SECTION 3.
Synergy of Artificial Intelligence, Digital Competence and Analytical Modeling in the Context of Economic Modernization

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3.1. THE IMPACT OF ARTIFICIAL INTELLIGENCE ON UKRAINE'S NATIONAL SECURITY

Introduction. In today's world, national security has long gone beyond military strategy alone. It encompasses political stability, cybersecurity, critical infrastructure protection, economic stability, as well as information and cultural security of the state. The impact of digitalization on the level of national security has been studied by: Voronkova V. H., Cherep A. V., Nikitenko V. O., Cherep O. H. [1], Cherep A., Voronkova V., Cherep O., Ohrenych Yu., Dashko I., Kotliarov V. [2], Zhyvtsova L. I. [3], Trofymenko O. H., Lohinova N. I., Sokolov A. V., Chykunov P. O., Akhmametieva H. V. [4], Bolkvadze N. I., Bratko O. S., Myhal O. F. [5], Chaikina A. O., Maslii O. A., Cherviak A. V. [6], Novikova N., Boiko L. [7], Nieustroiev YU. H., Yehorova-Hudkova T. I., Ostrianko V. V. [8], Cherep A. V., Voronkova V. H., Dashko I. M., Ohrenych Yu. O., Cherep O. H. [9], Cherep A. V. [10], Cherep O. H., Oleinikova L. H., Bekhter L. A., Veremieienko O. O. [11], Cherep A. V., Dashko I. M., Ohrenych Yu. O. [12].

Summary of the main results of the study. The issue of studying the impact of artificial intelligence on national security has become especially relevant for Ukraine after the start of full-scale military aggression by the Russian Federation in 2022, when both traditional and non-traditional security threats, i.e. in the field of cyberspace and information influences, became apparent. In this context, advanced digital technologies, in particular artificial intelligence (AI), have begun to play a strategic role in ensuring the state's defense capability.

Artificial intelligence is a set of methods, algorithms and technical tools capable of self-learning, data analysis, forecasting scenarios and decision-making based on a large amount of information. This technology is rapidly transforming approaches to security, from rapid threat detection and automated response to complex analysis of psychological influence in the information space. It should be noted that the potential of AI in modern warfare, which combines classical warfare with cyberattacks, fake campaigns, and cyberespionage, can significantly enhance the state's defense capabilities.

Ukraine, which is at the center of the global geopolitical struggle, has become an example of successful adaptation of the latest technologies to the challenges of war. In particular, the introduction of AI-based solutions in the defense sector (e.g., the use of enemy vehicle detection systems, drone control, and information flow analysis) has become a tool of both tactical and strategic importance. Public and private initiatives (e.g., the Brave1 technology cluster) demonstrate the potential for integrating AI into Ukraine's defense industry.

At the same time, the use of AI has not only benefits, but also challenges. These challenges include legal issues of liability for the actions of algorithms, as well as the risks of using AI by the enemy, i.e., to create disinformation campaigns or cyberattacks on critical infrastructure. Therefore, the issue of safe, controlled and ethical use of artificial intelligence in the context of national security requires a comprehensive analysis [13].

The relevance of this study lies in the need for a comprehensive understanding of how artificial intelligence is changing the security landscape of Ukraine. An important issue is to study the main areas of AI implementation in the security sector, assess its potential, and analyze risks and limitations.

In recent decades, humanity has been witnessing the rapid development of digital technologies, digital transformation processes, and the introduction of information technologies, which is bringing changes to all spheres of life. One of the most significant achievements in this area is the creation and implementation of artificial intelligence (AI) technologies. At the same time, it should be noted that AI can be viewed as an interdisciplinary phenomenon that combines computer science, mathematics, logic, neuroscience, philosophy, and ethics.

Artificial intelligence covers such areas as speech recognition, learning, planning, problem solving, big data analysis, natural language understanding, pattern detection, and even creativity.

The most general and functional definition of AI is the ability of computer systems and programs to model human cognitive functions. These can be algorithms that learn on their own based on the input data (machine learning) or complex neural networks that mimic the structure and functioning of the human brain.

Today, there are several levels of AI classification (Fig. 1):

1. Harrow AI (weak AI) – systems specializing in specific tasks (e.g., face recognition or recommendation services).

2. General AI (general AI) – hypothetical systems that can solve any intellectual task as efficiently as a human.

3. Superintelligence (superintelligence) – a concept of the future when AI exceeds human capabilities in all areas, including emotional and social [21].

The most widespread today are weak AI systems that integrate into everyday life: electronic assistants, chatbots, navigation systems, banking services, healthcare, defense, etc.

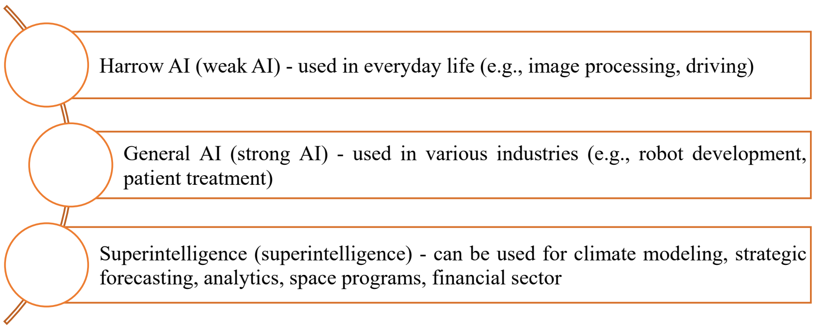

Figure 1. Levels of AI classification

Source: compiled on the basis of [21]

It should be noted that modern AI – is not a single technology, but a complex combination of several areas, in particular (Fig. 2):

- machine learning (Machine Learning, ML) – algorithms that learn from data without explicit programming [13; 22];
- deep learning (Deep Learning) – a subtype of machine learning that uses artificial neural networks of high complexity [13; 22];
- computer vision (Computer Vision) – Image and video analysis to recognize objects, people, actions, etc. [13; 22];
- natural language processing (Natural Language Processing, NLP) – technologies that allow machines to “understand” and generate human speech [13; 22];
- speech recognition (Speech Recognition) – systems that translate speech into text are used in voice assistants [13; 22].

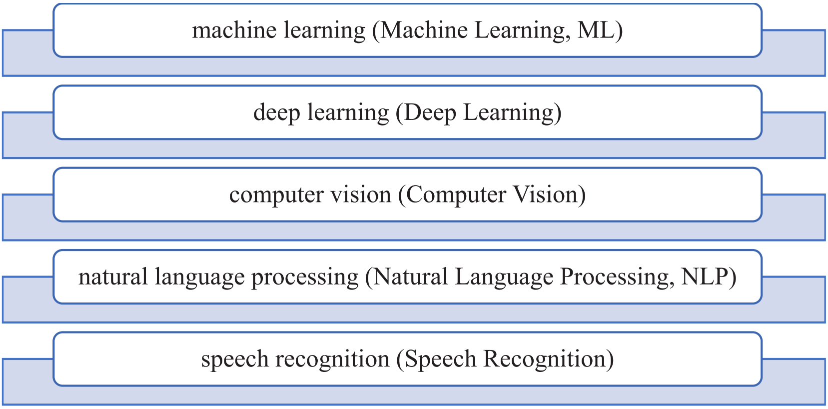

Figure 2. Areas of AI

Source: compiled on the basis of [13; 22]

In the 2020s, AI has evolved from an academic concept to a practical tool that is actively used in public administration, defense, business, medicine, and education. Its impact is so profound that some analysts are already talking about the "fourth industrial revolution" where intelligent systems will become the central technology.

In the context of national security, AI allows states to gain a competitive advantage in both defense and information space protection, which makes the study of this phenomenon extremely important for Ukraine's future [14].

Today, artificial intelligence is being actively integrated into various areas of human activity, changing approaches to management, analysis, maintenance, security, and communication. Moreover, AI ensures efficiency in solving various tasks due to its ability to predict events, self-learning, and analysis of large amounts of information. Therefore, it is advisable to analyze the main areas in which AI demonstrates the greatest potential (Fig. 3) [15].

AI plays a key role in transforming modern military strategies, as it is used in:

- autonomous combat systems (drones, robotic platforms);

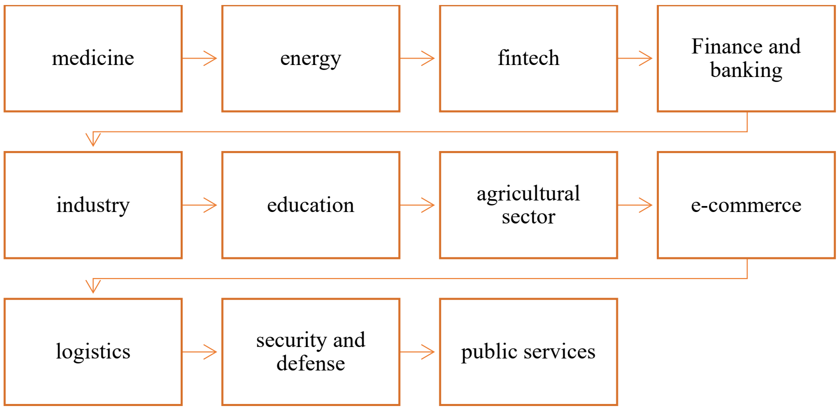

Figure 3. Areas of AI application

Source: compiled by the authors

- intelligence systems (processing of satellite images, vehicle recognition);
- analyzing data from the battlefield;
- countering cyber attacks;
- forecasting tactical scenarios.

Ukraine is actively implementing such systems, in particular through projects based on Brave1 and the Ministry of Digital Transformation of Ukraine [16].

In particular, artificial intelligence in the medical field is used to:

- Diagnostics of diseases (determination of pathologies on MRI, CT images);
- personalized medicine (analysis of genetic data);
- robotic surgery;
- epidemic forecasting;
- real-time monitoring of patients' condition.

Such systems help speed up clinical decision-making and reduce the risk of errors.

AI detects cyber threats, analyzes abnormal behavior in networks, and automates response to attacks. This is especially important in hybrid warfare, when the state is subjected to continuous cyber pressure from the aggressor. AI also allows to:

- detect phishing, malware, DDoS attacks;
- analyze risks;
- create dynamic cyber defense systems.

In the field of education, AI is used to:

- adaptive learning (platforms that adapt to the needs of the learner);
- knowledge assessment;
- creation of intelligent learning systems;
- automated support of students;
- language interpreters and assistants [17].

AI helps make education more accessible, personalized, and efficient.

In business, AI is transforming:

- process management;
- customer service (chatbots, virtual assistants);
- logistics and supply;
- financial analysis;
- risk management;
- marketing (analysis of customer behavior, personalized offers).

It is also actively used in fintech, in particular for fraud detection or automatic credit analysis.

AI ensures efficient organization of traffic flows, routes, and transportation, which reduces costs and improves the quality of service, in particular:

- autonomous driving (self-driving cars);
- smart transportation systems;
- congestion forecasting;
- optimization of warehouses and supply chains.

In the agricultural sector, AI can increase productivity, reduce environmental impact, and help:

- analyze the condition of soil and crops;
- forecast harvests;

- optimize the use of water and fertilizers;
- carry out precision farming with the help of drones and sensors.

Along with this, AI is used to:

- analysis of citizens' requests;
- management decision-making;
- automation of bureaucratic procedures;
- creation of e-governance systems;
- identification of social needs [18].

As a result, the quality of public services is improving and the level of corruption is decreasing. Thus, artificial intelligence is penetrating key areas of society, bringing benefits, efficiency, and new opportunities. Its importance will continue to grow, especially in the context of national security.

In the context of military conflict, economic instability, information pressure and cyber threats, the issue of security is of paramount importance. National security is the basis for economic stability and development of any country. The current situation in Ukraine clearly demonstrates the importance of a strategic approach to protecting the interests of the state in all spheres, from defense to social and humanitarian [19].

It should be noted that "national security is the protection of state sovereignty, territorial integrity, democratic constitutional order and other national interests of Ukraine from real and potential threats" [20]. This concept covers not only physical security (from war or terrorism), but also protection from economic pressure, cyberattacks, information aggression, environmental disasters, demographic risks, etc.

According to the Law of Ukraine "On National Security", the national security system includes the following main areas [20]:

- military security;
- political stability;
- economic security;
- cybersecurity;
- environmental security;
- energy security;

- information security;
- social and humanitarian security.

In wartime, these components are interconnected with cybersecurity breaches, which can destabilize the information space, affect the political situation and the state's defense capability. It should be noted that the main goal of national security is to create conditions under which the vital interests of the state, citizens and society will be protected from real and potential threats.

The full-scale aggression of the Russian Federation against Ukraine, which began in 2014 and entered a new phase in 2022, has changed the understanding of security. Ukraine has found itself in a hybrid war that combines classical military operations with information, cyber, economic and psychological aggression.

The key threats today include:

1. Military aggression (constant hostilities in the east and south of the country, use of high-tech weapons, drones, missiles, AI for warfare).
2. Cyber threats (attacks on state registries, banking systems, energy infrastructure, the use of viruses such as NotPetya, cyber espionage and destructive attacks on critical facilities).
3. Information warfare (large-scale dissemination of fakes, manipulative narratives, propaganda, creation of a destructive information field to undermine trust in the government, inciting panic and division in society).
4. Energy and economic instability (destruction or blocking of energy facilities, sanctions pressure, logistical difficulties, loss of investment.
5. Social vulnerability (mass migration, internal displacement, psychological trauma of society, decline in trust and social capital).
6. External interference (support of terrorist groups by other states, attempts to destabilize through subversive activities within the country).

It should be summarized that in the current conditions of war and hybrid threats, the impact of artificial intelligence on Ukraine's national security is multidimensional and it is a strategic tool that can influence changes in approaches to defense, security, resource management, and information counteraction. The main aspects of AI's impact on national security include the following (Fig. 4):

– cybersecurity – the use of AI allows for timely response to threats, detection of cyberattacks in real time (behavioral analytics, anomaly detection), and protection of critical infrastructure (energy, communications);

– military technologies – the use of AI allows for battlefield analytics (e.g., processing satellite images, video and radio intercepts for operational decision-making), threat forecasting (allows for detecting preparations for attacks, enemy logistics), automated control through the use of unmanned systems (UAVs, ground robots);

– resource management – the introduction of AI allows to improve the allocation of resources (medicine, fuel) based on forecasts, to model the logistics of humanitarian aid, to optimize the allocation of resources based on forecasts, to use intelligent risk monitoring systems (environmental, social, economic);

– information security and countering disinformation – the introduction of AI allows monitoring the information space using NLP, exposing fakes in the media and social networks;

– social stability – the use of AI allows predicting social tension by analyzing data in social networks and the media, supporting the public administration system, and providing access to quality services in a crisis;

– economic security – the introduction of AI allows protecting public finances by detecting tax evasion; predicting crises (inflation, deficit), analyzing the labor market (for example, to adapt education systems);

– state border security – AI implementation allows to improve video surveillance systems at the border (e.g., face recognition, license plates), analyze behavioral patterns to detect suspicious actions or intrusions, analyze external data flows and detect espionage activities, improve border control through automated document verification systems.

