядаються як пріоритетні складові модернізації оборонно-промислового комплексу України. Штучний інтелект належить до провідних технологічних сфер, які характеризуються високими темпами розвитку та значним потенціалом застосування в критично важливих галузях, зокрема: національній безпеці, обороні, військовій медицині, логістиці, розвідувальній та контррозвідувальній діяльності, а також в аеророзвідці (повітряній розвідці). Аналіз останніх досліджень і публікацій свідчить, що еволюція цифрової економіки відзначається активним впровадженням цифрових технологій, зокрема ШІ та Big Data, що призводить до синергетичних змін у різних секторах. Штучний інтелект та аналітика даних великих об'ємів

дозволяють з високою імовірністю прогнозувати дії противника, автоматизувати управління ресурсами, оптимізувати логістику та вогневе ураження. Це знижує навантаження на аналітичну діяльність управлінської ланки і пришвидшує прийняття нею рішень.

Наразі в нашій державі прийнято шість програмних довгострокових документів у безпековому напрямі, які стосуються (прямо або опосередковано) питань національної безпеки та обороноздатності України і торкаються проблематики використання ШІ, Big Data та сучасних ІКТ у вказаних сферах а саме, стратегія забезпечення державної безпеки [225], стратегія національної безпеки України [226], стратегія інформаційної безпеки [227], стратегія кібербезпеки України [228], стратегія воєнної безпеки України [229], стратегія розвитку оборонно-промислового комплексу України [230].

4. Підвищення безпеки**.** У контексті зростання кількості кіберзагроз, витоків конфіденційної інформації та атак на критичну інфраструктуру, безпека баз даних перетворилася з технічної опції на ключовий компонент інформаційної стратегії органів управління. Сучасні тенденції у сфері захисту баз даних охоплюють комплексний підхід, який поєднує криптографічні методи, системи виявлення аномалій, машинне навчання, а також політики управління доступом, що базуються на ризик-орієнтованих моделях.

Одним із провідних напрямів є впровадження шифрування даних як на рівні зберігання, так і в процесі їх обробки (end-to-end encryption), що забезпечує цілісність і конфіденційність навіть у разі несанкціонованого доступу. Особливу увагу приділяють гомоморфному шифруванню та технологіям обчислення над зашифрованими даними, які дозволяють здійснювати аналітику без розшифровки, мінімізуючи ризики компрометації.

Водночас активно розвиваються інтелектуальні системи виявлення вторгнень (IDS), що базуються на алгоритмах машинного навчання, здатні розпізнавати атипову поведінку користувачів і запити до бази даних, що можуть свідчити про спробу несанкціонованого доступу або кібератаку.

Іншою ключовою тенденцією є Zero Trust Architecture (ZTA) - модель, згідно з якою жоден користувач або система не вважається надійною за замовчуванням, навіть якщо вони знаходяться у внутрішній мережі. Це передбачає багаторівневу автентифікацію, гнучкі політики авторизації, аудит доступів та детальну перевірку кожної транзакції.

Крім цього, розширене застосування знаходять блокчейн-технології для гарантування незмінності історії транзакцій у розподілених базах даних, особливо в системах, де важлива доказова база, як-от в урядових, фінансових або військових інформаційних системах.

У сукупності ці підходи формують нову парадигму - превентивної, адаптивної та інтелектуальної безпеки, де бази даних функціонують не лише як пасивні сховища, але й як активні елементи кіберзахисту, що постійно аналізують загрози, адаптуються до нових умов і самостійно реагують на інциденти.

Актуальність задачі оптимізації структури розподілених баз даних визначається насамперед необхідністю ефективного використання обчислювальних і мережевих ресурсів. Нераціональний розподіл даних між вузлами призводить до надмірних витрат на передачу інформації, зростання часу виконання запитів і зниження пропускної здатності системи в цілому. Оптимальна структура РБД дозволяє суттєво скоротити міжвузлові комунікації та підвищити ефективність обробки даних.

Важливим фактором актуальності є зростання вимог до швидкодії та доступності інформації. Сучасні прикладні системи - хмарні сервіси, геоінформаційні системи, системи підтримки прийняття рішень, IoT-платформи - функціонують у режимі близькому до реального часу. У таких умовах структура розподіленої бази даних безпосередньо впливає на затримку доступу до даних і стабільність роботи сервісів.

Значну роль відіграє також підвищення вимог до надійності та відмовостійкості. Оптимізація структури РБД, зокрема вибір схем реплікації та

резервування даних, дозволяє мінімізувати ризики втрати інформації та забезпечити безперервність функціонування системи у випадку відмов окремих вузлів або мережевих з'єднань.

Актуальність досліджуваної задачі посилюється ускладненням архітектур розподілених систем. Сучасні РБД функціонують у гетерогенних середовищах, що поєднують локальні сервери, хмарні платформи та edge-пристрої. Це зумовлює необхідність розробки універсальних моделей оптимізації, здатних враховувати різнорідність ресурсів і змінні характеристики мережі.

Слід зазначити, що методи дискретної оптимізації широко застосовуються для рішення задач оптимізації структури РБД, оскільки більшість рішень у таких системах мають дискретний характер. До них належать задачі вибору вузлів розміщення фрагментів, визначення схем фрагментації, реплікації та маршрутизації запитів. Найпоширенішими представниками даного класу методів є цілочисельне лінійне програмування, булева оптимізація, комбінаторні та графові моделі.

Однією з основних переваг методів дискретної оптимізації є можливість точної формалізації структури розподіленої бази даних. Використання цілочисельних та булевих змінних дозволяє однозначно описати факт розміщення фрагмента на конкретному вузлі, наявність репліки або використання каналу зв'язку.

Важливою перевагою є здатність враховувати велику кількість обмежень. У межах дискретних моделей легко інтегруються обмеження цілісності даних, місткості вузлів, пропускної здатності мережі, допустимого часу відповіді, а також логічні залежності між елементами структури бази даних.

Методи дискретної оптимізації забезпечують глобальну оптимальність рішення. На відміну від евристичних або жадібних підходів, вони дозволяють отримати оптимальне або гарантовано близьке до оптимального рішення за обраним критерієм, що є критично важливим для систем з високими вимогами до ефективності.

Ще однією суттєвою перевагою є універсальність моделей. Одна й та сама математична постановка може бути адаптована до різних архітектур розподілених баз даних, типів навантажень та критеріїв оптимізації шляхом зміни параметрів або цільової функції.

Крім того, дискретні методи добре поєднуються з сучасними засобами оптимізації, такими як комерційні та відкриті ILP/MIP-солвери, що спрощує практичну реалізацію запропонованих моделей.

Основним недоліком методів дискретної оптимізації є висока обчислювальна складність. Більшість задач оптимізації структури розподілених баз даних належать до класу NP-складних, тому зі зростанням кількості вузлів, фрагментів і обмежень час рішення задачі може зростати експоненційно.

Суттєвим обмеженням є погана масштабованість класичних точних методів. Для великих розподілених систем із сотнями вузлів і тисячами фрагментів пряме застосування ILP або булевих моделей стає практично неможливим без спрощень або декомпозиції задачі.

Ще одним недоліком є висока чутливість до точності вхідних даних. Ефективність отриманого рішення напряму залежить від адекватності моделей вартості доступу, передачі даних та профілю запитів. У реальних системах ці параметри можуть бути змінними або стохастичними.

Також слід відзначити складність побудови математичних моделей. Формалізація всіх аспектів функціонування розподіленої бази даних у вигляді дискретної оптимізаційної задачі потребує високої кваліфікації та значних трудових витрат.

Окремим недоліком є обмежена придатність до динамічних середовищ. У випадках частих змін навантаження або топології мережі повторне рішення задачі дискретної оптимізації може бути надто ресурсоємним для використання в режимі реального часу.

Таким чином, методи дискретної оптимізації є потужним інструментом для формування оптимальної структури розподілених баз даних, забезпечуючи

точність і формальну строгість рішень. Водночас їх практичне застосування вимагає використання гібридних підходів, евристик або рангових методів для зменшення обчислювальної складності та підвищення адаптивності системи.

Результати порівняння методів оптимізації структури розподілених баз даних представлено в таблиці 1

Таблиця 1.

Порівняння методів оптимізації структури розподілених баз даних

Критерій порівняння	Цілочисельне лінійне програмування (ILP)	Евристичні методи	Метаевристичні методи
Тип рішення	Точний, глобально оптимальний	Наближений	Наближений, покращений
Гарантія оптимальності	Так	Ні	Ні
Обчислювальна складність	Висока (NP-складні задачі)	Низька	Середня–висока
Масштабованість	Обмежена	Висока	Вища, ніж у ILP
Придатність до великих РБД	Обмежена	Висока	Висока
Урахування обмежень	Повне, формально строге	Часткове	Часткове або гібридне
Адаптивність до змін навантаження	Низька	Висока	Висока
Чутливість до якості початкових даних	Висока	Середня	Низька–середня
Простота реалізації	Низька	Висока	Середня
Час отримання розв’язку	Значний	Малий	Середній
Можливість гібридизації	Висока (з евристиками)	Обмежена	Висока
Типові приклади	ILP, MIP, булева оптимізація	Жадібні алгоритми, правила розміщення	Генетичні алгоритми, ACO, PSO, SA

Розглянемо математичну модель оптимізації структури розподіленої бази даних. Введемо параметри моделі:

$I = \{1,2,...,n\}$ – множина фрагментів даних;

$J = \{1,2,...,m\}$ – множина вузлів (серверів) розподіленої системи;

$K = \{1,2,...,q\}$ – множина типових запитів (транзакцій);

c_{ij} – вартість зберігання фрагмента i на вузлі j;

d_{jk} – вартість передачі даних між вузлами j та k;

f_{ik} – частота звернення запиту k до фрагменту k;

s_i – об'єм фрагменту i;

C_j – доступна місткість вузла j;

T_{jk} – затримка передачі даних між вузлами j та k;

T^{max} – допустимий максимальний час обробки запиту.

Усі параметри вважаються відомими та невід'ємними. Введемо булеві змінні:

$$x_{ij} = \begin{cases} 1, \text{якщо фрагмент i розміщено на вузлі j}, \\ 0, \quad \text{інакше}, \end{cases} \tag{1}$$

$$y_{ijk} = \begin{cases} 1, \text{якщо запит k обслуговується із вузла j для фрагмента i}, \\ 0, \quad \text{інакше}. \end{cases} \tag{2}$$

Мета – мінімізувати сумарні витрати на зберігання та доступ до даних:

$$\min Z = \sum_{i\in I}\sum_{j\in J} c_{ij} x_{ij} + \sum_{k\in K}\sum_{i\in I}\sum_{j\in J} f_{ik} d_{jk} y_{ijk} \tag{3}$$

з урахуванням:

– обмеження по розміщенню фрагментів. Кожен фрагмент має бути розміщені щонайменше на одному вузлу (у разі заборони реплікації - рівність):

$$\sum_{j\in J} x_{ij} \geq 1, \forall\, i \in I; \tag{4}$$

– обмеження місткості вузлів. Сумарний об'єм фрагментів на вузлу не перевищує його ресурсів:

$$\sum_{i\in I} s_i x_{ij} \leq C_j, \forall j \in J; \tag{5}$$

– обмеження обслуговування запитів. Для кожного запиту та фрагмента має бути обраний один вузол доступу:

$$\sum_{j\in J} y_{ijk} = 1, \forall i \in I, \forall k \in K; \tag{6}$$

– обмеження часу обробки запитів. Сумарна затримка доступу до фрагментів не повинна перевищувати допустимого часу:

$$\sum_{i\in I}\sum_{j\in J} T_{jk}\, y_{ijk} \le T^{max},\ \forall k \in K; \tag{7}$$

– області визначення змінних

$$x_{ij} \in \{0,1\},\ y_{ij\kappa} \in \{0,1\}. \tag{8}$$

Постановка ЦЛП з БЗ на основі рангового підходу визначається:

$$\max_{x\in\langle 0,1\rangle^n} Z(x) = \sum_{j=1}^{n} c_j x_j, \tag{9}$$

з урахуванням обмежень:

$$\sum_{j=1}^{n} \alpha_{ij} x_j \le b_i,\ \ i = \overline{1,m}, \tag{10}$$

$$x_j \in \{0,1\},\ \ j = \overline{1,...,n}. \tag{11}$$

де, n - кількість булевих змінних (індекс $j = \overline{1,...,n}$);

m - кількість лінійних обмежень (індекс $i = \overline{1,...,m}$);

$x_j \in \{0,1\}$ - булева змінна (прийняття рішення про включення елемента j);

$c_j \in \Re$ - коефіцієнт цільової функції для змінної j;

$\alpha_{ij} \in \Re$ - коефіцієнт матриці обмежень у рядку i, стовпця j;

$A = (\alpha_{ij}) \in \Re^{m\times n}$ - матриця коефіцієнтів обмежень;

$b_i \in \Re$ - права частина i-го обмеження.

Для спрощення викладу математичної моделі розглянемо одномірну задачу, тобто максимізуємо функціонал

$$f(\vec{x}) = c_1 x_1 + c_2 x_2 + ... + c_n x_n, \tag{12}$$

при обмеженнях:

$$\sum_{j=1}^{n} a_{1j} x_j \le b, \tag{13}$$

$$c_1 \ge c_2 \ge ... \ge c_n; \qquad a_{ij} > 0; \qquad c_j > 0 \qquad j = \overline{(1,n)}. \tag{14}$$

Поставимо у відповідність задачі (12) – (14) граф G (рис. 1), що відображає бінарне дерево усіх рішень, число яких дорівнює 2^n.

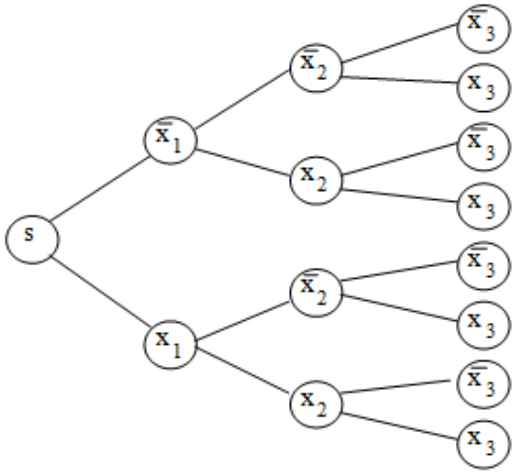


Рисунок 1. Граф G

Множина X = $\{x_j\}$ усіх векторів розмірності *n*, усі компоненти яких $x_j \in \{0,1\}$ становлять множину можливих значень.

Деяка його підмножина V, усі вектори якої задовольняють обмеженням (13) – (14), утворюють множину припустимих рішень.

Множина H $\subset$ V є множиною оптимальних рішень вихідної задачі, якщо для будь-яких векторів x $\in$ H функціонал (12) досягає свого екстремального значення.

Усю множину можливих рішень можна розбити на групи векторів, що містять: один компонент $x_j = 1$, $j = (\overline{1,n})$ і всі інші рівні 0; два компоненти $x_j = 1$ і всі можливі їхні сполучення по 2, а інші, рівні 0; три компоненти $x_j = 1$ і всі можливі їхні сполучення й т. д. n – компонент $x_j = 1$. Якщо позначити підмножини векторів цих груп через m^r $r = (\overline{1,n})$, тоді множину усіх можливих рішень можна записати як об'єднання підмножин m^r:

$$X = \bigcup_{j=1}^{n} m^r. \qquad (15)$$

Як показано в роботі [231-233], згідно з графом G можна побудувати граф G' (рис. 2), у якому множина шляхів рангу r (ранг шляху – число ребер, що утворять шлях) відповідає групам підмножин, які описуються співвідношенням

(15).

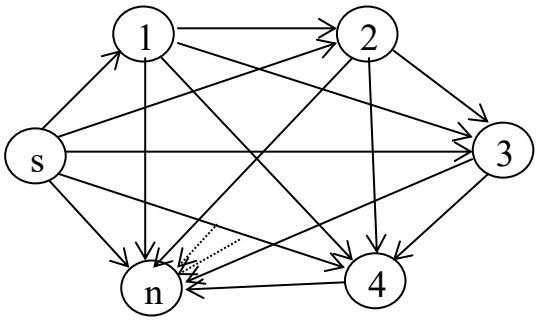


Рисунок 2. Граф G’

Для цього вершину s з'єднаємо спрямованими ребрами з вершинами 1,2,...,n і т. д.; вершину і з'єднуємо з вершинами i+1,...,n. В останню вершину n входять ребра, спрямовані із усіх вершин, і жодне ребро із цієї вершини не виходить.

Дерево шляхів DΔ графа G' з вершини s будується таким чином: на нульовому ярусі (r = 0) розташуємо вершину s. На першому ярусі розмістимо всі вершини графа G', що мають зв'язок з вершиною s і з'єднаємо їх з s (при цьому утворилася підмножина шляхів рангу r = 1). У другому ярусі розмістяться всі вершини, що мають зв'язок з вершинами першого ярусу, без вершини з номером 1 і з'єднаємо їх з вершинами першого ярусу (утворені всі шляхи рангу r = 2) і так далі доти, поки в останньому не залишиться одна вершина n. На рис. 3 наведено приклад, коли n = 4.

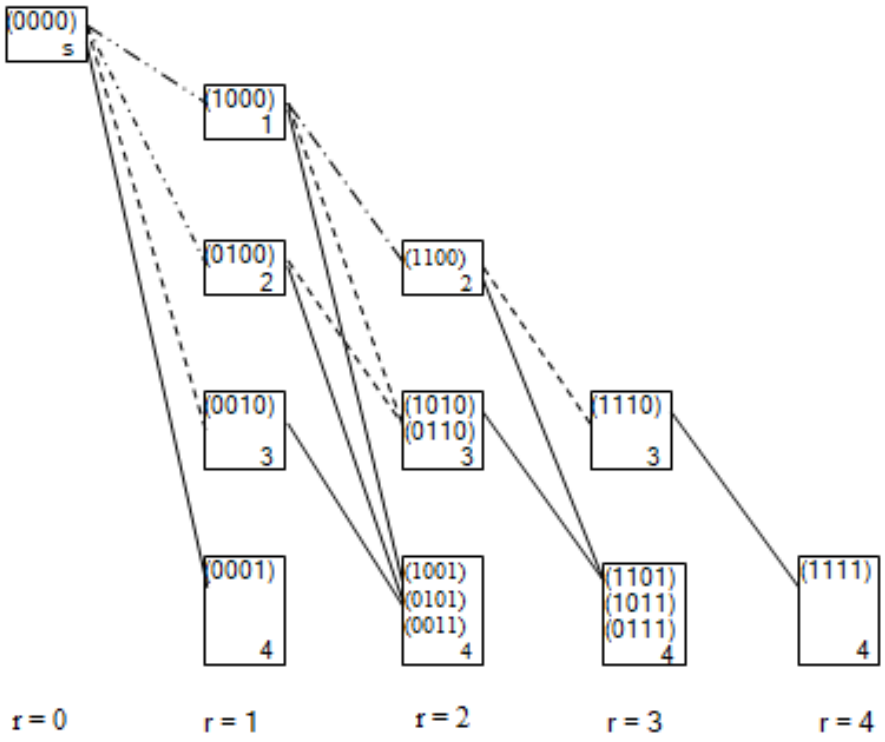


Рисунок 3. Геометрична інтерпретація графа D

Геометрично вершина k графа DΔ рангу r – це множина векторів $\vec{x}$ $(x_1,x_2,...,x_k,...,x_n)$, у яких $x_k = 1$, а на позиціях від 1 до k перебуває r одиниць. Ребру, що входить у вершину k графа DΔ, відповідає одиничний вектор $\vec{e}_k$ (0, 0, …,0, 1, 0, … 0) n-мірного одиничного куба B^n з одиницею в k-тій позиції. Тоді, шляху μ_{sj}^r рангу r у графі DΔ відповідає вектор $\vec{x}$, який дорівнює сумі одиничних векторів ребер, через які він досяг вершину j рангу r, починаючи з вершини s.

Наприклад, шляху $\mu_{s24}^{r=2}$ відповідає вектор $\overrightarrow{x_{s24}}$, що утвориться сумою нульового вектора $\vec{0}$ {0000} і одиничних векторів $\vec{e}_2$ = {0100}, $\vec{e}_4$ = {0001}, тобто:

$$\overrightarrow{x_{s24}} = \vec{0}\ \{0000\} + \vec{e}_2\ \{0100\} + \vec{e}_4\ \{0001\} = \{0101)$$

Нехай у графі DΔ кожному ребру, що входить у вершину j, $j = (\overline{1,n})$ відповідає дві ваги: вага c_j, якій дорівнює коефіцієнт при x_j у функціоналі (2.4), і вага a_{1j}, якій дорівнює коефіцієнту при x_j в обмеженні (13). Тоді, шлях μ_{sj}^r у графі

DΔ з вершини s у вершину j характеризується двома довжинами: $d_c\left(\mu_{sj}^r\right)$ - довжиною за вагою функціонала й $d_a\left(\mu_{sj}^r\right)_1$ – довжиною за вагою обмежень.

Множину шляхів $m_s^r(j)$ у графі DΔ до вершин j, розташовану на ярусах $r=(\overline{1,n})$ від вершини s, можна зобразити у вигляді

$$m_s^r(j)=m_{sj}^{r=1}\cup m_{sj}^{r=2}\cup\ldots\cup m_{sj}^{r=n},\qquad j=\overline{(1,n)}, \tag{16}$$

де m_{sj}^r – множина шляхів у графі DΔ від вершини s до вершин j, розташованим на r-х ярусах графа DΔ (ранг шляху $\mu_{sj}^r \in m_{sj}^r$ визначається числом ребер, що утворюють цей шлях). Варто мати на увазі, що множині шляхів $m_{sj}^{r=k}$ у графі DΔ відповідає множина векторів $\{\vec{x}_1,\vec{x}_2,\ldots,\vec{x}_v\}$, що містять k одиниць. Отже, $\left|m_{sj}^r\right|=C_n^{r=k}$, тобто кожному шляху в множині $m_{sj}^{r=k}$ відповідає деякий вектор $(x_1,x_2,\ldots,x_n)$. З множини (16) слідує, що:

$$\left|m_s^r(j)\right|=C_n^{r=1}+C_n^{r=2}+\ldots+C_n^{r=n}=2^n-1. \tag{17}$$

Таким чином, граф DΔ являє собою впорядкований за рангами еквівалент n-мірного одиничного куба B^n, у якому шляхи $\mu_{sj}^r \in m_{sj}^r$ відповідають вершинам B^n. Довжина кожного шляху за вагою функціонала визначає значення функціонала (12) у вершинах одиничного куба B^n. Довжина за вагою обмежень визначає, чи відповідає дана вершина B^n обмеженням (13), тобто належить вершина n-мірного одиничного куба B^n гіперплощини (13). Якщо $d_a\left(\mu_{sj}^r\right)_1 \le b$, то вершина належить гіперплощині (13), і будемо говорити, що шлях μ_{sj}^r задовольняє властивості ν. Якщо $d_a\left(\mu_{sj}^r\right)_1 > b$, то вершина n-мірного куба, що відповідає шляхам μ_{sj}^r, не належить гіперплощині (13), а шлях μ_{sj}^r вважаємо таким, який не задовольняє властивості ν.

Оптимальному рішенню задачі (2.4) – (2.6) в DΔ відповідає самий довгий

шлях за вагою функціонала, що задовольняє властивості ν.

У випадку m-мірної задачі (12) - (14) ребрам, що входять до вершин графа DΔ, крім ваги c_j функціонала, відповідає m ваг a_{ij} обмежень, а шлях μ^r_{sj} характеризується довжинами: $d_c\left(\mu^r_{sj}\right)$ – довжиною за вагою функціонала й $d_a\left(\mu^r_{sj}\right)_i$, $i=\overline{(1,m)}$ – довжинами за вагою m обмежень.

На основі математичної моделі рангового підходу для побудови алгоритмів рішення завдань ЦЛП із БЗ покладений принцип оптимізації у напрямку в дискретному просторі станів, заданому графом DΔ. Подання n-мірного одиничного куба у вигляді графа DΔ дозволяє розбити множину усіх шляхів графа DΔ з нульової вершини s на Ω локальних областей, де $|\Omega|$ не перевищує величину $\frac{n^2}{2}$, оскільки число вершин у графі DΔ визначається сумою чисел натурального ряду

$$\Omega = n + (n-1) + \ldots + 1 = \frac{n\cdot(n+1)}{2} \approx \frac{n^2}{2}, \qquad (18)$$

причому Ω-області в графі DΔ упорядковані за рангами і шляхи наступного рангу можуть бути отримані на основі шляхів попереднього рангу за рахунок приєднання до них ребра (j,p) у графі DΔ:

$$m^{r=r+1}_{sp} = \left\{\left(\forall\left(\mu^r_{sj} \in m^r_{sj}\right)\right) \cup (j,p)\right\}.$$

Нехай задані деякі правила відсікань $\{L_w\}$ шляхів μ^r_{sj} у множинах m^r_{sj}. Тоді, якщо в множинах утримуються шляхи, що задовольняють властивості ν і правилам $\{L_w\}$, то під оптимізацією за напрямком у графі DΔ до вершини p будемо розуміти формування множин $m^{r=r+1}_{sp}$ наступного рангу, які виходять за рахунок виділення в m^r_{sj} шляхів, приєднання до яких ребрам (j, p) дозволить у множині $m^{r=r+1}_{sp}$ одержати шляхи, що задовольняють правилам $\{L_w\}$ на основі наступного рекурентного співвідношення:

$$\forall\left(\mu^r_{sj} \in m^r_{sj}\right)\left[\mu^{r=r+1}_{sp} = L_w\left\{\mu^r_{sj} \cup (j,p)\right\}\right]; \quad p=\overline{(r+1,n)}; \quad j=\overline{(r,n)}, \qquad (19)$$

де $\mu_{sj}^{r} \cup (j,p)$ – шлях з вершини s графа DΔ у вершину p, що проходить через проміжну вершину j і який задовольняє правилам $\{L_w\}$, тобто який одержуємо за рахунок приєднання до шляху μ_{sj}^{r} ребра (j,p), якщо таке з'єднання не суперечить правилам $\{L_w\}$. Надалі для спрощення викладу, якщо шлях $\mu_{sp}^{r=r+1} = \mu_{sj}^{r} \cup (j,p)$ задовольняє правилам $\{L_w\}$, то будемо говорити, що він задовольняє й властивості ν.

Таким чином, для рішення задачі (9) – (11), використовуючи правила $\{L_w\}$ і оптимізацію за напрямком (19), побудуємо деяку узагальнену процедуру A_0, що дозволяє формувати множини локальних екстремумів Ω і виділяти серед них глобальний:

КРОК 1. З вершини s будуються множини шляхів $m_{sj}^{r=1}$, $j = \overline{(1,n)}$, що задовольняють властивості ν. Виділяються шляхи $\overset{*}{\mu}_{sj}^{r=1}$, що визначають локальні екстремуми областей Ω_j.

КРОК 2. Формуються множини шляхів $m_{sp}^{r=r+1}$ $p = \overline{(r+1,n)}$ наступного рангу, що задовольняють властивості ν, на базі множини шляхів m_{sj}^{r} попереднього рангу відповідно до рекурентного співвідношення (19). В утворених множинах $m_{sp}^{r=r+1}$ здійснюється відсівання шляхів відповідно до обраного правила відсікань $\{L_w\}$ і виділяються шляхи $\overset{*}{\mu}_{sp}^{r=r+1}$, що визначають локальні екстремуми областей Ω_p.

КРОК 3. Перевіряємо, чи всі множини $m_{sp}^{r=r+1}$ наступного рангу порожні. Якщо це так, то переходимо до кроку 4, якщо ні, то перевіряємо r = (n - 1). У випадку виконання рівності переходимо до кроку 4, інакше збільшуємо r на 1 і виконуємо крок 2.

КРОК 4. Виділяємо серед множин локальних екстремумів Ω_j $j = \overline{(1, n^2/2)}$ глобальний і процедура A_0 закінчує роботу.

Узагальнена процедура A_0 дозволяє визначити локальні екстремуми в Ω-областях графа DΔ щораз на кроці 2 і потім на кроці 4 виділити глобальний екстремум з $n^2/2$ локальних, які отримуються на основі принципу оптимізації за

напрямком (19) з використанням правил відсікань, що вводять, {Lw} шляхів у m_{sj}^{r} множинах [234-235].

Висновок. Таким чином, задача оптимізації структури РБД формалізується як задача ЦЛП з БЗ, метою якої є мінімізація витрат на зберігання та доступ до даних за умов обмежених ресурсів вузлів, вимог до часу обробки запитів та забезпечення цілісності структури розподілу даних.

Задача належить до класу NP-складних задач дискретної оптимізації, що зумовлює необхідність застосування методів зменшення розмірності, зокрема рангового підходу до вибору змінних.

SECTION 7. MATHEMATICS

DOI: 10.46299/ISG.2026.MONO.TECH.1.7.1

7.1 Basic methods and directions of information stochastic network research

The basic approaches to the study of mass service networks are based either on the direct method of finding expressions for the probabilities of the network conditions using the technique of constructing equations of the local balance, or on the method of constructing recurrent equations for the mean values. The above methods allow us to find the exact solution for multiplicative or, as they are often called, locally balanced networks, the stationary probabilities of states of which have a multiplicative form.

For these networks ([236], [238]), such an interesting fact was established: the stationary probabilities of the network states have a multiplicative form: in the stationary mode, the distribution of the number of requirements at the nodes of the network is independent, and their product is the stationary distribution of the entire network. This fact became the basis for further analyzes of the future of the MEMO of the general type, as well as the development of effective algorithms for the calculation of the characteristics of stochastic networks.

The search for the conditions for the existence of a multiplicative form of stationary distribution and in the last decades is reduced mainly to operation with the local equilibrium equation [240], [244]. This leads to the expansion of known results on a more general-looking network. The disciplines of service are generalized, depending on the intensity of the input stream from the state of the network and / or time, etc.

In recent years, a number of results have been obtained, which greatly expands the possibilities of analysis of mass service networks. The main methods of analysis, which today are rather complete character, are distinguished.

Here are some basic research methods.

The Martingual approach based on the semimartingal representation of the investigated process and the use of a well-developed apparatus for the theory of

martingales ([237], [242], [248]) for the diffusion approximation of service networks, for solving filtration and optimal control problems, and also for statistical analysis of networks.

The recurrence approach [249], which consists in the recurrence relations for the characteristics of the system under consideration, and for the further asymptotic analysis, the boundary theorems on the convergence of stochastic recurrence schemes to the solution of stochastic differential equations (SDE). This method is used to study a wide class of service systems with repeated calls and in the study of local area networks with multiple access protocols. VV Anisimov introduced a class of random switching processes, which is a convenient means for describing the asymptotic behavior of a broad class of stochastic models. The switching process, the author calls the service process, which can be represented as a semi-Markov process. As a rule, the random environment in which the service model operates is considered as an external process, which is not influenced by the behavior of internal processes. The theorems of the type of the principle of averaging and diffusion approximation are proved in [238], [239], [240], [241], and some classes of systems and mass service networks that can be represented by switching processes are considered. Asymptotic behavior has been investigated for these models, in particular under conditions of low-intensity input flows and under over-mode conditions.

The method of diffusion approximation in work [243] is used for analysis in the conditions of high load of open models of computer networks with arbitrary interval distributions between the moments of receipt of requirements to the network and the duration of their service. In this paper, common closed exponential stochastic networks are also investigated, when the number of requirements in them indefinitely increases. For such networks, conditions for congestion are formulated, in which the proposed deterministic and Gaussian approximations for the process of queue lengths are proposed. The authors managed to obtain an asymptotic schedule for the main indicators of the functioning of the networks.

Non-stationary mass service systems (MSS) also studied in works [243], who describes the process of serving claims in terms of birth and death processes and examining the SMO with the help of an advanced device for these processes. The proposed method is based on the logarithmic norm of the linear operator and the special transformation of the cut-off matrix of intensities of the Markov chain under consideration. This method is applicable to the class of Markovian MSS. In particular, [247] is devoted to the estimation of the convergence velocity for different types of inhomogeneous Poisson flows with a specific form of heterogeneity. Namely, when the intensity of birth and death (the intensity of the input flow and service) is asymptotically periodic functions of time.

The given different approaches allow the experts to choose from them the most convenient and effective in a concrete situation. The data of numerical and simulation modeling of networks demonstrate the fact that the results of approximative formulas are quite close to precise with a sufficiently large load.

In the classical theory of mass maintenance, there are not too many models whose research can be performed analytically and obtain final results in the form of formulas for probability-time characteristics of the MSS. These are primarily systems whose processes of changing states are described by the Markov process with a set of states. Semi-Markov systems, which can be used to analyze the method of the embedded Markov chains, are also included here. As an example, we can recall the formula of the Polachek-Hinchin system $M|G|1$. Erlang's formulas are also known for N - channel systems with arbitrary distribution of service time and stationary Poisson input flow, the process of changing the states of which is non-Markov.

At the same time, a large number of studies of real systems in various subject areas, in particular telecommunication systems, economic systems, made it possible to conclude that the essential inadequacy of the Markov models is real data. Research of real complex systems is carried out, as a rule, by numerical methods or by means of simulation modeling with all the disadvantages arising from these methods.

An alternative approach is the use of the asymptotic analysis method for the study of complex systems.

Different variants of asymptotic conditions are considered: the maximum interval of observation, the small or high intensity of service, the large delay of requirements in the source of recurring calls, the heavy load in models of real computer networks controlled by random multiple access protocols.

Asymptotic methods in the theory of mass service, as a rule, are understood by three following directions of research, the main purpose of which is the study of complex multidimensional servicing processes by approximating their processes with a simpler structure.

1. Asymptotic analysis of explicit formulas or equations describing the distribution (usually stationary) of one or another system characteristic. Since today the theory of mass service has exhausted almost all cases of "explicit solvability" of service systems, the search for other areas of asymptotic analysis is becoming relevant.

2. The second direction is much wider and related to the study of the limiting behavior of the most random processes describing the work of the system, when converging the system with some of its critical state. In the work of ([244]) shows that the basis of the phenomena arising in overloaded systems lies in the well-known principle of invariance. This principle allows using the Wiener process to describe relatively complex processes generated by sums of random variables.

The main objective of the second direction is to prove the boundary theorems and to identify the maximum general conditions under which their statements will be valid (for example, the convergence of the normalized queue length to the diffusion process). The methods in this direction obviously differ significantly from the methods in §1 and are based, as a rule, on the use of general functional boundary theorems for random processes.

3. The third direction is connected with the theorems of stability (or continuity). Essentially, the boundary theorems for processes are also considered here: the conditions under which service systems will be close (in the sense of the distribution

of a process describing the system) are set to a given system. The term "stability" is due to the fact that this type of theorem allows us to draw conclusions about small changes in stationary characteristics with small disturbances of the system parameters.

Often, the three classes of processes serve as limitations:

- Gaussian processes;
- diffusion processes;
- processes with independent growth.

In this paper, we will use multidimensional Gaussian processes to construct approximative processes for the requirements processing process in stochastic networks of different types.

The main problems that are considered in the dissertation are related to the approximation of some random processes that arise in the study of stochastic networks, with the help of others - simpler and better investigated. In this case, it is necessary to formalize which processes will be considered close. Naturally, in different tasks, the requirements for proximity can be different.

The concept of convergence of random processes is the basis for using the methods of the theory of random processes in problems of asymptotic analysis of various characteristics of mass service networks. Let's consider different approaches to the formalization of the concept of convergence of random processes. (see, for example, [238], [243], [249]) Let given sequence of processes $\xi^{(n)}(t,\omega)$ that process $\xi^{(0)}(t,\omega)$. A well-known notion of the convergence of random processes is the weak convergence of finite-dimensional distributions $\xi^{(n)}(t,\omega)$ to the corresponding distributions $\xi^{(0)}(t,\omega)$:

$$P\left\{\xi^{(n)}(t_j,\omega)\le x_j; j=1,...,k\right\}\underset{n\to\infty}{\to} P\left\{\xi^{(0)}(t_j,\omega)\le x_j; j=1,...,k\right\}$$

to all k, $t_1,...,t_k$ and $x_1,...,x_k$ such that

$$P\left\{\xi^{(0)}(t_j,\omega)=x_j\right\}=0, \qquad j=1,...,k.$$

Such a convergence is indicated

$$\xi^{(n)}(.) \overset{d}{\Rightarrow} \xi^{(0)}(.).$$

Symbol $\overset{d}{\Rightarrow}$ it is also stored to indicate a weak convergence of distributions of random variables (convergence at the points of continuity of the boundary distribution function).

As is known, the weak convergence of finite-dimensional distributions does not imply a convergence of characteristics, determined by the behavior of the trajectory in general, that is, different functionalities $f\left(\xi^{(n)}\right)$ from the process $\xi^{(n)}(t)$ (for example, the average length of the queue $\frac{1}{T}\int_0^T \xi^{(n)}(t)dt$, value of maximum queue $\sup_{0\le t\le T} \xi^{(n)}(t)$). To do this, some additional conditions associated with a fairly regular behavior of the trajectories of processes must be met. $\xi^{(n)}(t)$.

Consequently, the determination of the convergence of processes in general depends on the distribution of which of the functionals $f\left(\xi^{(n)}\right)$ we want to get closer to distributions $f\left(\xi^{(0)}\right)$.

Different approaches to the study of the conditions for the convergence of functionals from random processes were developed in the works [244], [245], where studied the boundary behavior of functional distributions from processes constructed on the sums of independent random variables. It was assumed that the functionals are continuous in the topology of uniform convergence, and the boundary process is the process of Brownian motion. It was argued that the desired boundary distribution coincides with the distribution of the same functional from the process of Brownian motion. Statements of this kind have been called "principle of invariance". Considering the class of continuous functions in this topology of functions from the sequence of random processes, we establish necessary and sufficient conditions under which the boundary of the distribution of the functional under consideration exists and coincides with the distribution of the same functionality from the boundary process. These

general theorems have been applied to specific classes of processes: processes with independent increments, Markovian and Gaussian processes.

So let it go X – complete metric separable space with metric $\rho(x,y)$, B_X – σ-algebra of Borel subsets in it, $\xi^{(n)}(t)$, $0 \le t \le T$, $n \ge 1$, – sequence of random processes with values in X. We will assume that the sample trajectories $\xi^{(n)}(t)$ at each one n with probability 1 belong to the set of functions $D_{[0,T]}(X)$, which have no breaks of the second kind and continuous business (at the point T – to the left).

Let $F_S(B)$ – set of functionals given in space $D_{[0,T]}(X)$, measurable relative σ-algebras of cylindrical sets $\mathrm{B}_{D_{[0,T]}(X)}$, and continuous with respect to some type of convergence (let's say S-convergence) on a set of functions B. This means that if the sequence of functions $x_n(\cdot)$ з $D_{[0,T]}(X)$ S-coincides with $x_0(.)$ and $x_0(.) \in B$, then

$$\lim_{n\to\infty} f\left(x_n(t)\right) = f\left(x_0(t)\right). \qquad (1.1)$$

For a sequence of random processes $\xi^{(n)}(t)$, $t \ge 0$, such that $\xi^{(n)}(t) \overset{\text{сл}}{\Rightarrow} \xi^{(0)}(t)$, $t \in Q$, where Q – it is somewhere dense set of points on everywhere $[0,T]$, containing points 0 and T, with a weak convergence of measures μ_n, generated $\xi^{(n)}(t)$ in space $D_{[0,T]}(X)$ with some metric h such that is appropriate to her σ-algebra of Borel sets is contained in σ-algebra of cylindrical sets follows $f\left(\xi^{(n)}(\cdot)\right) \overset{\text{сл}}{\Rightarrow} f\left(\xi^{(0)}(\cdot)\right)$, where $f(\cdot)$ – any limited and continuous metric h functional on $D_{[0,T]}(X)$.