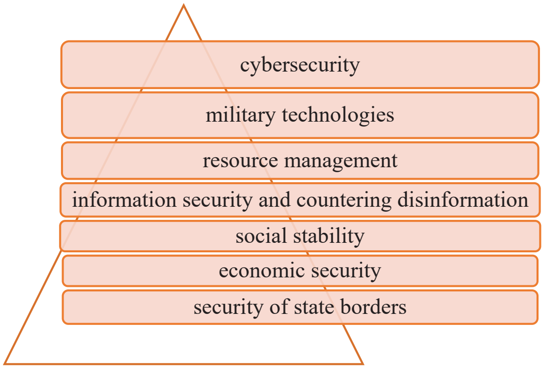

Figure 4. Key aspects of AI's impact on national security

Source: compiled by the authors

Conclusions. The introduction of artificial intelligence is becoming a strategic advantage for Ukraine in terms of automatic attack detection, analysis of large amounts of information, event forecasting, and protection of critical infrastructure. Thus, in the context of war, hybrid threats, and global instability, artificial intelligence plays an important role in strengthening Ukraine's national security. Integration of AI into the military, information, economic, and social spheres will increase the state's resilience, public administration efficiency, and ensure its competitiveness. It also helps not only to strengthen security but also to create an intellectual defense of the country's information and spatial sovereignty.

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3.2. DEVELOPING DIGITAL LANGUAGE COMPETENCE AS A FACTOR OF COMPETITIVENESS OF FUTURE MASTER'S DEGREE HOLDERS IN POWER ENGINEERING IN THE DIGITAL ECONOMY

Introduction. In the contemporary landscape of rapid technological advancement and global digitalisation, the development of high-level professional competencies among future engineers is no longer confined to technical knowledge alone. In fact, the demands of the digital economy call for a new type of specialist – one who combines deep subject-matter expertise with strong digital literacy and effective communication skills in international professional settings. For Ukrainian institutions of higher technical education, this shift requires a fundamental rethinking of pedagogical priorities, particularly in the realm of language instruction. Among the various competencies that contribute to the competitiveness of future master's degree holders in power engineering, digital language competence is emerging as a particularly vital element.

Digital language competence can be broadly defined as the ability to effectively use language – primarily English as the global language of science and technology – within digital environments to access, process, produce and communicate professional information. This competence involves not only linguistic and communicative skills, but also the confident use of digital tools and platforms to support these processes. For Ukrainian students in power engineering, whose future workplaces may range from international corporations to digitalised domestic enterprises operating within global supply chains, the ability to operate in multilingual digital contexts is a prerequisite for professional integration and success.

This chapter explores the formation of digital language competence as a key factor in enhancing the competitiveness of master's level students in the field of power engineering. In doing so, it seeks to contribute to the broader discourse on the role of digitalisation in higher education and, more specifically, on how linguistic preparation must evolve to meet the challenges of Industry 4.0 and beyond. The emphasis is placed on aligning the teaching of English for Specific Purposes (ESP) with digital educational technologies that support students' professional growth and readiness for real-world communicative situations in technical fields.

The Ukrainian context presents both unique challenges and opportunities. On the one hand, there is a strong tradition of engineering education and a growing awareness of the need for digital transformation in the academic sphere. On the other hand, the lingering effects of outdated teaching methodologies, underfunded infrastructure, and the consequences of the ongoing war have hampered the pace of educational innovation. Nevertheless, recent years have witnessed [1] an increased interest in integrating digital tools into ESP courses, with platforms such as Moodle, various learning management systems, online glossaries, technical text generators, and simulation software gaining traction. This shift has been particularly noticeable in technical universities, where the demand for relevant, industry-oriented English instruction is most acute.

The present chapter is structured into three interconnected sections. The first part analyses the role of digital language competence in preparing future power engineering professionals for the labour market. It draws attention to how digitalisation has changed communication patterns in engineering professions and emphasises the strategic importance of developing a flexible, digitally-supported command of English. The second part offers a detailed overview of digital educational technologies currently applied in ESP teaching, showcasing specific methods and tools used to enhance language instruction in technical disciplines. It highlights practical classroom solutions such as the use of Moodle for blended learning, electronic dictionaries and grammar tools for autonomous study, and project-based digital simulations for contextualised language practice. Finally, the third section presents actual recommendations for reinforcing digital language competence within master's degree programmes. These include curriculum integration strategies, examples of best practices, and proposals for fostering collaboration with European educational initiatives.

By focusing on the intersection of language, technology, and technical education, this chapter contributes to the broader effort of digitalising Ukraine's economy through the development of human capital. In particular, it underscores the role that language educators at technical universities play in shaping the communicative and digital readiness of the next generation of engineers. As Ukraine continues to move towards deeper integration with the European educational and economic space, the importance of equipping future specialists with strong digital language competencies cannot be overstated.

1. The role of digital language competence in the training of power engineering professionals

In the context of the digital economy, the competencies required of power engineering professionals are undergoing a significant transformation. Technical knowledge and hands-on skills, though still central to the profession, are no longer sufficient on their own. The globalisation of the labour market, the integration of smart technologies, and the widespread adoption of digital systems in the energy sector have brought forth new demands – particularly in the areas of communication, collaboration, and information processing within digital environments. As a result, digital language competence is becoming [2] a critical component of a modern engineer's skill set, directly influencing employability, mobility, and professional growth.

Digital language competence, especially in English, serves a dual function. On the one hand, it facilitates access to the vast body of global scientific and technical knowledge, which is predominantly published in English. On the other hand, it enables engineers to participate in international projects, communicate with colleagues from different linguistic backgrounds, and navigate technical documentation, software interfaces, and standards that are often available exclusively in English. In digitalised workplaces – be they local firms with global partners or transnational corporations – the ability to function effectively in such environments is essential.

For power engineering students in Ukraine, this competence is particularly important. The country's energy sector is actively engaging in digital modernisation, with ongoing efforts to upgrade infrastructure, implement smart grid technologies, and adopt international safety and efficiency standards. These transformations are closely tied to European integration processes, requiring not only technological but also communicative alignment with the standards and practices of European partners. Consequently, Ukrainian graduates must be prepared not only to operate the latest digital equipment and systems but also to engage with digital content, follow technical procedures, and communicate with foreign colleagues – all in English.

It is important to recognise that digital language competence is not limited to traditional language skills such as grammar, vocabulary, or pronunciation. Rather, it encompasses the ability to use language purposefully within digital environments. This includes reading and interpreting technical specifications online, composing clear and concise reports using digital templates, participating in virtual meetings and discussions, searching for technical information using appropriate keywords, and adapting messages to different audiences and communication platforms. In many ways, this competence blends language proficiency with digital literacy and professional orientation.

The role of language educators at technical universities, therefore, extends far beyond teaching English as an academic subject. In today's context, it is about equipping students with the communicative tools they need to function effectively in a digitalised professional world. This involves integrating authentic materials into the learning process – such as user manuals, software documentation, online forums, and case studies drawn from real-life engineering scenarios – as well as fostering the use of digital platforms that mirror those used in the workplace. At the same time, it requires a pedagogical shift from passive learning to active, student-centred approaches that prioritise communication, problem-solving, and the practical application of language skills.

Moreover, the development of digital language competence contributes to a broader set of XXI century skills that are valued across all sectors of the economy. These include critical thinking, adaptability, collaboration, and intercultural communication – all of which are essential for engineers working in increasingly complex and interconnected environments. For master's degree holders in power engineering, who are likely to take on leadership roles, these skills are even more important. Their ability to present technical solutions to diverse audiences, write reports for international stakeholders, and collaborate across borders is directly linked to their success and the reputation of the institutions that trained them.

In all, the role of digital language competence in the training of power engineering professionals cannot be overstated. It is a foundational element that underpins effective participation in the digital economy and supports Ukraine's broader goals of innovation, integration, and competitiveness on the global stage. As such, its systematic development within technical universities should be viewed as a strategic priority – one that bridges the gap between language education and professional engineering practice in the XX century.

The importance of English for specific purposes (ESP) in the context of digital transformation of the economy

As the global economy continues to evolve under the influence of digital technologies, the significance of English for Specific Purposes (ESP) in professional education is growing markedly. This shift is particularly evident in technical and engineering domains, where the use of English is no longer merely an academic requirement but a practical necessity for full participation in professional life. The digital transformation of the economy has intensified the need for sector-specific language training that is directly aligned with the communicative demands of rapidly changing work environments. For students of power engineering, and indeed all STEM disciplines, ESP functions as a bridge between technical knowledge and its effective application in globalised, multilingual, and technology-driven settings.

Unlike General English, ESP is tailored to the specific linguistic and communicative needs of learners operating within particular fields – whether engineering, finance, medicine, or law. In the context of digital transformation, this means equipping students with the tools to navigate domain-specific language in digital formats: reading technical manuals in PDF, following software installation instructions, participating in online engineering forums, or presenting findings during virtual conferences. These are not hypothetical situations but routine professional tasks for XX century engineers. Therefore, ESP instruction must evolve to reflect these realities, focusing not only on traditional grammar and vocabulary, but also on digital communicative functions, genre-specific writing, and cross-cultural interaction.

In recent years, the digitalisation of workplace communication has led to the emergence of new professional genres – ranging from email briefings and real-time chat support to digital maintenance logs and remote troubleshooting protocols. These forms of communication require a high level of linguistic precision, clarity, and awareness of digital etiquette. ESP instruction, when designed thoughtfully, prepares learners to function confidently in such environments. For example, in a power engineering context, students might work with authentic materials such as datasheets for photovoltaic inverters, safety regulations published by international bodies, or operational manuals for smart grid systems – all in English. Through such exposure, they develop not only language skills but also professional literacy in their future domain.

Moreover, ESP plays a vital role in ensuring that graduates are capable of engaging with international standards and regulations, many of which are available exclusively in English. As Ukrainian industries become more integrated into European and global economic systems, the ability to understand and implement such standards becomes essential. In digitalised settings, where documentation is stored and shared electronically, and where systems often operate in English by default, this linguistic competence takes on an even greater level of importance. Whether calibrating a control system, interpreting sensor data, or preparing a project proposal for an EU-funded initiative, engineers must be able to interact fluently with English-language digital content.

ESP also supports the development of lifelong learning strategies – an essential attribute in the context of digital transformation, where technologies, platforms, and tools are constantly evolving. Engineers are increasingly expected to update their skills autonomously through online learning platforms, professional webinars, and digital certification programmes, the majority of which are conducted in English. In this regard, ESP instruction helps [3] students become independent users of English-language digital resources, giving them the capacity to stay current in their field and remain competitive in the labour market.

From a pedagogical perspective, teaching ESP in the context of the digital economy requires an innovative approach. It necessitates the integration of ICT tools, real-world tasks, interdisciplinary collaboration, and learner autonomy. Platforms such as Moodle can host ESP courses that incorporate multimedia materials, interactive exercises, and project-based learning activities. Students may be tasked with simulating online meetings, preparing reports using authentic templates, or conducting research using digital engineering databases.

These activities mirror the types of communicative situations they are likely to encounter in their future professions, making the learning process both relevant and engaging. By designing ESP courses around these digital practices, educators not only enhance students' language skills but also equip them with critical competencies needed to thrive in a technology-driven professional environment.

In all, English for Specific Purposes has become a fundamental pillar of professional education in technical disciplines. In the context of the digital transformation of the economy, its relevance has only deepened. ESP enables future engineers not only to communicate effectively within their professional community but also to access, interpret, and apply the wealth of knowledge that is increasingly mediated through English and digital platforms. For Ukrainian technical universities striving to prepare students for success in the international labour market, the integration of ESP into curricula is no longer optional – it is a strategic imperative.

ESP in Ukrainian technical universities: supporting national strategies for digital transformation

The integration of English for Specific Purposes (ESP) into the curricula of Ukrainian technical universities is increasingly recognised as a vital component of the country's broader digital transformation strategy. As Ukraine positions itself more firmly within the European and global knowledge economies, the demand for specialists who are both technically competent and communicatively agile in English continues to rise. Higher education institutions, particularly those specialising in engineering and applied sciences, are thus under growing pressure to modernise their language education in line with the needs of the digital economy and the strategic goals outlined in national policy documents.

The "Digital economy and society development concept of Ukraine" (2018) and related government initiatives have emphasized [4] the importance of digital skills, international cooperation, and the development of human capital as pillars of economic competitiveness. Language proficiency in English – especially in technical contexts – is explicitly recognised as a cross-cutting competence that enables access to international research, digital platforms, and innovation networks. In this regard, ESP instruction at technical universities not only contributes to individual career readiness but also supports the national effort to foster a digitally competent workforce capable of engaging with global partners and standards.

At Vinnytsia National Technical University, as well as other leading technical institutions in Ukraine, the teaching of ESP has undergone a gradual but visible transformation. Traditional, textbook-based approaches are being replaced with blended and technology-enhanced models that simulate real-world communication tasks. For example, ESP instructors now make extensive use of platforms such as Moodle, Prometeus and Coursera where courses can include interactive quizzes, collaborative writing tasks, vocabulary training, and online presentations. These platforms allow for flexible delivery and continuous feedback, encouraging students to take ownership of their learning.

Moreover, Foreign Language Department is increasingly collaborating with subject-matter experts from engineering faculties to ensure that ESP content reflects the actual needs of the students' future professions [5]. Such interdisciplinary cooperation helps bridge the gap between language learning and professional application, making ESP instruction more meaningful and contextually relevant.

A particularly promising direction is the integration of project-based learning within ESP courses. Students may be asked to develop a prototype presentation for a smart energy solution, write a user manual for a fictional power system, or simulate an international tender process using English. These tasks not only improve language competence but also train students in digital collaboration tools, critical thinking, and cross-cultural communication – skills that are indispensable in today's digital work environment.

In addition, universities are starting to incorporate [6] open educational resources (OERs) and massive open online courses (MOOCs) into their ESP programmes. These materials, often developed by prestigious institutions and available in English, enable students to engage with up-to-date content and broaden their understanding of both language and technology. They also reflect a shift towards lifelong learning, one of the key principles of the European Higher Education Area and a cornerstone of Ukraine's integration into the European educational space.

Despite positive developments, challenges remain. The digital infrastructure in some regions is still insufficient, particularly in wartime conditions, and not all language instructors have received adequate training in the use of educational technologies or the design of ESP content. Furthermore, the lack of unified national standards for ESP instruction in technical education results in a fragmented approach across institutions. Addressing these issues will require sustained investment, policy coordination, and professional development for educators.

Nevertheless, the current trajectory is encouraging. The increasing visibility of ESP within curriculum reform, the growing engagement of language teachers in digital innovation, and the alignment of educational goals with national strategies all point to a promising future. As Ukrainian technical universities continue to evolve in response to the digital age, the role of ESP – as both a linguistic and strategic tool – will only grow in importance.

Language competence as part of professional readiness for international cooperation and smart technologies

In the era of smart technologies and interconnected global systems, professional readiness extends far beyond technical mastery. It increasingly encompasses the ability to communicate, collaborate, and solve problems across cultural, disciplinary, and linguistic boundaries. As digitalisation reshapes the landscape of engineering, energy systems, and industrial operations, language competence – particularly in English – emerges as a core element of a future professional's toolkit. This is especially relevant for students of power engineering, who are preparing to enter workplaces that are both technologically sophisticated and globally integrated.

International cooperation is no longer a peripheral aspect of engineering; it is a central reality. Power engineers routinely engage with colleagues, clients, and partners from other countries – whether through joint infrastructure projects, collaborative research, or transnational supply chains. The shift towards smart technologies, including smart grids, AI-driven monitoring systems, and Internet of Things (IoT) applications in the energy sector, further amplifies the need for precise, efficient, and adaptive communication. In such a context, language competence becomes [7] more than a communication skill – it becomes a tool for interoperability, knowledge transfer, and trust-building.

English has firmly established itself as the lingua franca of science, technology, and international business. Mastery of English allows professionals to access the latest scientific research, follow global engineering trends, and participate in professional networks. In the context of smart technologies, where innovation cycles are short and terminology evolves rapidly, the ability to engage with English-language content is vital for staying up to date. For example, understanding updates to technical standards, reading operational manuals for smart meters, or participating in international webinars requires not only technical literacy, but also strong language proficiency.

Moreover, the implementation of smart technologies in energy systems often involves working with international software solutions, digital control systems, and platforms whose user interfaces, documentation, and support services are provided exclusively in English. Without the necessary linguistic competence, the ability to effectively operate, troubleshoot, or adapt such systems is severely limited. From this perspective, language competence directly influences technical performance and operational efficiency.

Beyond technical tasks, engineers are expected to communicate their ideas clearly to non-technical stakeholders, including project managers, regulatory authorities, or international investors. This may involve writing technical reports, preparing presentations, contributing to feasibility studies, or defending proposals – all of which require fluency in both professional content and appropriate language use. For Ukrainian students entering such global arenas, the ability to articulate their knowledge and collaborate in English is essential for building credibility and fostering long-term partnerships.

At the educational level, integrating language competence into professional training is a forward-looking strategy. It supports the holistic development of future engineers who are not only experts in their field but also communicators, team members, and innovators. For example, at Ukrainian technical universities, ESP courses increasingly incorporate scenarios such as drafting a project proposal for an EU-funded energy initiative, simulating a multilingual team meeting on a smart grid rollout, or translating field-specific terms into accessible language for diverse audiences. These tasks prepare students for the kinds of international and interdisciplinary interactions they will encounter in real life.

Language competence also reinforces key soft skills that are crucial for success in the digital economy: adaptability, critical thinking, intercultural awareness, and digital communication literacy. These competencies enable professionals to navigate the dynamic, unpredictable environments characteristic of international engineering projects, where challenges are often complex, time-sensitive, and require collaboration across time zones and cultural frameworks.

In all, language competence is not a peripheral skill in the age of smart technologies – it is an integral part of professional readiness. For Ukrainian power engineering students and other future specialists in technical domains, mastering English means gaining access to the tools, communities, and innovations that drive global progress. As such, developing this competence must be seen not just as an educational goal, but as a strategic investment in the country's integration into the international digital economy.

Current demands of the labour market for digitally competent and linguistically agile engineers

The digital transformation of global industry has significantly reshaped the skillsets expected of engineering graduates, particularly in high-tech and energy sectors. The modern labour market is no longer seeking engineers who possess only technical proficiency;

rather, it increasingly demands professionals who are digitally competent, linguistically agile, and capable of functioning effectively in multicultural and multidisciplinary environments. This shift is especially evident in the field of power engineering, where digital tools, international cooperation, and innovation ecosystems define the nature of contemporary work.

Recruitment trends across Europe and internationally demonstrate a strong preference for candidates who exhibit not only domain-specific expertise but also high levels of digital literacy and communication skills in English. Employers expect future engineers to be proficient in operating digital platforms for project management, remote collaboration, data analysis, and system simulation. Tools such as SCADA systems, digital twin technologies, and cloud-based energy modelling platforms are now standard in many companies, and the ability to use them confidently is a clear hiring advantage. In parallel, English remains the dominant language for software interfaces, technical documentation, global standards, and cross-border team communication.

This dual requirement – of technological and linguistic agility – has important implications for engineering education. Language and digital skills are no longer considered "soft" or supplementary; they are core employability traits. International companies operating in Ukraine or recruiting Ukrainian graduates for positions abroad frequently list English proficiency and experience with digital tools as prerequisites in job descriptions. Furthermore, with the rise of remote and hybrid working models, engineers must often participate in international projects without leaving their home country, further intensifying the need for fluent digital communication.

Another defining characteristic of the modern labour market is the need for lifelong learners. Engineering roles today are dynamic, often involving upskilling and reskilling throughout one's career. Digital competence is central to this, as most ongoing professional development takes place through online platforms, webinars, digital certifications, and international e-learning courses – almost all of which are delivered in English. Engineers unable to access and understand these resources risk falling behind in both knowledge and relevance.

In this context, linguistic agility refers not only to the ability to read and understand technical English but also to actively use the language in varied professional scenarios – writing emails, conducting virtual meetings, participating in collaborative design sessions, and explaining complex ideas to non-technical stakeholders. Such competence enables engineers to contribute meaningfully in international consortia, present research findings at global conferences, and even take leadership roles in multinational teams. For Ukrainian graduates seeking to enter this landscape, language proficiency significantly broadens career horizons, allowing access to employment opportunities across Europe, North America, and increasingly, Asia-Pacific regions.

Moreover, surveys of employers in the energy and engineering sectors often highlight a "skills gap" between what is taught in universities and what is required in real-world practice. One of the most cited gaps is communication in English, particularly in digital professional settings. Addressing this disconnect requires the early integration of digital and linguistic training into engineering curricula, with ESP courses playing a central role in this transformation.

Forward-thinking employers are also looking for candidates who demonstrate digital confidence – the ability to navigate new technologies, evaluate digital information critically, and adapt to emerging platforms. Combined with language skills, digital confidence creates professionals who are not only technically skilled but also versatile, innovative, and collaborative. These are the individuals who can thrive in agile project teams, contribute to sustainable energy solutions, and lead digital innovation efforts within their organisations.

In all, the labour market is sending a clear message: tomorrow's engineers must be fluent in both the languages of technology and of global communication. For Ukrainian students of power engineering, responding to this demand requires a learning environment that fosters digital literacy and robust ESP competence from the outset. Universities that invest in the development of these competencies are not only preparing students for employment – they are equipping them to shape the future of the digital economy.

The evolving expectations of the labour market underscore a pressing need for educational strategies that develop not only domain-specific expertise, but also the digital and communicative competencies that empower students to thrive in globalised, tech-driven industries. As this chapter has illustrated, digital language competence is no longer a peripheral consideration in engineering education – it is a central pillar of professional preparedness, particularly in the context of Ukraine's integration into the European and global knowledge economies.

In response to these demands, Ukrainian technical universities must adopt innovative, practice-oriented approaches to teaching English for Specific Purposes (ESP), with a strong emphasis on digital tools and platforms that reflect real-world communication practices in the energy sector. The following section of this chapter will explore how such tools – ranging from learning management systems to AI-powered writing assistants and interactive simulations – can be effectively integrated into the ESP curriculum. It will also examine specific pedagogical techniques that enhance learner engagement, foster autonomy, and bridge the gap between classroom instruction and workplace expectations.

Through a closer look at these digital methodologies, we aim to highlight practical solutions for developing the kinds of language competencies that make future engineers not only employable but truly competitive in the digital economy of Ukraine and the whole world.

2. Integrating digital educational technologies into ESP teaching for power engineering students

The effective development of digital language competence among engineering students requires not only the recognition of its importance, but also the implementation of targeted, technology-enhanced teaching practices. English for Specific Purposes courses must evolve to reflect the linguistic demands of the modern engineering workplace, which is increasingly mediated by digital tools and collaborative platforms.

In Ukrainian technical universities, this evolution is not just desirable – it is essential. By strategically incorporating digital educational technologies into the ESP classroom, educators can create immersive, practical learning environments that prepare students for authentic communication tasks in the digital economy. Such an approach ensures that graduates are not only proficient in technical English but are also confident users of the digital communication tools that define contemporary engineering practice.

One of the most versatile and widely adopted tools in this context is the Moodle learning management system. Moodle allows instructors to design flexible, blended ESP courses that combine traditional classroom instruction with independent online learning. Through Moodle, students can access technical vocabulary modules, complete interactive grammar tasks, watch instructional videos, participate in forums, and submit assignments – all within a structured, accessible digital environment. This flexibility is especially valuable in the current educational landscape, where online and hybrid formats have become the norm due to logistical, geographical, and security-related challenges faced by Ukrainian institutions.

A key advantage of Moodle lies in its capacity to host authentic, field-specific materials that reflect the language used in professional engineering contexts. For instance, power engineering students can engage with real-world documents such as electrical safety regulations, user manuals for smart grid components, and excerpts from international standards (e.g. IEC or ISO guidelines). These resources not only improve students' technical reading skills but also expose them to the terminology and discourse structures typical of their future work environments. Additionally, instructors can integrate comprehension quizzes, vocabulary lists, and writing tasks based on these materials, encouraging both passive and active language use.

Beyond structured course content, ESP teaching can also benefit from digital tools that support independent language learning and language production. For example, the use of electronic dictionaries (such as ABBYY Lingvo or Cambridge Online Dictionary) enables students to quickly look up technical terms and examples of use in real contexts. More advanced learners can also benefit from AI-based grammar and writing tools like Grammarly or QuillBot, which provide real-time feedback and encourage learners to reflect on their own language output. These tools are particularly useful for writing professional documents such as maintenance reports, incident logs, and technical summaries – genres commonly encountered in engineering workplaces.

Another promising innovation in the ESP classroom is the use of technical text generators and translation engines. Tools such as DeepL and ChatGPT can help students explore technical phrasing, sentence structuring, and genre conventions by generating model texts based on given prompts. While these tools should be used critically, under teacher guidance, they can enhance students' awareness of professional language use and offer support in developing their own written texts. For example, students can be tasked with generating a user manual section or a project description using such tools and then refining the output collaboratively, with a focus on clarity, accuracy, and register.

The table below (table 1) presents a comparative analysis of three prominent machine translation tools – DeepL, Google Translate, and ChatGPT – highlighting their strengths and limitations across key performance and usability criteria. This comparison provides insight into their suitability for different linguistic and professional contexts.

To foster communication skills in more dynamic ways, simulations and role-based scenarios offer highly effective methods. ESP instructors can design activities where students assume professional roles – such as project engineers, safety inspectors, or client representatives – and participate in simulated meetings, technical briefings, or problem-solving sessions. These scenarios can be supported by digital communication tools such as Microsoft Teams, Zoom, or Miro, which are widely used in industry and provide students with hands-on experience in navigating digital communication environments. Through such simulations, learners practise both linguistic skills and digital soft skills such as turn-taking in online discussions, presenting data via screen sharing, and negotiating meaning in intercultural teams.

Table 1

Comparative analysis of DeepL, Google Translate, and ChatGPT based on translation quality, context awareness, and usability features

Feature	DeepL	Google Translate	ChatGPT
1	2	3	4
Translation quality	Very high for European languages; natural and idiomatic	Good across many languages; sometimes literal or robotic	High-quality, context-aware translations; can adapt to tone
Context awareness	Moderate – considers sentence context	Low – often translates sentence-by-sentence	High – understands broader context (paragraphs or documents)
Supported languages	~30 languages	Over 130 languages	Over 50 languages (depending on model version)
Specialization handling	Good for business and general topics	Broad coverage, but less specialized	Can handle technical, legal, academic, and creative texts
Idioms & figurative speech	Generally good for common phrases	Often mistranslates or translates literally	Excels at interpreting idiomatic and figurative language
Customization and style control	Limited (formal/ informal in some languages)	Limited	High – can mimic specific tone, register, or user instructions
Real-time translation	Yes, via web and desktop app	Yes, in mobile and web apps	No real-time, but fast with longer inputs

Continuation of Table 1

1	2	3	4
Offline availability	Desktop app (partially offline)	Yes (mobile app downloads)	No (requires cloud access)
Text length limit	Limited (max ~5000 characters per input)	~5000 characters	Much higher (especially in Plus/ GPT-4 versions)
Document translation	Yes (supports .docx, .pptx, .pdf)	Yes (limited formatting retention)	Yes (retains structure if prompted well, but no file upload)
Cost	Free for basic, paid for Pro features	Free (ads may appear)	Free or subscription-based (ChatGPT Plus)
Best use cases	Formal documents, emails, business texts	Everyday phrases, travel, quick translations	Academic, technical, nuanced texts, content rewriting

Source: Created by authors

In addition to simulations, case-based learning provides another valuable pedagogical strategy. By working through real or hypothetical case studies related to smart technologies, renewable energy integration, or system failures, students engage with professional language in context. These tasks encourage the development of problem-solving skills, critical thinking, and the ability to articulate complex ideas in English – an essential competence for future engineers involved in strategic decision-making and international cooperation.

Project-based learning, too, has shown [8] excellent potential in combining digital and linguistic development. For instance, students might be asked to design a bilingual brochure for an energy-efficient solution, create a video presentation on the benefits of solar panels for rural areas, or prepare a technical briefing for foreign stakeholders.

These projects integrate the use of technical vocabulary, digital tools (e.g. Canva, PowerPoint, video editing platforms), and communication strategies, reflecting the authentic demands of contemporary engineering professions.

In sum, the thoughtful integration of digital educational technologies into ESP instruction creates a more responsive, realistic, and engaging learning environment. It enables students not only to acquire professional language skills, but also to practise using them in the kinds of digital contexts that they will encounter in the workplace. For Ukrainian universities committed to preparing globally competitive graduates, the implementation of such methods should be seen not as an optional enhancement, but as a core element of XX century professional education. By embracing this shift, institutions can foster a new generation of engineers who are linguistically agile, digitally competent, and fully prepared to meet the complex demands of the international labor market.

The use of moodle for blended and distance learning formats

The increasing need for flexibility in education, particularly in times of crisis and transition, has prompted higher education institutions worldwide to adopt learning management systems (LMS) as integral components of curriculum delivery. Among the various platforms available, Moodle has established itself as one of the most accessible, versatile, and pedagogically effective solutions for both blended and distance learning environments. In the context of teaching English for Specific Purposes to power engineering students, Moodle provides a structured, interactive space where language instruction can be closely aligned with professional needs and digital literacy development.

At its core, Moodle serves as a virtual classroom that enables the delivery of content, the facilitation of communication, and the monitoring of student progress – all in one platform. Its open-source nature makes it particularly suitable for Ukrainian universities operating under budget constraints, while its modular structure allows educators to design courses that reflect the specific linguistic and technical demands of their students' future professions. In ESP settings, where relevance and contextualisation are key, Moodle supports the creation of learning pathways that mirror real-world communication tasks encountered by engineers.

In blended learning formats, Moodle complements face-to-face instruction by allowing students to engage with digital content before or after in-class activities. For example, an instructor might assign a pre-lesson vocabulary module on smart grid terminology, followed by an in-class discussion on energy distribution systems. Alternatively, students may be asked to watch a video explanation of a technical process and complete a quiz on Moodle to check comprehension prior to a live seminar. This structure encourages flipped learning, where classroom time is reserved for active language use, such as collaborative problem-solving or technical debates, while individual preparation happens online at the learner's own pace.

In fully distance-based scenarios, such as those necessitated by wartime disruptions or public health emergencies, Moodle becomes the central hub for instruction. All components of ESP teaching – reading, writing, listening, and speaking – can be adapted to the online environment using Moodle's built-in tools. These include forums for asynchronous discussions, assignment upload features, integrated video links, quizzes, glossaries, and grading systems. Students can submit technical descriptions, respond to simulated workplace scenarios, or participate in peer-reviewed writing tasks, with timely feedback provided by instructors. This model ensures continuity of learning even when face-to-face interaction is not possible.