In studying the conditions of convergence of classes of functional, continuous with respect to different metrics h, with the use of Prokhorov's theorem ([244]) we must look for a general form of compact in the corresponding space. In this connection, when studying the conditions of convergence of specific functionals, it is sometimes more convenient to use constructive probabilistic methods and the method of one probabilistic space developed by ([245]). We note that the conditions for convergence for a "certain" functional are given in the work of [246].

We give in accordance with [250] the conditions for the convergence of functions that are continuous on the set of functions B relative to some S - convergence. Assume that there is an inseparable monotone non-decreasing in $c>0$ functional $\Delta_S\left(c,x(.)\right)$ such that sequence $x_n(.)$ S - coincides with $x_0(.)$ if and only if the conditions are fulfilled:

$$\lim_{n\to\infty} x_n(t) = x_0(t), \;\; t \in Q, \tag{1.2}$$

where Q – some numbered dense set of points on everywhere $[0,T]$, containing points 0 and T;

$$\lim_{c\to+0} \overline{\lim_{n\to\infty}} \Delta_S(c, x_n(.)) = 0 . \tag{1.3}$$

These conditions and that $x_0(.) \in B$ enough to fulfill the condition (1.1).

In work [252] introduced five different types of convergence satisfying (1.2), (1.3). For our purposes we confine ourselves to the introduction of uniform convergence (U - convergence), since during the whole work the limiting process has a probability unit of continuous trajectories.

Let's put it:

$$\rho_U(x(\cdot), y(\cdot)) = \sup_{0\le t\le T} \rho(x(t), y(t)) .$$

Sequence $x_n(.)$ called convergent in a uniform topology (U -converging) to $x_0(.)$ on the segment $[0,T]$, if

$$\lim_{n\to\infty} \rho_U(x_n(\cdot), y_n(\cdot)) = 0 .$$

Sequence $x_n(.)$ called convergent in J - topology (J -converging) to $x_0(.)$ on the segment $[0,T]$, if there is a sequence of continuous mutually unambiguous mappings $\lambda_n(t)$ on the segment $[0,T]$ on yourself such that

$$\lim_{n\to\infty} \sup_{0\le t\le T} \left\{ \rho_U\left(x_n(t), x_0(\lambda_n(t))\right) + \left|\lambda_n(t) - t\right| \right\} = 0 .$$

Note that J - Convergence means that you can enter a "small" deformation of time (replacing time using the function $\lambda_n^{-1}(t)$) for a prefetch function $x_n(t)$ in such a way

that the moments of the jumps of functions $x_n\left(\lambda_n^{-1}(t)\right)$ and $x_0(t)$, who do not go to 0, coincide, and functions will be close in uniform topology. From the definition it follows that with U - convergence follows J - convergence.

By $D_{[0,T]}^m$ we will denote the space of functions with values in $\mathbb{R}^m$ without breaks of the second kind and continuous business (at the point T – left). Sequence of functions $x_n(t)$ whith $D_{[0,T]}^r$ called convergent in a uniform topology (U-converging) to $x_0(t)$ on the segment $[0,T]$, if

$$\lim_{n\to\infty}\sup_{0\le t\le T}|x_n(t)-x_0(t)|=0$$

($|a|=\sqrt{\sum_{k=1}^{m}a_k^2}$ – the norm of the vector $a'=(a_1,...,a_r)$).

The conditions of convergence can be described in terms of the sequence itself, using the concept of the continuity module.

Let's denote $t_c=\max(0,t-c)$, $t^c=\min(T,t+c)$. Let's put it

$$\Delta_U(c,t,x(.))=\sup\left\{\rho\left(x(t),x(t_1)\right):\ t_c+c/2\le t_1\le t^c-c/2\right\};$$

$$\Delta_J(c,t,x(.))=\sup\left\{\min\left(\rho\left(x(t),x(t_1)\right),\rho\left(x(t),x(t_2)\right)\right):\ t_c<t_1<t<t_2<t^c\right\},$$

Let's denote through S one of the topologies U, J. Let's put it

$$\Delta_S(c,x(.))=\sup_{0\le t\le T}\Delta_S(c,t,x(.)).$$

In [253] it is shown that the introduced topologies satisfy the conditions (1.2), (1.3).

For functionals from random processes, the conditions of weak convergence look like this.

In order for any functional $f(\cdot)\in F_S(B)$ distribution $f\left(\xi^{(n)}(.)\right)$ weakly coincided with the distribution $f\left(\xi^{(0)}(.)\right)$, enough to

1) $$\xi^{(n)}(t)\overset{d}{\Rightarrow}\xi^{(0)}(t),\ \ t\in Q,$$

where Q – a number of dense sets of points on everywhere $[0,T]$, containing points 0 and T;

2) for any one $\varepsilon > 0$

$$\lim_{c \to +0} \overline{\lim_{n \to \infty}} P\left\{\Delta_S(c, \xi^{(n)}(.)) > \varepsilon\right\} = 0;$$

$$P\left\{\xi^{(0)}(\cdot) \in B\right\} = 1.$$

In the future, if the two last conditions are fulfilled, we will say that the sequence $\xi^{(n)}(\cdot)$ S - coincides with $\xi^{(0)}(\cdot)$.

Note that a uniform topology is commonly used in the study of convergence to continuous functions. If the boundary function is discontinuous, then U - convergence can occur only in cases where for any $\varepsilon > 0$ starting with some n moments of jumps larger than ε, coincide, which in practice occurs quite rarely.

As can be seen from the above, the variable intensity of the input flow requirements is much closer to real networks, but the intensity dependence of time adds additional difficulties in the study of the corresponding models. The analysis of such systems and mass-servicing networks is a complex mathematical task. At the same time, despite the fact that some published materials contain studies of mass service systems with variable parameters, there is still no general methodology for researching such models. In general, stochastic networks with variable characteristics have been studied very little.

One of the approaches that may be promising in this area of research is the use of asymptotic methods such as Gaussian or diffusion approximation. This approach is developed in this dissertation. It examines the behavior of the requirements servicing process in multichannel networks of the Markov and Semi Markov type, in which the input flow parameters depend on time and fulfill the critical loading conditions. Models of stochastic networks described in the dissertation are quite close to real information and computer networks and communication networks. From the systems of mass service they are distinguished, first of all, by the multidimensionality of the service process and the complex structure of the input stream for each service node of the

network.

In the work for multichannel stochastic networks with variable external load, asymptotic research methods based on the approximation of the hopping processes of service requirements by continuous Gaussian and diffusion processes were proposed. In particular, the network with periodic and asymptotically periodic external input flow requirements is considered. In the case when network maintenance is not index-distributed, a phase-in-service case is distinguished. It is shown that by increasing the number of service nodes and the dimensionality of the phase space, it reduces to the Markov stochastic network.

Stochastic model of type $[M_t \mid M \mid \infty]^r$**.** The main mathematical model studied in this section is a mass service network, which consists of "r" knots From outside to the network input there is a heterogeneous Poisson flow of requirements $\nu(t)$ with a parameter $\lambda(t)$, $\Lambda(t) = \int_0^t \lambda(u)du$ – the leading function of the Poisson flow. The request that came to the network with probability p_{0i}, $i = 1,2,...r$, to service at i node. Each of them "r" the nodes function as a multichannel stochastic system. Upon receipt of the requirement in such a system, its maintenance is commenced immediately. Time service in i - so the node is indexed to the parameter μ_i, $i = 1,2,...r$. After the service is completed in i - so nodes claim with probability p_{ij} go to service in j node with probability $p_{ir+1} = 1 - \sum_{j=1}^{r} p_{ij}$ leaves the network, $P = \left\| p_{ij} \right\|_1^r$ – matrix network routing. Additional nodes with numbers "0" and "$r+1$" is interpreted as "input" and "exit" from the network respectively. (Figure 1.1)

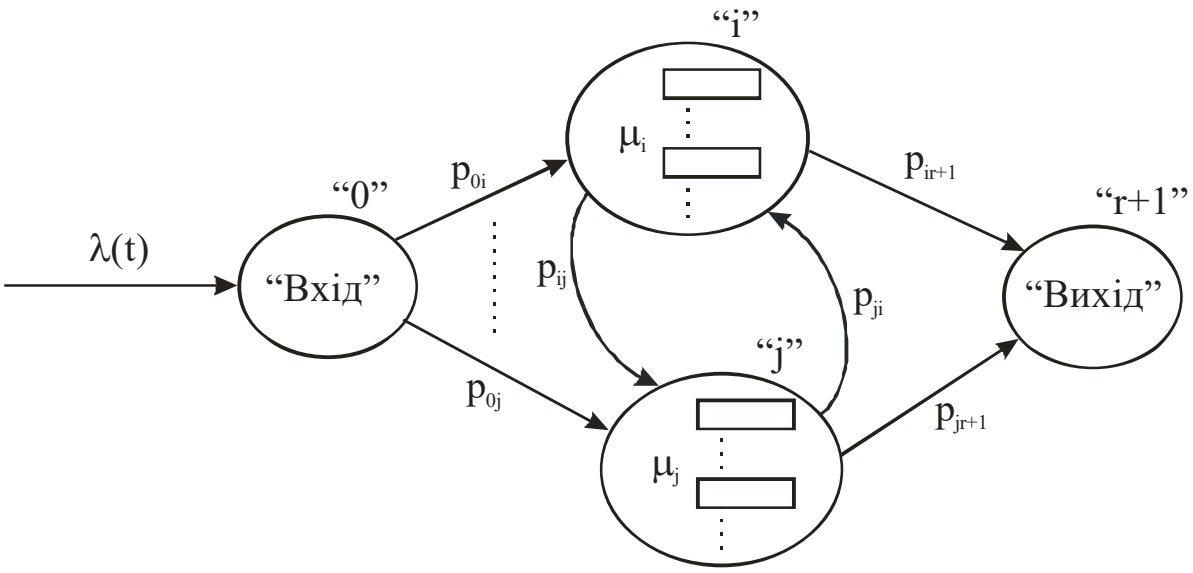


Fig. 1.1. Structure of multichannel network with one common input flow of requirements

According to the system of notation adopted in the theory of stochastic networks, the model described above will be denoted by a symbol $[M_t \mid M \mid \infty]^r$.

Stochastic networks of this type are used in the simulation of data processing processes in data networks and mobile communication systems ([246]), in the study of track ionization parameters in track cells ([252]), in pharmacokinetics ([255]) and in other areas .

The process of service requirements in a network type $[M_t \mid M \mid \infty]^r$ will be called r - measurable process $Q'(t) = (Q_1(t),...,Q_r(t))$, where $Q_i(t)$, $i = 1,2,...r$ – number of requirements in i nodes at the time t. Our main goal is to study the behavior of the process $Q(t)$, $t \geq 0$, when the intensity is $\lambda(t)$ is a periodically variable function of time. As noted earlier, such behavior of external loading is often encountered in practice.

It is known (see, for example, [254]) that the Poisson process is a random process $\nu(t)$, $t \geq 0$, which accepts integral non-essential values and satisfies such conditions:

1) $\nu(0) = 0$;

2) $\nu(t)$ – a separable process with independent increments whose trajectories with probability 1 at each point have boundaries on the left and a continuous matter;

3) at $0 \le s < t$ random variable $\nu(t) - \nu(s)$ distributed by Poisson's law with a parameter $\Lambda(t) - \Lambda(s)$, where $\Lambda(t)$ – non-infinite continuous function function $\Lambda(0) = 0$.

Function $\Lambda(t)$, $t \ge 0$, called the leading function of the Poisson process.

The Poisson process with probability unit has a step-like trajectory, with all its jumps positive.

Function $\Lambda(t)$ can have no more than a counted set of rupture points. Let's denote through a_n break point of the function $\Lambda(t)$ and let it $\lambda_n = \Lambda(a_n) - \Lambda(a_n - 0)$, $n = 1, 2, \ldots$. Then the process $\nu(t)$ can be submitted as a sum of two terms: $\nu(t) = \nu_0(t) + \nu_1(t)$, where $\nu_0(t)$ and $\nu_1(t)$ – independent processes with independent increments, called the regular and singular process of Poisson, respectively.

The Poisson singular process may have jumps only at moments of time a_n. With

$$P\{\nu_1(a_n) - \nu_1(a_n - 0) = k\} = \frac{(\lambda_n)^k}{k!} \exp\{-\lambda_n\}.$$

The regular Poisson process with probability 1 has no jumps whose values differ from 1. Removing from $\Lambda(t)$ jumps, we obtain a continuous leading function of the regular Poisson process:

$$\Lambda_0(t) = \Lambda(t) - \sum_{n: a_n \le t} \lambda_n .$$

Consider the regular Poisson process with a leading function $\Lambda_0(t)$ and let it τ_n – moment n jump in ascending order. The function of the distribution of a random variable τ_1 looks like $F_{\tau_1}(x) = 1 - e^{-\Lambda_0(x)}$, $x \ge 0$. If values are known $\tau_1, \ldots, \tau_n$, and $\tau_n = z$, then the conditional distribution function τ_{n+1} equals $F_{\tau_{n+1}}(x / z) = 1 - e^{-(\Lambda_0(x) - \Lambda_0(z))}$, $x \ge z$. Thus, the trajectory of the regular Poisson process can be obtained on the basis of the index distribution.

For any moment of time $T \geq 0$ consider the random variable $\hat{\tau}$ with distribution function

$$\hat{F}_T(x) = \begin{cases} 1, & x > T \\ \Lambda_0(x)/\Lambda_0(T), & 0 \leq x \leq T \\ 0, & x < 0 \end{cases};$$

Let $\hat{\tau}_{(1)},...,\hat{\tau}_{(n)}$ – ordinal sampling statistics from distribution $\hat{F}_T(x)$. Then the following is true of the connection between the Poisson process and ordinal statistics.

Theorem 1.1. ([240]) Let it be $\nu_0(t)$, $t \geq 0$, *– a regular Poisson process with a leading function* $\Lambda_0(t)$. *Then for any* $T \geq 0$ *and* $0 < x_1 < x_2 < ... < x_n < T$

$$P\{\tau_1 \leq x_1,...,\tau_n \leq x_n / \nu(T) = n\} = P\{\hat{\tau}_{(1)} \leq x_1,...,\hat{\tau}_{(n)} \leq x_n\}.$$

Based on the statement of this theorem, we can propose an effective algorithm for simulating the trajectory of a regular Poisson process.

Let $\nu_0(t)$ is considered only on the segment $[0,T]$. His trajectory on this segment can be constructed in two stages. Initially, a random variable is implemented $\nu_0(T)$, which is distributed by Poisson's law with a parameter $\Lambda_0(t)$. If $\nu_0(T)$ accepted the meaning n, then realized n independent random variables $\hat{\tau}_1,...,\hat{\tau}_n$, the distribution function of which coincides with $\hat{F}_T(x)$. If $\hat{x}_1,...,\hat{x}_n$ – realization $\hat{\tau}_1,...,\hat{\tau}_n$, then realization of the Poisson process $\tilde{\nu}_0(t) = \sum_{i:\hat{x}_i \leq t} 1$, $0 \leq t \leq T$.

Modeling the Poisson process through the Poisson distribution and distribution function $\hat{F}_T(x)$ in many cases it simplifies the solution of tasks.

If for a regular Poisson process the leading function is absolutely continuous, $\Lambda_0(t) = \int_0^t \lambda(u)du$, then $\nu_0(t)$ called a Poisson process with a variable parameter $\lambda(t)$, $t \geq 0$. On $\lambda(t)$ are referenced as an instantaneous parameter value. At $\lambda(t) \equiv \lambda$ we will have a homogeneous Poisson process. In this case $\hat{F}_T(x)$ coincides with the distribution function of uniform on $[0,T]$ the law of distribution.

Bearing in mind the interpretation of the Poisson process in the theory of stochastic networks, the notion of "Poisson process" and "Poisson flow of requirements" will be assumed to be equivalent.

Consider now the type of stochastic network described in subsection 1.1 $[M_t \mid M \mid \infty]^r$, the input of which the outside of the Poisson flow of requirements with a variable parameter is introduced $\lambda(t)$. Then the process of service $Q'(t) = (Q_1(t),...,Q_r(t))$, $t \geq 0$ will be a heterogeneous Markov chain in a plurality of states $S = \underbrace{N^+ \times ... \times N^+}_{r} = \left(N^+\right)^r$, $N^+ = \{0,1,...\}$, local characteristics of which $q_{ij}(t)$, $i' = (i_1,...,i_r)$, $j' = (j_1,...,j_r) \in S$ have a look:

$$q_{ij}(t) = \begin{cases} \lambda(t)\, p_{0k}, & j' = (i_1,...,i_k + 1,...,i_r), \quad k = 1,...,r; \\ i_k \mu_k p_{ks}, & j' = (i_1,...,i_k - 1,...,i_s + 1,...,i_r), k,s = 1,...,r, k \neq s, i_k \neq 0; \\ i_k \mu_k p_{kr+1}, & j' = (i_1,...,i_k - 1,...,i_r), \quad k = 1,...,r, i_k \neq 0; \\ -(\lambda(t) + \sum\limits_{k:i_k \neq 0} \mu_k (1 - p_{kk})), & i \neq j. \end{cases}$$

By $p_j^i(s,t) = P\{Q(t) = j / Q(s) = i\}$, $i, j \in S$, $s < t$, we will denote the transition probabilities of the Markov chain $Q(t)$.

Provided that $\lambda(t)$ – periodic with period $T > 0$ function, i.e.

$\lambda(nT + \theta) = \lambda(\theta)$ for $n = 1,2,...$ and $0 \leq \theta < T$,

for $Q(t)$ we can introduce the concept of quasierandom distribution (see, for example, [265]): distribution of probabilities $\{\pi_j(\theta), j \in S, 0 \leq \theta \leq T\}$ will be called quasiperogic for $Q(t)$, if irrespective of $i \in S$

$$\lim_{n \to \infty} P(Q(nt + \theta) = j / Q(0) = i) = \pi_j(\theta).$$

Our immediate goal is to analyze the transition process $Q(t)$ and find a quasierogodic distribution for it.

To analyze the transition mode of the process $Q(t)$, $t \geq 0$, use the generatrix method.

Let $Q'(0) = (Q_1(0),...,Q_r(0)) = k' = (k_1,...,k_r)$ and

$$\Phi(z,t) = Ez_1^{Q_1(t)} \times ... \times z_r^{Q_r(t)} = \sum_{k'=(k_1,...,k_r)} z_1^{k_1} ... z_r^{k_r} P\{Q'(t) = (k_1,...,k_r)\},$$

$$|z| \le 1, \quad z' = (z_1,...,z_r),$$

– multidimensional generator of the vector $Q'(t) = (Q_1(t),...,Q_r(t))$.

Lemma 1.1. *Generatrix* $\Phi(z,t)$ *can be filed in the form*

$$\Phi(z,t) = \prod_{i=1}^{r} \left[1 - \sum_{j=1}^{r} (1 - z_j) p_j^i(t) \right]^{k_i} \exp\left\{ -\sum_{j=1}^{r} (1 - z_j) \rho_j(t) \right\}, \qquad (1.1)$$

where $\rho_j(t) = \sum_{i=1}^{r} p_{0i} \int_0^t p_j^i(t-u) \lambda(u) du$, $P(t) = \left\| p_j^i(t) \right\|_1^r = \exp\{\Delta(\mu)(P - I)t\}$,

$$\Delta(\mu) = \left\| \mu_i \delta_{ij} \right\|_1^r, \; I = \left\| \delta_{ij} \right\|_1^r \; - \textit{unit matrix.}$$

Proving. Maintenance of a separate requirement in the nodes $[M_t \,|\, M \,|\, \infty]^r$ - the network does not depend on other requirements. In order to constructively set up a service process, consider the Markov chain $x(t)$, $t \ge 0$, in the set of states $\{1,2,...,r,r+1\}$, which is given by infinitesimal characteristics

$$a_{ij} = \begin{cases} -\mu_i(1 - p_{ii}), i = j = 1,2,...,r; \\ \mu_i p_{ij}, i \ne j, i = 1,2,...r; j = 1,2,...,r,r+1; \\ 0, i = r+1, j = 1,2,...,r,r+1; \end{cases}$$

and the initial distribution $p'(0) = (p_1(0),..., p_{r+1}(0))$.

If $p_i(0) = 1$, then the corresponding chain will be denoted $x^{(i)}(t)$. State "$r+1$" for the chain $x(t)$ is absorbent. Transient probabilities $P\{x(t) = j \,/\, x(0) = i\} = P\{x^{(i)}(t) = j\}$, $i, j = 1,...,r$, coincide with $p_j^i(t)$.

Trajectory requirements from the moment of network entry through i the node can be described by the chain before the exit from it $x^{(i)}(t)$, while absorbing in a state "$r+1$" is interpreted as an exit requirement from a network.

With the Markov chain $x^{(i)}(t)$, $i=1,...,r$, We associate two families X and Γ independent r - dimensional random vectors

$$\mathrm{X}=\left\{\chi_h^i(t)=\left(\chi_{1h}^i(t),\chi_{2h}^i(t),...,\chi_{rh}^i(t)\right),i=1,...,r;h=1,2,...\right\},$$

$$\Gamma=\left\{\gamma_h^i(t)=\left(\gamma_{1h}^i(t),\gamma_{2h}^i(t),...,\gamma_{rh}^i(t)\right),i=1,...,r;h=1,2,...\right\}.$$

Their distribution depends on the index «i»and does not depend on the index «h», family X and Γ also independent of each other. If e_0 – r - dimensional vector consisting of 0, e_j – r - dimensional vector, j - whose component is equal 1, and the rest are 0, then the vector $\chi_h^i(t)$ becomes important e_j with probability $p_j^i(t)$ and that value e_0 with probability $p_{r+1}^i(t)$. Similarly, the vector $\gamma_h^i(t)$ becomes important e_j with probability $\frac{1}{\Lambda(t)}\int_0^t p_j^i(t-u)\lambda(u)du$ and that value e_0 with probability $\frac{1}{\Lambda(t)}\int_0^t p_{r+1}^i(t-u)\lambda(u)du$, where $\Lambda(t)=\int_0^t\lambda(u)du$.

Let it now $\nu_i(t)$, $i=1,2,...,r$, – number of requests received from outside i network node in time t. Obviously, $\nu_i(t)$ is a Poisson flow with a variable parameter $p_{0i}\lambda(t)$. Using the connection of the Poisson stream with ordinal statistics (Theorem 1.1), we find that the distribution $Q'(t)=(Q_1(t),...,Q_r(t))$ coincides with the distribution of the vector:

$$\sum_{j=1}^{r}\sum_{h=1}^{k_j}\chi_h^j(t)+\sum_{j=1}^{r}\sum_{h=1}^{\nu_j(t)}\gamma_h^j(t), \qquad (1.2)$$

where $Q'(0)=(k_1,k_2,...,k_r)$.

Since the generatrix of the sum of random variables to a random index goes into a superposition of the generator, then from the representation (1.2) we immediately obtain (1.1). Lemma proved.

Enter the designation:

$$EQ'(t) = (EQ_1(t),...,EQ_r(t))',\ R(t) = \left\|\mathrm{cov}(Q_i(t),Q_j(t))\right\|_1^r,$$

and for any vector $x = (x_1,...,x_r)'$ let $\Delta(x) = \left\|x_i\delta_{ij}\right\|_1^r$ – diagonal matrix with vector x on the main diagonal. Then, calculating the derivatives of the first and second order on both sides of the relation (2.1), we obtain the following result.

Consequence 1.1. For the service process $Q'(t) = (Q_1(t),...,Q_r(t))$ in network type $[M_t \mid M \mid \infty]^r$ moments of the first and second order have the form:

$$EQ(t) = \rho(t) + P'(t)k, \tag{1.3}$$

$$R(t) = \Delta(\rho(t)) + \Delta\left[k'P(t)\right] - P'(t)\Delta(k)P(t), \tag{1.4}$$

where: $Q(0) = k = (k_1,...,k_r)'$, $\rho(t) = (\rho_1(t),...,\rho_r(t))'$.

Proving It's easy to see that the partial derivative is a variable z_i from the generatrix of the form (1.1) will have the following form:

$$\frac{\partial\Phi(z,t)}{\partial z_i} = \prod_{s=1}^{r}\left[1 - \sum_{m=1}^{r}(1-z_m)p_m^s(t)\right]^{k_s} \times \exp\left\{-\sum_{m=1}^{r}(1-z_m)\rho_m(t)\right\} \times$$

$$\times\left\{\sum_{s=1}^{r}\frac{k_s p_i^s(t)}{1 - \sum_{m=1}^{r}(1-z_m)p_m^s(t)} + \rho_i(t)\right\}.$$

Now substituting this expression for a value $z = \bar{1}$, we will get:

$$\left.\frac{\partial\Phi(z,t)}{\partial z_i}\right|_{z=\bar{1}} = \sum_{s=1}^{r}k_s p_i^s(t) + \rho_i(t).$$

Writing the resulting expression in a matrix form, we have the formula for the vector of mathematical expectations (1.3).

Similarly, we can obtain the formula for calculating the correlation matrix (2.4).

Mixed derivative of second order in variables z_i, z_j from the generator will have appearance:

$$\frac{\partial^2\Phi(z,t)}{\partial z_i\partial z_j} = \prod_{s=1}^{r}\left[1 - \sum_{m=1}^{r}(1-z_m)p_m^s(t)\right]^{k_s} \times \exp\left\{-\sum_{m=1}^{r}(1-z_m)\rho_m(t)\right\} \times$$

$$\times\left[\left\{\sum_{s=1}^{r}\frac{k_s p_i^s(t)}{1-\sum_{m=1}^{r}(1-z_m)p_m^s(t)}+\rho_i(t)\right\}\times\left\{\sum_{s=1}^{r}\frac{k_s p_j^s(t)}{1-\sum_{m=1}^{r}(1-z_m)p_m^s(t)}+\rho_j(t)\right\}-\right.$$

$$\left.-\sum_{s=1}^{r}\frac{k_s p_i^s(t)p_j^s(t)}{\left(1-\sum_{m=1}^{r}(1-z_m)p_m^s(t)\right)^2}\right].$$

Substituting a single vector instead of a vector z, we will have:

$$\left.\frac{\partial^2\Phi(z,t)}{\partial z_i\partial z_j}\right|_{z=\bar{1}}=\left(\sum_{s=1}^{r}k_s p_i^s(t)+\rho_i(t)\right)\left(\sum_{s=1}^{r}k_s p_j^s(t)+\rho_j(t)\right)-\sum_{s=1}^{r}k_s p_i^s(t)p_j^s(t).$$

Now we find the elements of the correlation matrix: $R(t)=\left\|r_{ij}(t)\right\|_{i,j=1}^{r}$. For $i\neq j$

$$r_{ij}(t)=\left.\frac{\partial^2\Phi(z,t)}{\partial z_i\partial z_j}\right|_{z=\bar{1}}-\left.\frac{\partial\Phi(z,t)}{\partial z_i}\right|_{z=\bar{1}}\cdot\left.\frac{\partial\Phi(z,t)}{\partial z_i}\right|_{z=\bar{1}}=$$

$$=-\sum_{s=1}^{r}k_s p_i^s(t)p_j^s(t).$$

Diagonal elements of the matrix have the form:

$$r_{ii}(t)=\left.\frac{\partial^2\Phi(z,t)}{\left(\partial z_i\right)^2}\right|_{z=\bar{1}}+\left.\frac{\partial\Phi(z,t)}{\partial z_i}\right|_{z=\bar{1}}-\left(\left.\frac{\partial\Phi(z,t)}{\partial z_i}\right|_{z=\bar{1}}\right)^2=$$

$$=\sum_{s=1}^{r}k_s p_i^s(t)+\rho_i(t)-\sum_{s=1}^{r}k_s p_i^s(t)p_j^s(t).$$

By writing these formulas in the matrix form, we obtain the expression (1.4).

As a consequence of Lemma 1.1, we can also obtain an explicit form of the generator $\Phi_\theta(z)=\lim_{n\to\infty}\Phi(z,nT+\theta)$, $0\le\theta<T$, quasiherogic distribution of the service process $Q(t)$.

Theorem 1.2. *If $\lambda(t)$ – periodic with period T function, spectral radius of the matrix P strictly less than 1, then for $[M_t \mid M \mid \infty]^r$ - the network has a quasiherogic distribution and for any one $\theta \in [0,T)$:*

$$\Phi_\theta(z) = \exp\{-\sum_{k=1}^{r}(1-z_k)\hat{\rho}_k(\theta)\}, \qquad (1.5)$$

$$\partial e \quad \hat{\rho}_k(\theta) = \sum_{m=0}^{\infty}\sum_{j=1}^{r} p_{0j}\int_0^T p_k^j(mT+\tau)\lambda(T-\tau+\theta)d\tau,$$

$$P(t) = \left\| p_j^i(t) \right\|_1^r = \exp\{\Delta(\mu)(P-I)t\}.$$

Proving. Obviously, the condition imposed on the spectral radius of the routing matrix means that the network is open, and each requirement entered into the network for service, with the probability of 1 coming out of the network. It is easy to see that when moving to the boundary of the generator (.1) at $t \to \infty$ the first multiplier goes to 1.

It remains to show that :

$$\lim_{n\to\infty}\rho_j(nT+\theta) = \hat{\rho}_j(\theta).$$

So, let's consider in more detail the integral:

$$\int_0^{nT+\theta} p_j^i(nT+\theta-u)\lambda(u)du.$$

We will get:

$$\int_0^{nT+\theta} p_j^i(nT+\theta-u)\lambda(u)du = \int_0^{nT+\theta} p_j^i(\tau)\lambda(nT+\theta-\tau)d\tau =$$

$$= \sum_{m=1}^{n}\int_{(m-1)T}^{mT} p_j^i(\tau)\lambda[(n-m)T+(mT-\tau)+\theta]d\tau + \int_{nT}^{nT+\theta} p_j^i(\tau)\lambda(nT+\theta-\tau)d\tau =$$

$$= \sum_{m=1}^{n}\int_{(m-1)T}^{mT} p_j^i(\tau)\lambda(mT-\tau+\theta)d\tau + \int_{nT}^{nT+\theta} p_j^i(\tau)\lambda(nT+\theta-\tau)d\tau =$$

$$= \sum_{m=0}^{n-1}\int_0^T p_j^i(mT+\tau)\lambda(T-\tau+\theta)d\tau + \int_{nT}^{nT+\theta} p_j^i(\tau)\lambda(nT+\theta-\tau)d\tau.$$

Now:

$$\lim_{n\to\infty}\rho_j(nT+\theta)=$$

$$=\lim_{n\to\infty}\{\sum_{i=1}^{r}p_{0i}\{\sum_{m=0}^{n-1}\int_0^T p_j^i(mT+\tau)\lambda(T-\tau+\theta)d\tau+\int_{nT}^{nT+\theta}p_j^i(\tau)\lambda(nT+\theta-\tau)d\tau\}\}=$$

$$=\sum_{m=0}^{\infty}\sum_{i=1}^{r}p_{0i}\int_0^T p_j^i(mT+\tau)\lambda(T-\tau+\theta)d\tau=\hat{\rho}_j(\theta),$$

which proves the statement of the theorem.

We note that under the conditions of Theorem 2.2, the quasierandom distribution for $[M_t\,|\,M\,|\,\infty]^r$ - The network has a multiplicative form. Such a form of ergodic distribution is well known for stochastic networks, for which the multidimensional process of service requirements can be described by a homogeneous Markov chain ([259], Chapter 3).

We will now analyze the consistent distribution of the service process at times t_1,t_2 $(t_1<t_2)$. Let:

$$\Phi(z(1),z(2),t_1,t_2)=E(z_1^{Q_1(t_1)}(1)\cdot\ldots\cdot z_r^{Q_r(t_1)}(1)\cdot z_1^{Q_1(t_2)}(2)\cdot\ldots\cdot z_r^{Q_r(t_2)}(2))$$
$$=Ez^{Q(t_1)}(1)z^{Q(t_2)}(2)$$

– compatible generatrix of vectors $Q(t_1)$ і $Q(t_2)$.

To obtain for this generator, the result similar to the result given in Lemma 2.1, we consider an dimensional random process of the indicator type $\chi^i(t)=(\chi_1^{\,i}(t),...,\chi_r^{\,i}(t))$, which is determined by the Markov chain $x^{(i)}(t)\in\{1,2,...,r,r+1\}$ so:

$$\chi^i(t)=\begin{cases}e_j, & \text{якщо } x^{(i)}(t)=j,\ j=1,2,...,r;\\ e_0, & \text{якщо } x^{(i)}(t)=r+1.\end{cases}$$

Obviously, the distribution $\chi^i(t)$ at fixed t coincides with the distribution of vectors $\chi_h^{\,i}(t)$, $h=1,2,...$, which were introduced during the advent of the Lemi 2.1.

By $\varphi^{(i)}(z(1),z(2),t_1,t_2)$ We will mark a compatible generator $\chi^i(t_1)$ and $\chi^i(t_2)$:

$$\varphi^{(i)}(z(1),z(2),t_1,t_2) = Ez(1)^{\chi^i(t_1)} \cdot z(2)^{\chi^i(t_2)}, \quad i = 1,2,...r.$$

It's easy to check that:

$$\varphi^{(i)}(z(1),z(2),t_1,t_2) = p^i_{r+1}(t_1) + \sum_{j=1}^{r} p^i_j(t_1) p^j_{r+1}(t_2 - t_1) z_j(1) +$$

$$+ \sum_{j,m=1}^{r} p^i_j(t_1) p^j_m(t_2 - t_1) z_j(1) z_m(2) = \qquad (1.6)$$

$$= 1 - \sum_{j=1}^{r} p^i_j(t_1)(1 - z_j(1)) - \sum_{j,m=1}^{r} p^i_j(t_1) p^j_m(t_2 - t_1) z_j(1)(1 - z_m(2)).$$

The result of formula (1.6) and Theorem 1.1 is the following result.

Lem 1.2 *Generatrix* $\Phi(z(1),z(2),t_1,t_2)$ *can be filed in the form*:

$$\Phi(z(1),z(2),t_1,t_2) = \prod_{i=1}^{r} \Bigg[1 - \sum_{j=1}^{r} p^i_j(t_1)(1 - z_j(1)) -$$

$$- \sum_{j,m=1}^{r} p^i_j(t_1) p^j_m(t_2 - t_1) z_j(1)(1 - z_m(2)) \Bigg]^{k_i} \cdot \exp\Big\{ - \sum_{j=1}^{r} \rho_j(t_1)(1 - z_j(1)) -$$

$$- \sum_{j,m=1}^{r} \rho_j(t_1) p^j_m(t_2 - t_1) z_j(1)(1 - z_m(2)) - \sum_{j=1}^{r} \rho_j(t_1,t_2)(1 - z_j(2)) \Big\},$$

where, $Q'(0) = (k_1,...,k_r)$, $\rho_j(t_1,t_2) = \sum_{i=1}^{r} p_{0i} \int_{t_1}^{t_2} p^i_j(t_2 - u) \lambda(u) du$

Now we can get a correlation matrix $R(s,t)$ vectors:

$$Q'(s) = (Q_1(s),...,Q_r(s)) \quad \text{and} \quad Q'(t) = (Q_1(t),...,Q_r(t)), \quad 0 \le s < t.$$

Consequence 1.2. *For vectors* $Q'(s) = (Q_1(s),...,Q_r(s))$ *and* $Q'(t) = (Q_1(t),...,Q_r(t))$, $0 \le s < t$, *the correlation matrix has the form:*

$$R(s,t) = P(t-s)\Delta(\rho(s)) + \Delta\big[k'P(s)\big]P(t-s) - P'(t)\Delta(k)P(s)P(t-s), \quad (1.7)$$

$$\partial e \ Q(0) = k = (k_1,...,k_r)', \ \rho(t) = (\rho_1(t),...,\rho_r(t))'.$$

Proving. The elements of the correlation matrix can be derived from the corresponding generator of the corresponding vectors by the formula:

$$r_{ij}(s,t)=\left.\frac{\partial\Phi(z(1),z(2),s,t)}{\partial z_i(1)\partial z_j(2)}\right|_{\substack{z(1)=\bar{1}\\ z(2)=\bar{1}}}-\left.\frac{\partial\Phi(z(1),z(2),s,t)}{\partial z_i(1)}\right|_{\substack{z(1)=\bar{1}\\ z(2)=\bar{1}}}\cdot\left.\frac{\partial\Phi(z(1),z(2),s,t)}{\partial z_j(2)}\right|_{\substack{z(1)=\bar{1}\\ z(2)=\bar{1}}}$$

Consequently, we find partial derivatives of the first and second order of variables $z(1),z(2)$ from a compatible generator $\Phi(z(1),z(2),t_1,t_2)$ and we will substitute the value of the vectors $z(1)=\bar{1},\ z(2)=\bar{1}$.

$$\left.\frac{\partial\Phi(z(1),z(2),s,t)}{\partial z_i(1)}\right|_{\substack{z(1)=\bar{1}\\ z(2)=\bar{1}}}=\sum_{\alpha=1}^{r}k_\alpha p_i^\alpha(s)+\rho_i(s),$$

$$\left.\frac{\partial\Phi(z(1),z(2),s,t)}{\partial z_j(2)}\right|_{\substack{z(1)=\bar{1}\\ z(2)=\bar{1}}}=\sum_{\alpha=1}^{r}k_\alpha\cdot\left(\sum_{m=1}^{r}p_m^\alpha(s)p_j^m(t-s)\right)+$$

$$+\sum_{m=1}^{r}\rho_m(s)p_j^m(t-s)+\rho_j(s,t).$$

$$\left.\frac{\partial\Phi(z(1),z(2),s,t)}{\partial z_i(1)\partial z_j(2)}\right|_{\substack{z(1)=\bar{1}\\ z(2)=\bar{1}}}=\left[\sum_{\alpha=1}^{r}k_\alpha p_i^\alpha(s)+\rho_i(s)\right]\times$$

$$\times\left[\sum_{\alpha=1}^{r}k_\alpha\cdot\left(\sum_{m=1}^{r}p_m^\alpha(s)p_j^m(t-s)\right)+\sum_{m=1}^{r}\rho_m(s)p_j^m(t-s)+\rho_j(s,t)\right]+$$

$$+\sum_{\alpha=1}^{r}\left[k_\alpha p_i^\alpha(s)p_j^i(t-s)-k_\alpha p_i^\alpha(s)\cdot\left(\sum_{m=1}^{r}p_m^\alpha(s)p_j^m(t-s)\right)\right]+$$

$$+\rho_i(s)p_j^i(t-s).$$

Substituting these values, we obtain an expression for the elements of the correlation matrix:

$$r_{ij}(s,t)=p_j^i(t-s)\left[\rho_j(s)+\sum_{\alpha=1}^{r}k_\alpha p_i^\alpha(s)\right]-\sum_{\alpha=1}^{r}\left[k_\alpha p_i^\alpha(s)\cdot\left(\sum_{m=1}^{r}p_m^\alpha(s)p_j^m(t-s)\right)\right].$$

Writing this formula in a matrix form, we arrive at the expression (1.7).

In [262], the concept of asymptotically periodic flow was introduced in the following way: the variable parameter $\lambda(t)\geq 0,\ t\geq 0$ will be asymptotically periodic if it can be presented in the form:

$$\lambda(t) = \lambda_1(t) + \lambda_2(t),$$

where:

$$\lambda_1(t+T) = \lambda_1(t), \;\; t \geq 0, \; \lim_{t\to\infty} |\lambda_2(t)| = 0.$$

Note that all results for networks with periodically variable input stream parameters can also be transferred to this case.

In this subsection, the method of Gaussian approximation for multichannel is developed $[M_t \mid M \mid \infty]^r$ - A network with a periodic input stream described in section 1.1, which operates under critical load conditions. The essence of the method is that the multidimensional hopping process of service is approximated by a continuous Gaussian process.

Throughout the research in the dissertation, the convergence of random processes describing the service in multichannel networks, to the Gaussian processes is considered. We describe briefly this class of random processes and introduce their main characteristics.

The Gaussian process is defined as a process whose finite-dimensional distributions are normal distributions. The normal multidimensional distribution is completely determined by the vector of mean values and the matrix of other moments. Therefore, the distribution of the Gaussian process is completely determined by two functions:

$$m(t) = E\xi(t),$$

$$R(s,t) = E\big(\xi(s) - m(s)\big)\big(\xi(t) - m(t)\big) = R(t,s).$$

Function $R(s,t)$ called correlation function. If a linear combination of values 1, $\xi(t_1)$, ..., $\xi(t_k)$ not equal to 0 with probability 1, then function $R(s,t)$ with the need to be positively defined. If $A = R^{-1}$ – matrix, inverse to the matrix $R = \left\| R(t_i, t_j) \right\|$, then a compatible distribution $\xi(t_1),...,\xi(t_k)$ is determined by k - measurable density

$$p_{t_1,...,t_k}(x_1,...,x_k) = \frac{(2\pi)^{-n/2}}{\sqrt{|A|}} \exp\left\{-\frac{1}{2}(x-m)' A (x-m)\right\},$$

where $(x-m)$ – this is a vector - a column with components $x_1 - m(t_1),...,x_k - m(t_k)$, $(x-m)'$ – vector is a string.

If:

$$R(s,t) = R(s-t), \;\; s > t,$$

then the process is called stationary or homogeneous.

The finite-dimensional distributions of the Gaussian process are completely determined by the characteristic function:

$$Ee^{i(z,\xi(t))} = Ee^{i\sum_{j=1}^{k} z_j \xi(t_j)} = \exp\left\{-\frac{1}{2}(z-m)R(z-m)'\right\},$$

where $z = (z_1,...,z_k)$, $\xi(t) = (\xi(t_1),...,\xi(t_k))$,

$$(z-m)R(z-m)' = \sum_{i=1}^{k} \sum_{j=1}^{k} (z_i - m_i)(z_j - m_j)R(t_i,t_j).$$

If the function is $R(s,t)$ continuous, then process $\xi(t)$ stochastically continuous in rms, i.e. $E\left[\xi(t)-\xi(s)\right]^2 = R(t,t) + R(s,s) - 2R(t,s) \equiv D(t,s) \to 0$ при $t \to s$.

If $R(s,t)$ for each of the variables equally satisfies the condition of Gölder, then $D(t,t+\Delta) < H|\Delta|^{\alpha}$ for some $H > 0$, $1 \geq \alpha > 0$. In this case, the trajectory of a one-dimensional separable Gaussian process $\xi(t)$ will be continuous with probability 1. By Kolmogorov's theorem (see, for example, [245]) it suffices to show that for some $\alpha > 0$, $\varepsilon > 0$, $c < \infty$:

$$E|\xi(t) - \xi(t+\Delta)|^{\alpha} \leq c|\Delta|^{1+\varepsilon}.$$

But:

$$E|\xi(t) - \xi(t+\Delta)|^{2k} \leq c_k D^k(t,t+\Delta) \leq c_k H^k |\Delta|^{\alpha k}.$$

So, there is enough choice $k > 1/\alpha$.

For continuity $\xi(t)$ may be a sufficient and weaker condition:

$$D(t,t+\Delta) \leq H\left(\log\frac{1}{\Delta}\right)^{a}, \;\; a > 3,$$

which, obviously, provides the same kind of inequality for the function $R(t,t+\Delta)-R(t,t)$ ([263]).

The vector Gaussian process with real components is also similarly determined. Let $\xi(t),\ t\in T$ – random process with values in r - dimensional space $\mathbb{R}^r$. It is called Gaussian if the consistent distribution of all components of the sequence $\{\xi(t_1),\xi(t_2),...,\xi(t_n)\}$ at any one $n\geq 1$ and any $t_k\in T$ is normal. The corresponding characteristic function has the form:

$$\phi(t_1,...,t_n,z_1^{(1)},...,z_r^{(1)},...,z_1^{(n)},...,z_r^{(n)})=$$

$$=\exp\left\{i\sum_{j=1}^{r}\sum_{k=1}^{n}z_j^{(k)}m^{(j)}(t_k)-\frac{1}{2}\sum_{k,\alpha=1}^{n}\sum_{j,s=1}^{r}R^{js}(t_k,t_\alpha)z_j^{(k)}z_s^{(\alpha)}\right\}.$$

This expression is easier to write if you enter vectors:

$z^{(k)}=(z_1^{(k)},z_2^{(k)},...,z_r^{(k)})',\ m(t)=(m^{(1)}(t),m^{(2)}(t),...,m^{(r)}(t))',$

with values in $\mathbb{R}^r$ and the matrix $R(t_1,t_2)$ with elements $R^{js}(t_1,t_2),\ j,s=1,2,...,r$. Then the previous expression takes the form:

$$\phi(t_1,...,t_n,z^{(1)},...,z^{(n)})=$$

$$=\exp\left\{i\sum_{k=1}^{n}\left(z^{(k)},m(t_k)\right)-\frac{1}{2}\sum_{k,\alpha=1}^{n}\left(R(t_k,t_\alpha)z^{(\alpha)},z^{(k)}\right)\right\}.$$

In this case, the vector function $m(t)$ can be arbitrary, but a real matrix function $R(t_1,t_2)$ must be symmetric and satisfy the condition: for any integer $n\geq 1$, any $t_k\in T$ and $z^{(k)}\in\mathbb{R}^r$

$$\sum_{k,\alpha=1}^{n}\left(R(t_k,t_\alpha)z^{(\alpha)},z^{(k)}\right)\geq 0. \qquad (1.8)$$

The inverse statement is also valid: arbitrary function $m(t)$ with values in $\mathbb{R}^r$ and matrix function $R(t_1,t_2)$, satisfying the condition (2.8) corresponds to the Gaussian random process $\xi(t)=\left(\xi_1(t),\xi_2(t),...,\xi_r(t)\right)$, for which:

$$m^{(k)}(t)=E\xi_k(t),$$

$$R^{js}(t_1,t_2)=E\left(\xi_j(t_1)-m^{(j)}(t_1)\right)\left(\xi_s(t_2)-m^{(s)}(t_2)\right)',\ j,s=1,2,...,r\ .$$

Often, there are necessary moments of the Gaussian random process. They can be obtained from the expansion of the characteristic function in a series.

The fact that Gaussian random processes are important in practical problems can often be explained by the following. In broad terms, the sum of a large number of independent and small random processes is approximately Gaussian random process regardless of the theoretical-probabilistic nature of individual terms. This is the so-called theorem on normal correlation, which is a multidimensional generalization of the central limit theorem. Here is one of her formulations. Let a sequence of series of random functions be given $\left\{\alpha^{(nk)}(t)=(\alpha_1^{(nk)}(t),...,\alpha_r^{(nk)})',t\in T\right\}$, $k=1,2,...m_n$, $n=1,2,...$, which take values from $\square^r$ and for which there are averages:

$$m^{(nk)}(t)=E\alpha^{(nk)}(t)=(E\alpha_1^{(nk)}(t),...,E\alpha_r^{(nk)}(t))'$$

and covariance matrices:

$$R^{(nk)}(s,t)=E(\alpha^{(nk)}(s)-m^{(nk)}(s))(\alpha^{(nk)}(t)-m^{(nk)}(t))',\qquad s,t\in T\ .$$

Consider the sequence of sums of random functions:

$$\alpha^{(n)}(t)=\sum_{k=1}^{m_n}\alpha^{(nk)}(t)\ ,\qquad t\in T\ ,\qquad n=1,2,....$$

Let's formulate for $\alpha^{(n)}(t)$ one of the variants of the normal correlation theorem, which is close to the analogous result in [264].

Theorem 1.3. *Let each function* $\alpha^{(n1)}(t),\alpha^{(n2)}(t),...,\alpha^{(nm_n)}(t)$ *are independent in aggregate and satisfy the following conditions:*

1) $\lim\limits_{n\to\infty}\sum\limits_{k=1}^{m_n}m^{(nk)}(t)=m^{(0)}(t)$,

$$\lim_{n\to\infty}\sum_{k=1}^{m_n}R^{(nk)}(s,t)=R^{(0)}(s,t),\qquad s,t\in T\ .$$

2) at fixed $t\in T$ *the Lindeberg condition is fulfilled: for any* $\varepsilon>0$,

$$\lim_{n\to\infty}\sum_{k=1}^{m_n} E\left|\alpha^{(nk)}(t)-m^{(nk)}(t)\right|^2 \chi_\varepsilon\left(\left|\alpha^{(nk)}(t)-m^{(nk)}(t)\right|\right)=0,$$

where $\chi_\varepsilon(\cdot)$ *- interval indicator* $(0,\varepsilon)$.

Then a random function $\alpha^{(n)}(t)$ *at* $n\to\infty$ *weakly coincide with the Gaussian random function* $\alpha^{(0)}(t)$ *with a vector of mathematical expectations* $m^{(0)}(t)$ *and a covariance matrix* $R^{(0)}(s,t)$, $s,t\in T$.

The proof of this theorem can be obtained as a consequence of the Cramer-Wold criterion for the weak convergence of random vectors and the central limit theorem with the Lindeberg condition (see, for example, [261]).

Let's return now to the type of stochastic network described above $[M_t\,|\,M\,|\,\infty]^r$.

Critical loading mode for $[M_t\,|\,M\,|\,\infty]^r$ - a network with a periodic input stream means that the service intensities in the nodes of the network depend on "n" (number of the series) in such a way that the following condition is fulfilled.

Condition 1.1.

$$\lim_{n\to\infty} n\mu_i^{(n)}=\mu_i>0,\quad i=1,2,...,r.$$

In the context of Condition 1.1, we consider the sequence of random processes:

$$\xi^{(n)}(t)=n^{-1/2}(Q^{(n)}(nt)-q^{(n)}(nt)),\qquad t\ge 0,$$

where $q^{(n)\prime}(nt)=(q_1^{(n)}(nt),...,q_r^{(n)}(nt))$,

$$q_j^{(n)}(nt)=\sum_{i=1}^{r} p_{0i}\int_0^{nt} p_j^{i(n)}(nt-u)\lambda(u)du,\ j=1,...,r,$$

$p_j^{i(n)}(t)$ - matrix elements $P^{(n)}(t)=\left\|p_j^{i(n)}(t)\right\|_1^r=\exp\{\Delta(\mu^{(n)})(P-I)t\}$,

$$\mu^{(n)\prime}=(\mu_1^{(n)},...,\mu_r^{(n)}),$$

$\Delta(x)=\left\|\delta_{ij}x_i\right\|_1^r$ - diagonal matrix with vector $x'=(x_1,...,x_r)$ on the main diagonal.

In order to describe the boundary of the sequence of random processes $\xi^{(n)}(t)$ at $n\to\infty$, we introduce two independent Gaussian processes:

$$\xi^{(i)\prime}(t) = (\xi_1^{(i)}(t),...,\xi_r^{(i)}(t)), \quad i = 1,2.$$

Process $\xi^{(1)}(t)$ is determined by average values:

$$E\xi^{(1)}(t) = 0$$

and correlation matrices:

$$R^{(1)}(t) = E\xi^{(1)}(t)\xi^{(1)\prime}(t) - E\xi^{(1)}(t)E\xi^{(1)\prime}(t) = \int_0^t P'(u)\Delta(\bar{\lambda})P(u)du,$$

$$R^{(1)}(s,t) = E\xi^{(1)}(s)\xi^{(1)\prime}(t) - E\xi^{(1)}(s)E\xi^{(1)\prime}(t) = R^{(1)}(s)P(t-s), \quad s < t,$$

where $\bar{\lambda}' = (\lambda_1,...,\lambda_r)$, $\lambda_i = p_{0i}\int_0^T \lambda(u)du$.

For the process $\xi^{(2)}(t)$:

$$E\xi^{(2)}(t) = 0,$$

$$R^{(2)}(t) = \int_0^t [\Delta(\bar{\lambda}'P(u)) - P'(u)\Delta(\bar{\lambda})P(u)]du,$$

$$R^{(2)}(s,t) = R^{(2)}(s)P(t-s), \quad s < t.$$

The following theorem gives approximation for the maintenance process under critical network load.

Theorem 1.4. Let it be for $[M_t \mid M \mid \infty]^r$ - The network with periodic input flows fulfills condition 1.1, and at the initial moment of time the network is empty: $Q^{(n)\prime}(0) = (0,...,0)$. Then on any finite interval $[0,T]$ sequence of random processes $\xi^{(n)}(t)$ at $n \to \infty$ coincides in a uniform topology before $\xi^{(1)}(t) + \xi^{(2)}(t)$.

Before we prove the theorem, we obtain a series of auxiliary results.

Let $\nu(t)$ – inhomogeneous Poisson process with a leading function $\Lambda(t)$, for which the condition is fulfilled:

$$\lim_{t\to\infty} t^{-1}\Lambda(t) = \lambda > 0. \qquad (2.9)$$

Then on any finite interval $[0,T]$ sequence of random processes $W^{(n)}(t) = n^{-1/2}(\nu(nt) - \Lambda(nt))$ at $n \to \infty$ coincides in a uniform topology to the Wiener process $W^{(0)}(t)$ with zero transfer and diffusion coefficient λ.

Proving. Convergence of finite-dimensional process distributions $W^{(n)}(t)$ to $W^{(0)}(t)$ stems from the fact that for any natural N and moments of time $0 < t_1 < ... < t_N$ characteristic joint distribution function $\nu(t_1),...,\nu(t_N)$ equals:

$$E\exp\{i\sum_{k=1}^{N} s(k)\nu(t_k)\} = \prod_{k=0}^{N-1}\exp\{[\Lambda(t_{k+1}) - \Lambda(t_k)][\exp(i\sum_{m=k+1}^{N} s(m)) - 1]\},$$

where , $(s(1),...,s(N)) \in \square^{N}$, $t_0 = 0$.

Now, in order to prove the convergence in a uniform topology, it is enough to check the fulfillment of the condition:

$$\lim_{h\to 0}\overline{lim}_{n\to\infty}\sup_{|t_2-t_1|\le h} P\{\left|W^{(n)}(t_2) - W^{(n)}(t_1)\right| > \varepsilon\} = 0 \qquad (1.10)$$

from [265]. According to Chebishov's inequalit:

$$\sup_{|t_2-t_1|\le h} P\{\left|W^{(n)}(t_2) - W^{(n)}(t_1)\right| > \varepsilon\} \le \varepsilon^{-2}\sup_{t\in[0,T]}[n^{-1}\Lambda(n(t+h)) - n^{-1}\Lambda(nt)].$$

From condition (1.9) it follows that for any $0 < \delta < T$:

$$\sup_{t\in[0,\delta)}[n^{-1}\Lambda(n(t+h)) - n^{-1}\Lambda(nt)] \le n^{-1}\Lambda(n(\delta+h)) \le (\lambda+\varepsilon_n)(\delta+h)$$

And:

$$\sup_{t\in[\delta,T]}[n^{-1}\Lambda(n(t+h)) - n^{-1}\Lambda(nt)] \le \lambda h + (2T+h)\varepsilon_n,$$

where $\varepsilon_n \to 0$ at $n\to\infty$. From here we find:

$$\lim_{h\to 0}\overline{\lim}_{n\to\infty}\sup_{|t_2-t_1|\le h} P\{\left|W^{(n)}(t_2) - W^{(n)}(t_1)\right| > \varepsilon\} \le \lambda\delta\varepsilon^{-2}.$$

Because $\delta > 0$ arbitrary, then the condition (2.10) is fulfilled.

Lemma proved.

Remark 1.1. *The condition (2.9) of the lemma is fulfilled for a nonuniform Poisson stream with periodic intensity* $\lambda(t)$ *для* $\lambda = \int_0^T \lambda(u)du$.

Really,

$$\frac{\Lambda(t)}{t} = \frac{\int_0^t \lambda(u)du}{t} = \frac{[t]_T \int_0^T \lambda(u)du + \int_0^{\{t\}_T} \lambda(u)du}{[t]_T + \{t\}_T} \underset{t\to\infty}{\to} \lambda,$$

where $[t]_T = \max\{n \in Z_+ : nT \le t\}$, $\{t\}_T = t - [t]_T$, Z_+ - the set of integers is nonnegative.

Remark 1.2. *The condition (2.9) of the lemma is also valid for periodic Poisson processes with an asymptotically periodic parameter as a function of time.*

Thus, Lemma 2.3 can be applied to Poisson flows $\nu_i(t)$, $i = 1,2,...,r$. By $W_i^{(0)}(t)$, $i = 1,2,...,r$, we denote independent Wiener processes with zero transfer and diffusion coefficient λ_i in accordance. According to Lemma 2.3, they approximate the input flows $\nu_i(t)$, $i = 1,2,...,r$.

For $W^{(0)\prime}(t) = (W_1^{(0)}(t),...,W_r^{(0)}(t))$ we will need such a result.

Theorem 1.4. *Finite-dimensional distributions* $\int_0^t dW^{(0)\prime}(u)P(t-u)$ *coincide with finite-dimensional distributions of the Gaussian process* $\xi^{(1)}(t)$.

Proving. The fact that r - measurable random process:

$$\varsigma(t) = \int_0^t dW^{(0)\prime}(u)P(t-u),$$

is Gaussian, derives from the properties of a stochastic integral (see, eg, [253]). We find correlation characteristics $\varsigma(t)$ and make sure they match the correlation characteristics $\xi^{(1)}(t)$.

Consider two moments of time $t_1, t_2 > 0$, $t_1 < t_2$, and choose a sequence of segment breaks $[0, t_2]$ points:

$$0 = t_{n_0} < ... < t_{n_{m_n^{(1)}-1}} < t_{n_{m_n^{(1)}}} = t_1 < t_{n_{m_n^{(1)}+1}} < ... < t_{n_{m_n^{(2)}}} = t_2,$$

such that:

$$\max_{0 \le k \le m_n^{(2)}-1} \Delta t_{n_k} \underset{n\to\infty}{\to} 0,\ \Delta t_{n_k} = t_{n_{k+1}} - t_{n_k},\ k = 0,1,...,m_n^{(2)} - 1.$$

Than, $s'(1) = (s_1(1),...,s_r(1))$, $s'(2) = (s_1(2),...,s_r(2)) \in \square^r$

$$E\exp\left\{i\varsigma'(t_1)s(1) + i\varsigma'(t_2)s(2)\right\} =$$

$$= E\exp\left\{i\int_0^{t_1} dW^{(0)\prime}(u)\left[P(t_1-u)s(1) + P(t_2-u)s(2)\right]\right\}\times$$

$$\times E\exp\left\{i\int_{t_1}^{t_2} dW^{(0)\prime}(u)P(t_2-u)s(2)\right\} =$$

$$= \lim_{n\to\infty}\prod_{k=0}^{m_n^{(1)}-1} E\exp\left\{i\Delta W^{(0)\prime}(t_{n_k})\left[P(t_1-t_{n_k})s(1) + P(t_2-t_{n_k})s(2)\right]\right\}\times$$

$$\times\prod_{k=0}^{m_n^{(2)}-1} E\exp\left\{i\Delta W^{(0)\prime}(t_{n_k})P(t_2-t_{n_k})s(2)\right\} =$$

$$= \lim_{n\to\infty}\prod_{k=0}^{m_n^{(1)}-1} \exp\left\{-\frac{1}{2}\left[P(t_1-t_{n_k})s(1) + P(t_2-t_{n_k})s(2)\right]'\Delta(\bar{\lambda})\times\right.$$

$$\left.\times\left[P(t_1-t_{n_k})s(1) + P(t_2-t_{n_k})s(2)\right]\Delta t_{n_k}\right\}\times$$

$$\times\prod_{k=m_n^{(1)}}^{m_n^{(2)}-1} \exp\left\{-\frac{1}{2}\left[P(t_2-t_{n_k})s(2)\right]'\Delta(\bar{\lambda})P(t_2-t_{n_k})s(2)\Delta t_{n_k}\right\},$$

where:

$$\Delta W^{(0)}(t_{n_k}) = W^{(0)}(t_{n_{k+1}}) - W^{(0)}(t_{n_k}),\ k = 0,1,...,m_n^{(2)} - 1.$$

From here we have:

$$E\exp\left\{i\varsigma'(t_1)s(1) + i\varsigma'(t_2)s(2)\right\} =$$

$$= \exp\left\{-\frac{1}{2}s'(1)\int_0^{t_1} P'(u)\Delta(\bar{\lambda})P(u)du\ s(1) -\right.$$

$$= -\frac{1}{2}s'(2)\int_0^{t_2} P'(u)\Delta(\bar{\lambda})P(u)du\ s(2) -$$

$$-\frac{1}{2}s'(1)\int_0^{t_1} P'(u)\Delta(\bar{\lambda})P(\Delta t_1 + u)du\ s(2) -$$

$$-\frac{1}{2}s'(2)\int_0^{t_1} P'(\Delta t_1 + u)\Delta(\bar{\lambda})P(u)du\ s(1)\Big\},\ \Delta t_1 = t_2 - t_1,$$

and correlation characteristics of Gaussian processes $\varsigma(t)$ and $\xi^{(1)}(t)$ coincide, which was to be proved.

Random vector:

$$(\chi_h^m(t))' = (\chi_{1h}^m(t),...,\chi_{rh}^m(t)),$$

will be considered as r - a measurable random process whose trajectory is based on the trajectory of the Markov chain $x_h^{(m)}(t)$, as previously defined. Because distributions $\chi_h^m(t)$ $(x_h^{(m)}(t))$ from h do not depend, then this index will be omitted when it comes to divisions.

For an arbitrary natural N and $z'(i) = (z_1(i),...,z_r(i))$, $i = 1,2,...,N$, $|z(i)| \le 1$, by $\Phi^{(m)} = \Phi^{(m)}(z(1),...,z(N),t_1,...,t_N)$, $m = 1,2,...,r$, we will denote the compatible generator of vectors:

$$\chi^m(t_1),...,\chi^m(t_N),\ 0 < t_1 < ... < t_N,\ \Phi' = (\Phi^{(1)},...,\Phi^{(r)}).$$

Theorem 1.5. *For arbitrary* $N = 1,2,...$ *and* $0 < t_1 < ... < t_N$

$$\Phi = \bar{1} + \sum_{i=1}^{N} P(\Delta t_1)\Delta[z(1)]...P(\Delta t_{i-1})\Delta[z(i-1)]P(\Delta t_i)(z(i) - \bar{1}), \quad (1.11)$$

where $\bar{1}$ – r - *dimensional vector consisting of units;* $\Delta t_i = t_i - t_{i-1}$ ($t_0 = 0$), $i = 1,2,...,N$.

Proof (1.11) can be obtained by the method of mathematical induction by parameter N.

Let's return to the analysis of the service process in $[M_t \mid M \mid \infty]^r$ - network [266].

Proof of Theorem 1.4. Analyze behavior with $n \to \infty$ one-dimensional process

distributions $\xi^{(n)}(t)$, $t \geq 0$.

With a fixed path of the process $\bar{\nu}(t) = (\nu_1(t),...,\nu_r(t))'$ distribution $Q(t)$ coincides with the distribution:

$$\sum_{m=1}^{r} \sum_{h=1}^{\nu_m(t)} \chi_h^m(t - \tau_h^m),$$

where τ_h^m – moment of receipt h requirements in m network node.

Taking into account this fact, as well as formula (1.11) for $N = 1$, generatrix $\Phi(z,t)$, $z' = (z_1,...,z_r)$, $|z| \leq 1$, vector $Q(t)$ can be filed in the form:

$$\Phi(z,t) = E\prod_{m=1}^{r} \prod_{h=1}^{\nu_m(t)} [1 - p^{m'}(t - \tau_h^m)(z - \bar{1})], \qquad (1.12)$$

where: $p^{m'}(\tau) = (p_1^m(\tau),..., p_r^m(\tau))$ – m matrix line $P(\tau)$.

Let $\varphi^{(n)}(s)$, $s' = (s_1,...,s_r) \in \mathbb{R}^r$ - characteristic function $\xi^{(n)}(t)$. Taking into account (1.12)

$$\varphi^{(n)}(s) = Ee^{i\xi^{(n)\prime}(t)s} = \exp\{-in^{-1/2} q^{(n)\prime}(nt)s\} \times$$

$$\times E\exp\{\sum_{m=1}^{r} \sum_{h=1}^{\nu_m(nt)} \ln[1 - p^{m(n)'}(nt - \tau_h^m)(e^{is/\sqrt{n}} - \bar{1})]\},$$

where: $(e^{is/\sqrt{n}})' = (e^{is_1/\sqrt{n}},...,e^{is_r/\sqrt{n}})$.

Let's denote through $(s^2)' = (s_1^2,...,s_r^2)$. Then:

$$\lim_{n\to\infty} \varphi^{(n)}(s) = \lim_{n\to\infty} \exp\{-in^{-1/2} q^{(n)\prime}(nt)s\} \times$$

$$\times E\exp\left\{\sum_{m=1}^{r} \sum_{h=1}^{\nu_m(nt)} \left[\frac{i}{\sqrt{n}} p^{m'}(t - \frac{\tau_h^m}{n})s - \frac{1}{2}\frac{1}{n} p^{m'}(t - \frac{\tau_h^m}{n})s^2 + \right.\right.$$

$$\left.\left. + \frac{1}{2}\frac{1}{n} s' p^m(t - \frac{\tau_h^m}{n}) p^{m'}(t - \frac{\tau_h^m}{n})s \right]\right\} =$$

$$= \lim_{n\to\infty} \exp\{-in^{-1/2} q^{(n)\prime}(nt)s\} E\exp\{in^{-1/2} \int_0^t d\bar{\nu}'(n\tau) P(t - \tau)s -$$

$$-\frac{1}{2}\frac{1}{n}\int_0^t d\bar{v}'(n\tau)P(t-\tau)s^2+\frac{1}{2}\frac{1}{n}\sum_{m=1}^{r}\int_0^t dv_m(n\tau)s'p^m(t-\tau)p^{m'}(t-\tau)s\}=$$

$$=\lim_{n\to\infty}\exp\{-\frac{1}{2}\frac{1}{n}\int_0^t d\bar{\Lambda}'(n\tau)P(t-\tau)s^2+$$

$$+\frac{1}{2}\frac{1}{n}\sum_{m=1}^{r}\int_0^t d\Lambda_m(n\tau)s'p^m(t-\tau)p^{m'}(t-\tau)s\}E\exp\{i\int_0^t dW^{(n)'}(\tau)P(t-\tau)s\},$$

where: $\bar{\Lambda}'(t)=(\Lambda_1(t),...,\Lambda_r(t))=(p_{01}\int_0^t\lambda(u)du,...,p_{0r}\int_0^t\lambda(u)du)$,

$W^{(n)'}(t)=(W_1^{(n)}(t),...,W_r^{(n)}(t))$, $W_h^{(n)}(t)=n^{-1/2}(\nu_h(nt)-\Lambda_h(nt))$, $h=1,2,...,r$.

Using Theoremas 1.4, 1.5, we find:

$$\lim_{n\to\infty}\varphi^{(n)}(s)=\exp\{-\frac{1}{2}\bar{\lambda}'\int_0^t P(u)dus^2+\frac{1}{2}\sum_{m=1}^{r}\lambda_m\int_0^t s'p^m(u)p^{m'}(u)sdu-$$

$$-\frac{1}{2}s'\int_0^t P'(u)\Delta(\bar{\lambda})P(u)dus\}=$$

$$=\exp\{-\frac{1}{2}s'\int_0^t[\Delta(\bar{\lambda}'P(u))-P'(u)\Delta(\bar{\lambda})P(u)]dus-\frac{1}{2}s'\int_0^t P'(u)\Delta(\bar{\lambda})P(u)dus\}.$$

The boundary expression is a characteristic function $\xi^{(1)}(t)+\xi^{(2)}(t)$. Thus, the convergence of one-dimensional distributions is proved.

Now consider the two-dimensional distributions. At a fixed trajectory of the input stream, the vector distribution $(Q(t_1),Q(t_2))$, $0<t_1<t_2$, coincides with the distribution:

$$\sum_{m=1}^{r}(\sum_{k=1}^{\nu_m(t_1)}\chi_k^m(t_1-\tau_k^{(m)}),\sum_{k=1}^{\nu_m(t_1)}\chi_k^m(t_2-\tau_k^{(m)})+\sum_{k=\nu_m(t_1)+1}^{\nu_m(t_2)}\chi_k^m(t_2-\tau_k^{(m)})).$$

Applying formula (1.9) for $N=2$, compatible generator $\Phi(t_1,t_2,s(1),s(2))$, $s(1),s(2)\in R_r$ vector $Q(t_1),Q(t_2)$ can be written in this form:

$$\Phi(t_1,t_2,z(1),z(2))=E\{\prod_{m=1}^{r}\prod_{k=1}^{\nu_m(t_1)}[1+p^{m'}(t_1-\tau_k^{(m)})(z(1)-\bar{1})+$$

$$+p^{m'}(t_1-\tau_k^{(m)})\Delta[z(1)]P(\Delta t_2)(z(2)-\bar{1})]\times.$$

$$\times\prod_{k=\nu_m(t_1)+1}^{\nu_m(t_2)}[1+p^{m'}(t_2-\tau_k^{(m)})(z(2)-\bar{1})]\}$$

This view allows us to find the boundary of a compatible characteristic feature: $\varphi^{(n)}(s(1),s(2))$, $s(1),s(2)\in R_r$, vectors $\xi^{(n)}(t_1)$ and $\xi^{(n)}(t_2)$:

$$\lim_{n\to\infty}\varphi^{(n)}(s(1),s(2))=\lim_{n\to\infty}E\exp\{i\xi^{(n)'}(t_1)s(1)+i\xi^{(n)'}(t_2)s(2)\}=$$

$$=\lim_{n\to\infty}\exp\{-i\frac{1}{\sqrt{n}}q^{(n)'}(nt_1)s(1)-i\frac{1}{\sqrt{n}}q^{(n)'}(nt_2)s(2)\}\times$$

$$\times E\exp\{\sum_{m=1}^{r}\{\sum_{k=1}^{\nu_m(nt_1)}\ln[1+p^{m(n)'}(nt_1-\tau_k^{(m)})(e^{is(1)/\sqrt{n}}-\bar{1})+$$

$$+p^{m(n)'}(nt_1-\tau_k^{(m)})\Delta[e^{is(1)/\sqrt{n}}]P^{(n)}(n\Delta t_2)(e^{is(2)/\sqrt{n}}-\bar{1})]+$$

$$+\sum_{k=\nu_m(nt_1)+1}^{\nu_m(nt_2)}\ln[1+p^{m(n)'}(nt_2-\tau_k^{(m)})(e^{is(2)/\sqrt{n}}-\bar{1})]\}\}=$$

$$=\lim_{n\to\infty}\exp\{-i\frac{1}{\sqrt{n}}q^{(n)'}(nt_1)s(1)-i\frac{1}{\sqrt{n}}q^{(n)'}(nt_2)s(2)\}\times$$

$$\times E\exp\{i\frac{1}{\sqrt{n}}\int_0^{t_1}d\bar{\nu}'(n\tau)P(t_1-\tau)s(1)-\frac{1}{2}\frac{1}{n}\int_0^{t_1}d\bar{\nu}'(n\tau)P(t_1-\tau)s^2(1)+$$

$$+i\frac{1}{\sqrt{n}}\int_0^{t_1}d\bar{\nu}'(n\tau)P(t_1-\tau)\Delta[e^{is(1)/\sqrt{n}}]P(\Delta t_2)s(2)-$$

$$-\frac{1}{2}\frac{1}{n}\int_0^{t_1}d\bar{\nu}'(n\tau)P(t_1-\tau)P(\Delta t_2)s^2(2)++\frac{1}{2}\frac{1}{n}\sum_{m=1}^{r}\int_0^{t_1}s'(1)p^m(t_1-\tau)p^{m'}(t_1-\tau)s(1)d\nu_m(n\tau)+$$

$$+\frac{1}{n}\sum_{m=1}^{r}\int_0^{t_1}s'(1)p^m(t_1-\tau)p^{m'}(t_1-\tau)P(\Delta t_2)s(2)d\nu_m(n\tau)+$$

$$+\frac{1}{2}\frac{1}{n}\sum_{m=1}^{r}\int_0^{t_1}s'(2)P'(\Delta t_2)p^m(t_1-\tau)p^{m'}(t_1-\tau)P(\Delta t_2)s(2)d\nu_m(n\tau)+$$

$$+i\frac{1}{\sqrt{n}}\int_{t_1}^{t_2}d\bar{\nu}'(n\tau)P(t_2-\tau)s(2)-\frac{1}{2}\frac{1}{n}\int_{t_1}^{t_2}d\bar{\nu}'(n\tau)P(t_2-\tau)s^2(2)+$$

$$+\frac{1}{2}\frac{1}{n}\sum_{m=1}^{r}\int_{t_1}^{t_2} s'(2)p^m(t_2-\tau)p^{m'}(t_2-\tau)s(2)d\nu_m(n\tau)\}=$$

$$=E\exp\{i\int_0^{t_1} dW^{(0)'}(\tau)P(t_1-\tau)s(1)+i\int_0^{t_2} dW^{(0)'}(\tau)P(t_2-\tau)s(2)\}\times$$

$$\times\exp\{-\frac{1}{2}s'(1)\int_0^{t_1}[\Delta[\bar{\lambda}'P(\tau)]-P'(\tau)\Delta[\bar{\lambda}]P(\tau)]d\tau s(1)-$$

$$-\frac{1}{2}s'(2)\int_0^{t_2}[\Delta[\bar{\lambda}'P(\tau)]-P'(\tau)\Delta[\bar{\lambda}]P(\tau)]d\tau s(2)-$$

$$-s'(1)(\int_0^{t_1}[\Delta[\bar{\lambda}'P(\tau)]-P'(\tau)\Delta[\bar{\lambda}]P(\tau)]d\tau)P(\Delta t_2)s(2)\}.$$

The resulting boundary is a characteristic function of a two-dimensional distribution:

$$\xi^{(1)}(t)+\xi^{(2)}(t).$$

Similarly, convergence is checked N - dimensional distributions for $N>2$.

The convergence of finite-dimensional distributions can be increased to convergence $\xi^{(n)}(t)$ in a uniform topology, as it was done in the paper [267]. To do this, use the convergence of the normalized input stream $W^{(n)}(t)$ to $W^{(0)}(t)$ in a uniform topology and representation of the maintenance process as the sum of the indicator-type processes on the input stream.

The theorem is proved.

Note that part $\xi^{(1)}(t)$ the boundary process is associated with the fluctuations of the input stream, and $\xi^{(2)}(t)$ – with fluctuations of service time.

SECTION 8. MECHANICAL ENGINEERING

DOI: 10.46299/ISG.2026.MONO.TECH.1.8.1

8.1 Ecological transformation of technical means: electrification and hybrid solutions in construction, agriculture and transport

Introduction

The current stage of development of the construction industry, agriculture and road transport is characterized by a rapid increase in the use of mobile technical equipment, which play a key role in ensuring the efficiency of production, logistics and transport and technological processes. On the one hand, the active introduction of modern technology contributes to increasing labor productivity, reducing work deadlines and optimizing the use of resources. On the other hand, the intensification of the operation of mobile machines and vehicles leads to an increase in energy consumption, increased emissions of harmful substances into the atmosphere, increased noise pollution and a general negative impact on the environment. Traditional approaches to the design, production and operation of technical equipment, which are based mainly on the use of internal combustion engines, increasingly often do not meet modern environmental standards, energy efficiency requirements and sustainable development principles. Strengthening environmental legislation, the rise in the cost of fuel and energy resources and increased public attention to environmental protection problems necessitate the search for alternative technical solutions. In this context, the implementation of electrified and hybrid technical means capable of reducing the negative impact on the environment while simultaneously maintaining or increasing operational efficiency is becoming a relevant direction of development.

In a global context, environmental challenges, including climate change, air pollution, and energy depletion, require a transition to new models of technological development. In these circumstances, electrification and hybridization of technical means are considered a priority direction of ecological transformation, which can

ensure a reduction in pollutant emissions, increased energy efficiency, and improved operating conditions of mobile machines.

A characteristic feature of the electrification process of construction, agricultural and transport equipment is its pronounced cross-sectoral nature. Despite the differences in functional purpose, design features and operating modes, the specified types of technical means have a common energy basis, which is based on the use of electric and hybrid power plants. During operation, they interact with each other within the framework of unified transport and technological systems, ensuring the continuity of production, logistics and technological processes. Such an interrelationship determines the expediency of a comprehensive consideration of electrified technical means within the framework of a single scientific and methodological approach. This allows us to identify common patterns of environmental and energy transformation, assess the effectiveness of the use of electrified and hybrid solutions in various industries, and also determine generalized directions of their practical implementation. In addition, an interdisciplinary approach creates the prerequisites for the unification of technical solutions, optimization of power supply systems, and the formation of integrated strategies for the development of electrified technology, taking into account the requirements of sustainable development and modern environmental standards.

However, the implementation of electrified and hybrid solutions is accompanied by a number of technical, economic and infrastructural limitations that require thorough scientific research. The issues of choosing optimal power plants, assessing environmental and technical and economic efficiency, as well as forecasting development prospects remain relevant for scientists and practitioners in such areas as mechanical engineering, transport and agricultural engineering.

In this regard, this section considers the ecological transformation of technical means through the introduction of electrification and hybrid solutions in construction, agriculture and road transport. The main attention is paid to the analysis of the prerequisites for the transition to electrified technical means, technical solutions for the use of electric drives and hybrid schemes, the assessment of their environmental and

technical and economic efficiency, as well as the definition of strategic prospects for further development. This approach allows us to form a holistic view of the role of electrification as a tool for the sustainable development of modern technical systems in agriculture, construction and the transport industry.

8.1.1. Prerequisites and conceptual foundations of ecological transformation

The intensive development of the construction industry, agriculture and road transport over the past decades has been accompanied by a significant increase in anthropogenic load on the external environment. Mobile technical means, which are the production base in these areas, have become one of the key sources of pollutants entering the atmosphere, noise pollution, as well as soil degradation and ecosystem disruption. The traditional use of internal combustion engines (ICE) in combination with the high energy intensity of technological operations determines the need for a systematic review of approaches to the design, operation and further development of technical means in the construction, agricultural and transport sectors of the national economy.

Increasing environmental requirements for technical equipment in modern conditions should be considered not as an isolated or local improvement of individual machines, mechanisms or units, but as a complex inter-sectoral process covering a wide range of technical, energy, economic and organizational factors. This approach involves a systematic review of the principles of design, operation and maintenance of technical equipment, taking into account the requirements for reducing harmful emissions, increasing energy efficiency and rational use of resources throughout the entire life cycle of machines. In this context, electrification and hybridization of mobile technical equipment are gaining the status of one of the key tools for implementing environmentally friendly transformation of production and transport systems. The use of electric and combined power plants allows for a significant reduction in emissions of pollutants and greenhouse gases, a reduction in noise pollution, and an increase in the overall energy efficiency of equipment. In addition to environmental benefits,

electrified and hybrid solutions contribute to the optimization of operating costs, increased reliability of individual components and units, and also create the prerequisites for the implementation of intelligent energy consumption management systems. Taken together, this forms the basis for a transition to more sustainable models of production, construction, and transportation that meet modern requirements for environmental safety, economic feasibility, and long-term development.

One of the main prerequisites for such a transformation is the growth of global environmental problems, in particular climate change, air pollution and depletion of non-renewable energy resources. The growing number of emissions of carbon dioxide, nitrogen oxides, particulate matter and other harmful elements, which are formed as a result of the operation of internal combustion engines. Such emissions directly depend on the intensity of operation of construction, agricultural and automotive equipment, which is one of the key consumers of traditional fuels. At the same time, the specific operating modes of such equipment - long loads, frequent acceleration and braking cycles, idling - lead to a decrease in fuel efficiency. The result is an increase in specific fuel consumption and, accordingly, an increase in the volume of harmful emissions per unit of work performed, which increases the negative impact on the environment and complicates compliance with modern environmental requirements.