An important pedagogical advantage of Moodle is its support for authentic materials and task-based learning. Teachers can upload real industry documents – such as user manuals, technical specifications, or professional standards – and build exercises around them. For example, a lesson on reading technical diagrams might include an embedded PDF of a wiring schematic, followed by comprehension questions and a writing task requiring students to describe the system in English. These materials can be supplemented with digital dictionaries, video explainers, and vocabulary games, allowing for multimodal input that accommodates diverse learning preferences.

Furthermore, Moodle enables the personalisation of learning through adaptive pathways and differentiated tasks. Students with varying levels of English proficiency can be directed towards resources that match their competence, while those requiring additional support may receive individualised feedback or remedial activities. This adaptability is particularly useful in large, mixed-ability groups, which are common in Ukrainian technical universities. It also fosters learner autonomy, as students can revisit materials, track their own progress, and manage their time effectively – essential skills in both academic and professional contexts.

From an administrative perspective, Moodle offers robust tracking features that allow educators to monitor student engagement and performance over time. Attendance, activity completion, quiz scores, and assignment submissions can all be analysed to identify learning gaps or students at risk of falling behind. Such insights are valuable not only for day-to-day teaching, but also for programme evaluation and curriculum development, particularly when aiming to align language training with industry expectations.

In all, the use of Moodle in ESP teaching provides a sustainable and scalable solution for developing digital language competence among power engineering students. Whether in blended or distance formats, Moodle supports pedagogical innovation, fosters independent learning, and ensures that language instruction remains relevant, accessible, and integrated with students' professional development. For Ukrainian universities navigating the twin challenges of digital transformation and geopolitical instability, platforms like Moodle offer a path toward resilience, continuity, and educational excellence.

Application of electronic dictionaries, AI-based grammar tools, and online technical glossaries to enhance vocabulary and grammar acquisition

In the teaching of English for Specific Purposes (ESP), particularly within technical disciplines such as power engineering, the development of a precise and contextually appropriate vocabulary is essential. Equally important is the acquisition of grammatical accuracy, especially when dealing with complex sentence structures often required in technical writing. The integration of digital tools such as electronic dictionaries, AI-powered grammar assistants, and online technical glossaries into ESP instruction represents a significant advancement in language learning methodology, providing students with immediate access to linguistic support tailored to their field.

These tools not only assist in real-time correction and clarification but also foster learner autonomy by encouraging students to actively engage with authentic materials. For example, engineering students can use online corpora to analyze how specific technical terms are used in real-world academic and industrial contexts. This exposure helps bridge the gap between classroom learning and professional communication. AI-powered grammar assistants further support students in constructing syntactically complex sentences that meet the conventions of technical documentation. As a result, students gain greater confidence in producing written reports, abstracts, and project descriptions that are both linguistically accurate and professionally appropriate.

In addition, the use of digital platforms allows instructors to monitor student progress more effectively, providing targeted feedback and adaptive support based on individual learning trajectories. This level of personalization was rarely achievable with traditional methods. Importantly, the integration of technology does not replace the teacher but enhances the instructional process, allowing educators to focus on higher-order language skills such as critical reading and effective argumentation. In this context, digital tools function as an extension of the learning environment, reinforcing classroom instruction and preparing students to operate confidently in a globalized, digitally driven workforce. Ultimately, the thoughtful incorporation of these resources into ESP instruction supports not only linguistic development but also the broader goal of professional readiness.

Electronic dictionaries serve as indispensable tools for ESP learners, allowing for quick, context-sensitive look-up of unfamiliar terms.

Unlike traditional print dictionaries, digital platforms such as ABBYY Lingvo, Cambridge Dictionary Online, and Longman Dictionary of Contemporary English offer learners multiple definitions, example sentences, collocations, pronunciation guides, and sometimes even translations. For instance, a student encountering the term "*inverter*" in a text about photovoltaic systems can access not only a general definition but also sample uses within technical contexts, such as "*solar inverter*" or "*DC to AC inverter*." This deepens understanding and reinforces domain-specific usage.

Moreover, electronic dictionaries are accessible across various devices – computers, tablets, smartphones – which supports learning anytime and anywhere. Teachers can integrate dictionary tasks into ESP lessons, encouraging students to build personal glossaries, identify synonyms, and compare usage across contexts. These activities foster active vocabulary engagement and raise learners' awareness of subtle distinctions in meaning that are especially relevant in technical communication.

The table below (table 2) provides a comparative overview of three major digital language platforms – ABBYY Lingvo, Cambridge Dictionary Online, and the Longman Dictionary of Contemporary English (LDOCE). The comparison covers key aspects such as linguistic functionality, usability, and educational value, offering insights into their respective strengths for learners, translators, and educators.

In addition to dictionaries, AI-based grammar tools such as Grammarly, QuillBot, and LanguageTool have become highly effective assistants in developing grammatical competence among ESP students. These tools go beyond basic spell-checking: they analyse sentence structure, detect register mismatches, and provide suggestions for improving clarity, coherence, and tone. For example, when a student writes a sentence such as "*This system allow to reduce energy consumption*," Grammarly will immediately flag the error and suggest a corrected version: "*This system allows energy consumption to be reduced*."

Table 2

Comparison of digital language platforms: ABBYY Lingvo, Cambridge Dictionary Online, and LDOCE

Feature	ABBYY Lingvo	Cambridge Dictionary Online	LDOCE
1	2	3	4
Primary function	Translation dictionary with multiple bilingual pairs	Monolingual English learner’s dictionary	Monolingual English learner’s dictionary
Language support	20+ languages; strong in Russian-English / French-German	English only (with some bilingual support for learners)	English only
Pronunciation	Audio in multiple accents (e.g., UK, US)	Audio in UK and US accents	Audio + phonetic transcription using IPA
Example sentences	Varies by dictionary pack; often good for context	Rich, contextual examples from real usage	Extensive examples from real-life usage
Collocations & usage notes	Moderate; varies by dictionary used	Yes; highlights common collocations and grammar notes	Yes; includes 'Collocation boxes' and grammar patterns
Grammar & language notes	Limited (depends on dictionary pack)	Comprehensive grammar, word family, and frequency notes	Strong focus on grammar, usage, and learner-friendly features
Search features	Fast search, wildcard, morphology-aware	Instant search, search suggestions	Smart search, wildcard, integrated thesaurus
Offline availability	Yes (Windows, mobile apps)	No (online only)	Yes (premium versions)

Continuation of Table 2

1	2	3	4
Customization	Yes (user dictionaries, add own words)	No	Limited (some personalization in premium tools)
Integrated learning tools	Flashcards, quizzes, history	Word lists, quizzes, English grammar exercises	Word frequency indicators, vocabulary trainer
Audience focus	General users, professionals, translators	ESL/EFL learners, students, teachers	ESL/EFL learners, exam takers (e.g., IELTS, TOEFL)
Cost	Paid (with free basic versions available)	Free	Freemium (basic free, paid extras for LDOCE Online)
Best use cases	Fast translation, reference for multilingual users	Language learning, pronunciation, academic writing	Learning academic and spoken English, preparing for exams

Source: Created by authors

This instant feedback is especially beneficial for learners who are preparing professional texts such as reports, abstracts, or maintenance instructions, where precision and clarity are non-negotiable. Students also benefit from explanations provided by the software, which helps them understand not just what is wrong, but why – a critical feature for long-term grammar acquisition. Teachers may assign grammar improvement tasks using these tools or ask students to revise their writing based on AI suggestions and reflect on the changes made.

Another valuable resource in ESP instruction is the use of online technical glossaries, which provide field-specific terminology with definitions written for professionals or learners in the target domain. Platforms such as Electropedia (by the IEC), IEEE Glossary, and Energy Glossary by the U.S. Energy Information Administration offer reliable, up-to-date definitions of specialised terms used in the power and energy sectors. For example, a student researching "smart metering" can refer to Electropedia for the official IEC definition, which provides context and precise usage relevant to international standards. Such resources not only enhance students' understanding of domain-specific terminology but also familiarize them with the standardized language used in international technical communication, which is essential for their future professional engagement.

The following table compares (table 3) three specialized terminology platforms – Electropedia by the International Electrotechnical Commission (IEC), the IEEE Glossary, and the Energy Glossary by the U.S. Energy Information Administration (EIA). These resources are critical for ensuring consistency and clarity in technical and energy-related documentation.

Table 3

Comparison of technical glossary platforms: Electropedia, IEEE Glossary, and EIA Energy Glossary

Feature	**Electropedia (IEC)**	**IEEE Glossary**	**Energy Glossary (EIA)**
1	2	3	4
Publisher	International Electrotechnical Commission (IEC)	Institute of Electrical and Electronics Engineers (IEEE)	U.S. Energy Information Administration (EIA)
Scope	Electrotechnical and energy-related terms	Electrical, electronic, and computing terms	Energy production, consumption, and policy terms
Terminology depth	Highly structured and internationally standardized	Concise definitions from IEEE standards	General definitions intended for policymakers and the public

Continuation of Table 3

1	2	3	4
Audience	Engineers, standards developers, international regulators	Researchers, engineers, standards developers	General public, policymakers, educators
Search functionality	Alphabetical + thematic browsing	Search via IEEE Xplore or standards documents	Keyword search with straightforward results
Update frequency	Regularly updated as standards evolve	Updates align with standard revisions	Updated periodically with changes in energy sector
Cross-references	Yes, includes links to related terms and standards	Limited; depends on document structure	Basic internal linking within glossary entries
Access	Free online access	Access varies (some content behind paywall)	Fully free online access
Best use cases	Developing international standards, precise technical writing	Understanding IEEE standards, technical documentation	Public communication, energy education, and policymaking

Source: Created by authors

These glossaries are particularly useful when students work on reading comprehension tasks, translation exercises, or project-based writing in ESP courses. By consulting authoritative sources, students learn to recognise correct terminology, differentiate between similar technical concepts (e.g. "*current transformer*" vs. "*potential transformer*"), and avoid literal translations or incorrect usage that may arise from general-language resources.

To maximise the benefits of these tools, instructors can design integrated tasks that combine vocabulary acquisition, grammar refinement, and professional reading or writing. For example, in a lesson on renewable energy systems, students might be asked to:

- read a short excerpt from a manufacturer's datasheet on wind turbine controllers;
- use an electronic dictionary to clarify unfamiliar terms (e.g. "*yaw control*," "*anemometer*," "*cut-in speed*");
- draft a paragraph summarising the system's operation using appropriate grammar and technical vocabulary;
- run the paragraph through Grammarly or QuillBot, compare the original and revised versions, and reflect on the corrections.

Such tasks promote learner autonomy, digital literacy, and linguistic accuracy – three pillars of successful ESP education in the digital age.

In all, the application of electronic dictionaries, AI-based grammar tools, and online technical glossaries empowers engineering students to engage with technical content more confidently and accurately. These tools not only support the development of linguistic competence but also mirror the resources professionals rely on in real workplaces, thereby reinforcing the authenticity and practicality of ESP instruction. Their integration into the language curriculum is both a pedagogical necessity and a strategic enhancement of students' readiness for participation in the global digital economy.

Simulations and case-based learning as tools for developing digital communication and language skills

As the demands of the modern labour market evolve, so too must the methodologies used in English for Specific Purposes (ESP) instruction. Traditional approaches, while still useful for foundational skill-building, are often insufficient to prepare learners for the realities of XX century workplaces – particularly those shaped by globalisation, digitalisation, and interdisciplinary collaboration. To address this, simulations and case-based learning have emerged as powerful, practice-oriented strategies that mirror authentic workplace communication scenarios and foster both linguistic and digital competencies. These methods are especially relevant in the context of power engineering education, where the ability to engage in problem-solving communication is central to professional success.

Simulations offer students a structured opportunity to experience workplace-like communication tasks within a safe, educational environment. In ESP courses, this often means replicating realistic technical or professional interactions such as safety briefings, project coordination meetings, technical presentations, or maintenance report discussions. These activities are conducted using the language of the target field, and, where possible, via digital platforms that are also commonly used in industry – such as Zoom, Microsoft Teams, or Slack. By engaging in these simulations, students not only practice relevant vocabulary and discourse patterns but also develop essential soft skills like clarity, teamwork, and digital communication etiquette that are increasingly valued in modern engineering workplaces.

For example, students may be assigned roles in a simulated international engineering team tasked with evaluating the feasibility of implementing smart grid infrastructure in a rural area. Each student is given a specific function – such as system designer, environmental analyst, or financial coordinator – and must prepare and present their analysis in English. The simulation may take place entirely online, requiring students to use screen-sharing features, upload digital documents, respond to real-time queries, and collaborate in breakout rooms. Through this process, learners practise domain-specific vocabulary, improve fluency, and gain experience in managing digital tools for communication – skills directly transferable to future employment settings.

The table below (table 4) compares three widely-used collaboration platforms – Zoom, Microsoft Teams, and Slack. Each of these tools supports communication and teamwork in professional and educational settings, but they differ in features, integrations, and optimal use cases.

Table 4

Comparison of collaboration platforms: Zoom, Microsoft Teams, and Slack

Feature	Zoom	Microsoft Teams	Slack
1	2	3	4
Primary function	Video conferencing	Integrated communication and collaboration	Messaging and collaboration
Strengths	High-quality video/audio, webinars, virtual backgrounds	Strong Office 365 integration, videochat, collaboration tools	Fast and organized messaging, robust app integrations
Video conferencing	Excellent; focus on meetings and webinars	Very good; integrates with scheduling and calendar	Basic; best used with third-party plugins
Messaging & chat	Basic in-meeting chat	Full-featured persistent chat, threads, mentions	Excellent chat with threads, emojis, reactions, rich formatting
File sharing	Available during meetings	Integrated with OneDrive and SharePoint	File sharing with Slack storage or linked cloud services
Integrations	Good: Outlook, calendar, whiteboards, Zoom Apps	Excellent with Microsoft products, third-party apps	Extensive app directory: Google, Microsoft, Trello, GitHub
Breakout rooms	Yes (strong feature)	Yes (limited flexibility)	No native support (some workarounds)
Security & compliance	End-to-end encryption (E2EE) available	Enterprise-grade security, compliance features	Good security; enterprise-level compliance

Continuation of Table 4

1	2	3	4
Mobile app	Full-featured and intuitive	Robust mobile experience	Highly rated mobile chat app
Free version	Yes, limited to 40-minute meetings	Yes, with limited features	Yes, with limited integrations and storage
Best use cases	Online meetings, webinars, education	Corporate environments, team collaboration	Agile teams, project management, developer collaboration

Sourse: Created by authors

Case-based learning complements simulations by engaging students in the in-depth analysis of real or hypothetical scenarios drawn from professional contexts. These cases typically involve [9] a technical problem or decision-making challenge and require students to work collaboratively to identify solutions, justify their recommendations, and communicate their findings in English. In power engineering contexts, this might include topics such as analysing the causes of a transformer failure, evaluating competing renewable energy proposals for an industrial site, or drafting a response to a customer complaint about voltage irregularities.

A well-designed case study encourages students to read and interpret technical documents, extract relevant information, apply critical thinking, and present conclusions in written or oral form. For example, after reviewing a manufacturer's fault log and a customer's complaint email, students may be asked to write a short formal report summarising the findings and recommending preventive measures. The instructor may then guide students through a peer review process, followed by submission through Moodle, where additional feedback can be provided using AI-assisted writing tools or grading rubrics.