An equally important prerequisite for the ecological transformation of modern technical means is the systematic strengthening of regulatory and legal regulation in the field of environmental protection, which is formed at the national and international levels. In the leading countries of the world, there is a tendency to introduce comprehensive and increasingly stringent environmental standards that establish maximum permissible emissions of carbon dioxide, nitrogen oxides, carbon oxides, hydrocarbons and particulate matter, which is reflected, in particular, in the requirements of the Euro series environmental classes. In parallel, permissible noise levels of vehicles during movement and operation of power plants are regulated, and standards are also established for fuel economy and energy efficiency, which limit the specific consumption of fuel or electricity per unit of work performed or mileage.

These regulatory restrictions significantly affect the development strategy of the machine-building and transport industries, making it necessary to deeply modernize existing structures and implement innovative technical solutions. In these conditions, manufacturers are forced to focus not only on achieving high performance indicators, but also on ensuring that products meet modern environmental requirements, which include minimizing harmful emissions, reducing noise levels, and increasing the overall efficiency of power plants. As a result of the above factors, electric and hybrid power plants are gradually evolving from experimental and demonstration developments to full-fledged industrial solutions that are integrated into mass production and are gaining wide practical application. Such a transformation indicates the formation of a new paradigm for the development of technical systems, focused on the principles of sustainable development, environmental responsibility, and rational use of energy resources.

At the same time, the ecological transformation of technical means cannot be reduced only to the simple replacement of traditional power plants with alternative ones. It should provide for a comprehensive change in the concept of the functioning of mobile technical means in the structure of modern production and transport systems, covering both the constructive and organizational and technological aspects of their use. In this context, a systematic approach based on the assessment of the full life cycle of equipment, which includes the stages of extraction and processing of raw materials, production of materials and components, operation, maintenance, disposal and reuse of resources, is becoming increasingly important. This approach allows us to take into account not only direct emissions of pollutants during the operation of technical means, but also indirect environmental impact associated with energy consumption and material consumption at all stages of the life cycle. In this regard, electrification is considered not as an end in itself, but as a component of a broad integrated strategy aimed at reducing the total environmental footprint of technical means, optimizing the use of energy resources, and increasing the level of environmental sustainability of transport and production systems as a whole.

A characteristic feature of construction, agricultural and motor transport equipment is their close functional relationship within the framework of single transport and technological processes that ensure the continuity of production and logistics activities. Construction machines play a key role in the creation, modernization and maintenance of engineering and transport infrastructure, forming the material basis for the development of other sectors of the economy. Agricultural equipment, in turn, ensures the efficiency of agricultural production and plays a decisive role in the formation of food security, while motor transport performs the functions of logistical support, combining production facilities, warehouse complexes and consumers into a single system. All of these types of equipment are operated in a common spatio-temporal environment and, as a rule, use similar or interconnected energy resources, which causes a total impact on the environment. The interdependence of operating modes, intensity of use and technical characteristics of these machines leads to the accumulation of environmental consequences within one production and transport chain. That is why the ecological transformation of technical means cannot be considered in isolation within a separate industry, but must have a pronounced inter-industry character. This approach assumes taking into account the specifics of the operation of each type of equipment, while ensuring the consistency of technical, energy and organizational solutions at the system level. The implementation of an inter-industry strategy of ecological transformation creates the prerequisites for increasing the overall efficiency of transport and technological processes, reducing the total environmental load and forming sustainable models of development of production and logistics systems.

In general, the introduction of electrification and hybridization of mobile vehicles is based on an approach focused on increasing energy efficiency by optimizing the use of energy resources and reducing losses in the processes of their conversion and transmission. Electric drives are characterized by a higher efficiency compared to internal combustion engines, as well as the ability to provide stable traction characteristics in a wide range of operating modes. An important advantage of electric

drives is the ability to recover energy during braking or load reduction, which helps to increase the overall efficiency of the vehicle's energy consumption. In hybrid energy systems, the combination of a traditional internal combustion engine with an electric drive and energy storage devices allows you to adapt the operating mode of the power plant to real operating conditions. This approach provides a reduction in peak loads on the engine, a reduction in operating time in inefficient modes, and optimization of fuel consumption. Taken together, this creates the prerequisites for reducing the level of harmful emissions and increasing the technical and economic performance of mobile vehicles, which is consistent with the overall strategy of ecological transformation of transport, technological and production systems.

An important conceptual basis for the ecological transformation of technical means is the transition from an isolated consideration of a separate technical means to a comprehensive analysis of its functioning as an element of a broader production and transport system. This approach involves taking into account the interaction of technical means with other components of the technological process, infrastructure, energy networks and organizational structures that determine the conditions of its operation. Within the framework of a system analysis, it is necessary to assess not only the efficiency of the operation of a separate machine, but also the total environmental and energy effect that is formed as a result of the coordinated operation of all elements of the system. For construction equipment, this means the need to take into account the logistics of material flows, the organization of transport services for construction sites and interaction with vehicles that deliver raw materials and remove waste. In agricultural production, a systemic approach involves the integration of equipment with the energy infrastructure of the farm, including the use of renewable energy sources, storage tanks and local energy systems, which allows reducing dependence on traditional energy carriers. For road transport, ecological transformation in a systemic context is associated with the coordination of traffic parameters, energy consumption and infrastructure provision with urban and intercity transport systems, as well as with the implementation of intelligent traffic management systems. The use of such a

systemic approach creates conditions for a more complete realization of the potential of electrification and hybridization, contributes to the optimization of energy flows and allows minimizing the environmental risks associated with the operation of mobile transport and technological means in modern conditions.

At the same time, it should be noted that the process of ecological transformation of technical means is accompanied by a number of objective technical, economic and infrastructural limitations that significantly affect the pace and scale of implementation of electrified solutions. The main constraining factors include the limited energy capacity of modern battery systems, which leads to a decrease in the range or duration of autonomous operation of equipment, especially under high load conditions typical of the construction and agricultural industries. In addition, the production of batteries is associated with the use of so-called critical materials, such as lithium, cobalt and nickel, the availability and cost of which are determined by global market and geopolitical factors. Another significant limitation is the need to create an extensive charging and service infrastructure adapted to the specifics of the operation of heavy and special equipment, which requires significant capital investments and a long implementation period. In addition, at the initial stage of the introduction of electrified vehicles, there is an increased level of investment costs, due to the high cost of batteries, power electronics and control systems. In these conditions, hybrid power plants are often considered as an intermediate and technologically feasible stage of ecological transformation, which allows combining the ecological advantages of electric drive with the operational flexibility and autonomy of traditional internal combustion engines. This approach ensures a gradual reduction in fuel consumption and the level of harmful emissions without radical changes to the existing infrastructure, creating the prerequisites for the subsequent transition to fully electrified transport and technological systems.

Thus, the prerequisites for the ecological transformation of technical means are formed under the influence of a set of interrelated environmental, regulatory, technological and economic factors, which in the complex determine the directions of

development of modern transport and technological systems. The exacerbation of global environmental problems, increased requirements for reducing anthropogenic load on the environment, as well as improving the regulatory framework in the field of environmental protection create an objective need to revise traditional approaches to the design and operation of technical means. The conceptual foundations of this transformation are the transition to energy-efficient, low-carbon and systemically integrated technical solutions that are focused on optimizing the use of energy resources and reducing the total environmental impact throughout the entire life cycle of equipment. In this context, the electrification and hybridization of construction, agricultural and transport equipment are considered not as an end in themselves, but as tools for implementing a broader strategy for the sustainable development of technical systems, which involves the coordination of technical, energy and infrastructure solutions at the inter-sectoral level. Given the complexity and multifactorial nature of these processes, the implementation of electrified and hybrid technologies requires a comprehensive scientific analysis, which includes the assessment of technical and economic indicators, environmental efficiency, operational limitations and development prospects. It is this comprehensive approach that allows us to formulate scientifically sound recommendations for the further ecological transformation of technical means in modern conditions.

8.1.2. Technical solutions for electrification and hybridization of mobile equipment

The implementation of ecological transformation of technical means in the construction, agriculture and transport sectors is directly related to the implementation of innovative technical solutions in the field of power plants, energy supply systems and energy flow management. Modern trends in the development of mobile machines involve a gradual transition from traditional energy schemes to more complex and flexible architectures that combine different energy sources and ensure adaptation of operating modes to changing operating conditions. Electrification and hybridization of

mobile technical means cover a wide range of constructive and functional approaches that differ in the level of the electrical component in the power plant, the type and characteristics of energy storage devices, as well as the nature of the interaction between traditional and electric drives. Depending on the purpose and conditions of use of the equipment, various configurations are used - from auxiliary electrical systems that perform the functions of starting or energy recovery, to fully electric drives with autonomous power supply. An important element of such solutions are energy flow management systems that ensure optimal power distribution between power units, storage devices and energy consumers. Intelligent control algorithms allow taking into account load, driving modes, battery status and external conditions, which contributes to increasing energy efficiency, reducing losses and reducing the level of harmful emissions. Taken together, these technical solutions form the basis for the practical implementation of the ecological transformation of mobile machines in modern transport and technological systems.

In general, electrified and hybrid technical means should be classified according to the degree of involvement of the electric drive in providing traction, transport and operating modes, as well as by the nature of the interaction between electric and traditional power plants, in particular internal combustion engines. This approach to classification makes it possible to organize a wide range of modern design and circuit solutions used in mobile equipment for various purposes. Depending on the level of electrification, technical means can vary from systems with partial electrification of auxiliary or working bodies to fully electric machines in which the electric drive is the only source of mechanical energy. In hybrid systems, the method of combining power plants is of particular importance, which can be implemented in the form of serial, parallel or combined circuits. Each of such circuits has its own design features, advantages and limitations that affect energy efficiency, control flexibility and adaptation to different operating modes. The proposed classification creates a methodological basis for a comparative analysis of different types of electrified and hybrid technical means, allowing to assess their potential from the standpoint of energy

efficiency, level of harmful emissions, operational reliability and economic feasibility. In addition, it contributes to the informed choice of optimal technical solutions when designing and modernizing machines, as well as to the formation of directions for the further development of electrified equipment in the context of increasing environmental and energy requirements.

The first group includes fully electric technical means, in which all the main functions of movement, maneuvering and performance of work operations are implemented exclusively by means of electric drives. Such machines do not have internal combustion engines, and mechanical energy for driving the running systems and working elements is generated by electric motors of various types, in particular asynchronous, synchronous or permanent magnet motors. Electric drives are powered by electric energy storage devices, which include batteries of various chemical types (lithium-ion, lithium-iron-phosphate, etc.), supercapacitors, as well as from external power supply sources, in particular contact networks or stationary charging stations. The choice of a specific energy source is determined by the operating conditions, the duration of work cycles and the requirements for the mobility of the technical means. Fully electric vehicles are characterized by the absence of local emissions of harmful substances, significantly reduced noise and vibration levels, as well as a high efficiency of the power plant, which is due to the efficiency of the electric drive and the ability to precisely control operating modes. Due to these advantages, such technical means are particularly suitable for use in dense urban areas, in warehouses and production facilities, tunnels, as well as in environmentally sensitive areas where strict restrictions on emissions and noise pollution apply. At the same time, the spread of fully electric vehicles is constrained by a number of factors, the key ones being the limited range, the significant weight and cost of battery systems, and the duration of the charging process. In addition, the efficiency of their use largely depends on the level of development of the charging infrastructure and energy supply conditions. Despite these limitations, further progress in the field of energy storage and power electronics creates

the prerequisites for expanding the scope of application of fully electric technical means in various industries and transport.

The second group consists of hybrid technical means, the design of which combines internal combustion engines and electric drives operating within different energy interaction schemes. This approach allows integrating the advantages of traditional and electric power plants, ensuring more efficient use of energy resources compared to machines equipped only with internal combustion engines. Depending on the configuration of the power plant and the method of transferring energy to the driving and working elements, there are serial, parallel and combined (serial-parallel) hybrid systems. In serial hybrid schemes, the internal combustion engine, as a rule, does not have a rigid mechanical connection with the driving elements and is used mainly as a generator of electrical energy, which is directed to powering electric motors or charging batteries. Such a scheme ensures stable operation of the internal combustion engine in optimal modes, which contributes to reducing fuel consumption and emissions of harmful substances. In parallel hybrid systems, the internal combustion engine and the electric motor can simultaneously or separately transmit torque directly to the driving elements, which allows you to flexibly vary the traction characteristics depending on the operating conditions. Combined (series-parallel) schemes combine the functionality of both approaches and are characterized by increased design complexity, but at the same time provide the highest adaptability to variable operating modes and loads. The use of hybrid power plants creates conditions for optimal control of energy flows, the use of braking energy recovery, reducing the load on the internal combustion engine and increasing the overall energy efficiency of the machine. As a result, fuel consumption is reduced, harmful emissions are reduced and operational flexibility is increased, which makes hybrid technical means a promising intermediate stage on the way to full electrification of mobile equipment in the construction, agricultural and transport industries.

Within the second group, it is advisable to distinguish an additional subclassification depending on the level of electrification of the power plant and the

functional purpose of the electric drive. From this point of view, the so-called mild hybrids, full hybrids and plug-in hybrids are distinguished. Mild hybrids are characterized by the presence of an electric power plant of relatively low power, which does not provide independent movement of the technical means, but is used to implement auxiliary functions, such as starting the internal combustion engine, recuperation of braking energy and short-term traction support during acceleration. Such systems are characterized by relative structural simplicity and a moderate reduction in fuel consumption and emissions. Full hybrids are capable of operating both in the mode of joint use of the internal combustion engine and electric drive, and in a limited all-electric mode at low speeds or under low loads. The electric drive in such systems has greater power, which allows for a significant increase in energy efficiency in cycles with frequent stops and changes in operating modes, typical of urban and technological transport. Plug-in hybrids are distinguished by the ability to charge batteries from external sources of electricity and the presence of a significantly larger reserve of electric power. This allows the technical means to be operated in fully electric mode for a significant part of the operating cycle, combining the advantages of an electric drive with the autonomy of a traditional power plant. Such systems are considered one of the most promising transitional options on the way to the full electrification of technical means.

The proposed division of electrified and hybrid technical means is universal in nature and can be effectively applied to both road transport and construction and agricultural machinery. Despite the differences in the functional purpose, operating conditions and operating modes of the specified types of machines, they are united by a common energy structure and similar principles of formation and use of traction power. Due to such universality of the classification, it becomes possible to apply unified methodological approaches in the analysis of technical characteristics, assessment of energy efficiency, environmental indicators and operational reliability of electrified and hybrid solutions. This, in turn, significantly simplifies the comparative analysis of alternative design schemes, allows to reasonably assess the

feasibility of their implementation in different industries and conditions of use, and also contributes to the unification of approaches to the design and standardization of technical means. In addition, the use of a single classification base creates the prerequisites for the inter-industry transfer of technical solutions and operating experience, which is especially important in the conditions of intensive development of electrified technology. This approach allows for more informed formation of strategies for modernization of the machine fleet, optimization of investment decisions, and determination of priority areas for the implementation of electrified and hybrid technologies, taking into account the specifics of a particular industry.

The key element of electrified technical equipment is an electric drive, which ensures the conversion of electrical energy into mechanical energy with a high efficiency and minimal losses at intermediate stages of energy conversion. Compared to traditional power plants based on internal combustion engines, electric drives are characterized by increased controllability, the ability to smoothly and precisely adjust torque and speed in a wide range of modes, as well as high stability of traction characteristics regardless of load conditions. An important advantage of the electric drive is also a reduction in noise and vibration levels, which helps to improve the working conditions of operators and reduce the negative impact on the environment, especially in dense urban areas. For construction machines, this is of fundamental importance when performing work in residential areas, on reconstruction sites and in confined spaces. In agricultural machinery, the electric drive provides more uniform operation during long technological cycles, reducing operator fatigue and increasing the overall productivity of machines. In addition, electric drives integrate well with modern automated control and monitoring systems, which opens up opportunities for implementing adaptive control algorithms, optimizing energy consumption, and introducing elements of autonomous operation. Taken together, these features make the electric drive a basic technical component that determines the efficiency, environmental characteristics, and prospects for the further development of electrified and hybrid technical means.

Battery systems are the main source of energy for most modern electric and hybrid vehicles, as they determine the autonomy, operational flexibility and overall efficiency of the latter. The choice of battery type is determined by a set of requirements for energy density, specific and peak power, mass-dimensional characteristics, resource in terms of the number of charge-discharge cycles, as well as safety and operating conditions. In the practice of electrification of mobile equipment, the most common are lithium-ion and their modified varieties, which provide an acceptable balance between energy density, durability and charging speed. For mobile machines, it is characteristic that there is a need to achieve a compromise between the range or duration of continuous operation, the time of restoration of the energy resource and the permissible mass of the battery system, which directly affects the load capacity and energy consumption of the equipment. This is especially true for construction and agricultural equipment, where an increase in the mass of batteries can limit maneuverability or change the distribution of loads on the chassis. In construction and agricultural machines operating within relatively closed production cycles or in limited areas, preference is often given to solutions with the possibility of partial, accelerated or intermediate recharging during technological breaks. Another promising direction is the use of replaceable or modular battery packs, which allow for the reduction of simple equipment and an increase in its utilization rate. Thus, battery systems act not only as a source of energy, but also as an important element shaping the architecture, operating modes and economic feasibility of electrified and hybrid technical means.

An important direction of development of technical solutions in the field of electrification is the implementation of energy recovery systems aimed at increasing the overall energy efficiency of mobile technical equipment. During operation, a significant part of the mechanical energy in traditional machines is irretrievably lost during braking, speed reduction, changes in load modes or performance of cyclic work operations. The use of electric drives with the ability to operate in generator mode allows this energy to be converted into electrical energy and returned to the battery or intermediate storage devices, such as supercapacitors. Energy recovery directly

contributes to reducing total energy consumption, reducing the load on the main energy source and extending the service life of battery systems. In addition, reducing heat losses in braking mechanisms has a positive effect on their durability and reduces operating costs. The effectiveness of regenerative systems largely depends on the nature of the machine's operating modes, electric drive control algorithms and energy storage device parameters. In construction machinery, recuperation is particularly effective during the operation of lifting and conveying and earthmoving machines, where loads, booms or working bodies are often lowered under the action of their own weight. In road transport, the greatest effect is achieved in urban traffic conditions with frequent accelerations and stops, as well as in hybrid power plants, where the recuperated energy is used to maintain traction or power auxiliary systems. In agricultural machinery, recuperation can be implemented during turns, reducing the load on the working bodies and transporting from the field, which further increases the efficiency of using energy resources within the production cycle.

Hybrid technical solutions occupy an intermediate position between traditional machines with internal combustion engines and fully electric ones and play a key role at the current stage of the ecological transformation of mobile equipment. Their relevance is due to the possibility of combining the advantages of an electric drive - high energy efficiency, energy recovery and reduced local emissions - with the reliability and energy autonomy inherent in traditional power plants. This makes hybrid systems particularly attractive for industries where full electrification is currently limited by operational or infrastructure factors. A feature of the use of hybrid systems in agricultural machinery is the ability to adapt the energy regime to changing operating conditions - from traction operations to driving working elements. This creates the prerequisites for reducing fuel consumption and minimizing the negative impact on the soil by optimizing mass and load distribution. In road transport, hybrid solutions provide increased fuel efficiency in conditions of changing road profiles and heavy traffic.

A significant role in the implementation of electrification and hybridization of mobile equipment is played by energy flow control systems that ensure coordinated and rational operation of all elements of the power plant. Modern electrified equipment is equipped with multi-level control systems that combine hardware measurement tools and software data processing algorithms capable of analyzing motion parameters, load, technical condition of units and charge level of energy storage devices in real time. Intelligent control algorithms allow automatically determining the optimal mode of operation of the power plant, taking into account current operating conditions, type of work performed and energy efficiency requirements. In hybrid systems, such algorithms ensure rational load distribution between the internal combustion engine and the electric drive, minimizing fuel consumption and limiting pollutant emissions. In electric machines, control systems are responsible for optimizing energy consumption, effective use of recuperation and protection of battery systems from overloads and premature wear. Control systems are of particular importance in conditions of variable and cyclic operating modes, typical for construction, agricultural and motor transport equipment. The ability to adapt the parameters of the power plant to real operating conditions allows not only to increase energy efficiency, but also to improve the reliability and durability of the main components. Thus, energy flow control systems are an integral part of modern electrified and hybrid machines and play a key role in achieving the environmental and economic benefits declared in the concept of sustainable development of technical systems.

In the context of ecological transformation, special attention should be paid to the possibility of integrating electrified vehicles with external energy systems, which significantly expands the functional and environmental benefits of their use. Such integration allows us to consider mobile equipment not only as an energy consumer, but also as an active element of the energy infrastructure, capable of interacting with local and centralized sources of electricity supply. For agricultural equipment, integration with energy systems may involve the use of local renewable energy sources, in particular photovoltaic installations, wind generators or bioenergy complexes

located directly on the farm. This creates the prerequisites for the formation of closed energy cycles, within which energy production, storage and consumption are carried out with minimal losses and reduced environmental impact. In addition, such integration increases the energy autonomy of agricultural enterprises and reduces dependence on external energy suppliers. For construction equipment, a promising direction is the connection of electrified machines to temporary or stationary power grids deployed at construction sites. This allows for a reduction in the use of diesel generators, a reduction in noise and emissions in the work area, and an increase in safety and comfort of work. In combination with energy storage systems, such infrastructure provides flexible management of energy consumption of construction equipment, taking into account its operating modes. Road transport, in turn, requires the development of an extensive and standardized charging infrastructure compatible with the requirements of various types of electrified and hybrid vehicles. This includes both public urban charging stations and specialized facilities for commercial and freight transport, as well as integration with intelligent energy networks. Harmonization of charging parameters, data exchange protocols and operating modes of charging systems is a necessary condition for the large-scale implementation of electrified transport and increasing the efficiency of its operation within modern transport and energy systems.

Thus, technical solutions for electrification and hybridization of mobile technical means are complex, multi-component in nature and cover a wide range of interconnected elements, including power plants, energy storage and conversion systems, recuperation means, as well as intelligent energy flow control systems. The efficiency of such machines is determined not by individual technical solutions, but by the level of their integration into a single energy and technologically coordinated system. The use of electrified and hybrid solutions in construction, agricultural and motor transport equipment is based on common principles of increasing energy efficiency and reducing negative environmental impact, but at the same time requires taking into account the industry specifics of operation, operating modes, requirements

for autonomy and interaction with infrastructure. It is the combination of universal technological approaches with adaptation to specific application conditions that determines the practical feasibility and effectiveness of the implementation of electrification and hybridization. In view of this, the need for a systematic analysis of the environmental, technical and economic efficiency of relevant solutions, as well as an assessment of their impact on the structure of energy consumption and operational indicators of mobile technological means, is becoming more urgent. Such an analysis allows us to justify the appropriateness of choosing specific technologies and identify promising directions for their further development.

8.1.3. Environmental and technical and economic efficiency of electrification and hybridization

Evaluating the effectiveness of electrification and hybridization of construction, agricultural and motor transport equipment is a key stage in the scientific justification of the feasibility of their implementation in practical activities. Unlike a purely technical analysis, which focuses mainly on the design and energy parameters of technical means, such an assessment is comprehensive, interdisciplinary and involves simultaneous consideration of environmental, economic and operational indicators:

- the environmental aspect of the assessment includes an analysis of the levels of emissions of pollutants and greenhouse gases, energy consumption during the life cycle of the technical means, as well as the impact on the environment during operation, production and disposal;

- the economic component includes a comparison of capital and operating costs, an assessment of the payback periods of investments, maintenance and repair costs, as well as the dependence of economic efficiency on the modes of use of the equipment;

- operational indicators, in turn, reflect reliability, productivity, adaptability to changing operating conditions and the convenience of integrating new machines into existing production and transport processes.

It is the integration of technical, energy, environmental and economic aspects of the analysis that allows us to form an objective and comprehensive picture of the real advantages and existing limitations of electrified and hybrid technical solutions compared to traditional machines equipped with internal combustion engines. Such a comprehensive approach makes it possible to take into account not only the operational characteristics of individual units and systems, but also the impact of technical solutions on the entire life cycle of machines, including the stages of production, use, maintenance and disposal. The use of integrated analysis creates a methodological basis for a well-founded choice of directions of technical development, allows us to identify the most promising technologies and design schemes, as well as objectively assess the feasibility of their implementation from the point of view of long-term efficiency. In addition, such an approach is a necessary tool for determining investment priorities, since it takes into account not only the initial capital investment, but also the expected operating costs, environmental benefits and potential social effects. In a broader context, a comprehensive assessment of electrified and hybrid vehicles contributes to the development of effective strategies for a gradual transition to more environmentally sustainable transport and technological systems. This allows for the coordinated development of technology, energy infrastructure and the regulatory environment, which is a key prerequisite for the implementation of sustainable development principles in the construction, agriculture and transport sectors.

It is important to note that the environmental impact of electrification and hybridization of technical means should be assessed not only at the level of a single machine or unit, but also taking into account the overall balance of energy consumption and the structure of energy generation. A direct reduction in local emissions during operation does not always fully reflect the real impact on the environment, since a significant part of the environmental load can be transferred to the stage of electricity generation or the manufacture of energy storage devices. And if electricity is used from renewable or low-carbon sources, such as solar, wind, hydropower or nuclear power, total greenhouse gas emissions during the life cycle of the machine can be significantly

reduced compared to traditional technical means equipped with internal combustion engines. In this case, electrified and hybrid solutions are an effective tool for achieving climate goals and reducing anthropogenic impact on the environment. Thus, electrified and hybrid technical means create the prerequisites for a comprehensive reduction of the environmental burden, especially in combination with the development of a sustainable and decentralized energy infrastructure, the introduction of energy storage systems and intelligent management of electricity consumption. At the same time, an objective and scientifically based assessment of the environmental effect requires taking into account the full life cycle of technical means, which includes all stages of their existence - from the extraction of natural resources and the production of structural materials to operation, maintenance, disposal and reuse of components. In this context, the production of battery systems requires special attention, which is accompanied by significant energy consumption, the use of scarce and strategically important materials, as well as the formation of additional environmental burden at the initial stages of the machine's life cycle. These factors can partially offset the environmental benefits of electrification at the early stages of operation. However, provided that the technical equipment has a long service life, high energy efficiency, and electricity is generated from low-carbon sources, the overall environmental impact of electrified and hybrid vehicles remains positive, which confirms the feasibility of their implementation in the long term.

The technical and economic efficiency of electrified and hybrid technical means is determined by the ratio of initial investment costs, operating costs and total economic and functional benefits obtained throughout their service life. This approach involves assessing not only the direct costs of acquiring equipment, but also long-term effects related to energy consumption, maintenance, reliability and environmental impact. As a rule, electric and hybrid machines are characterized by a higher initial cost compared to traditional counterparts, which is due to the more complex structure of power plants, the use of modern power electronics, energy flow control systems and the high cost of batteries. Additional factors contributing to the increase in capital costs are the need to

purchase specialized diagnostic equipment, software, as well as the creation or modernization of infrastructure for charging, maintenance and repair of electrified equipment. At the same time, electrified and hybrid machines, as a rule, demonstrate a significant reduction in current costs during operation. This is achieved primarily due to the lower cost of electricity compared to traditional types of motor fuel, as well as due to the higher efficiency of electric drives. A significant role is also played by the reduction in maintenance and repair costs, which is associated with a smaller number of moving and wear parts, the absence of complex lubrication, gas distribution and cooling systems typical of internal combustion engines. In addition, the reduced thermal and mechanical load on the main components of electric and hybrid power plants contributes to their increased reliability and increased service intervals, which has a positive effect on the overall economic efficiency of operation. This is especially important for construction and agricultural machinery, which often operates under conditions of high loads, dustiness, variable modes and long operating cycles.

In conclusion, despite the increased initial investment, electrified and hybrid vehicles can provide economic feasibility in the medium and long term by reducing operating costs, increasing reliability and meeting modern environmental requirements. This makes them an important element of the strategy for modernizing technical fleets and transitioning to more efficient and sustainable transport and technological systems.

The technical and economic efficiency of electrified and hybrid technical equipment is significantly affected by the conditions of their use and the nature of operation. With high intensity of work, significant annual operating hours and a long service life, the accumulated savings on fuel, energy consumption and maintenance can compensate for the increased initial investment costs, providing acceptable or even reduced payback periods for the invested funds. In such conditions, electrified and hybrid machines demonstrate the greatest economic effect compared to traditional equipment. Operating modes and the specifics of the operations performed also play an important role. Machines operating in cyclic or alternating modes with frequent

starts, stops and partial load modes, as a rule, receive additional benefits from the use of electric drives and hybrid power plants. This is due to the high efficiency of electric motors in a wide range of loads and the possibility of using energy recovery, which contributes to a further reduction in energy costs. For hybrid vehicles, an additional advantage is high operational flexibility, which allows adapting the operation of the power plant to different conditions and operating modes. The combination of electric and traditional drives reduces dependence on the level of development of the charging infrastructure, ensures autonomy in remote areas and increases the reliability of the operation of technical means in the event of limited access to electricity sources. Thus, the technical and economic feasibility of implementing electrified and hybrid solutions is determined not only by the totality of their technical and economic characteristics, but also by the specifics of operating conditions, the scale and intensity of use, as well as long-term strategic goals for the development of transport and technological systems. Taking into account these factors allows you to reasonably choose the optimal directions for the modernization of technical parks and form effective strategies for the transition to more energy-efficient and environmentally sustainable solutions.

In construction equipment, the economic effect of electrification and hybridization is particularly pronounced in conditions of long operating cycles, which are characterized by frequent stops, starts, reversing of movement and significant load fluctuations. It is in such modes that traditional internal combustion engines operate with reduced efficiency, which leads to increased fuel consumption and increased wear of the main units. In contrast, electric and hybrid power plants are able to quickly adapt to variable operating modes, ensuring more rational use of energy. The use of an electric drive allows for a significant reduction in fuel consumption due to the high efficiency of electric motors in a wide range of loads, the use of energy recovery systems during braking and lowering of loads, as well as optimization of the operating modes of the internal combustion engine in hybrid machines. As a result, the overall energy consumption of the equipment is reduced and operating costs are reduced, which is especially important during intensive and long-term operation of construction

machines. In addition to the direct economic effect, the electrification of construction equipment provides a number of additional indirect benefits. These include a significant reduction in noise and vibration levels, which has a positive effect on the working conditions of operators, reduces their fatigue and increases work productivity. Improving ergonomic and sanitary-hygienic conditions helps reduce industrial injuries and costs associated with downtime of equipment and personnel. It should be noted separately the possibility of performing construction work in areas with increased environmental requirements, in particular in dense urban areas, near residential areas, educational, medical and social facilities. The reduction in noise levels and the absence of local emissions of pollutants expand the temporal and spatial boundaries of the use of equipment, which increases the flexibility of the organization of construction processes. A significant part of the listed benefits has an indirect economic effect, which is difficult to formalize in the form of direct financial indicators, but it significantly affects the overall efficiency of the use of construction equipment, the competitiveness of enterprises and compliance with modern environmental and social requirements.

In agriculture, electrified and hybrid technical means create the prerequisites for a significant reduction in energy costs, thanks to a more rational and adaptive use of energy during technological operations. The high efficiency of electric drives allows you to optimize the operation of working bodies in different modes, reduce fuel consumption and reduce wear and tear of key equipment components. One of the important advantages is the possibility of integration with local power supply sources, including renewable energy installations - solar panels, wind generators, biogas and mini-hydroelectric power plants. This allows you to partially or fully compensate for the costs of traditional fuels, reducing dependence on external energy suppliers and increasing the energy autonomy of agricultural enterprises. In addition, hybrid power plants provide flexible adaptation to variable loads characteristic of field work, such as plowing, sowing, spraying, transporting crops and working in warehouses. This allows maintaining optimal engine operating modes, reducing specific operating costs and

increasing the productivity of technical equipment. The economic advantages of electrified and hybrid equipment become especially noticeable in the long term, when the benefits from reducing fuel costs, maintenance and repair, as well as from increasing the reliability and service life of machines accumulate. As a result, the implementation of such solutions contributes to the economic stability and sustainability of agricultural enterprises, increases the efficiency of agricultural production and creates conditions for the integration of modern environmentally friendly technologies into the agricultural sector.

In the automotive sector, the use of electric drives allows you to optimize the operation of wheel drives, gearboxes and working systems, reduce energy losses and increase the efficiency of the power plant. One of the key advantages is the ability to connect to local electricity sources, including renewable or low-carbon systems, such as solar charging stations, wind generators or low-emission city power grids. This allows you to partially or completely reduce dependence on traditional fuel resources, which is especially important for urban transport, logistics operators and companies engaged in long-distance transportation. Hybrid vehicles provide additional flexibility of operation, as they combine the advantages of an internal combustion engine and an electric drive. In urban routes with frequent stops and starts, the electric motor provides most of the driving cycles, while the internal combustion engine operates in optimal modes, feeding the batteries or connecting to the drive wheels at high loads. This system allows you to reduce fuel consumption, reduce CO_2 and harmful gas emissions, as well as reduce wear and tear of components and assemblies. Electrified and hybrid vehicles also improve the working conditions of drivers and technical personnel by reducing noise, vibration and heat load. In addition, such equipment allows you to work in areas with strict environmental restrictions - in city centers, residential areas, near schools, hospitals and social facilities, which expands the flexibility of transportation organization. In general, the long-term economic effect of the introduction of electrified and hybrid vehicles is formed by a comprehensive reduction in operating

costs, optimization of energy consumption, reduction in the frequency and cost of repairs, as well as increasing the reliability and service life of the fleet.

An important aspect of assessing the effectiveness of electrification and hybridization is their impact on the operational characteristics of technical equipment, which directly determine the suitability of machines for long-term and intensive use in real conditions. Key operational indicators include reliability, maintainability, adaptability to variable operating modes, as well as convenience and safety of use for service personnel. These parameters largely shape the total costs during the life cycle of technical equipment and affect the effectiveness of its application in a particular industry. Experience in operating electric and hybrid machines indicates the potential for increasing the reliability of power plants by reducing the mechanical and thermal load on the main components. Electric drives lack many elements characteristic of internal combustion engines that are prone to intensive wear, such as gas distribution, lubrication and fuel supply systems. In hybrid systems, optimizing the operating modes of the internal combustion engine allows you to reduce the frequency of its starts and operation in adverse modes, which has a positive effect on the durability of the units. At the same time, electrification leads to the emergence of new requirements for the organization of technical maintenance and repair. The use of high-voltage electrical systems, power electronics and batteries requires specialized equipment, compliance with increased safety requirements and the involvement of personnel with appropriate qualifications. This necessitates the adaptation of technical service systems, the development of new maintenance regulations and the implementation of training and retraining programs for personnel.

The adaptability of electrified and hybrid machines to changing operating conditions is largely determined by the efficiency of control systems that allow them to respond flexibly to changes in load, road or technological conditions. Combined with the high controllability of the electric drive, this increases the stability of work processes and operating comfort. At the same time, these features must be taken into account in economic calculations, since the costs of personnel training, updating

service infrastructure and implementing new technologies are an integral part of the overall assessment of the effectiveness of electrification and hybridization of technical means.

Special attention in the process of assessing the feasibility of introducing electrified and hybrid technical means should be paid to socio-economic effects that go beyond traditional financial calculations. Reducing the level of noise, vibrations and emissions of harmful substances during operation has a positive effect on the working conditions of operators, reduces the level of occupational risks and contributes to improving the sanitary and hygienic indicators of the working environment. This is especially relevant for construction and motor transport equipment used within urban areas or in close proximity to residential and public facilities. For the population of urban and suburban areas, the introduction of electrified machines means reducing noise pollution, improving air quality and, as a result, reducing negative health impacts. Although these effects cannot always be directly expressed in the form of economic indicators, they have long-term social significance and contribute to increasing the attractiveness of territories for living and conducting business. In a broader context, such changes can lead to a reduction in healthcare and social infrastructure costs. In addition, the development of electrified and hybrid technology stimulates the formation of new areas of economic activity related to the production, maintenance and disposal of battery systems, power electronics and charging infrastructure. This creates additional jobs and increases the need for specialists with new competencies, which has a positive impact on the labor market and the vocational education system. Thus, the socio-economic effects of electrification and hybridization of technical means are an important component of the concept of sustainable development and should be taken into account during strategic planning of the development of transport and technological systems.

Thus, the environmental and technical and economic efficiency of electrified and hybrid technical means is formed under the influence of a complex of interrelated factors, among which the level of harmful emissions, energy consumption indicators,

total costs during the life cycle, as well as operational and reliability characteristics of the equipment play a key role. A comprehensive assessment of these parameters allows us to objectively compare traditional and innovative power plants, determine the potential advantages of electrified and hybrid solutions, and also outline the existing technical and economic limitations of their implementation. The results obtained indicate the validity and prospects of a phased transition to the use of electrified and hybrid technologies in construction, agricultural and transport equipment. At the same time, they emphasize the need for further improvement of battery systems, power electronics, control algorithms, as well as the development of charging and service infrastructure. The implementation of these measures creates the prerequisites for increasing energy efficiency, reducing negative environmental impact, and forming long-term strategic directions and forecasts for the development of technical systems on the basis of sustainable development.

8.1.4. Prospects for further development and integration of electrified technology

The further development of electrification and hybridization of construction, agricultural and motor transport equipment is determined by a set of technological, energy and socio-economic factors that interact with each other and form a new paradigm for the development of mobile technical equipment. At the present stage, these processes are gradually going beyond local experimental or pilot projects and are becoming systemic, covering wide classes of machines, infrastructure solutions and organizational approaches to their operation. Technological progress in the field of battery systems, power electronics, electric drives and digital control systems creates the prerequisites for increasing the reliability, efficiency and versatility of electrified equipment. In parallel, the development of energy infrastructure is taking place, in particular smart grids, energy storage systems and renewable sources, which provides the possibility of integrating mobile machines into the overall energy balance of enterprises and regions. In this context, electrified equipment is considered not only as

an energy consumer, but also as an active element of energy systems, capable of interacting with them in a two-way mode.

Socio-economic factors, in particular, increasing environmental requirements, the rise in the cost of traditional energy sources and the focus on sustainable development principles, further stimulate the spread of electrified and hybrid solutions. In this regard, it is advisable to consider the prospects for the development of electrified technology not only from the perspective of improving individual machines or their components, but also in the context of deep integration with production processes, logistics chains and energy infrastructure. It is this systemic approach that allows us to fully realize the potential of electrification and ensure the sustainable development of transport and technological systems in the long term.

One of the key areas of further development of electrification and hybridization of mobile technical means is the improvement of energy storage systems, which largely determine the operational capabilities and economic feasibility of their use. Increasing the energy capacity of batteries allows to increase the range and duration of autonomous operation of machines without recharging, which is especially relevant for heavy construction and agricultural machinery with high energy needs. At the same time, increasing the life of batteries and reducing the rate of their degradation contribute to extending the service life of energy systems and reducing costs during the life cycle of technical means. Reducing the specific cost of batteries is another important factor that opens up opportunities for large-scale implementation of fully electric machines in industries where their use was previously economically limited. The development of new chemical systems, improving production technologies and material reuse create the prerequisites for increasing the availability of electrified equipment and reducing dependence on critical raw materials.

In parallel with the improvement of traditional battery technologies, alternative energy solutions are actively developing, in particular hydrogen systems using fuel cells, which provide high energy density and rapid replenishment of energy reserves. Such systems are considered a promising direction for equipment with large ranges and

long operating cycles. In addition, new generation hybrid circuits are becoming widespread, combining several types of energy storage devices, such as batteries and supercapacitors, in order to ensure high power, flexibility and reliability of operation under variable load conditions. The combination of these development directions forms the technological basis for further expansion of the scope of application of electrified and hybrid technical means in various sectors of the economy.

An important prospect for further development is the deepening integration of electrified technical means with renewable energy sources, which corresponds to the general logic of decentralization of energy supply and the transition to low-carbon energy systems.

In agriculture, such integration opens up opportunities for the formation of local energy complexes, within which electrified equipment interacts with solar, wind or bioenergy installations, using the energy produced directly at the place of its generation. This allows reducing the load on external power grids, increasing the energy autonomy of farms and reducing energy costs, while simultaneously reducing the carbon footprint of production processes.

In the construction industry, similar approaches can be implemented on temporary construction sites, where the use of autonomous or hybrid power sources based on renewable resources creates the prerequisites for environmentally friendly organization of work. The use of mobile solar power plants, battery energy modules or combined systems with backup generators allows to significantly reduce dependence on traditional energy carriers, limit pollutant emissions and noise pollution, which is especially relevant in urban conditions. In a broader context, such integration contributes to the formation of flexible energy solutions, in which electrified machines are considered not only as consumers, but also as active elements of the energy system, capable of participating in balancing and increasing the sustainability of energy supply.

The development of digital technologies and intelligent control systems is another strategic direction that directly determines the prospects for the electrification and hybridization of mobile technical equipment. The introduction of telematics systems,

means of collecting and analyzing operational data, as well as digital models of machines allows for constant monitoring of the technical condition, energy consumption and operating conditions in real time. Based on the information obtained, it becomes possible to apply predictive control methods that take into account not only current loads, but also expected operating modes, driving routes or technological cycles. The use of adaptive control algorithms for power plants and energy storage systems contributes to the optimal distribution of energy flows between the electric drive, batteries and, in the case of hybrid schemes, the internal combustion engine. This ensures an increase in overall energy efficiency, a reduction in losses during energy conversion and an extension of the resource of battery systems by preventing their overload and deep discharge cycles. At the same time, the intensity of wear of the main components is reduced, which has a positive effect on reliability and reduces operating costs.

In the future, the development of digital technologies creates the prerequisites for the formation of integrated platforms for managing technical fleets for various purposes, within which individual machines are considered as elements of a single cyber-physical system. Such platforms can provide coordination of the work of electrified machines, optimization of charging schedules, interaction with energy infrastructure and renewable energy sources, as well as support for management decisions at the strategic level. As a result, digitalization is not only a tool for increasing the efficiency of individual technical means, but also a key factor in the systemic transformation of industries in which electrified and hybrid technology is being introduced.

The formation of an appropriate infrastructure is essential for the further development of electrified technology, without which its full potential cannot be fully realized. For road transport, the key tasks are the expansion and spatial balancing of the network of charging stations, the introduction of high-speed and ultra-high-speed charging modes, as well as the standardization of interfaces and data exchange protocols between the vehicle and the charging equipment. This ensures the

compatibility of equipment from different manufacturers, increases ease of use and reduces barriers to the mass introduction of electrified transport. In construction and agricultural machinery, infrastructure solutions must take into account the specifics of dispersed and often temporary places of operation. Mobile charging complexes, autonomous power plants, as well as modular battery systems with the ability to quickly replace or rotate energy storage devices without long machine downtimes are promising in this context. This approach allows you to ensure the continuity of production processes and flexibly adapt electrified equipment to changing operating conditions. In addition, infrastructure development involves the integration of charging and energy systems with the general energy network and local power supply sources, which is especially relevant for agricultural enterprises and construction sites. In the long term, infrastructure development should be considered as a component of a single technical and energy ecosystem, within which electrified equipment, energy resources and control systems operate in harmony, ensuring high efficiency, reliability and minimal environmental impact.

The prospects for electrification also depend to a large extent on the regulatory and economic environment that creates the conditions for making investment and technological decisions. The introduction of incentive mechanisms, in particular tax breaks, subsidies, state support programs or preferences for environmentally friendly equipment, can significantly reduce the payback period of electrified and hybrid machines and increase their attractiveness for end users in the construction, agricultural and transport industries. Such tools are especially important in the initial stages of introducing new technologies, when the market value of equipment is still relatively high. At the same time, strengthening environmental requirements and the gradual introduction of more stringent standards for pollutant emissions, noise levels and energy efficiency create additional prerequisites for the transition to electrified solutions. In this context, the harmonization of technical standards, safety regulations and electromagnetic compatibility requirements will contribute to the unification of design approaches, reducing the number of options for specialized solutions and, as a

result, reducing the costs of development, certification and serial production of electrified vehicles. In addition, a stable and predictable regulatory framework is an important condition for long-term planning of production and infrastructure development. The coherence of state policy in the areas of energy, transport and environmental protection allows creating systemic incentives for innovation, supporting research and development and ensuring a gradual, economically justified transition to electrified and hybrid vehicles as part of a sustainable development strategy.

In the long term, electrified and hybrid technical means have the potential to become the basis of integrated transport and technological systems, in which construction, agricultural and motor transport equipment operate in a single energy and information space. This approach involves coordinated management of energy consumption, machine operating modes and logistics flows using digital platforms, monitoring systems and real-time data exchange. As a result, individual technical means cease to be considered as autonomous units and become elements of an integrated system focused on increasing the overall efficiency of production and transport processes. The integration of electrified equipment with the energy infrastructure, in particular with renewable energy sources and storage systems, creates the prerequisites for a more rational use of resources and reducing peak loads on the power grid. In the conditions of construction sites or agricultural enterprises, this allows the formation of local energy clusters, within which the production, storage and consumption of electricity are optimized taking into account the real needs of the equipment. For transportation systems, such integration contributes to increased throughput, reduced downtime, and more efficient route planning.

The synergistic effect of the implementation of integrated transport and technological systems is manifested in the reduction of total energy consumption, reduction of pollutant emissions and optimization of logistics processes at the inter-sectoral level. At the same time, the resistance of such systems to external influences increases, in particular, fluctuations in energy prices and increased environmental

requirements. Taken together, this creates the prerequisites for the formation of a new model of technical equipment functioning, combining economic feasibility, environmental responsibility and technological flexibility.

Thus, the further development of electrified technical means is directly related to the comprehensive improvement of key components, in particular energy technologies, element base, charging and service infrastructure, as well as intelligent control and monitoring systems. The introduction of modern electric drives and hybrid power plants opens up new opportunities for increasing energy efficiency, reducing harmful emissions and improving the operational characteristics of technical means. The transition to electrified and hybrid technology is considered one of the priority strategic directions for the modernization of the construction, agricultural and transport industries, which is fully consistent with the concept of sustainable development and modern environmental requirements. Concluding this section, it should be emphasized that the practical implementation of the outlined prospects is possible only if a systemic and interdisciplinary approach is applied. This approach should combine fundamental and applied scientific research, engineering and technological developments, as well as a coordinated state policy aimed at supporting innovation, developing infrastructure and stimulating the ecological transformation of technical means. Only with the interaction between science, industry and government bodies is it possible to form an effective and competitive system of electrified technology in the long term.

Summary and conclusions.

Within the framework of this section, a comprehensive analysis of the prerequisites, technical solutions, efficiency and prospects for the development of electrification and hybridization of technical means in construction, agriculture and road transport has been carried out. The results obtained allow us to formulate a number of generalized provisions that reflect the current state and strategic directions of the ecological transformation of mobile equipment.

It has been established that the ecological transformation of technical means is due to a set of interrelated factors, among which the most important are the growth of anthropogenic load on the environment, increased environmental requirements for mobile equipment, and the need to increase the energy efficiency of production and transport and technological processes. Electrification and hybridization are key tools for implementing the concept of sustainable development.

It is shown that technical solutions for electrification and hybridization have a universal technological basis, suitable for use in construction, agricultural and transport equipment, but require adaptation taking into account the industry-specific operating modes. The combination of electric drives, energy storage and recovery systems, as well as intelligent control creates the prerequisites for a significant increase in the energy efficiency of mobile machines.

It has been proven that the environmental efficiency of electrified and hybrid technical means is manifested in the reduction of pollutant emissions and noise levels during operation, especially in conditions of intensive use and operation in environmentally sensitive areas. At the same time, an objective assessment of the environmental effect requires taking into account the full life cycle of the equipment, including the stages of production and disposal of energy components.

It has been established that the technical and economic feasibility of electrification and hybridization is determined not only by the initial investment costs, but also by the total life cycle costs. Under conditions of intensive operation and the availability of appropriate infrastructure, electrified and hybrid vehicles demonstrate the potential to reduce operating costs and increase reliability, which compensates for their higher initial cost.

It is substantiated that the further development of electrified technical means should be in the direction of integration with renewable energy sources, digital control systems and unified transport and technological systems. This approach ensures the achievement of a synergistic effect and creates conditions for a systematic reduction of the environmental load in construction, agriculture and transport.

It is summarized that the electrification and hybridization of mobile technology is not a temporary technological trend, but a strategic direction of modernization of technical means, which requires interdisciplinary scientific research, coordinated engineering solutions and targeted state policy. The implementation of these approaches creates the basis for the formation of environmentally friendly and energy-efficient technical systems of a new generation.

SECTION 9. SOFTWARE ENGINEERING

DOI: 10.46299/ISG.2026.MONO.TECH.1.9.1

9.1 Analysis of graphics pipeline performance scaling weaknesses

Considering the specifics of rendering three-dimensional images, graphics processors are computing systems whose architecture is oriented towards parallel computing in real time. Due to the increase in the number of cores, the complexity of the graphics pipeline and the use of SIMD architecture [276], the performance of graphics cards has grown much faster than the performance of central processors. The main goal was to involve hardware parallelism [277], which provides greater performance when rendering complex scenes.

However, practical experience with graphics engines and the results of numerous experimental studies indicate that performance increases are not linear. More complex scenes or increased image quality have a lower performance gain than expected given the hardware capabilities. This is evidence of the presence of system limitations of the graphics pipeline that cannot be eliminated by increasing computing power.

Typically, the reasons for poor scaling efficiency are attributed to individual hardware limitations, such as memory bandwidth, the number of final merge blocks, or limitations of the rasterization subsystem. However, this approach analyzes bottlenecks separately, i.e. without considering the interconnection between the stages of the graphics pipeline. As a result, optimizations are aimed at local improvements in one of the stages.

This paper proposes a systematic approach to analyzing the performance of the graphics pipeline. Bottlenecks are considered because of the action of various factors. Special attention is paid to the fragment shader, which in many practical scenarios becomes the main performance limitation. It is shown that the poor parallelization efficiency at this stage is due not so much to the hardware characteristics of the GPU, but to the performance of many redundant calculations.

The purpose of this article is to analyze the weaknesses of scaling the performance of the graphics pipeline, considering the interaction of its stages and the nature of the calculations performed. The paper examines the main sources of performance degradation at different stages of rendering, investigates the impact of logical redundancy on the effectiveness of parallelization, and justifies the feasibility of software approaches to reducing redundant calculations as a key direction for increasing performance.

9.1.1. General architecture of the graphics pipeline

Modern graphical software interfaces implement a step-by-step model of graphic data processing, within which the image formation process is divided into a certain sequence [278]. Each stage performs a specific function and passes the results to the next, forming a graphic pipeline. Shown in Figure 1.

The initial stage is the generation of rendering commands on the CPU side. This step prepares and passes commands from the CPU to the graphics card, including geometry descriptions, pipeline states, resource bindings, and primitive display calls. Although this stage does not perform any direct graphics calculations, it determines the order and structure of further data processing.

The next stage is the vertex stage, which processes individual vertices of primitives. Typical operations of this stage are geometric coordinate transformations, calculation of auxiliary attributes, and data preparation for the formation of graphic primitives. The vertex stage is characterized by a high degree of data processing independence and lends itself well to parallelization.

Next, the formation of graphic primitives and their clipping by the volume of visibility occurs. At this stage, the vertices are grouped into primitives - triangles, while primitives that completely or partially go beyond the visibility area are modified or discarded.

The step of rasterization transforms geometric primitives into a set of fragments that correspond to potentially painted pixels on the screen. This step determines the

coverage of pixels by primitives and interpolates attributes in screen space. Rasterization is a key step that connects the geometric description of a scene with the discrete nature of the image.

Fragment shading performs color and other parameter calculations for each generated fragment. This stage applies lighting models, material properties, texture sampling, and other calculations that directly shape the visual quality of the image.

The fragment shading results then go through depth testing, color blending, and writing to output buffers. These operations determine which fragments make it into the final image, as well as the order and how they are combined with the data already in the frame buffer.

The final stage is the formation of a frame in the frame buffer, which is displayed on the screen or transmitted for further processing. As a result of passing through all these stages, the final image is formed, which is the result of the joint work of the software and hardware components of the graphics pipeline.

The described model is generalized and does not take into account specific optimizations or extensions of specific graphical programming interfaces, but it provides the necessary basis for further analysis of the weaknesses and limitations of scaling the performance of graphics cards.

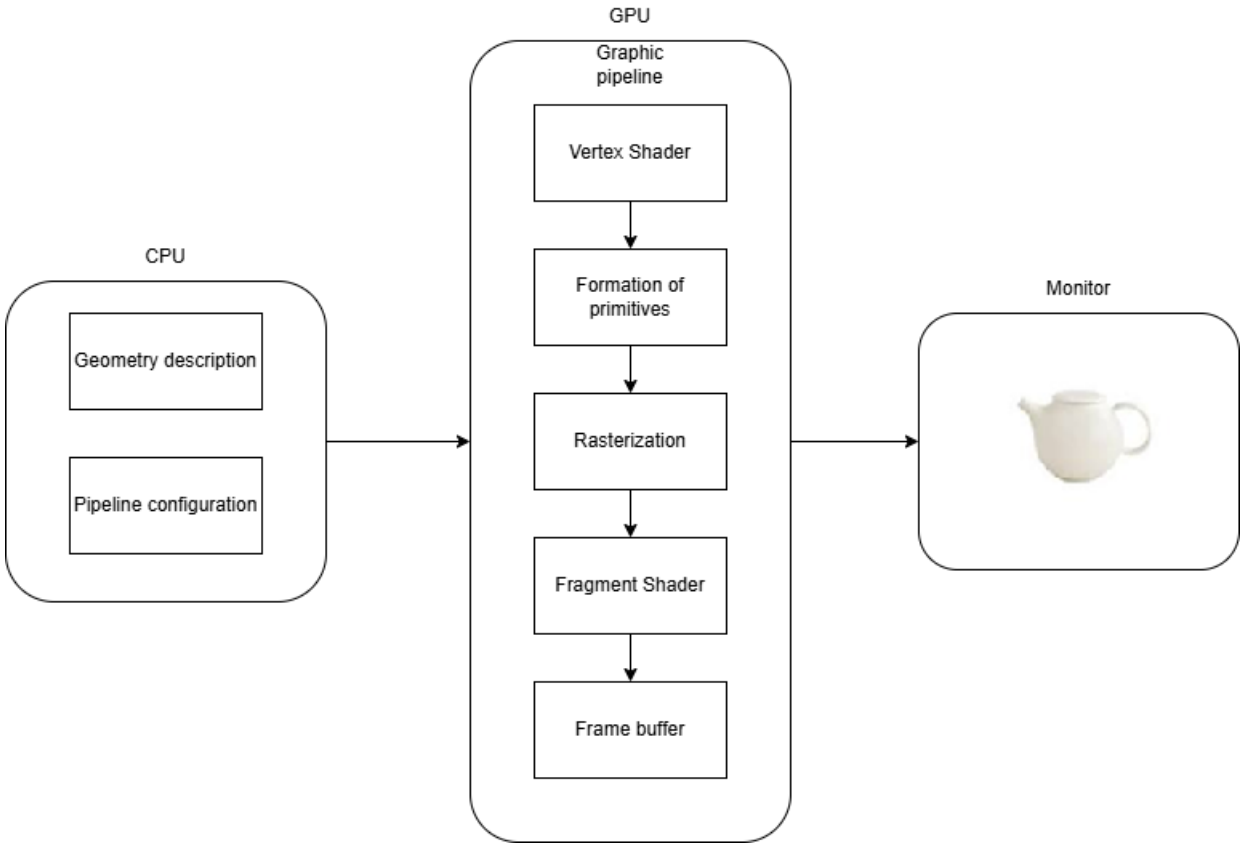


Figure 1. General architecture of the rendering process.

9.1.2. Parallelism in the graphics pipeline

The high performance of modern graphics processors is achieved primarily due to massive parallelism, which is implemented at almost all stages of the graphics pipeline. The main model for performing calculations is the SIMD/SIMT approach, the essence of which is that many threads execute the same instructions operating on different data sets [276]. This model is especially effective for tasks with a regular structure and the absence of dependencies between data elements.

Within the graphics pipeline, parallelism is implemented both at the data processing level and at the level of specialized hardware blocks. Vertex and fragment shaders are implemented as programmable stages that operate on arrays of independent elements – vertices and fragments, respectively. Each such stage is capable of simultaneously processing thousands of elements, which creates the impression of almost unlimited parallelism.

Along with the programmable stages, fixed hardware blocks play a significant role, in particular, rasterization, attribute interpolation, depth testing, and result fusion modules. These components are optimized to perform specific operations and provide high throughput at minimal cost. At the same time, their functionality is rigidly specified and not subject to software control [279].

Despite the availability of significant computing resources, the real efficiency of parallelization depends significantly on the nature of the calculations being performed. Theoretical parallelism, which is determined by the number of available computing blocks and threads, does not always translate into effective parallelism, which manifests itself in the form of a proportional increase in performance. The main factors that reduce the efficiency of parallel execution are uneven load, thread divergence, competition for shared resources, and the need to serialize individual operations.

A feature of the graphics pipeline is that its different stages have different natures of parallelism. For example, the vertex stage is characterized by high regularity of calculations and a minimum number of dependencies, which provides close to linear scaling. On the other hand, the fragment stage, despite the formal independence of fragments, often suffers from logical redundancy of calculations, spatial unevenness and interaction with memory and final merge blocks, which reduces the real efficiency of parallelization.

Thus, the presence of massive hardware parallelism does not guarantee a corresponding increase in performance. To correctly analyze the bottlenecks of the graphics pipeline, it is necessary to distinguish between theoretical parallelism, which is determined by the GPU architecture, and actual parallelism, which is formed by the nature of the algorithms and the organization of calculations at different stages of the pipeline. This distinction is key for further analysis of bottlenecks.

9.1.3. Analysis of bottlenecks at different stages of the graphics pipeline

The performance of a graphics pipeline is determined not by individual processing stages, but by their interaction within the entire pipeline. Even with a high

level of parallelism at each stage, the overall system performance can be significantly limited due to uneven load distribution, serialization of individual operations, or redundant calculations arising from the peculiarities of the rendering organization.

Unlike the localized approach, in which bottlenecks are analyzed separately, for example, only at the fragment shader or memory bandwidth level, in this paper, bottlenecks are considered as a systemic phenomenon that is formed due to the cascading action of several stages of the graphics pipeline. Limitations that arise in early stages can lead to the generation of excess work in later stages, amplifying the overall effect of performance degradation.

The feature of the graphics pipeline is the combination of programmable and fixed hardware stages, each of which has its own parallelism and its own limitations. As a result, the overall performance is determined not by the maximum capabilities of individual components, but by the minimum bandwidth between them. This effect is consistent with the classical provisions of the theory of parallel computing, in particular with Amdahl's law, according to which even a small sequential part of the calculations can significantly limit scaling [280].

The analysis begins with the CPU-side instruction generation stage and includes vertex processing, primitive generation, rasterization, fragment shading, as well as the depth testing, color blending, and frame buffer writing stages. For each stage, the typical causes of reduced parallelization efficiency and their impact on overall system performance are identified.

This approach allows not only to identify individual bottlenecks, but also to show their interdependence, which is a prerequisite for substantiating software optimization methods aimed at reducing logical redundancy of calculations and increasing the efficiency of using hardware parallelism of the graphics card.

9.1.3.1. Bottlenecks at the team formation stage

The first potential bottleneck in the graphics pipeline is the stage of generating and transmitting rendering commands from the CPU to the GPU. Although the main

calculations are performed on the GPU, the CPU is responsible for preparing the graphics commands, describing the pipeline states, and binding the necessary resources. The limitations at this stage are often logical in nature and are not directly related to the computing power of the hardware components.

One of the key factors is the overhead associated with the large number of display calls - commands that come from the CPU to the GPU. Each call requires checking the correctness of the states, preparing the parameters and passing the command to the GPU driver. If there is a scene consisting of many small objects or materials, the number of such calls can reach tens or hundreds of thousands per frame, which leads to a significant increase in the load on the CPU without a proportional increase in the amount of useful work on the GPU. A potential solution to this problem is to optimize the scene, namely, to reduce the number of objects to display or to simplify the objects themselves.

An additional source of limitations is serialization within the graphics driver. Even in the case of a multithreaded application, some of the instruction preparation and state management operations remain serialized. This limits the ability to effectively utilize multicore CPUs and leads to a situation when increasing the number of threads on the application side does not provide the expected performance gain.

The limitations of CPU multithreading are closely related to the architectural features of graphics APIs. Traditional programming interfaces such as OpenGL have historically focused on performing most operations in a single context, which makes it difficult to scale instruction preparation. Even in more modern APIs that support multithreaded instruction generation, much of the state and resource management logic remains centralized.

The number and frequency of pipeline state changes and resource bindings also play an important role. Switching shaders, textures, buffers, or rendering parameters requires additional checks and synchronization, which increases the load on the CPU. Without effective grouping of objects by state, such operations can become the dominant factor in reducing performance.

Thus, the performance degradation at the CPU-to-GPU instruction handoff stage is largely software-based and arises from the way the rendering code is structured, the number of rendering calls, and state management, rather than from hardware performance limitations of the GPU. Eliminating or reducing this bottleneck requires not hardware changes, but optimization of the rendering structure and rational organization of instruction preparation.

9.1.3.2. Top-down stage: possibilities and limitations of parallelization

The vertex stage of the graphics pipeline is one of the most parallelized components of modern graphics cards. The main reason for this is the complete independence of vertex processing: each vertex of a primitive can be processed in parallel, without the need for synchronization with other vertices. This property is ideally consistent with the SIMD and SIMT execution models and allows for efficient use of arrays of GPU cores [276].

Typical vertex stage operations include geometric transformations, auxiliary attribute calculations, and data preparation for subsequent stages. These procedures are regular in nature and do not require access to shared resources with strict order requirements. Due to this, vertex shaders typically exhibit near-linear performance scaling with increasing number of available GPU compute units.

In practical scenarios, the vertex stage rarely becomes the main bottleneck of the graphics pipeline. Even in scenes with a lot of geometry, the increase in computational complexity of the vertex shader is usually compensated by the high GPU bandwidth and efficient caching of vertex data. In addition, vertex reuse via indexed buffers further reduces the load on this stage.

The vertex stage can only cause latency under specific conditions. These include extremely high geometry density, complex deformation algorithms such as multiple skinning or morphing, and inefficient vertex access management that results in frequent cache misses. However, even in these cases, the problem is usually local and can be fixed by optimizing the geometric representation or simplifying vertex calculations.

Thus, the vertex stage, despite its importance in the graphics pipeline, is not the key factor limiting the scaling of GPU performance in most practical applications. Its high level of effective parallelism contrasts with the subsequent stages of the pipeline, where the logical and organizational features of data processing led to much more pronounced delays. It is these stages that are of primary interest for further analysis.

9.1.3.3. Constructing Primitives and Clipping

The stage of primitive formation and their visibility clipping is an intermediate link between vertex processing and rasterization. At this stage, individual vertices are grouped into graphic primitives, most often triangles, after which their belonging to the visibility region is checked. Although this stage is implemented in hardware and is characterized by high throughput, it can be a source of indirect performance limitations [279].

One of the key challenges at this stage is the processing of many small triangles. In modern scenes, especially when using detailed models or tessellation algorithms, the size of individual triangles when projected onto the screen can be commensurate with the size of a pixel or even smaller. Such primitives are often called microprimitives. Despite their small area coverage, each of them undergoes a full processing cycle in the graphics pipeline.

The peculiarity of microprimitives is that they create significant overhead in stages that do not scale proportionally to the coverage area. Primitive generation, boundary condition calculations, and preparation for rasterization are performed regardless of how many pixels will ultimately be painted. As a result, a significant amount of computational work is spent on primitives that make minimal or zero contribution to the final image.

The negative impact of this phenomenon is not so much at the primitive assembly stage itself, but at the subsequent stages of the graphics pipeline. Many small triangles lead to an increase in the number of rasterization calls, fragment generation, and fragment shader launches. Even if an individual primitive covers only one or a few

pixels, it causes additional load on the fragment stage, the depth testing system, and the result merging blocks.

Thus, primitive construction and clipping are sources of cascading performance improvements, in which local redundancy at an early stage leads to a disproportionate increase in computational load at later stages of the pipeline. In this case, the bottleneck is not localized directly at the primitive generation stage but manifests itself in the form of a decrease in the efficiency of parallelization of fragment shading and result recording operations.

Introducing the concept of cascading performance degradation is important for further analysis, as it helps explain why optimizing individual stages, such as the fragment shader, does not always lead to the expected performance increase. Eliminating or mitigating such limitations requires considering the relationship between the stages of the graphics pipeline, rather than an isolated approach to optimization.

9.1.3.4. Rasterization as a generator of redundant work

The rasterization stage performs the transformation of geometric primitives into a set of fragments corresponding to discrete screen elements. At this stage, the coverage of pixels by primitives is determined, and data is also prepared for subsequent fragment shading. Rasterization is implemented by hardware fixed blocks of the GPU and is characterized by high throughput. However, it is at this stage that a significant part of the redundant work is formed, which subsequently becomes a source of performance limitations.

Coverage generation is a geometric operation that determines which pixels or screen samples are covered by each primitive. An important feature of this process is that it is independent of the complexity of the fragment shader. Each triangle, no matter how large or how prominent it is in the final image, triggers the process of generating fragments for all covered pixels.

The consequence of this approach is the phenomenon of overdrawing - multiple drawings of the same pixel with different primitives. In scenes with complex geometry or a significant number of overlaps, the number of generated fragments can exceed the number of pixels in the final image by many times. In this case, hardware rasterization does not distinguish between fragments that will eventually become visible and those that will be discarded at later stages of depth testing or overlapped by other primitives.

An additional factor in the increase in the number of fragments is the use of multi-sample anti-aliasing. In this mode, each pixel is represented by several samples, for which the coverage is determined separately. Although MSAA improves the visual quality of the image, it also leads to a multiple increase in the number of operations associated with the generation of coverage, depth testing and recording of results. Thus, even with the same scene geometry, the overall load on the later stages of the pipeline can increase significantly.

A key feature of rasterization is that the number of generated fragments is determined primarily by the geometric properties of the scene, rather than directly by the quality or complexity of the final image. Two visually similar frames can require radically different amounts of computation at the fragment stage, depending on the number of overlaps, the size of the primitives, and the order in which they are processed. In this sense, rasterization acts as a mechanism that converts local geometric features of the scene into a global increase in computational load.

Thus, rasterization, despite its hardware efficiency, is a key generator of redundant work in the graphics pipeline. It creates a stream of fragments, the number of which can significantly exceed the minimum required to form the final image. It is this stream of redundant fragments that enters the fragment stage, where logical redundancy of calculations becomes the main factor in reducing the efficiency of parallelization.

9.1.3.5. Fragment stage as a concentrator of parallelization constraints

The fragment stage of the graphics pipeline is the stage where the consequences of the limitations formed in the previous stages converge. It is here that the excess number of fragments generated during the rasterization process is transformed into a significant amount of computational load. Despite the high level of hardware parallelism, fragment stage often becomes the main bottleneck when rendering complex scenes [281].

It is important to emphasize that the basic operations required to run the fragment shader are performed in hardware. Attribute interpolation is performed by fixed hardware blocks based on barycentric coordinates calculated during rasterization. Thus, the fragment shader receives ready-made, perspectively correctly interpolated values and does not waste computing resources on geometric transformations or interpolation.

Formally, fragments are independent processing objects, which perfectly correspond to the SIMD and SIMT execution models. Each fragment can be processed in parallel, without the need to synchronize with other fragments, which creates the prerequisites for a high level of parallelization. However, in practice, this formal independence does not guarantee efficient use of hardware resources.

The main reason for the decrease in the efficiency of parallelization at the fragment stage is the logical redundancy of calculations. A significant part of the fragments for which the fragment shader is run either does not enter the final image or has a minimal contribution to its formation. At the same time, a full set of calculations is performed for each such fragment, including texture sampling, lighting calculations, and other operations that are computationally expensive.

An additional factor is the divergence of threads within SIMD and SIMT groups. The presence of conditional transitions depending on material parameters or texture sample results, which in turn leads to different fragments in the same group executing different branches of code. In such conditions, hardware parallelism is reduced, since

execution occurs sequentially for each branch, even if many threads are formally started.

The load on the memory subsystem also has a significant impact on performance. Fragment shaders actively use texture fetches and access buffers, which reduces memory bandwidth. Even with efficient caches, memory access delays can lead to idle computing units, reducing the real level of parallelism. In this case, the bottleneck occurs not due to a lack of computing resources, but due to waiting for data.

Thus, the fragment stage acts as a concentrator of parallelization limitations, in which the consequences of excessive fragment generation, execution divergence, and high memory load accumulate. It is important to note that these limitations are mainly logical in nature and are associated with the way the calculations are organized, and not with the imperfection of the GPU hardware implementation. This makes the fragment stage a key point for applying software optimization methods aimed at reducing logical redundancy and increasing the efficiency of parallel execution.

9.1.3.6. Depth testing, color mixing, and frame buffer recording

After the fragment shader is executed, the processing results go through the stages of depth testing, color mixing, and writing to the frame buffer. These stages, often combined under the general name ROP – Raster Operations [279], play a crucial role in the formation of the final image. Although they are implemented in hardware and optimized for high throughput, it is at this stage that specific limitations arise.

The early depth testing mechanism is usually considered an important optimization that allows fragments to be cut off before the fragment shader is executed. However, the effectiveness of early-z depends significantly on the nature of the fragment code and the order in which primitives are processed. The use of fragment discard operations, modification of depth values, or complex conditional constructs can lead to early testing being disabled. In such cases, fragments undergo a full processing cycle, and depth checking is performed only after the fragment shader has completed, which significantly increases the number of redundant calculations.

Color blending operations are another source of parallelization limitations. Which, unlike most computational steps, requires accessing existing pixel values in the frame buffer and combining them with new results. If multiple fragments simultaneously access the same pixel, it becomes necessary to serialize the write operations to ensure the correctness of the result. Thus, even with many parallel threads, some operations are inevitably performed sequentially.

An additional drawback of hardware is the limited number of ROP blocks in the GPU. The number of such blocks is significantly less than the number of computing cores, which leads to a situation where the overall performance of writing results to memory does not scale proportionally to the increase in computing resources. In scenes with many transparent objects or with intensive use of color blending, it is the ROP blocks that can determine the maximum throughput of the entire pipeline.

The use of multi-sample anti-aliasing MSAA further exacerbates these limitations through write amplification. Each pixel is represented by multiple samples, which require separate depth testing, blending, and writing operations. As a result, the number of memory access operations and the load on ROP blocks increases exponentially, which further reduces the efficiency of parallelization.

Thus, the depth testing, color mixing, and rasterization stages form a bottleneck where hardware limitations combine with logical requirements for correctness of calculations. These limitations cannot be overcome solely by increasing the number of computational units and require software approaches aimed at reducing the number of conflicting writes and redundant fragments that pass to the final stages of the pipeline.

9.1.4. Logical redundancy of calculations as a systemic cause of reduced productivity

Analysis of individual stages of the graphics pipeline shows that most of the limitations in scaling graphics card performance do not arise from a lack of hardware resources or architectural imperfections. Modern graphics processors provide an extremely high level of parallelism in both programmable and fixed stages of the

pipeline. However, in practice, this parallelism is used inefficiently, which is due to the performance of a significant number of logically redundant calculations.

Logical redundancy is the execution of calculations that are formally correct from the point of view of the graphics algorithm, but do not have a proportional impact on the formation of the final image. Such calculations cannot be eliminated by hardware without changing the rendering logic, since from the GPU's point of view they are an integral part of the standard graphics pipeline.

Unlike classic hardware bottlenecks, where performance is limited by bandwidth or the number of functional blocks, logical redundancy manifests itself as a mismatch between the amount of work performed and its utility. It is this mismatch that leads to a situation where an increase in the number of computing resources does not provide a proportional increase in performance.

9.1.4.1. Classification of logically redundant calculations

Within the graphics pipeline, several main types of logical redundancy can be distinguished, each of which affects parallelization efficiency differently.

Spatial redundancy arises from high correlation between neighboring fragments. In most cases, the values of color, lighting, or material parameters change smoothly in screen space, but the calculations are performed independently for each fragment. This leads to multiple repetitions of almost identical operations within SIMD and SIMT groups.

Geometric redundancy is associated with the generation of fragments that do not make it into the final image. Redrawing, overlapping primitives, and microprimitives cause fragment shaders to be run on fragments that are later rejected by the depth test or overlapped by other objects.

Perceptual redundancy occurs when calculations are performed with a precision or frequency that exceeds the ability of human vision to perceive. Minor differences in color or lighting that are not discernible to the user still require a full computational cycle.

Temporal redundancy occurs when calculations are repeated from frame to frame without significant changes in the input data. Even with minor scene dynamics, most of the fragmented calculations are performed anew, which leads to duplication of work in time.

9.1.4.2. The impact of logical redundancy on parallelization efficiency

Logical redundancy directly affects the efficiency of parallelizing computations on GPUs. Although fragment shaders are formally independent and can execute in parallel, the redundant nature of the computations results in hardware parallelism being used to process data with low efficiency.

In such conditions, increasing the number of computational units leads to an increase in the amount of work performed, but not to an increase in useful results. This manifests itself in the form of sublinear scaling of performance and saturation, when further increase in hardware resources does not give a noticeable increase in performance.

In addition, logical redundancy amplifies the negative effects of thread divergence and memory contention. As a result, hardware delays hiding mechanisms lose their effectiveness, and the actual level of parallelism becomes much lower than theoretically possible.

9.1.4.3. Logical redundancy as a system issue

The key feature of logical redundancy is its systemic nature. It is not localized at one stage of the graphics pipeline but is formed gradually due to the interaction of several stages. Redundant geometry at the vertex stage leads to the generation of microprimitives, which, in turn, increase the load on rasterization and fragment shading. The results of this redundant work further increase the load on the depth testing blocks and ROPs.

Thus, bottlenecks observed in the later stages of the pipeline are only a manifestation of a deeper problem – a mismatch between the structure of calculations

and the real information needs of the rendering task. Their elimination requires not point optimizations, but a review of the principles of organizing calculations in the graphics pipeline.

This is what makes software methods for reducing logical redundancy a key area for improving parallelization efficiency, which will be discussed in the next section.

9.1.5. Software approaches to optimizing the graphics pipeline

As shown in the previous sections, the limitations of performance scaling are systemic in nature and are largely due to logical redundancy of calculations. Since these limitations are formed at the level of organization of the rendering process, their elimination or mitigation is possible primarily through software approaches. This section considers the main classes of methods aimed at reducing the amount of redundant work and increasing the efficiency of using hardware parallelism.

9.1.5.1. Methods for reducing the number of fragments

One of the most effective ways to reduce the load on the fragment stage is to reduce the number of fragments for which the shader is run. Such methods include methods that allow you to cut off fragments early in the graphics pipeline.

Using a depth pre-pass allows the depth buffer to be filled before the main rendering, thus ensuring that the early-z engine works efficiently. As a result, fragments that are guaranteed not to make it into the final image are cut off before expensive calculations are performed.

Further reductions in the number of fragments processed can be achieved by ordering primitives by depth, as well as various geometry culling techniques, including frustum culling and occlusion culling. While these approaches do not change the structure of the fragment shader, they significantly reduce the amount of input data for later stages of the pipeline.

9.1.5.2. Methods for reducing the number of fragment shading calls

One of the most effective ways to reduce logical redundancy in computations is to reduce the frequency of fragment shader execution. Unlike methods aimed at cutting off fragments, this approach assumes that not every fragment requires a full computational cycle to achieve acceptable visual quality. Thus, optimization is achieved by adaptively reducing the number of fragment shader runs without significant degradation of the result.

Adaptive shading involves varying the frequency or complexity of fragment calculations based on scene properties or local image characteristics. Adaptation criteria can include color, depth, normal gradients, or temporal motion. In areas with low spatial or temporal variability, the fragment shader can be executed less frequently, and the results of the calculations are reused for neighboring fragments.

This approach directly reduces spatial and perceptual redundancy, as computations are performed only where they have a noticeable impact on the final image. However, adaptive shading requires additional control logic and can complicate the implementation of the rendering algorithm.

Checkerboard rendering is a special case of downsampling of fragmented shading, in which calculations are performed on only a subset of pixels, usually in a checkerboard pattern. The remaining pixels are restored by interpolation or reconstruction based on neighboring values or data from previous frames.

This approach allows you to almost halve the number of fragment shader runs while maintaining the overall image structure. Checkerboard rendering effectively reduces the computational load and pressure on the memory subsystem, but its use requires careful control of artifacts, especially in rapidly changing scenes.

Variable Rate Shading is a hardware-supported mechanism that allows you to explicitly specify the frequency of execution of a fragment shader for different regions of the screen. Unlike purely software approaches, it integrates the idea of reducing the frequency of shading directly into the graphics pipeline, allowing you to run a shader for a group of pixels once. This mechanism is a prime example of how the problem of

excessive fragment calculations is recognized not only at the algorithmic but also at the architectural level. At the same time, even with VRS, the logic of determining areas with a reduced frequency of shading remains a software task and requires an analysis of the perceptual significance of the image.

The methods considered have a common ideological basis: not all fragments are equivalent in terms of information value. Reducing the frequency of fragment shading allows to reduce logical redundancy of calculations and increase the efficiency of parallelization without changing the hardware architecture of the GPU. This makes such approaches one of the key tools for optimizing the performance of modern graphics systems.

9.1.5.3. Using compute shaders

The use of compute shaders opens the possibility of implementing alternative approaches to organizing rendering calculations, in which the structure of parallelism is determined programmatically. Unlike the classic graphics pipeline, where parallelism is fixed and tied to the processing of individual vertices or fragments, the compute stage allows for flexible control of the size and composition of thread groups, as well as the order of data processing.

One common approach is tile-based processing, in which the screen or rendering area is divided into small blocks so called tiles that are processed independently. Within a single tile, information about geometry, lighting, or material properties can be aggregated and calculations can be performed at the pixel block level, rather than individual fragments. This approach significantly reduces spatial redundancy, since data common to the region is calculated once and reused for all pixels in the tile.

An extension of the tile-based approach is clustered methods, in which the space is further divided by depth or other parameters of the scene. This allows for more precise localization of calculations and limits them to only those regions where they are really needed. As a result, the number of redundant operations associated with

processing fragments that have similar properties or minimal contribution to the final image is reduced.

The key advantage of the compute stage is the ability to implement controlled parallelism. The developer can explicitly define the size of workgroups, the structure of memory access, and the order of computations. This allows for reduced thread divergence, improved memory access locality, and more efficient use of GPU caches. In such conditions, parallelism becomes not only massive, but also controllable, which significantly increases its efficiency.

At the same time, transferring calculations to the compute stage is accompanied by an increase in the complexity of the software implementation. The developer assumes responsibility for the correct synchronization of flows, the organization of data exchange and ensuring consistency of results. Therefore, the use of compute approaches is appropriate primarily in cases where the gain from reducing logical redundancy exceeds the overhead of complicating the algorithm.

Thus, the compute stage provides tools for rethinking the traditional fragment shading model and creates conditions for implementing algorithms focused on reducing redundant computations. This confirms the thesis that increasing the efficiency of graphics pipeline parallelization is possible through software control over the computation structure, and not solely through increasing hardware resources.

9.1.6. Experimental confirmation

To investigate the impact of the complexity of the fragment stage of the graphics pipeline on the overall rendering performance, an experimental software was developed based on OpenGL 3.3. The program renders a single full-screen triangle, which allows minimizing the impact of the vertex and geometry stages and focusing on the work of the fragment shader.

Vertical synchronization was disabled to eliminate display refresh rate limitations and ensure correct measurement of graphics execution time. All CPU-side

calculations were performed in a single thread, eliminating the influence of multi-threaded frame preparation on the experimental results.

MSI Afterburner was used to monitor GPU hardware parameters such as load and temperature. During the experiments, the GPU temperature did not exceed 66 °C, which indicates the absence of thermal frequency limitation and ensures stability of measurements. In turn, the GPU load consistently exceeded 80%, which indicates high load and no GPU downtime.