Both simulations and case-based activities promote communicative competence in context, which is a core aim of ESP. Importantly, they also strengthen soft skills – such as teamwork, adaptability, and digital collaboration – which are now recognised as vital components of professional readiness in engineering. In multilingual teams or international projects, engineers must frequently present their work, negotiate with stakeholders, and respond to feedback from diverse audiences. Case-based and simulation tasks provide students with a rehearsal space for these complex interactions.

Additionally, these methods support interdisciplinary integration, encouraging students to draw on their engineering knowledge while developing language and communication strategies. Teachers may collaborate with faculty from technical departments to design tasks based on current research or applied technologies in the field, thereby reinforcing the connection between language learning and students' core disciplines. Such collaboration also strengthens the authenticity of learning and increases student motivation, as learners can see a direct link between their ESP work and future professional roles.

In terms of assessment, simulations and case-based learning lend themselves well to formative and performance-based evaluation. Teachers can assess students not only on language accuracy but also on clarity, effectiveness of communication, teamwork, and professionalism. Rubrics that include language criteria alongside content and digital skills are particularly useful in capturing the multifaceted outcomes of these activities.

In all, simulations and case-based learning represent an effective response to the pedagogical challenges of preparing engineering students for global, digitally connected workplaces. They foster the development of ESP competencies in ways that are both engaging and aligned with real-world professional practices. By integrating these methods into ESP curricula, Ukrainian technical universities can ensure that their graduates are not only linguistically prepared, but also capable of navigating the digital tools and communicative demands of their future engineering careers.

Use of technical text generators and translation engines (e.g. DeepL, ChatGPT) for comprehension and production of engineering texts

The digitalisation of education and the growing presence of artificial intelligence in language processing have opened new opportunities for enhancing English for Specific Purposes (ESP) instruction in technical fields. Among the most transformative tools [10] in this area are technical text generators and translation engines, such as DeepL and ChatGPT, which enable students not only to access professional-level content but also to produce and refine their own texts in authentic formats. In the context of teaching ESP to students of power engineering, these technologies are proving to be valuable allies in supporting comprehension, vocabulary development, genre awareness, and written fluency.

DeepL, widely regarded for its high-quality machine translation capabilities, is especially useful for students working with technical documents that may be initially available in Ukrainian or another native language. Unlike earlier generations of translation software, DeepL excels in preserving terminology and syntactic clarity across complex subject matter. For example, when translating a section of an operating manual for a solar inverter system, DeepL provides not only accurate term equivalents (e.g. "*maximum power point tracking*", "*inverter efficiency*"), but also produces grammatically coherent English texts that are suitable for classroom analysis or adaptation into student reports.

In ESP instruction, teachers can leverage this tool in various ways. Students might begin with a Ukrainian-language technical document and use DeepL to generate a preliminary English version. This version can then be reviewed critically in class, allowing students to identify translation challenges, correct inaccuracies, and compare machine output with standard engineering phrasing found in original English-language manuals. This activity not only sharpens reading comprehension but also raises students' awareness of industry-specific terminology, collocations, and register.

Similarly, ChatGPT, powered by advanced natural language processing, offers [11] remarkable capabilities for generating technical texts on demand. Students and instructors can prompt the system to produce summaries, technical descriptions, formal letters, safety instructions, or product comparisons based on specific engineering topics. For instance, when asked to generate a paragraph describing the function of a synchronous generator, ChatGPT can provide a coherent, concise explanation in English, which students may then paraphrase, expand, or adapt for different purposes (e.g. a presentation slide or a maintenance instruction leaflet).

Beyond text generation, ChatGPT can also support language exploration and clarification. Students may input complex sentences or technical explanations and ask the tool to simplify them, define specific terms, or explain grammatical constructions. This promotes learner autonomy and provides immediate, tailored support for those working with unfamiliar content. Used under instructor supervision, ChatGPT can function as a digital assistant that helps students practise engineering communication in meaningful, targeted ways.

Importantly, these tools can also assist with text revision and editing. Students writing technical texts – such as system specifications, short reports, or project proposals – can use AI tools to check grammar, refine wording, and adjust tone. For instance, a student writing "*We install system for solar energy with good effectiveness*" might receive improved suggestions such as "*We install high-efficiency solar energy systems*", learning in the process about appropriate adjective use, article placement, and industry-preferred terminology.

From a pedagogical standpoint, incorporating AI-powered tools into ESP instruction supports [12] scaffolded learning. Beginners can use translation tools to understand input texts, while more advanced learners engage with generated texts as models for their own production. Tasks may include:

- comparing AI-generated texts with authentic technical manuals;
- editing or correcting AI-produced paragraphs based on grammar or factual accuracy;

- using ChatGPT to generate role-play scripts for simulations;
- analysing translation inconsistencies between DeepL and human-written equivalents.

Such tasks encourage students to think critically about language form, function, and appropriateness – core elements of communicative competence. However, it is crucial that these tools are used ethically and pedagogically, with clear guidance on their limitations. Students should be made aware that while AI tools are helpful, they are not infallible: terminology may still be used out of context, nuances can be lost, and factual errors may occasionally appear. Therefore, AI outputs must always be verified against reliable sources, especially in highly technical or safety-critical contexts.

In all, the integration of technical text generators and translation engines into ESP instruction offers significant benefits for comprehension, vocabulary acquisition, writing development, and learner engagement. For power engineering students in Ukrainian universities, these tools provide accessible, immediate support in navigating the linguistic demands of their field. When applied thoughtfully and critically, they not only accelerate language learning [13] but also familiarise students with the kinds of AI-assisted communication processes already shaping the future of engineering work worldwide.

The diverse range of digital tools explored in this section – from learning platforms like Moodle to AI-powered writing assistants and simulation-based learning – demonstrates the rich potential of technology to enhance language acquisition within technical education. These innovations not only support the development of digital language competence, but also reflect the real-world communication environments that engineering graduates will encounter in their professional lives. However, to ensure that such tools are used effectively and sustainably across institutions, broader strategic planning is required. The final section of this chapter outlines a set of practical, evidence-based recommendations for integrating digital language development into master's-level engineering programmes. These proposals aim to guide educators, administrators, and policymakers in strengthening the linguistic and communicative readiness of Ukraine's future engineers within the digital economy.

3. Practical recommendations for strengthening digital language competence in technical master's programmes

The effective integration of digital language competence into the training of future power engineers requires more than isolated classroom innovations – it demands a systematic, institution-wide approach that aligns educational objectives with the evolving needs of the digital economy. As Ukrainian technical universities continue to modernise their curricula and increase alignment with European standards, it becomes essential to embed English for Specific Purposes (ESP) instruction within a digital framework that reflects current labour market demands, technological trends, and international cooperation strategies. This section outlines practical, actionable and working recommendations aimed at strengthening and maintaining the sustainability of digital language competence in technical master's programmes in Ukrainian technical universities during full-scale russian invasion of Ukraine.

Integrate ESP and digital literacy into core curriculum design

Rather than treating ESP as an auxiliary or optional subject, universities should incorporate it as a core component of professional training. This requires a curriculum that recognises digital language competence as a cross-cutting skill, vital not only in academic settings but also in the workplace. Specifically, master's programmes in engineering should:

- include mandatory ESP modules focused on domain-specific vocabulary, documentation, and digital communication formats;
- align course content with actual workplace practices – e.g. writing system specifications, understanding technical standards in English, or participating in virtual project meetings;
- encourage interdisciplinary cooperation between language instructors and technical faculty to develop authentic tasks and assessments that blend language and subject knowledge.

Expand the use of digital tools through structured methodologies

While digital tools such as Moodle, Grammarly, ChatGPT, and DeepL are readily available, their educational impact depends on how thoughtfully they are embedded into teaching. Universities should:

- provide guidelines and training for ESP teachers on the pedagogical use of digital platforms and AI tools;
- create institutional repositories of ready-to-use tasks and lesson plans that integrate these tools in meaningful ways;
- promote the use of blended learning formats, with clear task sequencing, formative feedback, and real-world communication simulations;
- establish digital portfolios for students to document their language progress, project outputs, and AI-assisted writing samples.

Develop institutional support systems for teachers and learners

To successfully implement these innovations, support mechanisms must be put in place:

- offer continuous professional development for ESP instructors in educational technologies, curriculum development, and AI literacy;
- ensure access to updated infrastructure, including stable LMS platforms, online libraries, and AI-powered tools;
- provide technical assistance and mentoring for new staff members engaging with digital course design;
- encourage communities of practice where educators can share insights, challenges, and innovations in digital ESP teaching.

Promote collaboration with european educational and research platforms

One of the most effective ways to raise the standard of ESP instruction and digital competence is through international collaboration. Ukrainian institutions should:

- encourage student participation in MOOCs (e.g. FutureLearn, Coursera, edX) that offer content in English related to power engineering, sustainability, and innovation;
- apply for Erasmus+ mobility programmes and joint projects focusing on digital and linguistic competence development;

- engage in virtual exchanges and co-teaching opportunities with European partner universities to model real-life international communication;
- align ESP learning outcomes with CEFR descriptors and the European Framework for the Digital Competence of Educators (DigCompEdu).

Evaluate and certify digital language competence

Establishing a clear system for assessment and recognition of digital language skills reinforces the seriousness of ESP in technical education. Recommendations include:

- incorporating performance-based assessments, such as digital presentations, online report writing, and participation in virtual debates;
- offering micro-credentials or digital badges for the successful completion of ESP modules focused on digital communication;
- collaborating with industry partners to validate assessment tasks and ensure they reflect actual workplace expectations;
- encouraging students to sit for international certifications (e.g. IELTS, TOEIC, Cambridge BEC) alongside university ESP courses, with institutional support.

In summary, the development of digital language competence in technical master's programmes requires an integrated, future-oriented strategy. It is not sufficient to introduce technology into the classroom on an ad hoc basis; rather, universities must cultivate a digital learning culture that values communication as a professional tool, aligns language instruction with economic priorities, and empowers both teachers and students to engage confidently with the demands of the global labour market. By implementing the recommendations outlined above, Ukrainian technical universities can play a vital role in shaping a new generation of engineers who are not only technically proficient, but also linguistically agile and digitally fluent – ready to contribute meaningfully to the digital transformation of the economy.

Examples of successful implementation and student feedback

The effectiveness of digital tools and approaches in ESP instruction is most clearly demonstrated through real-life examples of classroom application and the experiences of students themselves. Across several Ukrainian technical universities, educators have begun systematically integrating digital platforms, AI-based tools, and task-based methodologies into ESP courses – often with highly positive outcomes. These case studies illustrate not only the pedagogical viability of such innovations, but also their perceived value by the very learners they are intended to support.

At Vinnytsia National Technical University, an ESP module for master's students in power engineering was recently redesigned to include blended instruction via Moodle, along with regular use of Grammarly and DeepL for writing support. The course focused on preparing students to communicate technical information clearly and accurately in international contexts. Assignments included writing product descriptions, composing responses to customer enquiries, and summarising technical reports using authentic data sheets and industry-standard templates.

Students were encouraged to use DeepL to translate Ukrainian-language engineering documents and then critically analyse the translation for terminology accuracy and tone. In writing tasks, Grammarly was used not only to identify surface-level grammatical errors, but also to prompt discussion about clarity, passive voice usage, and stylistic conventions in technical English. The final assessment included a simulated online presentation to international stakeholders, where students were evaluated on both linguistic clarity and digital delivery skills.

The study involved 103 students from the Faculty of Energy and Electromechanics, VNTU, all of whom participated voluntarily. In accordance with ethical research standards, informed consent was obtained from each participant, and all collected data was treated with strict confidentiality – no personal information was disclosed or published at any stage of the study.

Feedback from participants was overwhelmingly positive. In anonymous surveys, 88% of students reported increased confidence in reading and producing engineering texts in English. One student wrote:

"*Before, I was afraid to write technical reports in English because I wasn't sure of the grammar and the terms. With Grammarly and the glossary links, I could check myself and feel more secure. Also, it helped me understand the way professionals really write in English*."

Another commented on the benefits of Moodle's structured learning path:

"*I liked the combination of videos, tasks, and forums. It was like we were learning English, but with a clear purpose – for work, for communication in projects. It was not abstract*."

Similarly, ESP instructors introduced simulation-based learning activities into the master's programme in electrical systems and networks. In one project, students participated in a week-long role-play in which they were tasked with resolving a fictional blackout affecting multiple facilities. Working in teams, they had to compose internal memos, write service reports, and participate in video calls (via Zoom) with instructors posing as international consultants.

The instructors noted a marked improvement in both student engagement and language production. Many students took the initiative to use online glossaries (such as Electropedia and IEEE Glossary) to ensure accuracy in their descriptions of technical failures. AI tools like ChatGPT were allowed under supervision for drafting first versions of documents, which students then edited collaboratively using Google Docs, incorporating teacher feedback.

Student reflections following the activity indicated strong appreciation for the realistic context. As one group member shared:

"*It was like a real situation. We had to explain problems clearly, suggest solutions, and communicate formally. I learned not only new words but also how to organise my thoughts professionally in English*."

Another wrote:

"*Using Zoom and writing formal messages to 'consultants' was a new experience. It helped me think about how we will work in international teams in real jobs*."

Beyond this feedback, instructors observed increased student autonomy, improved collaborative writing skills, and greater willingness to take risks in English communication. Importantly, several students later reported applying the skills acquired in ESP courses during internship interviews and work placements, particularly in tasks involving technical correspondence or online collaboration with international colleagues.

These examples confirm that when digital tools are used purposefully – embedded in tasks that mirror authentic professional scenarios – they not only enhance language development but also contribute to the overall confidence and communicative readiness of engineering students. Moreover, student feedback reinforces the notion that ESP instruction should be practical, context-driven, and aligned with the digital realities of modern industry. These findings underscore the importance of rethinking traditional ESP methodologies in favor of dynamic, technology-enhanced approaches that better prepare students for the linguistic and professional demands of the XXI century engineering workplace.

Prospects for cooperation with European educational platforms (e.g. Coursera, FutureLearn, Erasmus+ projects)

The ongoing digitalisation of higher education, accelerated by global trends and local challenges, has opened up unprecedented opportunities for Ukrainian technical universities to engage in strategic cooperation with European educational platforms. These platforms – such as Coursera, FutureLearn, and Erasmus+ – offer not only access to high-quality, internationally recognised educational content, but also serve as catalysts for institutional development, cross-border collaboration, and the strengthening of digital and linguistic competence among both students and educators. By integrating these resources into ESP curricula, universities can better align their language education with European standards, while also fostering a more inclusive and future-ready academic environment. Such integration empowers students to participate in international academic and professional communities, enhancing their mobility, employability, and capacity to contribute meaningfully to global engineering challenges.

One of the most immediate benefits of partnering with platforms like Coursera and FutureLearn lies in their vast repositories of professionally relevant courses, many of which are offered in English and tailored to the needs of engineering and technology students. For instance, Coursera hosts courses on smart grid technologies, renewable energy systems, and data analysis for engineers, delivered by institutions such as the University of Colorado Boulder, Delft University of Technology, and Imperial College London. These modules often include authentic technical texts, English-language video lectures, interactive assignments, and automated assessments – providing an immersive language and content learning experience that supports both subject mastery and ESP development.

Integrating these courses into university ESP programmes can significantly enhance students' exposure to authentic English-language materials while also encouraging autonomous learning habits. For example, an instructor might recommend or require students to complete a FutureLearn course on *Energy Transition* as a supplement to classroom instruction, with subsequent reflective assignments or discussion tasks built around the terminology, case studies, and professional discourse encountered in the online course. Such integration not only enriches the learning process but also familiarises students with the genre conventions and rhetorical styles used by professionals in their field.

The table below (table 5) presents a comparison of three prominent educational platforms and programs – Coursera, FutureLearn, and Erasmus+. These platforms differ in their delivery models, geographic reach, and primary target audiences, yet all play significant roles in expanding access to global education and lifelong learning.

Beyond content access, cooperation with these platforms opens the door to digital credentialing, allowing students to earn verified certificates that can strengthen their CVs and LinkedIn profiles. This enhances their global employability and demonstrates initiative and language competence to potential employers. Furthermore, students gain experience working in English-language learning environments, where communication with instructors and peers from other countries develops intercultural competence alongside technical and linguistic skills.

Table 5

Comparison of educational platforms: Coursera, FutureLearn, and Erasmus+

Feature	Coursera	FutureLearn	Erasmus+
1	2	3	4
Type	Online learning platform	Online learning platform	EU-funded international education program
Provider	Private (Founded by Stanford professors)	Owned by The Open University (UK)	European Commission (EU initiative)
Delivery mode	Self-paced or instructor-led online courses	Scheduled online courses with social learning model	In-person mobility (exchange, internships) + virtual cooperation
Main focus	Professional development, university courses, degrees	Short courses, microcredentials, professional and academic skills	Student and staff exchange, institutional collaboration, capacity building
Target audience	Global learners, working professionals, students	Learners from the UK, EU, and globally	Higher education students, educators, youth workers, institutions
Certifications	Certificates, professional and university diplomas	Certificates of achievement, academic credit for some courses	Formal recognition through ECTS or learning agreements
Cost	Free audit; paid certificates, subscriptions, and degrees	Many free courses; paid upgrades for certificates	Grants and full funding for participants; free to access
Languages offered	Primarily English; some courses in Spanish, Chinese, etc.	English-focused; limited multilingual options	Multilingual (based on participating institutions)

Continuation of Table 5

1	2	3	4
Accreditation	University and industry accredited programs	Courses often from accredited universities	Official EU recognition; tied to higher education frameworks
Collaborators	Universities (e.g., Yale, Stanford), companies (e.g., Google)	Universities, British Council, professional bodies	EU universities, NGOs, vocational schools, national agencies
Best use cases	Upskilling, university degrees, career advancement	Short-term learning, professional development, academic enrichment	International study, teaching exchange, institutional development

Sourse: Created by authors

In parallel, participation in Erasmus+ projects offers [14] an invaluable avenue for building deeper institutional partnerships and fostering long-term cooperation between Ukrainian and European universities. Through Key Action 2 (Cooperation among Organisations and Institutions) and Capacity Building in Higher Education (CBHE) initiatives, Ukrainian institutions can:

- co-develop ESP and technical course content with European partners;
- implement joint digital learning programmes that blend language and subject instruction;
- train educators in CLIL (Content and Language Integrated Learning) methodologies and digital pedagogy;
- facilitate virtual exchanges and blended mobility projects, where students participate in international teamwork using English as a working language.

Such projects not only support curriculum innovation but also contribute to the internationalisation of education, a key objective for Ukraine's integration into the European Higher Education Area. Moreover, Erasmus+ fosters sustainable development by funding digital infrastructure, promoting inclusivity, and encouraging the exchange of best practices across institutions.

The prospects for future cooperation are promising, particularly as Ukrainian universities seek to align with EU digital and educational strategies. By embedding the use of European platforms into formal ESP curricula and institutional strategies, universities can:

- bridge gaps in digital and linguistic competence;
- diversify learning experiences;
- expand their academic networks;
- increase resilience in times of crisis through decentralised, cloud-based learning models.

In conclusion, collaboration with European educational platforms is not merely an option for enriching ESP instruction – it is a strategic pathway toward raising the quality, relevance, and international competitiveness of Ukraine's technical education sector. It empowers students with the tools and experiences needed to operate confidently in global digital environments and positions Ukrainian universities as active contributors to the shared European educational space.

Policy-level recommendations for aligning digital language training with national goals of economic digitalisation

As Ukraine continues its strategic transition towards a digital economy, the role of higher education – particularly in technical fields – has become central to the development of the human capital needed to support this transformation. Within this context, digital language competence should be viewed not as an isolated educational objective, but as a strategically important component of national economic resilience and international integration. Effective policy-level interventions are essential to ensure that digital language training, especially in English for Specific Purposes (ESP), is fully aligned with broader digitalisation goals and labour market demands.

To achieve this alignment, universities must collaborate closely with industry stakeholders to identify the specific digital and linguistic skills required across various sectors. Curriculum development should prioritize interdisciplinary approaches that integrate ESP with digital literacy, coding, data analysis, and critical thinking. This will not only enhance students' employability but also contribute to a more agile and innovative workforce. Policymakers must support these efforts by providing funding for educational technology, teacher training, and curriculum innovation. In addition, national standards for digital language competence should be developed to ensure consistency and quality across institutions. As digital transformation accelerates, the ability to communicate technical knowledge in English becomes a key differentiator in the global marketplace. Therefore, ESP programs should focus on real-world tasks, such as writing technical reports, engaging in virtual collaboration, and navigating international digital platforms. Universities should also foster partnerships with global institutions to offer students immersive language experiences and exposure to international best practices. Ultimately, a strategic emphasis on digital language competence will strengthen Ukraine's position in the global digital economy. By embedding ESP within a broader digital strategy, higher education can become a powerful driver of national resilience, innovation, and growth.

To further support this vision, academic institutions should leverage digital platforms and AI-powered tools to personalize ESP learning and make it more adaptive to individual needs. Emphasizing project-based learning and problem-solving in ESP courses can simulate real-world scenarios, reinforcing both linguistic and technical competencies. Government incentives for universities that demonstrate measurable progress in digital language integration could accelerate nationwide implementation. Moreover, strengthening teacher capacity through continuous professional development in digital pedagogy and ESP instruction is critical. Attention must also be paid to rural and underserved regions to prevent a digital and linguistic divide within the country. National education strategies should incorporate feedback mechanisms to continuously evaluate the effectiveness of ESP programs in meeting labour market expectations. Engagement with the tech industry can provide students with internships, mentorship, and exposure to evolving digital communication practices. Promoting multilingualism, with English as a foundational component, can enhance Ukraine's competitiveness in regional and global collaboration. Recognizing ESP as a strategic investment rather than a supplementary skill will reshape perceptions of language education. As Ukraine builds a knowledge-based economy, digitally fluent and linguistically competent graduates will be essential to driving sustainable development and innovation.

In this transformative era, embedding digital language competence into the core of higher education policy is not just beneficial but imperative for Ukraine's long-term economic sovereignty and global relevance.

Firstly, national education and innovation policies should explicitly recognise ESP and digital language competence as priority areas within the broader digital transformation agenda. Government documents such as the Digital Economy and Society Development Concept of Ukraine (2020) and subsequent implementation plans can be revised or supplemented to include specific reference to:

- the integration of digital ESP into technical and vocational education;
- the promotion of English-language proficiency in digital communication for engineers, IT professionals, and technical personnel;
- the development of educational standards that incorporate digital communication skills as a measurable graduate attribute.

Secondly, the Ministry of Education and Science of Ukraine, in collaboration with leading technical universities and employers, should develop national ESP curriculum guidelines for master's programmes in engineering and related fields. These guidelines recommend:

- the inclusion of technology-enhanced language learning (e.g. LMS, AI tools, simulations);
- the use of authentic digital content relevant to industry sectors;
- a minimum English language level (e.g. B2+) as an exit requirement for technical master's graduates;

- competency descriptors for digital communication in English, aligned with the Common European Framework of Reference (CEFR) and digital competence frameworks such as DigCompEdu.

Thirdly, it is recommended that national funding instruments be designed to support the upskilling of ESP educators in both linguistic and technological domains. This include:

- professional development grants for teacher training in AI-assisted instruction and digital pedagogy;
- institutional incentives for cross-disciplinary collaboration between language departments and engineering faculties;
- the creation of digital repositories of ESP materials, tasks, and case studies, accessible to educators across Ukraine;
- state-supported participation in international educational partnerships (e.g. Erasmus+ Capacity Building, eTwinning, European MOOCs).

In addition, industry-education cooperation mechanisms should be strengthened to ensure that digital language training remains responsive to the needs of the real economy. This can be achieved by:

- establishing sectoral advisory boards involving employers, industry experts, and ESP instructors to review and co-develop course content;
- encouraging companies to provide examples of real technical documentation, workplace communication formats, and digital language use cases;
- facilitating internship and project opportunities in which students use English in digital professional environments.

To ensure long-term sustainability, policymakers should promote the development of national certification systems that assess and recognise digital language competence within higher education. These could take the form of micro-credentials, digital badges, or part of a broader graduate profile framework, linked to both academic transcripts and the national qualification register. Such recognition would help standardise quality, increase student motivation, and provide clear signals to employers.

Aligning these certification systems with international standards would facilitate student mobility and enhance Ukraine's participation in global academic and professional networks. By embedding certified digital language competence into national education benchmarks, Ukraine can foster a future-ready workforce equipped for the demands of the digital age.

Finally, policy must acknowledge the role of digital ESP training in Ukraine's post-war recovery and reintegration into the European community. By preparing graduates to work in international settings, contribute to cross-border infrastructure projects, and access global research and innovation networks, digital language competence becomes an enabler of economic rebuilding and resilience.

In all, aligning digital language training with national economic digitalisation goals requires a coordinated policy response – one that integrates curriculum reform, teacher development, institutional innovation, and public-private cooperation. By embedding these priorities into strategic documents, funding mechanisms, and accreditation systems, Ukraine can position itself not only as a consumer of global technologies, but as an active and competitive participant in the international digital economy.

Conclusion. In the rapidly evolving landscape of the global digital economy, the importance of integrating digital language competence into the professional training of future engineers can no longer be overstated. For students of power engineering in Ukraine, the ability to operate confidently in English across digital platforms is not simply an added advantage – it is a critical component of employability, innovation, and international collaboration. This chapter has examined the multifaceted role of English for Specific Purposes (ESP) within the context of digital transformation, highlighting how language competence intersects with technological fluency to shape the modern engineering professional. Through the use of digital tools such as Moodle, AI-based writing assistants, translation engines, technical glossaries, simulations, and case-based tasks, students gain [15] not only linguistic proficiency but also valuable skills in digital communication, problem-solving, and autonomous learning.

Successful implementations at Ukrainian technical universities, backed by positive student feedback, underscore the practical relevance and transformative potential of digitally supported ESP instruction. Furthermore, prospects for cooperation with European educational platforms and the strategic alignment of digital language education with national policy objectives offer a roadmap for systemic, long-term progress. To fully realise this potential, universities must embrace a forward-looking vision supported by robust institutional policies, international partnerships, and investment in teacher development.

Ultimately, digital language competence is not merely a pedagogical goal – it is a strategic imperative for Ukraine's integration into the global knowledge economy. By embedding it within the fabric of technical education, Ukraine can empower a new generation of engineers to communicate, collaborate, and lead in an increasingly interconnected, digital world.

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3.3. MATHEMATICAL AND INFORMATION MODEL OF A SPECIAL TYPE OF TRANSPORT TASK AS A TOOL FOR INCREASING THE ECONOMIC EFFICIENCY OF FREIGHT TRANSPORTATION

Introduction. The digitalization of the country's economy includes not only the introduction of the latest technologies, but also a deep transformation of management, production and logistics processes based on data and mathematical models. In an environment where markets are becoming increasingly dynamic and the efficiency of operations is critically important, the development and implementation of mathematical and information models is a necessary tool for achieving competitiveness and sustainable development.

One of the most important application areas of such models is the organization of freight transportation.

It is here that the linear programming transport problem becomes of particular importance, which allows finding optimal cargo movement schemes based on the criterion of minimizing costs or delivery time.

In the digital economy, this task becomes the basis for creating intelligent logistics solutions that work in real time, take into account large amounts of data and adapt to changing conditions.

It is used not in isolation, but as part of digital platforms, information and analytical systems, cloud services and mobile applications that provide transparent, fast and efficient transportation management.

Such models allow to automate the processes of route planning, distribution of cargo between modes of transport, calculation of costs and delivery times.

They take into account numerous constraints – from logistics capacities and schedules to climatic conditions and road conditions. Thanks to this, state bodies and private companies can optimize cargo flows, reduce costs and improve the quality of logistics services.

The implementation of mathematical and information models of this type contributes to the digital transformation of the entire transport infrastructure, increases its sustainability, adaptability and economic efficiency. In the long term, this paves the way for building a national digital transport system that meets modern challenges and global standards of sustainable development.

The European experience in using mathematical and information models in the field of freight transportation is one of the most developed in the world, as many EU countries are actively implementing digital technologies to optimize logistics. The main goal of these approaches is to ensure effective management of transport flows, reduce costs and environmental impact, as well as increase transparency in logistics chains.

European models are based on integrated systems that combine mathematical optimization methods (linear and nonlinear programming, network planning methods, queuing theory) with modern information technologies – GPS monitoring, cloud computing, artificial intelligence systems. This allows not only to find optimal routes, but also to adapt them in real time, taking into account changes in traffic, weather conditions or infrastructure congestion.

Another important aspect of the European experience is the centralized management of logistics at the state or interregional level.

This contributes to the unification of information platforms that use common algorithms for calculating routes, pricing and delivery control. This ensures consistency of actions between private carriers, logistics companies and state authorities.

Particular attention in Europe is also paid to environmental parameters: mathematical models take into account CO_2 emissions when choosing routes, and also optimize vehicle loading to reduce "empty runs".

In general, European practice demonstrates that the use of mathematical and information models in the field of freight transportation contributes to the formation of a sustainable, efficient and high-tech logistics system, which is a benchmark for many countries around the world.

In addition to technical and organizational improvements, an important component of the European approach is the creation of a favorable legal environment for the development of mathematical information models. This not only reduces administrative costs, but also ensures the accuracy and relevance of data for the operation of mathematical models.

European logistics hubs are platforms for the implementation of innovative freight forecasting models. They use systems with machine learning elements that analyze large amounts of historical and real-world data to predict congestion, delivery times, and transportation demand. Such models not only optimize resources, but also provide flexibility in decision-making.

It is worth mentioning separately the active interaction between scientific institutions and business. In many EU countries, research consortia are being created, uniting universities, logistics companies and IT developers. Such partnerships allow creating and adapting mathematical and information models to specific market conditions, implementing pilot projects and testing the effectiveness of various algorithms in real conditions.

The analysis of sources indicates the presence of important theoretical and methodological principles and practical recommendations for the digitalization of the Ukrainian economy in the context of optimizing transport and logistics processes.

In [1; 2] contain sound theoretical approaches to the development of logistics infrastructure and procedures that form the basis for digital modeling and automation of transport tasks.

The works [6; 10; 11] offer mathematical methods and models that can be adapted to digital platforms to increase the efficiency of freight transportation.

In [3; 5; 12] consider strategic aspects of logistics development in the context of digital transformation of the economy, in particular through the integration of innovative technologies and the creation of transport and logistics clusters.