The execution time of graphics commands on the GPU t_gpu was measured using OpenGL timer queries GL_TIME_ELAPSED. The total frame generation time t_frame was determined on the CPU side using high-precision timers, and the frame rate per second was calculated as the reciprocal of the average value of t_frame.

Two variants of fragment shaders were used for comparative analysis. The first shader is computationally simple and performs only the writing of a constant color to the frame buffer, which corresponds to the minimum load on the fragment stage. The second shader is computationally intensive and contains a significant number of operations of sampling from the texture, trigonometric functions and accumulation of results in a loop, which allows for a controllably increasing the load on the fragment stage of the GPU graphics pipeline.

Thus, the proposed experimental setup allows us to isolate the impact of the complexity of the fragment shader on the total frame generation time and to investigate the limitations of parallelization efficiency under conditions of dominance of one stage of the graphics pipeline.

Figure 2 shows a triangle rendered using a simple fragment shader. Table 1 contains the timing metrics and frame rates. The GPU load and temperature are shown in Figure 3.

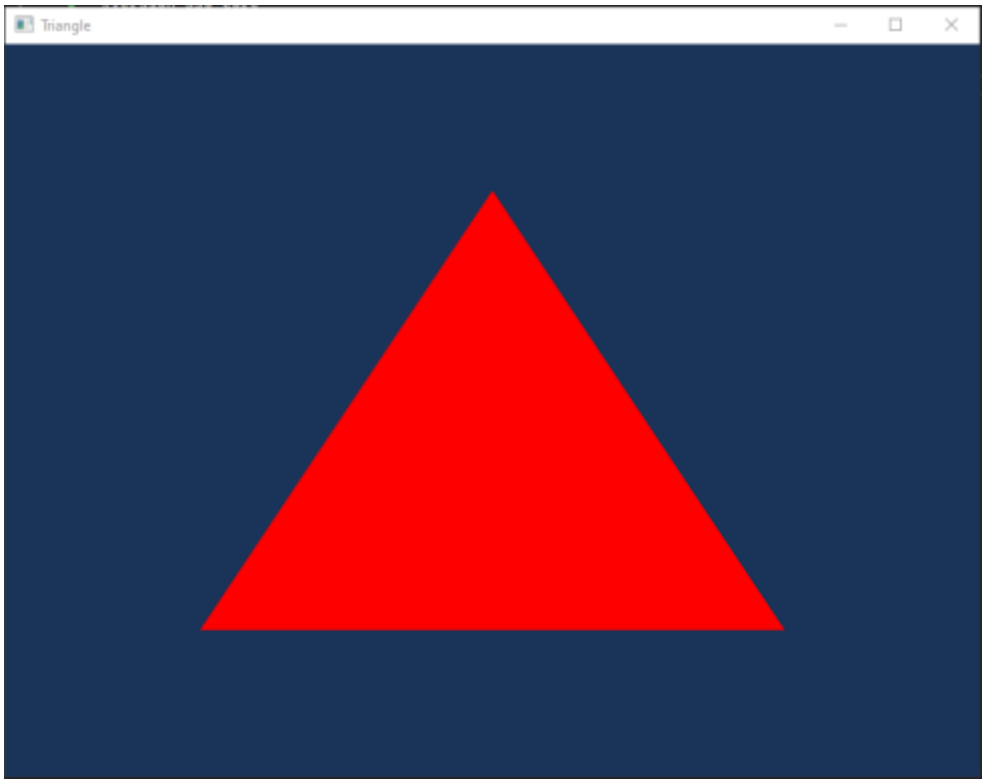


Figure 2. Image of a triangle when using a lightweight shader.

Table 1.

Measurement results when using a lightweight shader

No.	t_gpu, ms	t_frame, ms	FPS
1	0.055264	8.7696	114.03
2	0.055328	8.7183	114,701
3	0.05536	9.7725	102,328
4	0.055296	8.7744	113,968
5	0.055296	8.0474	124,264
6	0.055424	7.2662	137,624
7	0.055296	14.3843	69.5202
8	0.055136	11.3821	87.8572
9	0.055264	7.6877	130,078
10	0.055424	8.9772	111,393
11	0.05536	19.1302	52.2734
12	0.05552	9.2192	108,469
13	0.055584	12.4927	80.0467
14	0.055328	13.9368	71.7525
15	0.055488	8.1731	122,353

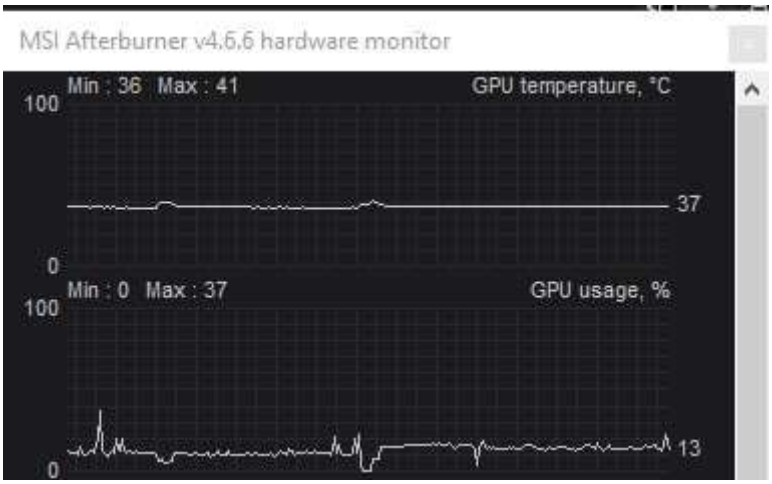


Figure 3. GPU utilization and temperature.

The average execution time of one drawing operation on the GPU is approximately 0.055 ms, the rendering time of one frame is approximately 7.688 ms. At the same time, the number of frames per second is approximately 130. These values indicate that the GPU does almost nothing. The frame is not limited by the GPU, but by overhead: CPU, driver, call to draw, frame replacement, window compositor. That is, GPU ≈ 1% of the frame.

GPU share in frame time:

$$p = \frac{0.055}{7.688} \approx 0.0072\,(0.72\%)$$

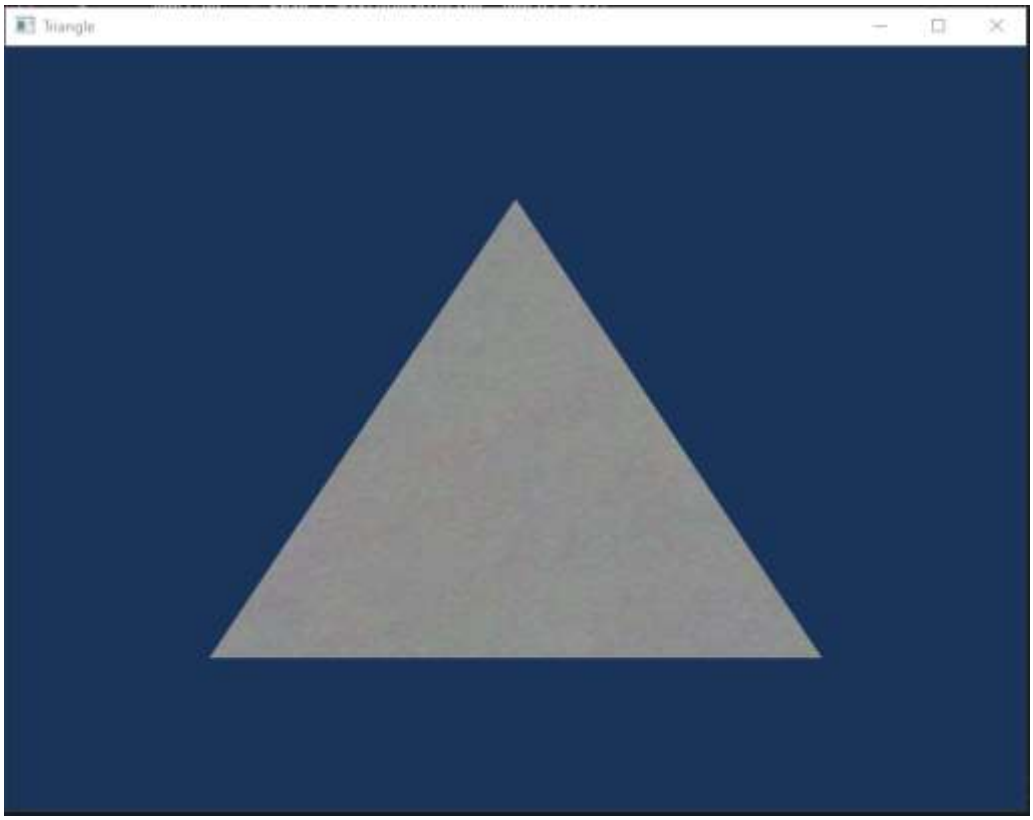


Figure 4. A triangle when using complex shader (white noise. Each pixel is painted many times).

Table 2.

Measurement results when using a heavy shader

No.	t_gpu, ms	t_frame, ms	FPS
1	10.2967	12.1935	82.0109
2	10.2778	11.5432	86.6311
3	10.2874	11.8119	84.6604
4	10.2724	12.4641	80.2304
5	10.2744	11.3832	87.8488
6	10.2702	11.578	86.3707
7	10.2979	12.282	81.42
8	10.2834	11.7582	85,047
9	10.2769	12.4252	80.4816
10	10.2682	12.5718	79.5431
11	10.2766	11.6618	85.7501
12	10.2828	13.2443	75.5042
13	10.2614	11.8154	84.6353
14	10.2649	14.995	66.6889
15	10.2722	12.0007	83.3285

When using a heavy shader, the GPU execution share is on average 10.263 ms, the average frame time is 11.392 ms. At the same time, the approximate number of frames per second is 87.8. Here the fragment stage has become dominant. Approximately 90% of the frame is determined by the GPU.

GPU share:

$$p = \frac{10.263}{11.392} \approx 0.901\,(90.1\%)$$

The difference in t_gpu between shaders:

$$\frac{10.263}{0.055} \approx 186$$

The fragment stage is about 186 times harder, and this is directly visible in the GPU timing.

Let's define the part that is executed outside the GPU.

For a heavy shader this is:

$$t_{other} = t_{frame} - t_{gpu} \approx 11.392 - 10.263 = 1.129 \text{ ms}$$

Even if you make this part perfectly fast, the frame will be:

$$t'_{frame} \approx t_{gpu} = 10.263 \text{ ms}$$

Maximum win:

$$S_{max} \approx \frac{11.392}{10.263} \approx 1.11$$

That is, approximately 11% maximum.

9.1.6.1 Experimental conclusions

Despite the high level of internal parallelization built into the architecture of modern GPUs, experimental results have shown that as the complexity of the fragment shader increases, the corresponding stage of the graphics pipeline becomes dominant in the overall frame generation time. Under such conditions, rendering performance is limited precisely by the fragment stage, and potential optimizations or parallelization at other levels of the system do not lead to a significant reduction in frame time. The results obtained are consistent with the provisions of Amdahl's law and illustrate the fundamental limitations of the effectiveness of parallelization in the graphics pipeline in the mode high GPU load.

Conclusions

The paper conducts a systematic analysis of the weaknesses of graphics pipeline performance scaling and shows that the performance limitations of modern GPUs are not only hardware but also logical in nature.

Unlike the local approach, which focuses on individual stages of the pipeline, the proposed approach considers the graphics pipeline as a holistic system, within which bottlenecks are formed in a cascade due to the interaction of the stages of command generation, geometry processing, rasterization, fragment shading and result recording operations. It is shown that even in the presence of massive hardware parallelism, the scaling efficiency is limited by redundant calculations, thread divergence and competition for memory resources.

Experimental results confirmed that as the complexity of the fragment shader increases, it is the fragment stage that becomes dominant in the frame time structure, and potential off-GPU optimizations have limited effect.

This is consistent with Amdahl's law and demonstrates a fundamental limitation of parallelization under high GPU load. Thus, it is advisable to link the increase in the efficiency of the graphics pipeline not only with the increase in hardware resources, but primarily with software methods for reducing logical redundancy, reducing the number of fragments, adaptive shading, and controlled organization of parallelism. These approaches constitute a promising direction for further research in the field of optimizing the rendering of three-dimensional scenes.

SECTION 10. TRANSPORT

DOI: 10.46299/ISG.2026.MONO.TECH.1.10.1

10.1 Adaptarea modelelor de referință pentru managementul proceselor logistice. Fluxul de informații în întreaga afacere către deșeuri

10.1.1.1 Clasificarea documentelor

Document (lat. *dokument)* înseamnă literalmente dovadă, dovadă. Sensul larg al documentului este de a înțelege substanța materială utilizată în timpul procesului de alcalinizare, care, pe lângă diverse metode și metode, este înregistrată într-o formă suficientă pentru stropirea informațiilor.

Activitatea managerială este cunoscută ca fiind reflectată în documente care îndeplinesc diverse funcții: logistică, stabilirea prețurilor, proceduri organizatorice și administrative și altele. Un document este un document comercial care confirmă un fapt sau un drept la ceva; acestea sunt cele care recunosc oficial persoana celui care îl prezintă; aceasta este o scrisoare despre ceva. Din punct de vedere științific, un document este conceput pentru a consolida în diverse moduri informații materiale speciale despre fapte, idei, manifestări ale activității obiective și rționale a unei persoane. Totalitatea documentelor interconectate care fac parte din întreaga sferă de activitate formează un sistem de documentație. Nu există sisteme unificate. Una dintre cele mai extinse este documentația organizatorică și procedurală (ORD), care este inclusă în formalizarea deciziilor manageriale. Documentele sunt utilizate pe scară largă în activitățile cotidiene ale oamenilor. Deoarece conțin informații, ele conțin o organizare internă extinsă a oricărei întreprinderi și servesc drept bază pentru luarea deciziilor, legalizare și lucrări de cercetare. Documentul este, în special, o confirmare, o declarație a faptelor și, prin urmare, poate avea o mare semnificație juridică. Există o mulțime de documente care susțin astfel de beneficii, cum ar fi accesul la o conservare atentă și o acuratețe maximă. Pentru ca documentul să fie complet supra-umflat de putere, acesta trebuie să fie pliat corect atât din punct de vedere al formei, cât și al volumului . Un document este un obiect material care conține informații într-

o formă fixă, este formalizat într-un mod obișnuit și are forță juridică conform legii. Clasificarea documentelor - împărțirea lor în clase pe baza celor mai mari semne de similaritate și importanță. Clasificarea se bazează pe eficiența operațională sporită a aparatului de control și pe fiabilitatea Vikonavianilor.

Următoarele tipuri de documente cu marcaje de clasificare:

1. Pentru specializare:

- general;
- mese administrative;
- specializat în alimente comerciale;
- specializată în servicii financiare.

2. Pentru recunoaștere:

- organizare;
- răsfăț;
- informații;
- documente ale organelor colegiale.

3. Pentru păstrarea secretului:

- pentru wiki-ul serviciului;
- secret;
- complet confidențial.

4. Pentru skladnistyu:

- depozit unic (simplu);
- cladă.

5. Pentru plimbări:

- intern;
- fericit.

6. Direct:

- intrare;
- viidin.

7. Pentru dzherel viniknenya:

- începători;

- pervini.

8. În spatele tehnologiei creației

- manuscrise;

- creat mecanic (drukarski).

9. În spatele termenului Vikonanny:

- inițial fără linii;

- termeni;

- termeni uniformi.

10. În spatele etapelor creației:

- negru;

- originale;

- copie.

Un document preliminar este un document scris de mână sau dactilografiat care reprezintă munca autorului asupra textului.

Documentul este un original, deoarece informațiile despre autor, momentul și locul creării sale, pe care le deține, demonstrează eficacitatea acestuia. Originalul documentului oficial este primul și singurul exemplu. Copia reprezintă informațiile din document și toate sau o parte din semnele sale externe. Din punct de vedere juridic, originalul și copia au valoare egală.

11. În spatele termenului de economisire:

- post-ynogo;

- trivalogo (peste 10 pietre);

- oră-oră (până la 10 ore).

12. Pentru plimbări:

- oficial;

- obisti.

Un document oficial este creat de o organizație sau entitate juridică și este întocmit în conformitate cu procedura stabilită. Printre documentele oficiale pot exista

caracteristici care indică drepturi speciale, obligații, statut de serviciu sau social, precum și alte informații de natură biografică. Există, de asemenea, documente private care sunt create într-o poziție specială în sfera activității oficiale sau a stabilirii obligațiilor civile. Documentele sunt, de asemenea, clasificate în tipuri individuale și standard. Documente individuale în zona pielii pentru a aborda o situație managerială specifică. Documentele tipice afișează același conținut și sunt formate sub aceleași caractere.

Documentele sunt clasificate în funcție de următoarele caracteristici:

1. metodă de înregistrare a informațiilor;
2. conținut;
3. nume;
4. vedere;
5. skladnist;
6. loc de pliere;
7. Termen viconnian;
8. drumeție;
9. publicitate;
10. forță juridică;
11. etapa de pregătire;
12. economisire pe termen;
13. În ceea ce privește activitatea și nu numai.

Metoda de înregistrare a informațiilor este împărțită în următoarele documente:

1) scrisori, care includ toate documentele scrise de mână și dactilografiate, pregătite cu ajutorul altor echipamente tehnice și reproductibile de birou;

2) grafică, în care imaginile obiectelor sunt transmise folosind linii suplimentare, linii de contur și elemente luminoase. Acestea sunt grafice, hărți, desene, mici desene, diagrame, planuri.

Ulterior, documentele sunt împărțite în:

- proceduri organizatorice și administrative;

- dezvoltarea financiară și economică;

- după un timp - va fi diferit.

Documentele organizaționale și administrative (ORD) sunt documentație managerială care servește ca instrument special pentru reglementarea proceselor manageriale.

Documentele care trebuie predate înainte de percheziția operațională pot fi împărțite în mod inteligent în următoarele grupuri:

• organizatorice (regulamente, instrucțiuni, reguli, statute etc.);

• regulamente (decrete, rezoluții, ordine, completări etc.);

• informații documentare (rapoarte, protocoale, acte, note explicative și de serviciu, liste de servicii, emailuri, planuri de lucru, telegrame, telefoane, apeluri, confirmări etc.);

• din provizii de personal (aplicații, comenzi speciale, fișe speciale, caiete de muncă, caracteristici etc.);

• documente oficiale speciale (propuneri, declarații, documente de finanțare, autobiografii, chitanțe, declarații pe proprie răspundere etc.).

În spatele numelui se separă:

pedepse;

poziţie;

protocoale;

eliminare;

vkazivki;

instrucțiuni;

reguli;

statute;

viață;

comenzi;

planuri;

servicii pentru copii;

declar că.

Tipurile de documente se împart în:

• tipuri care sunt împărțite de autoritățile superioare pentru organizații subordonate cu funcții similare și pot avea un caracter obligatoriu;

• șabloane, care sunt pregătite într-un mod diferit: partea neschimbată a textului documentului este imprimată pe mașini de tipar, iar pentru informațiile modificate se scriu locuri libere. Astfel de documente sunt extrem de extinse, iar timpul petrecut cu ele la pliere și prelucrare este economisit;

• individual, care este creat de fiecare dată într-un mod nou. Acestea sunt note suplimentare, de serviciu, explicative, autobiografii etc.

Datorită complexității documentelor, există:

• este ușor să combini informații dintr-o singură masă;

• pliere, care poate găzdui informații pentru două sau mai multe alimente.

Trebuie menționat că documentele simple sunt mai ușor de sortat, de controlat tranzacțiile acestora și de efectuat căutări.

În același timp, următoarele documente sunt separate:

• intern, astfel încât alimentarea internă cu energie a întreprinderii (organizației, instalației, companiei) să fie menținută și să nu depășească limitele acesteia;

• corespondență externă, atât la intrare, cât și la ieșire.

Următoarele documente urmează termenul Vikonannya:

• termenii care apar pe linie, stabiliți prin lege, act juridic secundar, cod, precum și documentele cu pictograma „Terminovo”;

• netermeni care sunt concatenați în linii definite de organizație (organizație, instalație, companie).

Trebuie depuse următoarele documente:

• servicii care sprijină activitățile întreprinderilor (organizații, instalații, companii);

• personalitate oficială, care reprezintă indivizi specifici, deci sunt numiți (spuneți așa, scargs).

În scop publicitar, documentele sunt:

• limbă engleză,

• pentru service kostuvannya (DSK);

• tahmi;

• confidențial și de altă natură.

Forța juridică a documentelor se împarte în următoarele:

• spravni (adevărate) care se pregătesc în ordinea stabilită de lege pentru spravni (adevărate) care se pregătesc în ordinea stabilită de lege pentru toate regulile.

Următoarele documente sunt disponibile:

• chineză,

• nu este chinez.

Un document devine invalid dacă își pierde forța juridică din orice motiv

falsuri (detalii), caz în care designul nu reflectă adevărul.

Următoarele documente sunt împărțite în etape de pregătire:

• originale – primele sau singurele exemple de documente oficiale;

• copii - documente în care sunt reproduse cu exactitate informațiile altor documente, precum și toate semnele lor exterioare și unele dintre ele și modul de executare corespunzător.

Există următoarele tipuri de copii:

• eliberare (o copie duplicată a documentului de ieșire, pregătită simultan cu originalul prin intermediul unei hârtie de copie);

• vityag (copie a unui document oficial care confirmă partea principală a acestuia și este certificată în mod corespunzător);

• duplicat (exemplu repetat al unui document, care are forța juridică a originalului).

Termenul de economisire se împarte în:

• documente de depozitare permanentă;

• documente salvate (peste 10 ani);

• documentele de tip oră-oră (până la 10 zile) sunt salvate.

Tipul de activitate este urmat de sisteme de documentare care se clasifică după cum urmează:

proceduri organizatorice și administrative;

standarde și minți tehnice;

planificat;

științifico-statistic;

proiecta;

tehnologic;

rozrakhunkovo-groșova;

Prețul este diferit.

Cele mai răspândite sunt însă documentele contabile care se clasifică după următoarele simboluri:

1) după locul de pliere, 2) după sens, 3) după ordinea de pliere, 4) după metoda de pliere, 5) după loc etc.

1) Sunt incluse următoarele documente contabile:

procedurile în cadrul cărora sunt implementate procedurile pentru această operațiune guvernamentală și alte operațiuni; Nu există nicio bază pentru înregistrarea operațiunilor în cloud, deoarece nu există nicio confirmare că o astfel de operațiune a avut loc. Înainte de documentele necesare, există pedepse, ordine, sarcini etc.;

viconicele sau cele veridice, care confirmă faptele operațiunii viconice. Duhorile sunt prima etapă a înregistrării cloud. Înaintea lor există comenzi de primire, facturi, chitanțe care atestă primirea de valori, acte privind achiziționarea de bunuri etc.;

documente contabile, care includ situații de rutină și de grup, situații financiare, alocări etc. (de exemplu, alocarea de fonduri pentru pregătirea și adăugarea de active materiale);

o combinate - pentru a plasa semnele documentelor contabile oficiale, ordonate, cu inserție de o oră pentru a reflecta operațiunea suverană în departamentele contabile. Înainte de astfel de documente, sunt necesare avize prealabile, avize privind plata numerarului, încasări în numerar și comenzi pentru eliberarea materialelor din depozit.

2) Ulterior, documentele pliate se împart în externe și interne.

externe sunt cele care aparțin altor întreprinderi, organizații și se formează în afara limitelor acestei întreprinderi. Înaintea lor, există extrase de cont, note de plată ale funcționarilor poștali etc.

Documentele interne sunt documente stocate (notate) la o anumită întreprindere sau organizație.

3) Conform ordinii de pliere, acestea se împart în prima și a doua parte. Principalele sunt acele documente care semnifică mai întâi înregistrarea operațiunii suverane în momentul producerii acesteia sau imediat după producerea acesteia. Înaintea lor, există acte de acceptare și primire a principalelor plăți, facturi, chitanțe etc.

Toate documentele sunt stocate pe primul suport. În fața lor există diferite tipuri de informații, informații despre distribuție și plată etc.

4) În funcție de metoda de stocare a tranzacției, documentele se împart în temporare și acumulative.

unice sunt procesate doar pentru înregistrarea și procesarea unică a operațiunilor. Înaintea lor există comenzile de numerar ale Cumpărătorului și Widad, care sunt posibile pentru menținerea activelor materiale într-un depozit și într-un singur depozit.

cumulative sunt colectate pentru înregistrarea multiplă și înregistrarea operațiunilor pe o perioadă de timp desemnată (an, deceniu, lună). De exemplu, există carduri de colectare limitate, care sunt folosite pentru a oficializa eliberarea materialelor pentru producție (lucrări vikonannaya). Astfel de documente sunt similare cu documentația originală.

Clasificarea documentelor este reprezentată clar de diagrama prezentată în Fig. 1.1.

5) Ulterior, documentele sunt împărțite în penny, rozrakhunkov și material.

penny sunt folosite pentru a documenta tranzacțiile care implică bani penny. Înaintea lor există ordine de plată, chitanțe, cecuri bancare etc.

obișnuite sunt folosite pentru a oficializa tranzacțiile dintre persoane fizice și juridice (facturi, ordine de plată, chitanțe etc.).

materiale sunt utilizate pentru documentarea tranzacțiilor legate de manipularea activelor materiale (ordin de livrare, factură, card limită etc.).

6) Pentru tehnica de pliere a documentelor:

o Reumplut manual;

o Preparat cu mașina.

10.1.1.2 Gestionarea documentelor

Fluxul documentelor se referă la ordinea și fluxul documentelor din momentul în care sunt compilate sau achiziționate până în momentul în care sunt depuse la arhivă. În acest fel, ordinea și fluxul de informații sunt evitate prin fluxul de documente.

Bineînțeles, principalele sarcini ale fluxului de documente sunt de a accelera fluxul documentelor, iar cu cât acest proces este organizat mai scurt și mai rapid, cu atât va fi mai eficient, iar clienții vor putea prelua imediat informațiile pentru a le primi. Vă rugăm să acceptați decizia.

Îngrijirea pielii, bazată pe specificul activității sale guvernamentale și structura de management, înseamnă obligații directe de documentare și organizează fluxul de documente. Într-o întreprindere, fluxul de documente este responsabil pentru toate etapele fluxului de materiale. Regulile și tehnologia de prelucrare a informațiilor indică principalele etape ale prelucrării documentelor: compilarea documentelor inițiale sau înregistrarea celor găsite pe ambele părți, prelucrarea vizuală și înregistrarea documentelor; transferul documentelor pentru depozitare în arhivă.

O listă a formularelor standard de documente utilizate în fluxul de documente al]unei întreprinderi este prezentată în tabelul 1.1.1

Tabelul 1.1

Lista formularelor standard utilizate pentru documentarea inițială a afacerilor și proceselor guvernamentale la întreprinderile din Ucraina.

Codul formularului	Numele formularului
1	2
1) Apariția unui depozit special al întreprinderii	
F Nr. P-1	Ordin (ordin) privind angajarea
F Nr. P-2	Carte specială
F Nr. P-5	Comandă (comandă) privind transferul la un alt loc de muncă
F Nr. P-6	Ordin (ordin) privind acordarea permisiunii

Continuare tabel 1.1

1	2
F Nr. P-8	Ordin (ordin) privind atribuirea locului de muncă
F nr. P-13	Foaie de pontaj pentru orele de lucru
2) Forma de plată a salariilor	
Nr. F P-49	Rozrakhunkovo-informații de plată
Nr. F P-51	Contul lui Rozrakhunkova
Nr. F P-54	Rakhunok special
3) Apariția tranzacțiilor în numerar	
F nr. KO-1	Ordin de plată Pributkovy
F nr. KO-2	Ordin de plată Vidatkovy
F nr. KO-3	Jurnal de înregistrare a chitanțelor și documentelor de casă
F nr. KO-4	Registru de casă
4) Aspectul evoluțiilor așa cum sunt descrise de persoanele respective	
F nr. 807	Ziua Avansoviy
5) Tipul operațiunilor bancare	
F nr. 869	Textură Rakhunok
cod 040 1001	Plăți
cod 040 1002	Ordin de plată
cod 040 1003	Înregistrați-vă pentru confirmarea plății
cod 040 1004	Cerere de aprobare
cod 040 1007	Restaurare control
cod 040 1008	Zveda Vimogo
6) Tipul de materiale	
F Nr. M-1	Revistă cu avantaje găsite
F Nr. M-2	Doruchenya
F Nr. M-2a	Actul de a scrierea formularelor de mână
F Nr. M-3	Jurnal de înregistrare a rudelor consultate
F Nr. M-4	Ordinul Pributkovy
F Nr. M-7	Actul de confiscare a materialelor
F Nr. M-8	Limită - card de colectare (pentru un singur nume de material și un număr mare de puncte de vânzare)
F Nr. M-9	limită (pentru o singură furnizare de două până la cinci articole de materiale)
F Nr. M-10	Act de înlocuire (eliberare suplimentară) a materialelor
F Nr. M-11	Factură pentru eliberarea (mișcarea internă) de materiale
F Nr. M-12	Harta depozitării materialelor
F Nr. M-13	Registrul de confiscare și predare a documentelor

Continuare tabel 1.1

1	2
F Nr. M-14	Fiți conștienți de prezența materialelor în exces în depozit
F nr. M-15	Actul de acceptare
F nr. M-15a	Certificat de acceptare și transfer al instalației înainte de instalare
F Nr. M-16	Etichetă material
F nr. M-17	Raport nr. __ despre defectele de instalare identificate
F nr. M-18	Informații semnal despre recuperarea surplusului efectiv de materiale din normele de stoc
Nr. F M-19	Sunet material
F Nr. M-21	Lista de inventar
F nr. M-22	Legea nr. __ pentru radierea materialelor confidențiale
Nr. F M-23	Legea nr. __ privind transferul materialelor clienților
F nr. M-26	Card de instalare pentru instalare
F nr. M-28	Limită și card de colectare nr. __ pentru organizațiile de zi cu zi
Nr. F M-28a	Limită și card de colectare nr. ___
7) Aspectul articolelor de valoare scăzută și uzate	
F Nr. MS-1	Informații despre reaprovizionarea (reaprovizionarea) stocului permanent de scule
F nr. MS-2	Card pentru articole de valoare mică și articole purtabile
Nr. MS-4	Acțiunea de recuperare a obiectelor de valoare mică și uzate
Nr. MS-5	Act privind scoaterea din funcțiune a uneltelor (atașamentului) și schimbul acestora la accesoriul pentru un vikoristan
F nr. MS-6	Haine speciale pentru haine speciale, haine speciale și zapobizhnih pristosuvan
Nr. F MS-7	Apariția (rotirea) îmbrăcămintei speciale, a îmbrăcămintei speciale și a altor accesorii
Nr. MS-8	Acționează privind scoaterea din uz a articolelor de valoare mică și a articolelor purtabile
8) Aspectul principalelor caracteristici	
F Nr. 03-1	Actul de captare și transfer (mișcare internă) a principalelor - caracteristici
F nr. 03-2	Acte de achiziție și livrare a instalațiilor reparate, reconstruite și modernizate
F nr. 03-3	Act privind radierea activelor principale
F nr. 03-4	Legea privind scoaterea din uz a vehiculelor cu motor
F nr. 03-5	Legea nr. __ privind instalarea, punerea în funcțiune și demontarea echipamentelor de inginerie civilă
F nr. 03-6	Fișă de inventar a principalelor caracteristici
F Nr. 03-7	Descrierea fișelor de inventar pentru principalele caracteristici

Continuare tabel 1.1

1	2
F nr. 03-8	Harta principalelor caracteristici ale revoluției
F nr. 03-9	Lista de inventar a principalelor caracteristici
F Nr. 03-14	Rata de amortizare a activelor de capital (pentru întreprinderile industriale)
F Nr. 03-15	Rata de amortizare pentru activele de capital (pentru organizațiile de dezvoltare)
F Nr. 03-16	Rata de amortizare pentru autovehicule

Tabelul furnizat dovedește clar că nu există nicio activitate în cadrul întreprinderii care să nu fie documentată.

Documentele, de regulă, sunt compilate de către lucrătorii operaționali ai întreprinderii (casieri, lucrători în magazine , vânzători, maiștri etc.) sau trec în ambele sensuri prin birou cu înregistrare obligatorie (dosare, acte, foi). Atenție! Fiecare medic va primi un extras din planul de flux al documentelor (program), care include transferul documentelor referitoare la componentele funcționale ale biroului, termenul de depunere a acestora și transferul serviciilor (filialelor) întreprinderilor către care sunt transferate aceste documente. Un rezumat al programului de flux al documentelor pentru întreprindere este prezentat în tabelul 1.2.

Tabelul 1.2.

Vityag cu grafice ale fluxului de documente

Titlul documentului	Crearea și executarea documentului		Verificarea documentului		Prelucrarea documentului		Transfer la arhive	
	Vikonavеț	Termenul Vikonanny	Vikonavеț	Termenul Vikonanny	Vikonaveț	Termenul Vikonanny	Vikonaveț	Termenul Vikonanny
Vimoga-nakladna	Manager de depozit	luni miercuri	Contabil de magazin	Ziua de acceptare a documentelor	Contabil al sectorului material al contabilității	Timp de trei zile, 3 zile de captură	Avocatul contabilului șef	Timp de zece zile după formarea luminii râului

Îndrumările din programul de flux al documentelor indică posibilitatea de a monitoriza rapid fluxul de materiale. În acest fel, din momentul emiterii cererii (plierea facturii) până la procesarea finală, documentul poate parcurge următoarea perioadă:

Desemnat luni seara

Miercuri, înainte de pauză, depus la contabilul magazinului

Patru transferați la contabilul sectorului material al departamentului de contabilitate

Luni obrobleni și vikonani.

În acest fel, întreprinderea își petrece ziua procesând informații.

10.1.1.3 Formele actuale ale fluxului informațional

Pliabilitatea, dimensiunea mare și vizibilitatea numărului mare de documente utilizate în managementul afacerilor în mintea contemporană au dus la apariția conceptului de EDI („schimb electronic de date”). În cea mai comună interpretare, acesta este un schimb de informații între computere bazat pe un format de date standard, care deservește tehnologiile moderne de telecomunicații. Recent, introducerea EDI a schimbat literalmente procedurile de gestionare a tranzacțiilor în companiile străine.

În zilele noastre, tot mai mulți comercianți cu amănuntul merg până la a descifra abrevierea EDI ca fiind „ electronic”. document „interschimb - gestionarea electronică a documentelor.” Transferul unui document este o procedură mai inteligentă, mai complexă și mai necesară, deoarece reprezintă etapa finală a proceselor de flux informațional. Astfel, un sistem EDI poate fi înțeles ca un sistem informatic pentru schimbul electronic de documente, iar o tehnologie EDI poate fi înțeleasă ca un proces de luare a deciziilor pe baza documentelor electronice.

Tehnologia EDI a fost dezvoltată pe scară largă și este reprezentată pe scară largă în marile programe și proiecte economice, telematice , de transport și logistică internaționale (TACIS, TEDIM etc.).

Platforma EDI îmbunătățește fiabilitatea, relevanța și consecvența informațiilor logistice. Pentru a implementa toate aceste transferuri, este necesară conectarea tuturor

liniilor CPU, precum și a altor sisteme externe de informații logistice, cu canalele de telecomunicații. Această legătură este destinată dezvoltării rețelelor locale deținute de companie, a rețelelor de telecomunicații comerciale și necomerciale care operează într-o regiune, regiune sau la nivel global (de exemplu, Internetul).

Beneficiul imediat al instalării EDI în lancetele postoperatorii (ULP) este demonstrat:

- Creșterea productivității în domeniile funcționale ale Lanzyug Postachan (LP);
- Schimb sporit de canale între benzile LP;
- Productivitate sporită cu medicamente gestionate;
- A fost realizată o nouă integrare a activităților partenerilor în cadrul LP;
- Cheltuieli logistice operaționale și administrative (tranzacționale) modificate.

Creșterea productivității se realizează prin transmiterea și procesarea rapidă a informațiilor, fiabilitatea datelor - printr-o reducere a numărului de documente pe hârtie și o scădere bruscă a posibilității de erori de introducere a datelor. Costuri logistice mai scurte se obțin prin modificarea proporției costurilor operaționale și materiale asociate cu procedurile de tipărire, poștă și manipulare a documentelor pe hârtie; comunicații telefonice și fax scurte; modificări ale costurilor administrative și tranzacționale .

Una dintre problemele practice serioase ale managementului documentelor companiilor în cadrul SFM o reprezintă neregulile în datele și procedurile de livrare a documentelor și informațiilor către destinatar, care duc nu numai la costuri suplimentare, întârzieri în expedierea bunurilor, ci pot fi cauza cheltuielilor acestora, retragerii contractelor și pierderii încrederii clienților. În LP, neregulile pot duce la devalorizarea avantajelor tehnologice, organizaționale și structural-financiare ale integrării industriale și logistice. Probleme semnificative apar în dezvoltarea sistemelor electronice de management al documentelor EDI.

Tehnologiile informaționale de astăzi sunt capabile să stocheze și să schimbe informații. Un document electronic poate servi drept dovadă că a fost întocmit cu cel mai mare efort și poate fi folosit pentru a-i demonstra validitatea și relevanța. Astăzi,

gestionarea electronică a documentelor și semnătura digitală au devenit larg răspândite în sfera tranzacțiilor bancare și a tranzacțiilor comerciale de comerț electronic.

Utilizarea managementului electronic al documentelor și a semnăturii digitale este acum legalizată și reglementată de legile Ucrainei „Privind documentele electronice și managementul documentelor electronice" din 22 mai 2003 nr. 851-IV, „Despre semnătura digitală electronică" din 22 mai 2003 nr. 852-IV. Cu toate acestea, funcționarea cu succes a sistemului electronic de management al documentelor depinde de calitatea întreprinderii, care este responsabilă pentru declanșarea unui nivel scăzut de aprovizionare nesatisfăcătoare.

Fluxurile de informații (PI) în format electronic sunt incluse astăzi din ce în ce mai mult în sistemele de monitorizare pentru controlul fluxului de bani. Zokrema, activitatea companiei, deschide tehnologia pentru ca clienții să obțină informații despre numărul de scrisori de transport (TTN) prin intermediul internetului.

În prezent, piața software găzduiește un număr mare de sisteme informatice (CIS) cu modul încorporat al sistemului de management al lanțului de aprovizionare (engleză : Supply). Lanţ Management (SCM). Acest sistem este așa-numitul sistem de clasă ERP. Principalele sale avantaje sunt integrarea și versatilitatea. Pachetele de aplicații complete din clasa ERP se bazează pe sistemul de bază de gestionare a bazelor de date DBMS, care vă permite să combinați date din diverse servicii: departamente financiare, departamente de vânzări, depozite etc.

Pentru crearea unei baze de date ascunse, extragerea și stocarea datelor clienților. Aceste programe vor înlocui sistemul informațional și de căutare; un set de instrumente analitice și alte funcții pentru a sprijini luarea deciziilor; crearea unui model, prognoză, planificare pe termen lung; vă vor ajuta să vă analizați afacerea și să vă ajutați în procesele de afaceri; metode de gestionare a structurii proceselor de afaceri și a unităților organizaționale.

Comercianții naționali care sunt dispuși să studieze cu compania de management pentru unul dintre scopurile afacerii vor trebui să învețe instrumentele care vor fi utilizate în sistemul general de management al afacerii. Varto înseamnă că programele

actuale sunt caracterizate printr-un accent pus pe activitățile financiare ale întreprinderii și pe aspectul contabil. Însăși setul de instrumente, care este activat înainte de luarea deciziilor, este responsabil pentru generarea automată a documentației contabile: facturi, documente de plată, facturi. În mod surprinzător, acesta este un punct important în deciziile SCM care sunt inevitabil asociate cu serviciile financiare, însă, după cum arată dovezile că piața este în scădere, este departe de a fi singurul.