Regulatory documents [7–9] determine state policy in the field of digitalization of the transport system, in particular regarding the implementation of an electronic transit system, the development of international transport corridors and the implementation of the National Transport Strategy until 2030.

Thus, the analysis of the literature indicates the presence of agreed theoretical foundations and practical solutions that create the prerequisites for the development and implementation of digital mathematical and information models of specialized transport problems aimed at increasing the economic efficiency of freight transportation in Ukraine.

Thus, the European approach to the use of mathematical and information models in the field of freight transportation is systemic, comprehensive and high-tech. It is not limited to technical innovations, but covers managerial, regulatory and educational aspects, forming an integrated ecosystem.

The European Union also invests significantly in the development of data infrastructure, which is the basis for the effective functioning of mathematical and information models.

For example, within the framework of the CEF (Connecting Europe Facility) program, the modernization of the TEN-T transport corridors is financed, which provides not only for the physical renewal of the infrastructure, but also for its digitalization – the installation of sensors, monitoring systems, integration with logistics platforms in real time.

Another important element is the standardization of data and models. Within the framework of initiatives supported by the European Commission, common protocols for information exchange are being developed, allowing to unite the systems of different countries and operators into a single digital ecosystem.

This is especially relevant for cross-border transport, where models can take into account changing legislation, customs procedures, time zones and even language barriers.

Considerable attention is also paid to the resilience of logistics to risks – both natural (floods, snowfalls) and socio-economic (strikes, changes in legislation). European models include what-if analysis blocks, which allow simulating different scenarios and choosing the least risky or most profitable delivery strategies.

In addition, the concept of "Digital Twin" is actively used – the creation of a virtual digital twin of a transport system or a separate logistics network. This allows you to test new routes, warehousing logistics, changing modes of transport or even driver behavior in simulation mode.

Thus, mathematical and information models in Europe have long gone beyond theoretical calculations and have become a tool for strategic management of the transport industry.

Overall, the European approach demonstrates that the future of logistics is a symbiosis of intelligent mathematical algorithms, digital infrastructure and cross-sectoral cooperation. This is what allows us to maintain a balance between economic benefit, environmental responsibility and social efficiency of transport in modern logistics.

A significant feature of the European approach is the focus on personalization of logistics solutions.

Mathematical and information models increasingly take into account not only global efficiency indicators (speed, costs, volume of transportation), but also individual customer requirements – from precise delivery times to specifications for storage conditions or cargo tracking.

This "fine-tuning" is achieved by integrating models with CRM systems, e-commerce platforms, and blockchain technologies.

Another bright spot is green logistics, which is gaining more and more importance in EU strategies.

Mathematical models for route optimization include input data on energy consumption, greenhouse gas emissions, and the availability of charging stations for electric trucks. In some countries , in particular in the Netherlands and Norway – Routes for electric trucks are planned taking into account terrain, temperature fluctuations, and the rate of charge loss, which was made possible precisely thanks to deep mathematical data processing.

European experience also shows the effectiveness of interoperability: different transport management systems – for example, in Italy, Spain and Austria – can work together, exchanging data through common interfaces. This allows operators to quickly adapt to changes in traffic, customs procedures or political decisions without having to manually adjust the transportation plan.

An important trend is the active use of open data. EU governments publish real-time data on traffic, road conditions, port capacity and customs status.

This creates a favorable environment for the development of new models and services by both the state and the private sector. Such data is the basis for the development of innovative startups in the field of transport analytics and intelligent planning.

Let us consider the connection between the linear programming transportation problem and the digitalization of the country's economy.

The linear programming transportation problem is a classical mathematical model used to optimally allocate limited resources between supply and consumption points in order to minimize costs.

In the context of the digital transformation of the economy, this problem plays a key role in building efficient logistics systems, implementing automated management tools, and creating intelligent digital platforms.

1. The transportation problem as an optimization tool in the digital economy.

The transportation problem has become the basis for digital solutions in the fields of transport, logistics, manufacturing, trade and government.

It is used not only to calculate the shortest or cheapest routes, but also as a module in forecasting systems, supply chain management, and dynamic balancing of demand and supply.

In a digital economy where decisions are made based on data, the transportation task is integrated into analytical dashboards, mobile applications and government information systems. Thus, it ensures the transition from manual to automated resource management.

2. Digitalization as a catalyst for the application of transport models.

Digital technologies have radically expanded the capabilities of classical models. Now the transport problem is used not only as an abstract equation, but as an interactive part of a complex digital system:

Big Data – allows you to take into account thousands of variables: weather conditions, traffic, seasonality, consumer behavior, etc.;

IoT (Internet of Things) – connected devices (sensors, GPS, RFID) provide real-time updates of task parameters;

Cloud computing – makes it possible to process large transport models, accessible from anywhere in the world, without the need for expensive local software;

Artificial intelligence and machine learning optimize the process of finding solutions, even in non-standard or dynamic conditions.

These technologies allow for the implementation of adaptive models that automatically rebuild routes and strategies depending on changes in the system.

3. Effects on the country's economy.

The integration of the transport problem into the digital economy creates a significant socio-economic effect:

– reduction of logistics costs – optimal routes and loads reduce fuel, time, and human resources costs;

– improving infrastructure planning – models allow you to simulate various infrastructure development scenarios and determine the most appropriate investments;

– increasing business competitiveness – enterprises that implement digital logistics solutions adapt to the market faster and reduce costs;

– transparency and control in the public sector – digital models in transportation and logistics management increase the transparency of tenders, contracts and public transportation.

In addition, effective transportation management helps reduce environmental impact, as route optimization leads to a reduction in CO_2 emissions.

4. Implementation example.

As part of the digital transformation of the country's economy, the following solutions are being implemented:

– state logistics platforms: automated cargo flow control systems, such as electronic queues, transportation planning platforms, digital offices for carriers;

– private initiatives: services such as lardi-trans, zakaz.ua, uber freight integrate the transport task into their algorithms for selecting the optimal supplier or route;

– urban transport models: in megacities, the transport problem is used to plan public transport, freight transport, and optimize traffic schedules.

All this indicates the systemic penetration of mathematical modeling into all levels of the digital economy – from local enterprises to national-level public administration.

5. The role of education and science in the digital transformation of logistics.

The development of the digital economy and the active implementation of mathematical models, in particular the transport problem, require an appropriate scientific and educational base.

It is science and education that are the drivers of the integration of intelligent transport solutions into the practice of business and the state.

Universities and higher education institutions train specialists in applied mathematics, logistics, data analytics, and IT who are able to develop, adapt, and implement transportation models in digital systems.

Scientific research on optimization, modeling, and artificial intelligence allows us to improve the transport problem taking into account new parameters – stability, dynamism, and multi-criteria.

An interdisciplinary approach is becoming extremely important – today a logistics specialist must understand programming, mathematical methods, and digital technologies.

Learning platforms, simulators, and cloud laboratories allow students and young researchers to work with real data and solve problems similar to those that arise in business or the public sector.

The educational and scientific components are no less important than the technical or economic component, because without human and intellectual support, the digital transformation of the transport system will remain only at the level of ideas.

6. Integration of the transport problem into state digital platforms.

One of the key areas of digitalization of the economy is the creation of state platforms and services that automate logistics and transport processes at the national level. The transport task is used in such systems as:

- Prozorro.Sales – automated distribution of freight transportation or logistics services through tenders.
- Electronic logistics systems in the military or humanitarian sectors (e.g., delivery of humanitarian aid or military cargo).
- A unified transport system within the framework of the digital transformation of the Ministry of Infrastructure – for the coordination of rail, road, and sea transport.

The use of mathematical models in such systems allows for transparent and efficient resource management, which is especially important in conditions of limited budgets and the need for rapid response.

7. The impact of the transport problem on sustainable development and the “green” economy.

The modern digital economy is not only focused on profit, but also on environmental sustainability. Route optimization based on the transport problem allows:

- Reduce fuel consumption and emissions into the atmosphere, which is important in the context of the country's commitments to reduce its carbon footprint.

- Model environmentally friendly supply chains.
- Plan the use of alternative modes of transport (electric vehicles, rail instead of motor vehicles).

This directly contributes to the implementation of the sustainable development goals defined by the UN, and also corresponds to the concept of "green logistics", which is gaining popularity in the EU, and therefore in Ukraine.

Thus, the transport problem of linear programming, in combination with digital technologies, becomes a powerful tool for modernization of the economy.

It allows for the implementation of innovative approaches to logistics and resource management, which directly affects the efficiency of the country's economy in the context of digital transformation. Its active implementation contributes to the formation of sustainable, effective, analytically supported solutions in the field of transport, which ensures an increase in the level of digital maturity of the national economy.

Presentation of the main results of the study.

The aim of the work is to develop:

1. General approaches to modeling transport problems.

1.1. Theoretical foundations of the transport problem.

The transportation problem is considered one of the fundamental problems of linear programming.

It consists in determining the optimal way to transport goods from several points of departure to several points of destination with minimal costs. In the general case, the problem takes into account restrictions on the volume of goods, transport capabilities, delivery time, costs and other factors.

1.2. Approaches to mathematical formalization.

Mathematical modeling of the transport problem is based on the construction of an objective function of cost minimization under given constraints. Depending on the type of problem (balanced, unbalanced, multi-criteria, etc.), different formalisms are used. The work focuses on generalized structures that can be adapted to real logistics conditions.

1.3. Information support for modeling.

Effective solution of the transport problem is impossible without proper information support.

The main components of information support include databases on departure and destination points, transport costs, cargo volumes, restrictions, time frames, etc. An important direction is the integration of information systems with modern technologies for collecting, processing and analyzing data.

1.4. Optimization methods.

Traditional optimization methods include the simplex method, the potential method, and the least cost method.

However, in conditions of complex constraints and high dimensionality of the problem, heuristic and metaheuristic approaches (genetic algorithms, particle swarm algorithms, ant algorithms) become relevant.

They allow finding effective solutions in reasonable terms, even when classical methods are unsuitable.

1.5. Directions for further development.

Current trends in the development of transport problem models involve the creation of adaptive, intelligent systems that are able to independently update data, take into account unpredictable changes in conditions and make optimal decisions in real time.

Another important direction is the integration of such models with geographic information systems, cloud platforms and big data technologies.

2. Model and method for finding plans for the transportation problem when grouping suppliers.

2.1. Formulation of a transportation problem model when grouping cargo suppliers.

Transportation problems occupy a special place among linear programming problems, as they reflect typical situations that arise in logistics, transportation planning, and resource allocation optimization.

Their essence lies in the need to efficiently move a certain type of cargo or product from several points of departure, which can simultaneously be considered as production sites or warehouses, to destinations – consumers, stores, storage warehouses, etc.

The main goal of such a task is find the optimal transportation plan that meets the needs of all destinations at minimal transportation costs.

In the process of solving a transportation problem, two main types of constraints should be taken into account: supply constraints, which indicate the maximum volume of cargo that can be shipped from each supply point, and demand constraints, which determine the required amount of cargo that must arrive at each destination point. These constraints are an important component of the mathematical model, as they reflect the real physical and economic constraints that the logistics system faces.

In the classical formulation of the transport problem, the cost of transporting goods between each pair of "departure point – destination" is assumed to be known in advance and unchanging, and is assumed to be a linear function of the volume of cargo being transported.

That is, the cost of transporting one cargo unit remains constant regardless of the total volume of transportation, and the total cost is defined as the product of the cost per unit and the number of units being transported.

Despite the fact that the transport problem is a special case of the linear programming problem and, accordingly, can be solved by standard methods (for example, the simplex method), its special structure allows to significantly simplify the calculation process.

Due to this, specialized algorithms have been developed for solving transport problems, in particular the northwest corner method, the least cost method, the potential method, etc.

These methods allow to quickly find both the initial feasible solution and optimize it to the lowest possible cost.

In cases where it comes to grouping cargo suppliers, there is a need for additional analysis – for example, determining the optimal way to combine several suppliers into groups in order to reduce the number of routes or reduce transportation costs.

In such problems, the model structure can be complicated, and the solution process itself requires taking into account additional factors, such as the geographical location of suppliers, the presence of common routes, the volume of available transport and other logistical constraints.

This extends the classic transport problem to a more general model of transport network optimization with grouping, which, in turn, opens up new approaches to increasing the efficiency of freight transportation in modern conditions.

A graphical representation of the conditions of the transport problem is shown in Fig. 1.

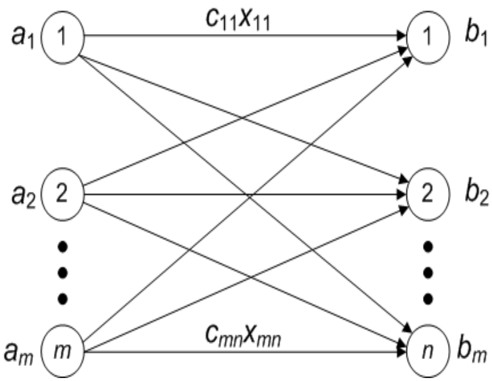

Figure 1. Schematic representation of the connections between the participants of the transportation process of the transport problem

Source: compiled by the author based on [10]

The figure shows m origin points and n destination points, which are nodes of the network.

The arcs connecting the nodes of the network correspond to the routes connecting the origin points and destinations.

Two parameters are associated with each arc (i, j) between points i and j: the transportation cost c_{ij} and the volume of goods transported x_{ij}.

The volume of goods at point i is a_i, the maximum quantity of goods at destination j is b_j. The problem is to determine the unknown quantities x_{ij}, which minimize the total transportation costs and satisfy the supply (a_i) and demand (b_j) constraints.

Within the framework of the transportation model, the problem of inventory management and the problem of distributing equipment for performing various tasks can also be considered.

The transportation problem is one of the key tools of operations research and can be presented not only in the form of a mathematical model, but also in a convenient tabular format.

In such a tabular representation, each individual row of the table corresponds to a specific departure point or source of products, that is, a supplier who has a certain amount of resources or cargo to transport.

At the same time, each column of the table corresponds to a destination, which is usually considered a consumer or a place where goods must be delivered. The value located in the cell at the intersection of the i-th row and the j-th column reflects the cost of transporting a unit of cargo from a specific departure point to the corresponding destination.

This can be, for example, a monetary amount or a conditional cost coefficient. If there is an unknown value in the cell, then it indicates the volume of transportation that must be determined in the process of solving the problem. In addition, in each row, the last cell indicates a restriction regarding the volume of supply – that is, how much product can be shipped from this source.

In turn, the last cell of each column records the amount of demand that needs to be satisfied at a specific destination. Thus, the tabular form allows you to conveniently structure the initial data of the problem, which greatly facilitates its analysis and subsequent solution.

Of particular note is the situation when cargo suppliers are grouped together. This is typical for hierarchical or multi-level logistics systems, where several lower-level suppliers are subordinate to one higher-level supplier or operator. In such a model, an additional restriction is introduced that regulates the total volume of cargo that can be exported from a certain group of suppliers.

This restriction can be significantly stricter than the simple sum of the stocks of all suppliers included in the corresponding group. The reasons for this can be technical, economic or organizational factors, for example, limited throughput of transport routes or regulated quotas for product export.

As a result of such changes, there is a need to adapt or even fundamentally redesign classical methods for solving the transport problem.

Well-known algorithms, such as the northwest corner method, the minimum element method or the potential method, may be ineffective or even unsuitable for solving problems with additional group restrictions. Therefore, modeling such problems requires the construction of specialized information and mathematical structures that allow for adequate consideration of the characteristics of supplier grouping and corresponding restrictions.