10.1.1.4 Analiza SWOT ca instrument pentru managementul strategic.

În concepția actuală, în contextul dezvoltării pieței, companiile care sunt ancorate în piața nouă și cele care abia intră pe piață se confruntă cu o sarcină din ce în ce mai dificilă. Problemele lor sunt asociate cu niveluri ridicate de concurență acerbă, prea multe produse și servicii similare, suprasaturația fluxurilor de publicitate și informații, beneficii tot mai mari pentru cei care încearcă să obțină aceleași produse, cu schimbări constante ale condițiilor de piață și ale localității, precum și cu inovații care vizează cucerirea a tot mai multor domenii. Prin urmare, pentru supraviețuirea și funcționarea cu succes a unei companii, creșterea forței și competitivității produselor sale, este necesar să se țină cont de dificultățile pe care le-ar putea întâmpina în viitor și de noile posibilități care i se pot deschide. Prin urmare, companiile trebuie să identifice domeniile prioritare de dezvoltare, să extindă planurile de afaceri, să se adapteze la schimbările din mediul actual, să adopte noi tehnologii pentru organizarea proceselor de management, să modifice strategiile de afaceri și, prin urmare, să creeze un management strategic. Unul dintre principalele instrumente ale managementului strategic, care este evaluat în mod complex de către funcționarii interni și externi care contribuie la dezvoltarea companiei, este analiza SWOT.

SWOT – literele de început ale punctelor forte (Strengths) , punctelor slabe (Weaknesses) , oportunităților (Oportunities) , amenințărilor (Threats). În 1963, la o conferință de la Harvard despre problemele politicii de afaceri, profesorul K. Andrews a anunțat public acronimul SWOT pentru prima dată. Acest acronim este prezentat vizual în matricea SWOT. Inițial, analiza SWOT se bazează pe cunoștințele exprimate

și structurate despre situația și tendințele actuale, ulterior - devenind mai importantă - pentru proiectarea strategiilor. Astfel, odată cu apariția modelului SWOT, analiștii au creat un instrument pentru munca lor intelectuală [284].

Analiza SWOT este procesul de stabilire a legăturilor dintre cele mai caracteristice oportunități pentru o afacere, amenințări, puncte forte (avantaje), puncte slabe, ale căror rezultate pot fi utilizate ulterior pentru formularea și selectarea strategiilor întreprinderilor [285]. Se realizează utilizând metoda investigării întreprinderii ca sistem de conducere într-un mediu de piață extins. Analiza SWOT este un instrument de sine stătător; este important să nu se lase informații reziduale pentru luarea deciziilor de management, ci mai degrabă să se organizeze procesul de compilare a tuturor informațiilor evidente din contextul gândurilor și evaluărilor autorităților. Analiza SWOT face posibilă formularea unei schimbări fundamentale a strategiilor de afaceri pe baza caracteristicilor acestora - adaptarea la mijloc sau modelarea la următorul. Utilizarea și dezvoltarea pe scară largă a analizei SWOT pot fi explicate prin faptul că managementul strategic este asociat cu volume mari de informații care trebuie colectate, procesate, analizate, analizate și astfel apare nevoia de căutare, dezvoltare și stagnare a metodelor de organizare a unei astfel de activități.

Problemele utilizării metodei de analiză SWOT și ale matricei de rezolvare au fost abordate de numeroși cercetători autohtoni și străini. În aceste cazuri, se înțelege că analiza SWOT oferă baza pentru evaluarea aspectelor eficiente ale activității și posibilitatea corectării punctelor slabe, ceea ce înseamnă atât fabrici externe, cât și interne [286].

Principala metodă de efectuare a unei analize SWOT este identificarea datelor fiabile despre capacitățile companiei și amenințarea intrării sale pe piața bunurilor și serviciilor. Prin urmare, pentru a atinge acest obiectiv, înainte de analiza SWOT, sunt stabilite următoarele sarcini: identificarea oportunităților de marketing care corespund resurselor companiei; identificarea amenințărilor de marketing și dezvoltarea de abordări pentru a preveni afluxul acestora; identificarea punctelor forte ale companiei și asocierea acestora cu capacitățile pieței; identificarea punctelor slabe ale companiei

și fragmentarea direcțiilor strategice ale activităților sale; identificarea avantajelor competitive ale companiei și formarea priorităților strategice.

Pentru a efectua o analiză SWOT asupra unei afaceri, este nevoie de informațiile necesare, care trebuie să includă: o bază de date; metode și modele necesare pentru analiza SWOT; un set de tehnici organizatorice și metodologice necesare pentru îmbunătățirea fiabilității securității informațiilor [287]. Metoda analizei SWOT se bazează pe o abordare care permite analiza simultană a aspectelor externe și interne ale afacerii. Folosind această tehnică, este posibil să se stabilească relații între punctele forte și punctele slabe ale entităților guvernamentale și amenințările și oportunitățile externe. Voi identifica mai întâi punctele forte și punctele slabe, precum și amenințările și oportunitățile, apoi voi stabili interacțiunile dintre acestea, care pot fi utilizate pentru a dezvolta o strategie de afaceri.

Atunci când se efectuează o analiză SWOT, este necesar să se definească clar domeniul de aplicare al analizei SWOT superficiale, să se înțeleagă diferențele dintre elementele sale, să se fie obiectiv și să se diferențieze diversele informații de intrare, unicitatea afirmațiilor ample și ambigue. O analiză SWOT trebuie efectuată cu participarea tuturor membrilor importanți ai organizației. Există o identificare subiacentă a părților slabe și forte, care pot fi clar vizibile în mijlocul organizației. Analiza SWOT poate fi contracarată prin metoda brainstorming. Domeniul de aplicare al analizei poate fi extins până la punctul în care nu este efectuată în fața organizației. Astfel de persoane pot acționa ca arbitri non-prejudiciari, care pot evalua propunerile și, de asemenea, prin stabilirea unor cerințe speciale, pot provoca organizația să își regândească pozițiile și acțiunile.

Metodologia de realizare a unei analize SWOT include mai multe etape:

I. Valorile principalelor puncte forte și puncte slabe ale întreprinderii (Tabelul 1.2) . Prima etapă permite identificarea punctelor forte și a punctelor slabe ale afacerii. De ce este necesar: să se modifice parametrii în funcție de care este evaluată afacerea; Pe baza parametrului skin, să se determine care este punctul forte al afacerii și care este

punctul slab; Pe parcursul întregului proces, să se aleagă cele mai importante puncte forte și puncte slabe ale afacerii.

Tabelul 1.2

Caracteristicile de bază ale punctelor forte și punctelor slabe ale afacerii care sunt analizate în analiza SWOT [288]

Avantaje interne potențiale	Deficiențe interne potențiale
1	2
- avantaje competitive (unicitate); - poziție puternică în segmente specifice de piață, bună cunoaștere a liderului; - un concurent acerb pe piață; - strategia ofensivă este o altă strategie importantă; - armonizarea numărului tot mai mare de grupuri țintă de însoțitori și a fidelizării acestora; - informații despre informațiile medii despre piață; - capacitatea de a se apăra împotriva concurenților; - diferențierea virusurilor, se realizează diversificarea; - resurse financiare suficiente; - elemente pentru dezvoltări tehnologice și inovatoare medii; management creativ;	- prezența unor avantaje competitive reale; - atacuri continue din partea competițiilor cheie privind chiriile; - rate de creștere mai mici decât media; - resurse financiare deficitare, venituri insuficiente; - pierderea reputației în rândul locuitorilor; - „curtea din spate” a dezvoltării de produse, specializare universitară; - deficiențe în activitățile strategice; - căsătoria pentru a reduce presiunea concurențială; - vyrobnitstvo cu vitamina C ridicată, vârstă înaintată la efort ; - numărul de abilități speciale reale în management, lipsa talentelor; - un „nou venit” într-o afacere a cărei reputație nu a fost încă stabilită;
- piața unui trai bun, bunuri de consum; - produse pentru profitabilitate medie și rentabilitate și abilități de marketing.	- o varietate de poziții sociale pentru combaterea amenințărilor;

II. Importanța oportunităților și amenințărilor pieței (Tabelul 1.3) . Aceasta este un fel de „recunoaștere a localității” - evaluarea pieței. Această etapă vă permite să evaluați situația din perspectiva dumneavoastră și să înțelegeți care sunt capacitățile dumneavoastră, precum și de ce amenințări ar trebui să vă temeți.

Tabelul 1.3

Principalele oportunități și amenințări externe pentru afaceri, analizate în analiza SWOT [288]

Posibilități externe potențiale	Amenințări externe potențiale
- dezvoltarea economiei regionale; -stabilitate socio-politică; - legislația este întemeiată; - deservirea unor grupuri suplimentare de angajați; - intrarea pe noi piețe (segmente); - extinderea producției pentru a satisface nevoile locuitorilor; - diversificare, produsele suplimentare sunt contestate; - integrare verticală; - posibilitatea unei revoluții în grupuri mai strategice; - automulțumirea concurenților cheie; - Închidere centrală electrică.	- inflamație; - există o concurență mare între noii concurenți (inclusiv cei străini); - creșterea bunurilor de înlocuire; - rata crescută de creștere a pieței; - „vrăjitoarele lumii” din partea statului; - tendințele de dinaintea recesiunii și scurtarea ciclului economic; - din cauza dificultăților în stabilirea unor acorduri cu angajatorii și colegii de muncă; - schimbări în nevoile și gusturile locuitorilor; - schimbări demografice negative; - situație negativă a mediului; -instabilitate socio-politică.

III. Compararea punctelor forte și a punctelor slabe ale afacerii cu oportunitățile și amenințările la adresa pieței. Pentru a oferi o perspectivă asupra pieței și a consolida rezultatele analizei SWOT, se creează matricea SWOT, care reprezintă imaginea actuală.

Pe rețelele următoarelor grupuri de factori de depozit se formează câmpuri pentru care sunt necesare condiții caracteristice de recepție, necesare în timpul dezvoltării strategiilor de următorul tip: câmpul SIM - prezintă dezvoltarea strategiilor de susținere și dezvoltarea punctelor forte ale eforturilor de realizare a posibilităților mediului modern; câmpul Ci3 - orientează strategia spre combaterea amenințărilor cu ajutorul recuperării rezervelor interne; câmpul SLM - acțiune directă asupra dezvoltării oportunităților de îmbunătățire a laturilor slabe ale potențialului intern; câmpul SZ - prezintă dezvoltarea unei astfel de strategii care ar permite întreprinderii nu numai să

își maximizeze potențialul, ci și să expună posibilele amenințări la adresa mediului extern. Având în vedere acest lucru, există o nevoie urgentă de a dezvolta strategii atât pentru a face față amenințărilor, cât și pentru a aborda punctele slabe ale întreprinderii, astfel încât sarcinile importante să poată fi realizate în viitor.

Analiza SWOT, comparativ cu alte metode, are atât avantaje, cât și dezavantaje. Principalul său avantaj este simplitatea și posibilitatea de a cheltui puțini bani pentru implementarea sa, precum și flexibilitatea și evidenta lipsei de opțiuni. De asemenea, această sistematizare a cunoștințelor despre factorii interni și externi care influențează procesul de planificare strategică; capacitatea de a identifica avantajele competitive ale unei afaceri și de a formula priorități strategice, efectuarea periodică a diagnosticelor pieței și resurselor afacerii. Câteva dintre lucrurile care trebuie luate în considerare într-o analiză SWOT sunt: imposibilitatea de a lua în considerare toate punctele forte și punctele slabe, oportunitățile și amenințările; subiectivitatea alegerii și ierarhizarea factorilor externi și interni; adaptarea deficitară la calea de mijloc, care se schimbă treptat.

De asemenea, efectuarea unei analize SWOT este de mare importanță pentru planificarea strategică, deoarece metodologia sa este o modalitate eficientă, accesibilă și ieftină de a evalua situația problematică și managerială dintr-o instalație. Aceasta permite sistematizarea situațiilor problematice; înțelegerea mai clară a structurii resurselor, care pot fi utilizate pentru a sprijini activitățile eficientizate și dezvoltarea companiei pentru viitor; menținerea spațiului exterior față de mediul de afaceri extern; observarea și explorarea de noi oportunități potențiale de la concurenți din ce în ce mai mulți sau mai puțini; alegerea căii optime de dezvoltare și evitarea problemelor; luarea unor decizii importante care vor avea un impact asupra dezvoltării afacerii. Deciziile strategice corecte și luate la timp joacă un rol cheie în funcționarea cu succes a unei organizații . Acest lucru în sine va avea un impact major asupra competitivității produselor și a afacerii în ansamblu.

10.1.1.5 Particularități ale abordării procesului

O abordare bazată pe procese este cel mai important semn al unui management fiscal temeinic. Această abordare, care se bazează pe nucleul standardelor internaționale ISO 9000:2000, nu este cu adevărat nouă. La sfârșitul anilor '60, a fost dezvoltată metodologia pentru analiza structurală și proiectarea sistemelor de pliere SADT.

Metodologia SADT a apărut pe piață în 1975. Aceasta va duce la o descriere a proceselor de înregistrare în conformitate cu Standardul Federal al SUA sub denumirea IDEFO. Cel mai mare interes pentru aceste procese a apărut după publicarea lucrărilor lui M. Hammer , D. Champi și colab. la mijlocul anilor '80. Abordarea procesului pentru includere în modelul Premiului Malcolm a apărut în 1988. Baldrige , și în 1991. - Modelul a fost distins cu Premiul European pentru Fire .

Un proces este un set de tipuri de activități interconectate și reciproce care transformă intrările în ieșiri (ICO 9000 2000). Vikhid Procesul (produsul) are valoare pentru angajat. Dacă vorbim despre abordarea bazată pe proces, trebuie să o respectăm pe prima linie pentru toți cei care controlează procesul , iar integrarea intrărilor într-un nou job (activitate, subprocese , procesul altui nivel sau următor sau funcție) se obține prin stabilirea unor metodologii speciale. recepții , dozează bunătăți și îți permit să oprești o mulțime de mese.

Mai jos sunt câteva situații tipice într-o companie în care o abordare bazată pe procese poate fi utilizată pentru a îmbunătăți eficiența.

Opțiunea 1. Organizația poate merge până la capătul norocului său, fie prin kerivniki , fie prin vlasniki, care prevăd o scădere a ratei de creștere a organizației, o creștere a concurenței pe piață, ținând cont de alți factori care reprezintă un risc pentru succes, organizațiile încep să caute modalități de a îmbunătăți eficiența organizației prin optimizarea proceselor de afaceri.

Opțiunea 2. Mediul de piață se dezvoltă și mai mult pentru organizație, iar viteza de creștere a dimensiunii și afacerii organizației depășește viteza de dezvoltare a sistemului de management și a funcționarilor guvernamentali. Odată cu dispariția

incertitudinii din mediul de afaceri, aceștia încep să exploreze noi modalități de a regla situația sub controlul modului de descriere și automatizare a proceselor de afaceri ale unei organizații [289].

De regulă, oficialii guvernamentali și ceremoniile se mulțumesc cu stagnarea abordării procesului până la gestionarea principalelor probleme actuale:

- Vitrat redus;

- Creșterea profitabilității;

- Îmbunătățirea ceramicii (îmbunătățirea sistemului de raportare al companiei, crearea unui sistem de management clar, accelerarea procedurilor de luare a deciziilor manageriale);

- Implicare redusă a factorului uman în conducerea unei companii.

În unele cazuri, birocrații creează grupuri de lucru (grupuri de proiect) cu cei mai calificați contabili pentru a le rezolva problemele. În căutarea deciziei corecte, echipa de bază și grupul de lucru încep să facă rearanjări în structura organizatorică a companiei, reordonând diviziile și subdiviziunile. Pe de altă parte, această activitate sugerează adesea o încercare de a obține o orchestră favorabilă prin reorganizarea muzicienilor.

Majoritatea companiilor nu reușesc să obțină rezultate semnificative pe termen lung prin schimbări organizaționale și prin creșterea intensității mișcării Vikonau. Adesea, directorii companiilor decid să apeleze la consultanți profesioniști. Kerivnitstvo și fakhivtsi încep să caute o firmă de consultanță care să le poată ajuta cu alimentația. Din păcate, recomandările consultanților sunt adesea de natură dubioasă , iar sfaturile lor nu aduc rezultatul dorit. În plus , lucrătorii întreprinderii ar trebui să stăpânească singuri metodele de management al proceselor și, atunci când fac schimbări în organizație, este important să se bazeze pe puterea forței [290].

Cu toate acestea, dovezile arată că o astfel de abordare este sigură de eșec, deoarece orice organizație este un sistem complex de interacțiune, iar o descriere a unuia dintre segmentele de activitate nu poate identifica problemele sistemice în managementul întregii organizații. Atunci când un sistem de control și o interacțiune sunt instalate

într-un singur proces, inevitabil veți dori să interacționați cu acest proces pilot și cu celelalte. Cu o descriere unilaterală a interacțiunii reciproce, pot apărea următoarele situații posibile:

Efectul de „trăgere a covorului" apare dacă nucleul procesului pilot urmărește să reglementeze și să controleze în continuare întreaga muncă din punctul de vedere al beneficiului și avantajului procesului său, și nu al întregii organizații.

Prezența informațiilor necesare în sistemul stabilit pentru reglementarea activităților din partea lucrătorilor din carieră și a autorităților procesului pilot trebuie efectuată înainte ca documentația creată , aprobată și aprobată să fie ajustată și corectată imediat la crearea documentației procesului în curs care interacționează cu structura.

Crearea unui sistem de control al proceselor transferă crearea unui sistem de control al proceselor de jos în sus și sistemul de control de jos în sus. Acest sistem poate fi construit doar de sus în jos, începând cu planurile pentru îngrijirea generală a organizației.

Problema informării rangurilor medii și inferioare ale miniștrilor despre planurile pentru poliție generală și afaceri guvernamentale este unul dintre primele locuri ca importanță. Conducătorul procesului, din cauza posibilității lipsei de informații despre planurile pentru marea biserică, va încerca să stabilească astfel de planuri precum în binecunoscutul Viconty [291].

Conceptul de abordare procesuală a managementului poziției se bazează pe:

1. Principiile sistemelor de management al calității, stabilite în standardele MS ISO, seria 9000, versiunea 2000 rub.;

2. Ciclul PDCA (Planifică-Efectuează-Verifică-Acțiune), adesea numit ciclul Deming ;

3. Principiile BSC (Echilibru) ScoreCard), dezvoltat de Norton și Kaplan;

4. Principii de management proiectele , orice schimbări în organizații , inclusiv introducerea unei abordări bazate pe procese, sunt considerate proiect;

5. Există o indicație clară a necesității unor sisteme de management și a îmbunătățirii activităților organizațiilor [292].

Abordarea bazată pe procese în managementul organizației se bazează pe perspective asupra organizării proceselor de afaceri și a managementului proceselor de afaceri.

de bază ale managementului nu depind de tipul, profilul și domeniul de activitate al companiei, care în viitor va avea un sistem de management al proceselor pentru compania desemnată, așa cum va fi definit termenul „organizație”. Acest termen este folosit în lumea reală pentru întreprinderi industriale, companii care administrează, firme de consultanță sau juridice, structuri comerciale sau guvernamentale.

Pentru toate tipurile de organizații, cerințele actuale necesită sisteme de management eficiente pentru a asigura succesul continuu al organizației și succesul acesteia în mediul mai larg.

Orice sistem de control poate fi dezvoltat doar pe baza obiectelor unice semnificative din care este format . Cele mai importante obiecte din orice sistem de management sunt „Obiectul de Management” - cele care sunt controlate, și „Subiectul de Management” - cel care gestionează. Se pare că , pentru un sistem de management al proceselor, aceste obiecte sunt desemnate prin termenii „Proces de Afaceri” și „Maestru de Proces”.

Procesul este o combinație constantă, complet directă, de tipuri de activități interconectate, care, prin intermediul tehnologiei individuale, transformă inputurile în outputuri valoroase pentru angajat.

Aceste valori se bazează pe cele specificate în standardul MS ISO 9000:2000 și sunt complementare.

Există trei grupuri principale de procese:

Procese transversale (interfuncționale) care trec prin mai multe subdiviziuni ale unei organizații sau prin întreaga organizație ce depășește granițele copii funcționali ;

- Procese (intrafuncționale) și subprocese ale subdepartamentelor, ale căror activități sunt încadrate în cadrul unui subdepartament funcțional al organizației;

- Operațiunile (funcțiile) de cel mai scăzut nivel de descompunere a activităților unei organizații sunt, de regulă, efectuate de o singură persoană.

Termenul „ proces de afaceri ” este utilizat în aceste cazuri atunci când este necesar să se privească procesul într- un sens mai larg, în special ca un set de subprocese de depozit .

Întrucât procesele sau subprocesele sunt în esența și acțiunile lor, atunci pentru identificarea acestor acțiuni este necesar ca denumirile proceselor, subproceselor (sau funcțiilor) să fie exprimate în cuvinte sau, de exemplu, „Proces de producție”, „Proces de vânzare”.

Pentru a gestiona procesul, este necesar să se recunoască persoana responsabilă pentru proces și rezultatul acestuia. Pentru ca primarul să supravegheze procesul, acesta este responsabil pentru gestionarea resurselor necesare pentru desfășurarea acestuia, delegarea drepturilor și restabilirea acestora. Procesul de eliminare a erorilor nu are loc de la sine, ci ca urmare a diverselor funcții din cadrul organizației și este controlat de structura mai largă a organizației. Fragmentele dintr-o serie de episoade din proces pot fi eliminate nu de un singur spivorotenik, ci de un organ de conducere colegial , apoi decizia va veni de către conducătorul procesului [293].

Liderul procesului este o persoană sau un organ colegial de conducere care are la dispoziție resursele necesare pentru implementarea procesului și este responsabil pentru rezultatul procesului.

Maestrul procesului gestionează procesul și partea de depozit invizibil a procesului.

o ieșire în timpul procesului .

Intrarea este întotdeauna de vină pentru mama șefului poștal. Înainte de a intra în proces, pot fi plasate următoarele: brânză, materiale , produse, documentație, informații , personal (pentru procesul de „Angajare”), servicii etc.

Introduceți procesul:

- Intrați în procesul de apel;

Angajamentul lor este planificat pentru unul sau mai multe cicluri ale procesului sau pentru eliberarea unui singur angajament față de produs.

Produsul (rezultatul) este un obiect material sau informațional sau un serviciu care este rezultatul procesului și al experienței clienților externi procesului.

Rezultatul (produsul) procesului va continua să se îmbunătățească. Prin urmare, dacă există un alt proces, atunci pentru acest proces rezultatul este intrarea. Rezultatul (produsul) unui proces poate fi, de asemenea, adăugat la resursă atunci când se adaugă un alt proces. Înainte de sfârșitul procesului, se pot specifica următoarele: produse finite , documentație, informații, inclusiv comunicații, personal , servicii etc.

O resursă pentru un proces de afaceri este un obiect material sau informațional care este adăugat constant procesului, mai degrabă decât să fie o intrare pentru proces.

10.1.1.6 Stabilirea modelelor de referință ale operațiunilor

Conform cercetărilor unor oameni de știință străini, există o relație strânsă între rezultatele înalte ale activității întreprinderii și dezvoltarea unui sistem de evaluare a activității sale guvernamentale. Se pare că în companiile care analizează în mod regulat consecvența rezultatelor obținute față de nivelul planificat, angajamentele de producție sunt cu 14-22% mai mari, mai mici acolo unde nu se iau în considerare abordări similare [294] .

Determinarea principalilor indicatori de eficacitate de către primul manager în procesul decizional din companie. Fără informații despre situația care s-a dezvoltat la un moment dat, este imposibil să se elaboreze un plan de îmbunătățire și să se evalueze efectul schimbărilor implementate. Prin urmare, primul lucru de făcut este să se îmbunătățească direct rezultatele și, mai ales, să se depună eforturi directe, trebuie să se efectueze o analiză a activității. În cadrul logisticii, aceste produse alimentare au fost tratate astfel încât să se privească problema în sine din poziția unui model de referință indirect al operațiunilor din lanțurile de aprovizionare (aprovizionare Lanţ Operațiuni Referinţă model , model SCOR).

În mod tradițional, organizațiile și-au concentrat atenția asupra aspectului financiar și și-au bazat deciziile și hotărârile pe această bază. Industria logistică a urmat principiile managementului financiar. Între sistemul de evaluare a afacerilor, care se

învârte în jurul indicatorilor financiari ai activității, criticii indică cel mai adesea o orientare către finalizarea rezultatelor și un orizont pe termen scurt al evaluărilor, imposibilitatea practică a etapei de imagistică a sistemului de a atinge obiectivele strategice. Pentru luarea deciziilor manageriale, informațiile au devenit rare până de curând disponibile. Importanța crescută a principiilor managementului strategic și a obiectivelor de piață în asigurarea funcționării eficiente a întreprinderilor a creat necesitatea regândirii parametrilor de evaluare a funcționării și dezvoltării acestora [295] .

Ca răspuns la această problemă, încă din anii '90 ai secolului trecut, a fost dezvoltat un model de referință al operațiunilor în lanțurile de aprovizionare, care reprezintă o schemă unică ce reunește indicatori de eficiență, procese și cele mai bune practici și specialiști într-o singură structură.

Modelul SCOR nu descrie niciun proces de afaceri sau tip de activitate. Nu acoperă vânzările și marketingul, cercetarea și dezvoltarea tehnologiei sau produselor. De asemenea, modelul presupune, dar nu ia în considerare, importanța energiei, a tehnologiei informației și a administrării. Prin utilizarea unui model de referință al operațiunilor lanțului de aprovizionare, este posibil să se descrie arhitectura procesului într-un mod semnificativ pentru partenerii cheie de afaceri. Acest lucru este util în special pentru descrierea valorii adăugate a unui număr de departamente și organizații care le furnizează resurse pentru gestionarea proceselor logistice. În general, modelul este un instrument important pentru managementul întreprinderii, deoarece oferă capacitatea de a descompune un proces complex pe un model de proces standardizat. Un astfel de mecanism permite evaluarea, gestionarea, ajustarea și reajustarea procesului de pliere [296-305] .

Modelul de referință al operațiunilor din lanțurile de aprovizionare include:

- indicatori de eficacitate – indicatori standard pentru monitorizarea eficacității procesului;
- procese – procese de control standardizate și scheme de interacțiune între procese;

- practici – metode de management care demonstrează o productivitate superioară în clasa lor;
- personal – oportunitățile de pregătire și avansare a calificărilor includ procese, practici avansate și demonstrații.

Să aruncăm o privire asupra unei părți a modelului care demonstrează eficacitatea. Acesta constă din două tipuri de elemente: criterii și indicatori. Printre criterii, modelul include fiabilitatea, fluiditatea, manevrabilitatea, costul și eficiența managementului activelor (Tabelul 1.4). Criteriul în sine nu poate fi măsurat, ci trebuie stagnat pentru a stabili o direcție strategică. Indicatorul, însă, este un standard pentru măsurarea eficacității procesului. Indicatorii modelului sunt diagnostici [297] .

Tabelul 1.3

Explicația principalelor criterii ale sistemului logistic

Criterium	Explicaţie
Nadijinist	data construcției clădirii, așa cum a fost realizată; transferul rezultatului în proces; caracteristică axată pe client
Lichiditatea vodcii	descrie capacitatea de a răspunde la influențe externe și capacitatea de a se schimba. Manevrabilitatea este o caracteristică care se concentrează pe client.
Manevrenișți	descrie splendoarea cu care este construită planta; este o caracteristică care se concentrează pe client.
Vitrați	descrie costul operării procesului. Acestea includ costul forței de muncă, al materialelor și al costurilor de transport. Această caracteristică este directă intern.
Eficiența gestionării activelor	descrie structura activelor vikoristovat eficiente. Strategiile de gestionare a activelor în Franța includ reducerea stocurilor și alegerea între resursele interne și externalizarea. Această caracteristică este directă intern

Modelul SCOR recunoaște trei niveluri de indicatori. Primul indicator este utilizat pentru a diagnostica problema sistemului logistic. Acești indicatori sunt cunoscuți și sub denumirea de indicatori strategici și indicatori cheie de performanță (KPI). Indicatorii de benchmarking de acest nivel ajută la stabilirea unor obiective realiste

care să susțină obiectivele strategice. Un alt nivel de indicatori servește la diagnosticarea primului nivel. Interacțiunea diagnostică ajută la identificarea cauzei sau cauzelor principale ale problemelor cu eficiență scăzută în primul rând. Indicatorii de al treilea nivel servesc la diagnosticarea unui alt nivel. Analiza indicatorilor de la primul la al treilea nivel se numește defalcare. Aspectul ajută la identificarea proceselor (care sunt în concordanță cu dovezile din primul secol și din celelalte secole) care trebuie analizate mai detaliat. Exemple de indicatori bazați pe criterii sunt prezentate în Tabelul 2 [297] .

Tabelul 1.4

Exemple de indicatori din diferite țări pe baza unor criterii

Criterium	Seducători
Nadijinist	Acuratețea contractului, acuratețea documentației, sute de produse furnizate în obligații constante, temeinicitatea produsului, garanțiile și retururile etc.
Lichiditatea vodcii	Timp operațional pentru asigurarea resurselor, timp operațional pentru producție, timp operațional pentru instalare etc.
Manevreniști	Flexibilitatea sistemului logistic este legată de creșterea populației, adaptabilitatea sistemului logistic la creșterea populației, adaptabilitatea sistemului logistic la o populație scăzută, variația globală a lumii riziku etc.
Vitrați	Cheltuieli pentru gestionarea sistemului logistic, cheltuieli pentru planificare, cheltuieli pentru asigurarea resurselor, cheltuieli pentru livrare etc.
Eficiența gestionării activelor	Valoarea ciclului de conversie a produselor, rotația creanțelor pe termen lung, rotația stocurilor, rentabilitatea capitalului investit etc.

Astfel, modelul de referință limitat al operațiunilor este acela că nu ia în considerare procese precum cercetarea și dezvoltarea, vânzările și marketingul și alte elemente ale serviciilor post-vânzare . Cu toate acestea, modelul va oferi un număr mare de indicatori bogați, a căror analiză este importantă pentru management.

10.1.1.6 Subiecte pe secțiuni

În urma analizei, s-au obținut următoarele constatări:

– Organizarea fluxului informațional în mijlocul întreprinderii are ca scop principal organizarea fluxului de documente. Transmiterea unui document este o procedură mai inteligentă, mai complexă și mai necesară, deoarece reprezintă etapa finală a proceselor de flux informațional.

– Toate procesele care au loc în cadrul întreprinderii se reflectă în documente, astfel încât organizarea managementului și fluxul de documente este același proces.

– Pentru a descrie întreprinderea , în concepția noastră actuală, este necesară efectuarea unei analize SWOT. Aceasta oferă beneficii prin planificare strategică.

– Utilizarea unei abordări bazate pe procese va ajuta la crearea unui sistem de management care poate atinge exhaustivitatea.

– Utilizarea modelelor de referință va ajuta la promovarea abordării bazate pe proces.

10.1.2. ADAPTAREA MODELELOR DE REFERINȚĂ PENTRU MANAGEMENTUL PROCESELOR LOGISTICE. ANALIZA STAȚIEI FINANCIARE A SRL-ULUI "XXX-1".

10.1.2.1 Valoarea întreprinderii

TOV „XXX-1” este specializată în mod tradițional în producția de ferestre din plastic. Compania operează cu brokeri pe baza unor acorduri contractuale pe termen lung , precum și cu contabili ai mecanismului de procesare pentru organizarea executării tranzacțiilor unice, inclusiv a serii mici de produse.

Laboratorul este dotat cu următoarele echipamente:

– 90% din producția Nimechchini;

– 5% din producția franceză;

– 5% posesie de virobnitstva

În timpul producției de virusuri, se utilizează materiale aplicate de la companii europene de top.

Prima etapă a analizei activității financiare și guvernamentale constă în monitorizarea dinamicii și structurii bilanțului contabil. Prin această metodă se efectuează o analiză orizontală și verticală a soldului, așa cum se indică în tabelul 2.1.

Valoarea totală a soldului valutar a crescut cu 3,84% față de anul 2012.

În 2022, suma din soldul activelor s-a modificat cu 495 mii UAH (7,61%) față de anul 2012. Prețul a fost pentru suma beneficiilor de bază, care s-a modificat la o sumă de 292 mii UAH, deși rezervele au crescut cu 243 mii UAH. Creanțe pentru distribuții, alte creanțe în linie, care au scăzut cu 100% și alte...

Influxul în activele întreprinderii a dus la o creștere a altor datorii pe termen lung cu 1325,00 mii UAH, o creștere a altor aprovizionări curente cu 392,00 mii UAH, o creștere a datoriilor creditoare directe pentru bunuri, lucrări, servicii cu 107 mii UAH. A avut un impact negativ asupra întreprinderii pasive din stocul neacoperit cu 1641,00 mii UAH.

Tabelul 2.1

Soldul agregatelor - net de SRL-ul „XXX-1”

Articol	2012	2013	2022	Aniversare 2022/2012 .	
				Mii de UAH	%
I. Active imobilizate, inclusiv	3844,00	3753,00	3552,00	-292,00	-7,60
Active necorporale	0,00	0,00	0,00	0,00	
Osnoni zasobi	3838,00	3747,00	3546,00	-292,00	-7,61
Alte investiții financiare	6.00	6.00	6.00	0,00	0,00
II. Active circulante, inclusiv	1911,00	2718,00	2424,00	513,00	26,84
Faceți provizii	1154,00	1438,00	1397,00	243,00	21.06
Datorii pentru produse, bunuri, roboți, servicii	359,00	402,00	340,00	-19.00	-5,29
Responsabilitatea creanțelor din buget	48,00	62,00	45,00	-3,00	-6,25

Continuare tabel 2.1

pentru progrese vizibile	152,00	535,00	485,00	333,00	219,08
Alte creanțe în linie	31.00	2,00	0,00	-31,00	-100,00
Pennies și echivalentele lor	48,00	116,00	44,00	-4.00	-8,33
Petreceți luna următoare	1,00	1,00	1,00	0,00	0,00
Alte active curente	118,00	162,00	112,00	-6.00	-5,08
III. Active imobilizate deținute în vederea vânzării, iar grupul va fi lichidat	0,00	0,00	0,00	0,00	-
Echilibru	5755,00	6471,00	5976,00	221,00	3,84
I. Capitalul energetic, inclusiv	1222,00	346,00	-419,00	-1641,00	-134,29
Capital social înregistrat	1312,00	1312,00	1312,00	0,00	0,00
Capital la evaluări suplimentare	397,00	397,00	397,00	0,00	0,00
Capital suplimentar	253,00	253,00	253,00	0,00	0,00
Profit neîmpărțit (surplus neacoperit)	-740,00	-1616,00	-2381,00	-1641,00	221,76
II. Guși și boli pe termen lung, inclusiv	2397,00	3572,00	3722,00	1325,00	55,28
Depunerea gușei	0,00	0,00	0,00	0,00	-
Alte gușe cu evoluție lungă	2397,00	3572,00	3722,00	1325,00	55,28
III. Mai precis, gușa și îngrijirea sănătății	2136,00	2553,00	2673,00	537,00	25.14
Credite bancare pe termen scurt	0,00	0,00	0,00	0,00	-
Datoria creditorului curent pentru:	0,00	0,00	0,00	0,00	-
- gușă pe termen lung;					
- bunuri, roboți, servicii;	7.00	95,00	114,00	107,00	1528,57
- planuri bugetare;	15.00	6.00	7.00	-8.00	-53,33
- cheltuieli și asigurări;	20.00	18:00	23:00	3,00	15.00

Continuare tabel 2.1

- plăți pentru plată	39,00	44,00	82,00	43,00	110,26
Alte tipuri de gușă	2055,00	2390,00	2447,00	392,00	19.08
IV. Active imobilizate asociate cu active imobilizate,	0,00	0,00	0,00	0,00	-
Utrimuvanimi de vânzare și vibutya în grupuri					
Echilibru	5755,00	6471,00	5976,00	221,00	3,84

În acest caz, se evită o creștere a gușelor pe termen lung și este necesară creșterea altor gușe pe termen lung pentru rata de 1175,00 mii UAH. În 2013 creșterea a fost, de asemenea, cu 150,00 mii UAH. În 2022, precum și o creștere a culturilor de producție și a securității cu 537,00 mii UAH, pentru creșterea rapidă a datoriei creditorilor liniare pentru bunuri, muncă, servicii cu 107,00 mii UAH, precum și o creștere a altor fluxuri continue cu 392,00 mii UAH.

10.1.2.2 Analiza activelor și a cererilor

Analizăm activele imobilizate . Valoarea s-a modificat la 292 mii grivne, inclusiv pentru furnizarea de beneficii de bază. Alte investiții financiare au înregistrat pierderi la nivelul anterior și au rămas neschimbate.

Activele circulante au crescut cu 513,00 mii UAH, iar pentru aceeași perioadă rezervele au crescut cu 243,00 mii UAH, o creștere a creanțelor și datoriilor pentru plățile anumitor avansuri cu 333,00 mii UAH, ceea ce se arată în. Este clar că o pondere crescută a capitalului circulant este indicată pozitiv în indicatorii de soliditate financiară și lichiditate, motiv pentru care putem confirma creșterea rezervelor, volumul producției, pregătirile pentru adăugarea factorilor materiali-vocali la producție.

Din cauza altor congestii ale fluxurilor, prețul s-a modificat, mai precis, în 2022 a devenit 0,00 mii UAH. Creanțele pentru produse, bunuri, lucrări și servicii s-au modificat, de asemenea, cu 19,00 mii. Datoria față de buget a creanțelor în UAH s-a

modificat cu 3,00 mii UAH, iar bănuții și echivalentul acestora s-au modificat cu 4,00 mii UAH.

O modificare a ponderii activelor circulante se reflectă negativ în indicatorii de soliditate financiară și lichiditate.

Zona din jurul capitalului statutar și a fluxului neacoperit către canalele interne de finanțare trebuie, de asemenea, creată cu ajutorul unei întreprinderi de înaltă calitate pentru a asigura eliberarea fluxurilor de numerar viitoare, a taxelor, a gușei, a căror dimensiune este într-adevăr mică.

În bilanțul contabil, care a fost ajustat în 2012, s-a înregistrat o modificare fatidică a capitalului propriu datorită creșterii capitalului neacoperit cu 1.641 mii UAH. Pentru a te ferești de o creștere a gușelor pe termen lung, va trebui să plătești pentru creșterea altor gușe pe termen lung cu 1.325 mii UAH, precum și pentru o creștere a culturilor de producție și îngrijire cu 537 mii UAH, pentru creșterea datoriei creditorilor în rate pentru bunuri, lucrări, servicii cu 107 mii UAH, precum și pentru o creștere a altor comenzi de lucrări continue cu 9.392 mii UAH.

Aceasta înseamnă o rambursare în esență scăzută, indicatori scăzuți de lichiditate și stabilitate financiară. Întreprinderea SRL „XXX-1” prezintă un risc ridicat de faliment.

Analizăm modificările ponderii globale a capitalului energetic din 2012 până în 2013. (Fig. 2.3.). Wonul s-a schimbat în mayzha în chotiri razi, iar el însuși a crescut la 876,00 mii UAH, apoi cu 134,29%. Acest lucru s-a datorat creșterii numărului de frișcă neacoperită. La acea vreme, gușa pe termen lung și problemele de sănătate au crescut în 2013 cu 1175,00 mii UAH, din cauza creșterii altor tipuri de gușă pe termen lung.

În 2012, cererea curentă și securitatea populației au crescut cu 537,00 mii UAH, confirmând prezența creditelor bancare pe termen scurt, o creștere a fluxului de conturi de plătit pentru bunuri, lucrări, servicii cu 107,00 mii UAH. Această tendință s-a manifestat printr-o creștere a altor comenzi curente în 2013, o creștere de 335,00 mii UAH.

10.1.2.3 Analiza costurilor

Analizând datele din tabelul 2.2, se poate concluziona că la întreprinderea SRL „XXXX-1" în anul 2012 s-a înregistrat o scădere a costurilor materialelor cu 2,31%, ceea ce înseamnă o scădere suplimentară a productivității.

Pe baza analizei noastre, costul plății produselor pentru animale de companie a crescut cu 1,15%, ceea ce înseamnă o creștere a intensității forței de muncă pentru acest produs.

Continuă tendința de creștere a amortizării, care a crescut cu 1,89%, ceea ce înseamnă o scădere a nivelului tehnic al producției.

Tabelul 2.2.

Structura Vitra pe elemente pentru rublele 2012-2022 , %

Numele statului	2012	2013	2022r.	Schimbări la nivelul structurii
Costuri materiale	16.38	19,89	11,86	-4,52
Cheltuiește pentru a plăti prețul	23.11	20,86	22,77	-0,34
Îngrijire medicală la ocazii sociale	8.05	7.26	7,86	-0,19
Amortizare	7,61	6.44	8.36	0,75
Alte cheltuieli de exploatare	44,83	45,53	49.13	4.3
Împreună	100	100	100	0

Datorită creșterii costurilor materiale în anul 2013, s-a înregistrat o ușoară tendință ascendentă, acestea crescând cu 3,51%. Se anticipează o creștere a cheltuielilor materiale pe fondul reducerii cheltuielilor pentru plata muncii și a asigurărilor sociale.

Productivitatea ta va crește.

Cuantumul amortizării se va modifica cu 1,17%, iar alte cheltuieli de exploatare vor crește cu 0,7%.

În urma analizării datelor din tabelul 2.2 și a cheltuielilor în sine, a reieșit că cea mai mare pondere revine altor cheltuieli operaționale, care reprezintă 49,13% la sfârșitul anului 2022 și sunt în creștere treptată.

Creșterea cheltuielilor materiale în 2013 este estimată să crească cu 3,51%, iar în 2022 creșterea acestora va scădea cu 8,03%, la același nivel ca în 2013.

În mod similar, în 2013, suma cheltuită pentru plata impozitelor s-a modificat cu 2,25%, iar în 2022, suma a crescut cu 2%.

Modificările pentru alte articole s-ar putea să nu fi fost evitate.

Rezultatele defalcării principalilor indicatori sunt prezentate în tabelul 2.3.

Tabelul 2.3.

Evaluarea ratei de creștere a întreprinderilor pentru coeficienți suplimentari

Nr. salariu	Seducători	2012 rik	2013 rik	2022 ric	Schimbări 2022 - 2012
1. Analiza industriei miniere					
1.1	Coeficientul de amortizare al principalelor caracteristici	0,44	0,47	0,51	+0,07
1.2	Coeficientul de atribuire a principalelor caracteristici	0,56	0,53	0,49	-0,07
2. Analiza lichidității întreprinderii					
2.1	Coeficient de acoperire	1. 80	1,47	1.33	-0,47
2.2	Raportul de lichiditate	1,26	0,91	0,81	-0,45
2.3	Raportul de lichiditate absolută	0,02	0,05	0,02	-0,01
2.4	Capital circulant net	1708,00	1200,00	879,00	-829,00
3. Analiza exigibilității (starea financiară)					
3.1	Coeficientul de autonomie	0,21	0,05	0,07	-0,14
3.2	Raportul de finanțare	2.12	2,40	2.39	+0,27
3.3	Coeficientul de securitate Wet Koshta	-0,11	0,06	-0,09	+0,01
3.4	Coeficientul de manevrabilitate al capitalului de apă	-0,18	0,48	-0,59	-0,41

Continuare tabel 2.3

4. Analiza activității economice					
4.1	Rata de rotație a activelor	0,61	0,72	0,55	-0,05
4.2	Rata de rotație a activelor principale	0,91	1.17	0,94	+0,04
4.3	Rata de rotație a capitalului de apă	2,57	5,65	8,98	+6,41
5. Analiza profitabilității întreprinderii					
5.1	Raportul rentabilității activelor	0,01	-0,10	-0,13	-0,14
5.2	Raportul rentabilității capitalului	-0,24	-0,72	-2,21	-1,97
5.3	Rata de rentabilitate a activității	-0,10	-0,20	-0,22	-0,12

Prin caracterizarea stării tehnice a principalelor caracteristici, este posibil să se tragă concluzii despre îmbunătățirea acesteia, ceea ce este confirmat de o rată de uzură în creștere. În general, se acceptă că valoarea coeficientului de amortizare peste 50% nu este necesară.

Conform lui Yak Bachimo din Fig. 2.4, chiar și la începutul perioadei de cercetare, coeficientul de amortizare era mai mic decât norma și a crescut treptat în anii următori. În prezent, acest indicator se situează la nivelul de 51%, ceea ce este mai mare decât raportul dintre principalele caracteristici. De asemenea, nivelul tehnic al principalelor caracteristici ale întreprinderii se îmbunătățește treptat.

La întreprinderea TOV „ XXX-1 ”, coeficientul de acoperire este mai mare decât unu și prezintă o tendință descendentă, ceea ce indică o prognoză nesatisfăcătoare a capacității de plată, care poate fi crescută în Fig. 5.

La același nivel ca în 2012, coeficientul s-a modificat la un maxim de 0,5, ceea ce indică faptul că producția de apă nu dispune de resurse suficiente.

Raportul de lichiditate este mai mic de 2, ceea ce înseamnă că afacerea nu necesită furnizori de servicii de plată. Atunci nu există suficiente oportunități de plată pentru a achita recoltele actuale.

În regulamentul nr. 323, valoarea coeficientului de lichiditate absolută este stabilită la valoarea sa teoretică, care nu poate fi mai mică de 0,2 – 0,35. În acest caz, valoarea acestui coeficient este semnificativ mai mică decât valoarea teoretică, ceea ce înseamnă că capacitatea de personal a acestei întreprinderi este considerată scăzută, indicând o parte din dificultățile pe termen scurt, cum ar fi achitarea datoriilor în viitorul apropiat.

Analizând Fig. 2.4, în plus, la această întreprindere valoarea capitalului circulant net se modifică reciproc, iar în 3 ani capitalul circulant net s-a modificat cu 829 mii UAH, ce putem spune despre faptul că nu se vor stinge imediat culturile pe termen scurt?

Coeficientul de autonomie este clar prezentat în Fig. 2.5, modificându-se cu 0,14, iar în 2022 populația este de 0,07; se observă că cei care au vândut produsul principal, turnat din piese umede, întreprinderea nu poate stinge gușa, precum și scăderea stabilității financiare a întreprinderii.

Raportul de finanțare a crescut la 2,39 în 2022. Aceasta arată ponderea activelor pozitive primite de întreprindere, per 1 grivnă investită în activele activelor financiare.

Coeficientul de securitate pentru costurile umede este de -0,09 în 2022, ceea ce indică faptul că activele funcționale evidente ale întreprinderii nu sunt acoperite de costurile umede și jerelurile echivalente.

Un astfel de raport este considerat normal dacă coeficientul de securitate la umiditate depășește 0,1. În cazul TOV „XXX-1 ”, coeficientul său în 2012 devine 0,11, activele circulante ale întreprinderii sunt acoperite cu ponderi egale cu acestea. Modificarea coeficientului între 2013 și 2022 poate însemna că întreprinderea nu mai este capabilă să acopere activele circulante existente în întreprindere cu active energetice.

Analizând, observăm că acest tip de producție este de așteptat să reducă coeficientul de manevrabilitate cu 0,41% timp de 3 ani, ceea ce indică o modificare a elasticității capitalului energetic, apoi va exista o modificare a ponderii capitalului energetic în activitățile operaționale.

Orez excelent. 2,7, indicatorul rotației activelor este de 0,55 în 2022, care este mai mic în 2012. De asemenea, este important de observat de câte ori în perioada de analiză apare un nou ciclu, ceea ce aduce un efect similar în apariția profitului.

Rata de rotație a capitalului energetic caracterizează eficiența creșterii capitalului energetic, iar în 2022 este de 8,98, ceea ce este semnificativ mai mare în același an din 2012, dar nu caracterizează o situație pozitivă pentru întreprinderi.

10.1.2.4 Analiza cost-beneficiu

Analiza indicatorilor de rentabilitate (profitabilitate) este prezentată în.

Raportul rentabilității activelor s-a modificat cu 0,14, iar în 2022 rata este de -0,13, ceea ce indică o scădere a cererii de produse pentru întreprinderi.

Rata de rentabilitate a capitalului hidrografic s-a modificat de 9 ori și este de -2,21 la sfârșitul anului 2022, ceea ce arată nivelul de rentabilitate al capitalului hidrografic.

Rata de rentabilitate pentru rata de creștere din 2022 este de -0,22, ceea ce este mai mic decât rata de creștere din 2012. Aceasta va indica o schimbare în eficacitatea activităților economice ale guvernului.

10.1.3. ADAPTAREA MODELELOR DE REFERINȚĂ PENTRU MANAGEMENTUL PROCESELOR LOGISTICE. VICTORISTANUL METODELOR DE CERCETARE PENTRU OPTIMIZAREA MUNCII ÎN ÎNTREPRINDERILE DE MUNCĂ

10.1.3.1 Importanța managementului întreprinderii

Stație de referință pentru conectarea cu sediul SRL-ului „XXX-2” (Companie) pentru producerea de ferestre din plastic. Statutul juridic al companiei se caracterizează prin:

1. Prelungirea termenilor Vikonian. Așadar, linia de mijloc a unui acord similar a crescut de la 16 în 2012 la 27 în 2022. Aceasta indică o viteză insuficientă de procesare a informațiilor conform contractului.

2. Îmbunătățirea calității produselor. Creșterea recentă a prețurilor la materiale și resurse energetice a fost semnificativ mai mică decât creșterea productivității. Salariul nu s-a modificat.

3. Loialitate redusă a personalului cel mai calificat. Episoade de disciplină de muncă deficitară și absenteism.

4. De la unii dealeri, inclusiv faptul că au făcut afaceri cu Compania de mult timp.

5. Lăsând accentul pe respectul pentru afacerile comerciale, cheltuielile de publicitate,

6. Apariția de noi oportunități pentru comportament corupt în rândul spionilor.

O astfel de companie a fost apelată atât de interesul banal de a intra în afaceri cu un conducător uriaș, cât și de domeniul banal al cumpărării și vânzărilor. Nivelul de respect al managerilor de top ai companiei pentru încrederea în procesele lor de afaceri a scăzut semnificativ. Drept urmare, au apărut tendințe înainte de pierderea unei părți din piață.

Pentru un nou proprietar, pentru o analiză SWOT suplimentară (scrisori inițiale privind punctele forte , punctele slabe , oportunitățile și amenințările), în pregătirea unei analize a afacerii, în ceea ce privește punctele forte și punctele slabe, precum și potențialele oportunități și amenințări externe:

Tabelul 3.1

Rezultatele analizei SWOT a SRL-ului „XXX-3”

Păgini simple	**Slabkii pagini**
Notorietate ridicată a mărcii	Conflicte prelungite legate de vânzarea afacerii, care afectează negativ imaginea
Tipuri de sisteme de profil în beneficiul rezidenților	Sistemul de control original nu oferă independența necesară producătorilor de filete.
Niveluri ridicate de eficiență energetică, depășind performanța concurenților	Demotivarea echipei, care este concentrată pe schimbări, nu produce nicio eficiență.
Fileuri rotative în regiuni promițătoare	Imposibilitatea creării de prețuri și a formării securității sociale
Eficiența producției este semnificativă	

Continuare tabel 3.1

Можливості	**Amenințа**
Structură de management îmbunătățită	Comoditizare ridicată a produsului (pierderea unor beneficii semnificative pentru angajați între produse dintr-o anumită categorie)
Creșterea vânzărilor pentru noi forme de vânzări (franciză)	Cenzura lui Mitsnyi se strânge din partea altor producători
Creșterea eficienței proceselor de management și asigurarea unei abordări stabile a proceselor	Capacitatea concurenților de a-și îmbunătăți eficiența energetică

Analizând tabelul 3.1 Este important de reținut că aspectele slabe provin din deficiențele în organizarea activităților de prelucrare a deșeurilor și oțel ale personalului militar din toate ramurile. Conform diferitelor estimări, controlul acestor activități ocupă până la 80% din orele de lucru ale managerilor de top, iar doar 20% din oră poate fi dedicată dezvoltării (cercetări noi, instruire etc.).

În plus, este necesar să se identifice relațiile dintre factorii „interni” (puncte forte și puncte slabe) și cei „externi” (oportunități și amenințări) care pot avea o importanță strategică. Aceste interconexiuni în sine ne permit să formulăm priorități, avantaje și riscuri egale, care stau la baza unei alegeri strategice - formularea obiectivelor strategice și operaționale pentru dezvoltarea întreprinderilor pe termen lung.

Capacitatea de a susține în mod tradițional punctele forte ale afacerii în sine:

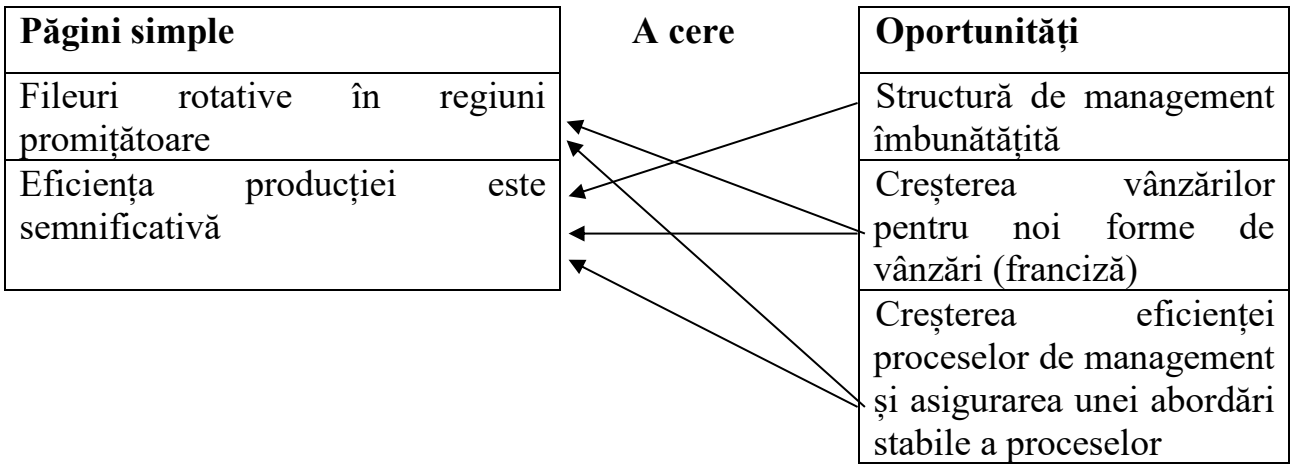


Figura 3.1 – Interacțiunile dintre punctele forte (factor intern) și capacitățile (factor extern).

3 induse Fig.3.1. Se poate observa că nu toate punctele forte sunt susținute, ci doar cele legate de management.

Există un aflux vizibil în schimbare de capabilități în aspectele slabe ale activităților Companiei:

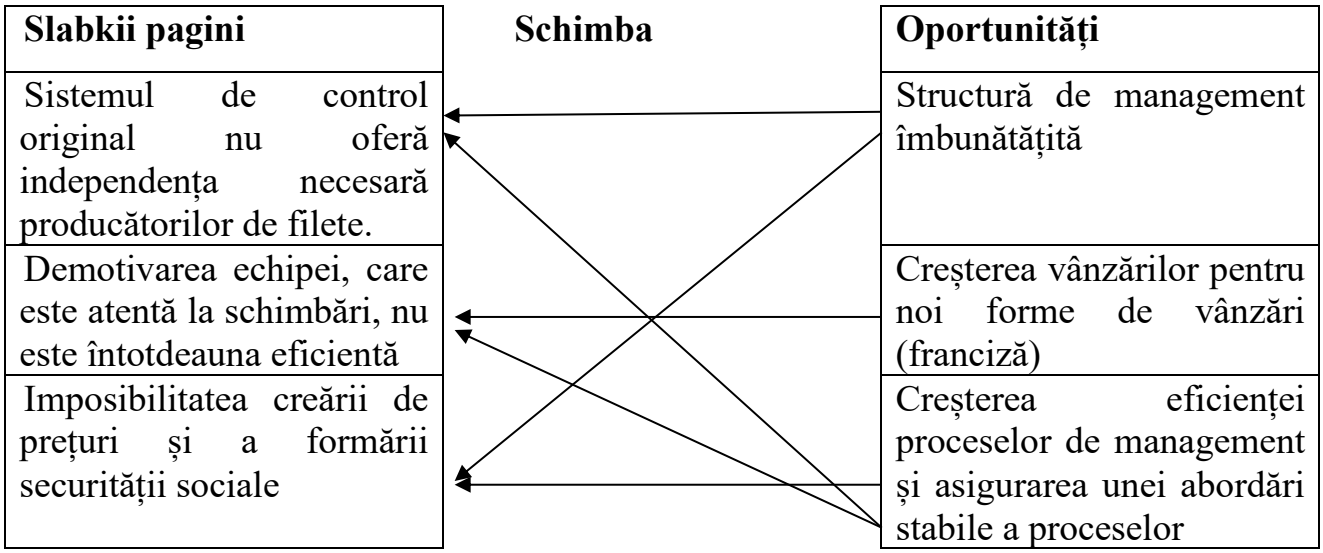


Figura 3.2. Interacțiuni dintre punctele slabe (factor intern) și capacitățile (factor extern)

Putem urmări relațiile dintre punctele slabe (factor intern) și amenințările (factor extern):

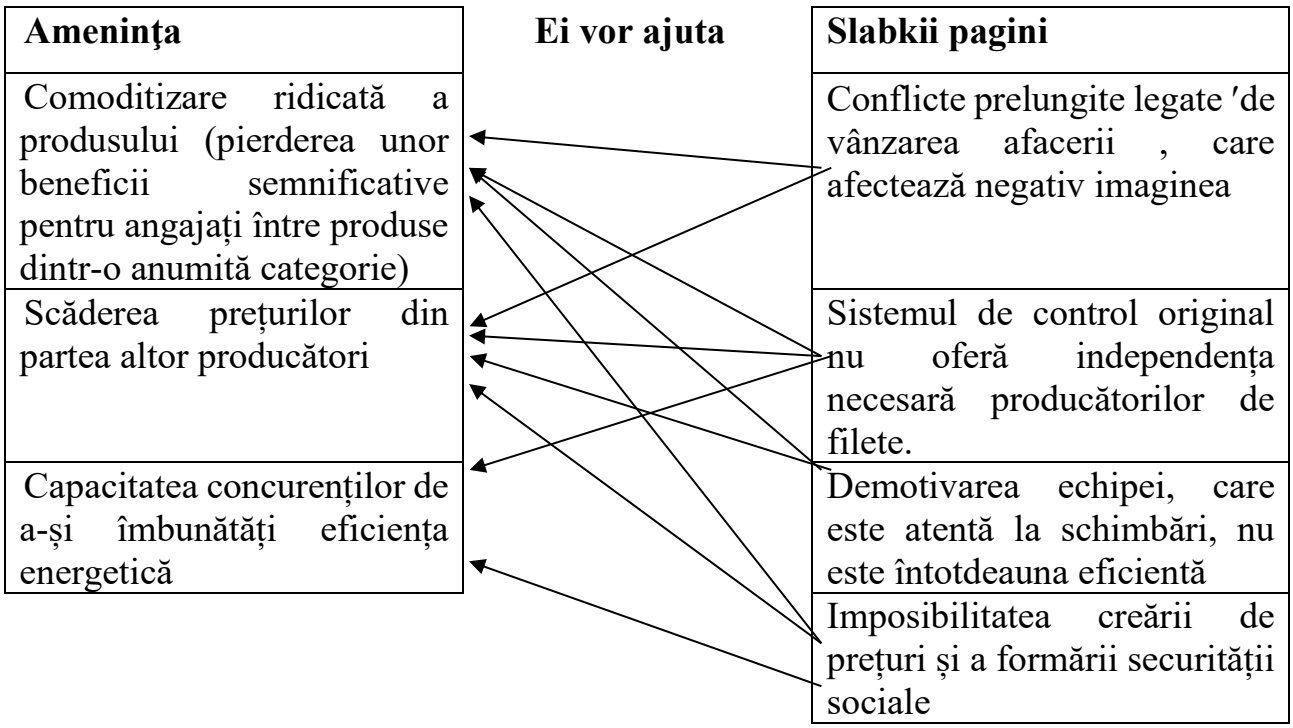


Figura 3.3 Interacțiuni dintre punctele slabe (factor intern) și amenințările (factor extern).

Prin stabilirea interacțiunilor (Fig. 3.1., 3.2. și 3.3.) este posibilă creșterea eficienței proceselor de control și asigurarea stabilității abordării procesului, care nu este Vikoristovyvaya, ci susține două dintre cele cinci puncte forte și înlocuiește trei dintre cele patru puncte slabe. Prin urmare, este important să se înțeleagă caracterul complet al abordării procesului SRL „XXX-3”.

În situația creată, Vlasnik și noii manageri de top au ajuns la concluzia că au nevoie de instrumente fundamental noi pentru organizarea proceselor de afaceri, create într-un timp scurt pentru a rezolva principalele probleme:

- integrarea muncii la toate nivelurile de management, de la guvern la mediul de afaceri,

- să promoveze fiabilitatea și eficiența personalului de securitate în activitatea sa; să le insufle inerția că acordarea grațierilor va fi în toate cazurile corectată cu ajutorul resurselor administrative și financiare, așa cum se practica sub marele domnitor,

- pentru a oferi managerilor de top oportunitatea de a se concentra pe proiecte de dezvoltare , care, de fapt, erau înghețate în Companie la momentul respectiv.

10.1.3.2 Descrierea structurii afacerii în termeni formali

Înainte de a analiza aplicații specifice, este necesar să înțelegem principiile de funcționare ale acestei „mașini de afaceri”:

Conceptual, „mașina de afaceri” oferă clienților săi produsele sale în schimbul banilor acestora, sub rezerva cerințelor legale.

Rezultatul ideal al acestui schimb: pe de o parte, clienții vor aprecia valoarea pe care au apreciat-o în urma produsului; pe de altă parte, conducătorii își ating obiectivele propuse (nu neapărat doar cele financiare, ci și cele legate de imagine, cele sociale).

Punctul central al acestui schimb: clientul comandă să plătească produsul conform principiului „puțin și apoi”, proprietarul - să retragă bănuții „din belșug, aici, imediat și în mod constant”.

Adică, conținutul laturilor este format din două benzi diferite sau strâns împletite. Pe o parte, există un obiectiv de valoare durabilă (formează satisfacția clientului,

săgeata roșie din diagramă), pe cealaltă parte, există un obiectiv de valoare durabilă, de exemplu, valoare suplimentară (formează satisfacția Vlasnik, săgeata albastră din diagramă).

Este clar că, atâta timp cât cele două șnururi sunt în poziții egale, fără a fi înclinate într-o direcție sau alta, este mai ușor pentru proprietari și clienți să își recunoască valorile.

Echilibrul constant al acestor două elemente se realizează doar dintr-o dată, deoarece procesele de afaceri ale companiei sunt inițial privite ca un sistem întreg. Când vine vorba de dezvoltarea unui sistem de procese de afaceri astăzi, cea mai cuprinzătoare abordare și, în opinia noastră, cea mai universală este abordarea bazată pe procese . Aceasta este aceeași abordare pentru alegerea realizării principalelor sarcini de afaceri în cadrul acestei companii.

La început, este necesar să se determine specificațiile pentru dezvoltarea unui nou sistem de interacțiune între sucursală și companie.

Noul sistem de management este responsabil, pe de o parte, pentru acordarea unui spațiu operațional mai mare directorilor sucursalelor, în calitate de „câștigători de bani”; pe de altă parte, pentru introducerea lor în noi beneficii corporative și, cel mai important, pentru acceptarea ascendenței lor. Principala afacere aleasă a fost: „Vânzări de structuri de ferestre”.

În prima etapă, au fost identificate relații cheie care ar permite acestei afaceri să derive direct din mediul extern și din structura subiacentă – SRL „XXX-3” .

De fapt, această mică imagine înfățișează o „mașină de afaceri înaltă cât ochiul unei păsări”; în practica modelării afacerilor, o astfel de diagramă se numește model de proces de afaceri de nivel superior.

Vaughn își imaginează:

1. Activitatea direcției în cooperare cu autoritățile locale.

2. Activitatea direcției cu beneficiile potențialilor asociați la nivel strategic.

3. Activitatea biroului pentru asigurarea principalelor activități cu resurse de forță de muncă.

4. Activitatea biroului pentru monitorizarea calității produselor.

5. Participarea biroului la activitățile comerciale zilnice.

6. Control mai precis.

7. Munca directorului pentru interacțiunea cu oficialii guvernamentali.

La fel ca în Figura 3.4. Puteți mări pozițiile rezultate (ieșirile) procesului de control de nivel superior. Și pentru dumneavoastră:

1. Elaborarea planului strategic.

2. Sunați rigla.

3. Coordonarea producției și a vânzărilor.

4. Intrați cu disciplină.

În alte etape și în etape ulterioare, au fost detaliate indicațiile privind conexiunea și activitatea și au fost furnizate denumiri specifice (suficiente pentru înțelegere în același timp, ceea ce este vizibil în acest moment). Astfel, „reglementările corporative” de care este responsabil directorul comercial sunt reprezentate de: „reglementări pentru planificarea directă a activităților” și „reglementări pentru raportarea directă a activităților”. La cele mai joase niveluri, reglementările sunt denumite extrem de specifice, de exemplu: „Metodologia de elaborare a unui plan calendaristic pentru un proiect ”.

În principiu, detalierea modelului de procese de afaceri al nivelului superior poate fi obținută, în funcție de sarcina atribuită, cu subtilitate:

- în managementul operațional: pentru a reglementa interacțiunea dintre subdiviziuni în cadrul afacerii preluate direct,

- în managementul strategic: pentru a reglementa interacțiunea dintre liniile de afaceri și compania pe care o administrează,

- în managementul corporativ: pentru a reglementa interacțiunea dintre compania pe care o administrează și proprietar. (Trebuie menționat că liderii marilor companii practică adesea furnizarea de alimente operaționale, uneori nu în mod specific, ci prin intermediul unor persoane de încredere - așa că aici modelul de afaceri poate părea ciudat).

Pentru a asigura sarcina de a se prezenta în fața Companiei, s-a decis concentrarea asupra procesării nivelului inferior al sistemului, care pierde serios bani - și asupra sistemelor de management operațional ale filialelor.

În Fig. 3.5 este prezentată detaliul „mașinii de afaceri" în stadiul actual și în sine, înainte de interacțiunea directorului comercial cu subordonații săi - directorii filialelor. Adică, în „marele pătrat" al imaginilor din Fig. 3.4., aici sunt prezentate și reprezentări ale acelorași „pătrate", legate într-o ordine melodică.

Vă rugăm să rețineți că descrierea proceselor „în jos" este deja la un alt nivel de detaliu:

- să le ofere managerilor de top un număr mare de sarcini manageriale serioase,

- vă permite să „reduceți" Compania pe baza unor procese care s-au „format istoric", de ale căror rezultate nimeni nu are nevoie de mult timp,

- face posibilă analizarea uneia și aceleiași situații din perspectiva diverselor beneficii și, prin urmare, găsirea unei soluții care să aducă cel mai mare număr de beneficii .

designului mecanic și a roboților companiei .

10.1.3.3 Etapa procesului de vânzare

Ceea ce s-a demonstrat a fost stagnarea abordării procesuale a fiarei „în jos", la scara întregii companii. Este demn de remarcat faptul că, pe lângă activitatea generală, abordarea procesuală oferă un efect economic vizibil în termeni completi.

S-a constatat că din 10 potențiali clienți, doar 3 au fost finalizați cu plasamente contractuale, astfel încât indicatorul de cheltuieli contractuale a ajuns la 70%.

Când am căutat motive, a devenit clar că nici prețul, nici calitatea produsului nu au fost o plângere pentru majoritatea potențialilor clienți. Prin urmare, s-a vorbit mult despre faptul că procesul de vânzare al organizațiilor în sine este suboptimal. Zokrema:

- De fapt, prima conversație de fond cu clientul nu a avut loc în departamentul de vânzări, ci în departamentul tehnic de instalare (congelare), ceea ce nu dăunează începătorului în vânzări,

- Sistemul de plată pentru tot ceea ce măsoară îi asigură adesea pe cei care negociază plasamente în cadrul Companiei sau nu. Acest lucru i-a permis să fure un client fără costuri pentru el înainte de a plasa un contract cu o companie concurentă (inclusiv comportamentul corupt).

- Au fost identificate întârzieri nejustificate în transmiterea rezultatelor extincțiilor în diferite diviziuni (până la câteva zile),

- Și așa este

Încă o dată, instrumentul clasic pentru analiza vânzărilor este „pâlnia de vânzări", pentru fiecare dintre „rivali" fiindu-i atribuit un indicator de control.

Ulterior, monitorizarea a fost efectuată la toate nivelurile „pâlniei de vânzări".

Această verificare a fost efectuată cu ajutorul unor precauții suplimentare și al testelor de control ale clienților.

Rezultatele monitorizării pe parcursul unei luni au arătat că implementările planificate au fost corecte: până la 60% din toate cheltuielile potențiale au fost rezolvate în mod constant imediat după efectuarea testelor pe teritoriul clientului.

Pe baza acestui fapt și a unei serii de alte fapte, este necesară dezvoltarea unui panou de control pentru etapa preliminară (subprocesul) vânzărilor. (Tabelul 3.2).

Participarea șefului departamentului de vânzări la acest proces a fost transferată la nivelul activităților operaționale - sub forma controlului asupra tehnologiei moderne de vânzări, care a reprezentat 80% din orele de lucru.

Tabelul 3.2.

Tabloul de control al indicatorilor în procesul de vânzare - activități operaționale

Nu.	Proces de procesare	Soarta șefului departamentului de vânzări	Vikonaveț	Indicatori ai virobinării	Indicatori de eficacitate
1	2	3	4	5	6
1	Oferirea de consultanță locuitorilor cu privire la achizițiile și serviciile alimentare.	Marți, în mișcare: revizuirea selecției lucrărilor 2-3 puncte de acceptare, înregistrare, instruire	Manager de vânzări la birou	Numărul de consultații cu clienții la punctul de vânzare pe lună, per manager	- Procentul de clienți potențiali care au transmis un punct de vânzare, altul decât consultările; - Ponderea consultărilor, cererilor neterminate pentru măsurarea unei structuri viitoare; - Ponderea consultărilor care nu au finalizat înregistrarea datelor inițiale de bază despre client;

Continuare tabel 3.2

					- Procentul de consultări nefinalizate a avut un rezultat pozitiv pentru client (verificat prin sondaje suplimentare la ieșirea din cont și prin campania „clientului misterios”). - Ponderea consultărilor efectuate privind alte daune.
2	Schimbați parametrii viitorilor viruși	Sereda, la birou: întâlnire cu managerii și oficialii departamentului	Manager de vânzări activ	Piața Vimiryan cu defalcarea importanței designului pe lună, defalcată pe manager	- Compatibilitate cu măsurarea unei unități de suprafață; - Proporția din suprafața măsurată cu tăieturi; - Brăzda este plată, rezultatele vor fi măsurate cu obturatorul; - Cota este fixă, rezultatele măsurătorilor sunt făcute fără informații suplimentare despre client; - Există o serie de clienți care s-au întors pe baza broșurilor managerului, pe care le-a lăsat în cutiile poștale în momentul măsurătorii.
3	Creșterea prețului bunurilor și serviciilor		Specialist în dezvoltare structurală	Zona a fost acoperită în funcție de importanța structurii, lunar, per manager.	- Compatibilitate cu dezvoltarea unei unități de suprafață; - Ponderea zonei acoperite cu cusătura liniilor; - Proporția din suprafața omisă în procesul de selecție din măsurători sau descompunere.
4	Purtați negocieri cu clientul privind termenii contractului	Joi, la birou: întâlnire cu managerii de vânzări activi	Manager de vânzări activ	% respectarea planului de venituri, care se suprapune peste fluxul de cheltuieli; % vâscozitate la planul de venituri, care se suprapune peste planul de profit; % din planul de venituri, care depășește planul de profit.	Profit extins din vânzări la venituri reduse (randamentul vânzărilor); Cota din profit, care provine de la clienții noi (dealeri); Participare la profituri, pentru clienții fideli (rezultat); Ponderea negocierilor care nu au fost finalizate conform acordului din diverse motive.
5	Stabilirea contractelor cu clienții			Numărul de pregătiri ale documentației primare și contractuale, per specialist	- Proporția documentației completate cu daune; - Ponderea documentației completate cu linii ascunse nu este vina clientului; - Ponderea tranzacțiilor finalizate de client din cauza întârzierilor în completarea documentației.

Panoul de control va fi, de asemenea, complet funcțional pentru ca robotul să își îmbunătățească activitățile.

Tabelul 3.3

Tabloul de control al indicatorilor în procesul de vânzare - activitate pe extindere

Nu.	proces de accelerare	Soarta șefului departamentului de vânzări	Vikonaveț	Indicatori ai virobinării
1	Umflă-ți pungile vara asta	Vineri, la birou: Dezvoltarea de soluții, pregătire pentru pregătire cu animale nebune	Șeful departamentului de vânzări raportează informațiile acumulate de-a lungul anilor	Calitatea pinilor din spatele pungilor (extras din nota analitică)
2	Îmbunătățiți interacțiunea cu personalul departamentului	Prima zi a lunii, luni: Mese negociate pentru recrutare și instruire a personalului	a văzut personal	Numărul de întâlniri orare cu diviziile (fără modificarea datelor), După leziunea cutanată, se formulează o concluzie analitică pentru a plasa propozițiile în funcție de interacțiunea redusă.
3	Vopsea în colaborare cu soclul de montare	A 2-a zi a lunii, luni: mese discutate abuz	secțiune de asamblare	
4	Îmbunătățiți cooperarea cu departamentul de marketing	A 3-a zi a lunii, luni: Discuția a fost benefică pentru marketing	a contribuit la marketing	
5	Îmbunătățirea interacțiunii cu departamentul de control al performanței serviciilor	A 4-a zi a lunii, luni: negocierile au fost posibile	Controlul calității serviciilor	

Pentru toți participanții la proces, s-au format următorii indicatori de productivitate, bazați pe indicatorii eficacității activităților. Pentru operator, indicatorul de eficacitate a fost adăugarea indicatorilor concreti ai activității operaționale a subiecților săi.

10.1.3.4 Optimizarea procesului de vânzare

După cum s-a anunțat anterior, procesul de vânzare a fost organizat de un oficial nepotrivit.

Am dezvoltat o nouă structură pentru departamentul de vânzări și am realocat echipamentele și echipamentele (Tabelul 3.4). A apărut o nouă poziție - un manager de vânzări activ, care aduce pe piață abilitățile unui asistent de vânzări și dezvoltă designul. În acest caz, cel mai adesea - în cazul tranzacțiilor aparent simple (standard) - măsurătorile pe teritoriul clientului au început să fie efectuate de manageri de vânzări activi, iar specialiștii în instalații tehnice au acum instrumente pentru măsurarea unor obiecte deosebit de mari sau pliabile, la cerere.

Tabelul 3.4

Noua structură a departamentului de vânzări

u.	Posada	Misceznahodzhennya	Legături
	2	3	4
	Șeful Departamentului de Vânzări al Sucursalului	La sediul central al filialei	Supervizează departamentul de vânzări
	Managerul de birou al sucursalei		Funcția principală este de director adjunct al filialei; În interesul șefului departamentului de vânzări, mă voi asigura de: - Căutați plasarea în puncte convenabile; - Monitorizarea prețurilor pentru publicitatea în ZMI la locația sucursalei; - Schimb de documente între sucursală și Banca Centrală.
Direct: vânzări și service pentru structuri de ferestre			
	Manager de vânzări la birou	La punctul de vânzare cu amănuntul	- Îl face pe uriașul om să înceapă un dialog, - Își fixează tipul pe dieta principală; - Îl informează despre toate mesele la cumpărare și servire; - Concluzionează cu cetățeanul asupra autorității de a efectua măsurători la amplasamentul viitoarelor structuri

Continuare tabel 3.4

	Manager de vânzări activ	La punctul de vânzare cu amănuntul	Când există multe vizite la clienți, managerii de vânzări din birouri încep să lucreze cu clienți „importanti”
		În drum spre un potențial client (divizie)	- Cunoașteți singuri regulile, atât în sectorul departamental, cât și în sectorul corporativ; - Oferă consultanță detaliată clienților cu privire la proiectarea spațiilor lor; - Propune soluții suplimentare cu privire la ceea ce face clientul fără a se gândi inițial la asta; - Obținerea deciziei informate a clientului cu privire la termenii acordului; - Semnează un acord cu clientul (în perioadele de aglomerație, deleagă această sarcină unui specialist mobil în grup) - Efectuați măsurători ale diferitelor dimensiuni (în cazuri importante, luați cu dumneavoastră un specialist în măsurători)
	Specialist în măsurători structurale	În drum spre un potențial client (divizie)	Măsoară acorduri corporative excelente și complexe (acorduri simple și disparate - managerii de vânzări activi își pierd locul)
	Specialist în design	La sediul central al filialei	Depozitul de asigurări și disponibilitatea viitoarelor vaccinuri informează managerul de vânzări despre aceasta, care depune o cerere de asigurare.
Direct: vânzări către profil și subdiviziune			
	Manager de vânzări activ	La sediul central al filialei	- Caută clienți noi pe profil și profil; - Controlează plasarea la timp a articolelor periodice; - Deservește spațiile; - Pregătește documentația justificativă.

Descrierea procesului de vânzare a afacerii

Tabelul 3.5

Panou de control pentru procesul de vânzare

Nu.	Proces de procesare	Rezultate	Vikonaveț
1	2	3	4
1	Consilierea clienților cu privire la achizițiile de alimente	1. aplicație pentru măsurare 2. cerere pentru razrakhunok fără măsurători 3. informații despre consultare	Manager de vânzări la birou
2	Schimbați parametrii viitorilor viruși	1. cerere pentru razrakhunok conform măsurătorilor. 2. apel bazat pe măsurători	Manager de vânzări activ
3	Asigurați prețul bunurilor și serviciilor	1. prețul și specificațiile produsului. 2. Spuneți-ne despre deconstrucția efectuată.	Specialist din Rozrakhunka

Continuare tabel 3.5

4	Purtarea negocierilor cu clienții privind încheierea unui contract	1. cerere pentru măsurători din vânzările active. 2. notificare privind acordul. 3. rapoarte despre negocieri.	Manager de vânzări activ
5	Încheiați contracte cu clienții	1. documentația de vânzare originală și convenită. 2. fluxul de aplicații pentru instalarea roboților de service și instalare. 3 fluxuri de câștiguri de cenți. 4. Anunțați-ne despre încheierea acordului.	Specialist în grupuri mobile
6	Monitorizați rezultatele vânzărilor	Date operaționale despre vânzări	Departamentul de vânzări Kerivnyk

10.1.4. VIȘNOVKI.

Lucrarea analizează organizarea fluxului informațional în mijlocul întreprinderii și identifică direcția de optimizare a acestuia.

A fost efectuată o analiză a stării financiare a întreprinderii, care a relevat o stare nesatisfăcătoare a referinței.

A fost efectuată o analiză SWOT a SRL-ului „XXX-2”, care a evidențiat punctele forte și punctele slabe ale întreprinderii, precum și oportunitățile și amenințările. A fost analizat „Pâlnia de Vânzări”, ceea ce ne-a permis să identificăm punctele slabe din sistemul de vânzări.

S-au luat măsuri pentru organizarea unui proces de management eficient.

După efectuarea acestor abordări, puteți trage concluzii despre caracterul complet al abordărilor în următoarea secvență:

- optimizarea pe etape ale procesului logistic;
- dezvoltarea unor indicatori de control detaliați;
- schimbare, în funcție de nevoile funcțiilor lucrătorilor;
- dezvoltarea unei noi structuri a subunității.

Acest lucru îmi va permite să maximizez potențialul industriei cât mai mult posibil.

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