A graphical representation of the conditions of such a transport problem, taking into account the grouping of cargo suppliers and the corresponding logistical connections, is shown in Fig. 2.

It allows you to visualize the supply structure, the relationship between suppliers and recipients, and also demonstrate the effect of restrictions imposed on the movement of goods within the model.

2.2. Method for finding a reference road transportation plan when grouping cargo suppliers.

A special algorithm for solving transport problems was specially developed for fast manual calculations. Currently, most computer programs use the simplex method to solve the transport problem. However, the special algorithm is still important because it allows you to identify the features of the transport problem. Let us consider the solution of the transport problem when grouping cargo suppliers, the conditions of which are given in Table 1.

The algorithm for solving the transport problem is closely related to the classical simplex method and repeats its main stages, but is adapted to the specifics of cargo transportation. The sequence of its implementation includes the following detailed steps.

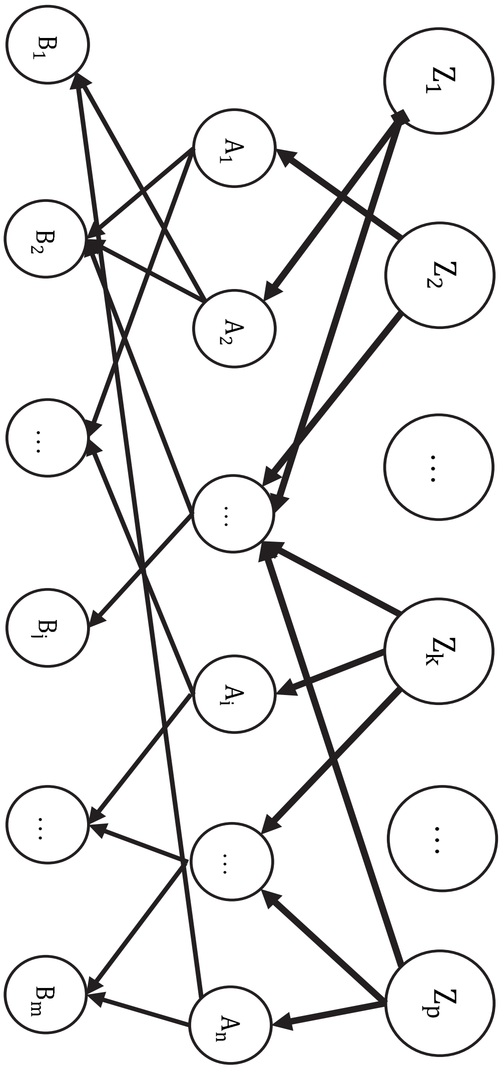

Figure 2. Schematic representation of the connections between the participants of the transport process of the transport problem provided that the cargo suppliers are grouped

Source: compiled by the author based on [10]

Table 1

Input data of the transport problem under the condition of grouping cargo suppliers

Grouping	Cargo suppliers	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
		Sp_1	Sp_2	Sp_3	…	Sp_n		
Gr_1	Ps_1	C_{11}	C_{12}	C_{13}	…	C_{1n}	b_1	g_1
	…	…	…	…	…	…	…	
	Ps_k	C_{k1}	C_{k2}	C_{k3}	…	C_{kn}	b_k	
…	…	…	…	…	…	…	…	…
Gr_u	Ps_r	C_{r1}	C_{r2}	C_{r3}	…	C_{rn}	b_r	g_u
	…	…	…	…	…	…	…	
	Ps_m	C_{m1}	C_{m2}	C_{m3}	…	C_{mn}	b_m	
Expected cargo quantity		a_1	a_2	a_3	…	a_n		

Source: compiled by the author based on [10]

1. Determination of the initial basic feasible solution.

At the first stage of solving the transport problem, it is necessary to find a reference plan, that is, an initial feasible solution that meets all the constraints of the problem: maintaining the balance between demand and supply and, if necessary, additional group or resource constraints. This solution is not necessarily optimal, but it serves as a starting point for further step-by-step improvement. It is usually built using one of the well-known methods – for example, the northwest corner method, the minimum element method or the potential method. In our case, a modified northwest corner method is used taking into account group constraints.

2. Checking the optimality of the current solution.

After constructing the initial plan, its optimality is analyzed. For this, the optimality condition is used, which is determined based on the estimates of non-basic variables. If all of them meet this condition, that is, they cannot improve the value of the objective function, then the calculation is completed – the resulting solution is considered optimal. If at least one non-basic variable allows you to reduce (or increase – depending on the goal of the problem) the value of the functional, it is selected for inclusion in the basis, which means moving to the next stage of plan correction.

3. Replacing the basic variable and forming a new solution.

In the third stage, it is determined which of the basic variables should be removed from the basis. This is done using the so-called admissibility condition – the impact of introducing a new variable on the structure of the solution is analyzed. According to the established rules, a cyclic route is found along which the values are adjusted, and the plan is updated accordingly. After this, the algorithm returns to the second stage – checking for optimality – and the cycle is repeated until an optimal solution is reached.

Building an initial plan using the northwest corner method, taking into account supplier grouping

In the case where suppliers are grouped together with restrictions on maximum transportation volumes, the classic northwest corner method is subject to appropriate modification. Its adaptation involves the inclusion of additional monitoring of the total cargo volumes in each supplier group so that they do not exceed the established values.

The process is carried out sequentially in the following detailed stages:

1. Assigning a value to cell x_{11}.

Starting from the top left cell (the so-called northwestern corner of the table), the maximum volume of cargo that can be assigned to this cell without violating the constraints on the demand of a specific consumer, the supply from a specific supplier, and the group constraints is determined. The resulting value is fixed as the initial delivery.

2. Analysis of the occupancy of rows, columns and groups.

After fixing the supply volume in the cell, it is checked whether the offer of the corresponding supplier has been fully used, the demand of the consumer has been satisfied, or the volume allowed for the group has been exhausted. If at least one of these restrictions is implemented, the corresponding row (supplier), column (consumer) or group is deleted from further consideration. If several restrictions are satisfied at the same time, a decision is made which element to delete, taking into account the logic of further construction.

3. Go to the next cell or end.

Then, move to the next matching cell: to the right if a column is crossed out, or down if a row is crossed out. The process continues in the same pattern: calculate an acceptable value for the new cell, check the constraints, cross out, and move on. If there is only one active row, column, or group left in the table, the algorithm stops because all allocation possibilities have been exhausted.

In this way, an initial reference plan is formed, which will subsequently be optimized according to the stages described above. Continuing to act similarly, we obtain the reference plan given in Table 2.

2.3. Method for finding the optimal road transportation plan when grouping cargo suppliers.

After forming an initial distribution plan that is acceptable from the point of view of the given input conditions, further processing of this solution is carried out using a special algorithm.

This algorithm is based on iterative calculations, the purpose of which is to consistently improve the existing plan until it reaches a state that can be considered optimal within the given constraints. The approach itself involves the use of a methodology that allows you to evaluate the effectiveness of the current distribution and make adjustments in accordance with the logic of the mathematical model underlying the problem.

During the implementation of the algorithm, additional constraints are introduced into the optimization process regarding the grouping of supply sources. This means that instead of analyzing each individual source individually, the model considers the combination of such sources into groups that have a common feature or function within a certain general system.

Table 2

Reference plan of the transport problem under the condition of grouping cargo suppliers

Grouping	Cargo suppliers	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
		Sp_1	Sp_2	Sp_3	…	Sp_n		
Gr_1	Ps_1	X_{11} C_{11}	X_{12} C_{12}	X_{13} C_{13}	…	X_{1n} C_{1n}	b_1	g_1
	…	…	…	…	…	…	…	
	Ps_k	X_{k1} C_{k1}	X_{k2} C_{k2}	X_{k3} C_{k3}	…	X_{kn} C_{kn}	b_k	
…	…	…	…	…	…	…	…	…
Gr_u	Ps_r	X_{r1} C_{r1}	X_{r2} C_{r2}	X_{r3} C_{r3}	…	X_{rn} C_{rn}	b_r	g_u
	…	…	…	…	…	…	…	
	Ps_m	X_{m1} C_{m1}	X_{m2} C_{m2}	X_{m3} C_{m3}	…	X_{mn} C_{mn}	b_m	
Expected cargo quantity		a_1	a_2	a_3	…	a_n		

Source: compiled by the author based on [10]

For each such group, a limit is defined on the total amount of resources that can be directed to various points of cargo consumers on the transport network.

Thus, the distribution is carried out not only in accordance with existing needs and capabilities, but also taking into account the total impact of each group on the overall transportation structure.

If, during the check of the current distribution status, it is found that the set limit for a particular group is exceeded in the corresponding direction, a change is made to the model.

The change is that part of the allocated volume is reduced in order to bring the situation into line with the introduced restrictions. Such correction is carried out in compliance with the general rules of the model, without disrupting the balance between sources and consumption points.

The process of verification and adjustment continues until a distribution is achieved that simultaneously satisfies both the initial conditions and additional constraints related to the groups.

In this approach, the very existence of a mechanism that allows you to automatically identify situations where the established limits are violated and promptly take measures to reduce the amount of resource that is distributed within the limits of the detected discrepancy is important.

This approach allows you to preserve the logic of the algorithm and ensures controllability of the optimization process even in the presence of complications in the form of additional conditions associated with grouping.

The algorithm maintains its consistency and integrity, gradually bringing the system closer to the target state without major failures or losses in the correctness of intermediate results.

As a result of the method, a plan is formed that is not only permissible, but also one that takes into account the specifics of the group structure of sources and adheres to restrictions on the level of the total impact of each of them within the overall distribution system.

After determining the initial basic solution, the potential method algorithm is applied, which allows finding the optimal solution to the transport problem.

The method adds conditions for not exceeding the total load for the established group limit at all points where this occurs.

If a violation is detected, the amount of cargo being redistributed should be reduced.

To find the optimal plan for the transportation problem when grouping cargo suppliers, we will use Table 3.

1. The variable to be introduced into the basis is determined using the simplex criterion I. If the optimal solution is achieved according to the criterion, the algorithm terminates.

2. Using simplex criterion 2, the variable to be excluded from the basis is determined. The basis is changed and the first stage is returned.

Table 3

Finding the optimal plan for the transportation problem when grouping cargo suppliers

Grouping	Cargo suppliers	Potentials	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
			Sp_1	Sp_2	Sp_3	Sp_4	Sp_n		
			Sp_1	Sp_2	Sp_3	…	Sp_n		
Gr_1	Ps_1		X_{11} C_{11}	X_{12} C_{12}	X_{13} C_{13}	…	X_{1n} C_{1n}	b_1	g_1
	…	…	…	…	…	…	…	…	
	Ps_k		X_{k1} C_{k1}	X_{k2} C_{k2}	X_{k3} C_{k3}	…	X_{kn} C_{kn}	b_k	
…	…	…	…	…	…	…	…	…	…
Gr_u	Ps_r		X_{r1} C_{r1}	X_{r2} C_{r2}	X_{r3} C_{r3}	…	X_{rn} C_{rn}	b_r	g_u
	…	…	…	…	…	…	…	…	
	Ps_m		X_{m1} C_{m1}	X_{m2} C_{m2}	X_{m3} C_{m3}	…	X_{mn} C_{mn}	b_m	
Expected cargo quantity			a_1	a_2	a_3	…	a_n		

Source: compiled by the author based on [10]

The determination of the variable introduced into the basis is carried out using the potential method, from which the coefficients of the objective function corresponding to the non-basic variables are determined. In the potential method, each row *i* and column *j* are assigned numbers (potentials) u_i and v_j that satisfy the condition:

$$u_i + v_j = c_{ij}. \quad (1)$$

In order to find the values of the potentials from this system of equations, it is necessary to give one of them an arbitrary value (usually $u_1 = 0$), and then sequentially calculate the values of the other potentials. The potentials are determined in the table.

Using the found potential values, the following quantities are calculated for each non-basic variable:

$$u_i + v_j - c_{ij}. \quad (2)$$

The coefficients found, together with the zero coefficients for the basic variables, are the coefficients of the row of the objective function of the simplex tableau.

Since the transportation problem seeks to minimize the cost of transportation, the variable with the largest positive coefficient in the row will be entered into the basis.

The described calculations are usually performed in the transport table. And here there is no need to write out the equations for the potentials explicitly.

The calculations of the transport table begin with assigning the potential u_1 a zero value.

Then the v-potentials of all columns with basic variables in the first row are calculated. Next, based on the equation for potentials corresponding to x_{22}, the values of the potential u_2 are determined.

Knowing the value of the potential u_2, we calculate the potentials v_3 and v_4, which allows us to find the potential u_3.

Since all the potentials are determined, the values $u_i + v_j - c_{ij}$ are calculated for each non-basic variable X_{ij}.

These values are shown in the table in the lower left corner of the cells of the transport table.

Now it is necessary to determine the basic variable, which is shown in Table. 4. Let θ denote the amount of cargo transported along the route.

The maximum possible value of θ is determined by the following conditions: 1) the constraints on demand and supply and the constraints on the group of suppliers must be met; 2) no route should carry out transportation with a negative volume of cargo. Let us construct a closed cycle, which is presented in Table 5.

A cycle in this context is formed as a clearly defined sequence of moves through the table, which includes only horizontal and vertical segments.

Table 4

Basic cell of the transportation problem when grouping cargo suppliers

Grouping	Cargo suppliers	Potentials	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
			Sp_1	Sp_2	Sp_3	Sp_4	Sp_n		
			Sp_1	Sp_2	Sp_3	…	Sp_n		
			v_1	v_2	v_3	…	v_n		
Gr_1	Ps_1	u_1	X_{11} C_{11}	X_{12} C_{12}	X_{13} C_{13}	…	X_{1n} C_{1n}	b_1	g_1
	…	…	…	…	…	…	…	…	
	Ps_k	u_k	X_{k1} C_{k1}	X_{k2} C_{k2}	X_{k3} C_{k3}	…	X_{kn} C_{kn}	b_k	
…	…	…	…	…	…	…	…	…	…
Gr_u	Ps_r	u_r	X_{r1} C_{r1}	X_{r2} C_{r2}	X_{r3} C_{r3}	…	X_{rn} C_{rn}	b_r	g_u
	…	…	…	…	…	…	…	…	
	Ps_m	u_m	X_{m1} C_{m1}	X_{m2} C_{m2}	X_{m3} C_{m3}	…	X_{mn} C_{mn}	b_m	
Expected cargo quantity			a_1	a_2	a_3	…	a_n		

Source: compiled by the author based on [10]

Such segments connect the cells corresponding to the basic variables currently participating in the transportation plan, as well as the cell corresponding to the new variable being introduced into the plan.

It is worth emphasizing that construction occurs exclusively through rectilinear movements along the grid – diagonal transitions are not allowed.

This approach provides clarity in constructing the cycle structure of the potential method.

For any variable that is entered into the plan, according to the logic of the calculations, it is always possible to form only one closed loop.

Table 5

Finding the optimal plan for a transportation problem when grouping cargo suppliers

Grouping	Cargo suppliers	Potentials	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
			Sp_1	Sp_2	Sp_3	Sp_4	Sp_n		
			Sp_1	Sp_2	Sp_3	…	Sp_n		
			v_1	v_2	v_3	…	v_n		
Gr_1	Ps_1	u_1	X_{11} C_{11}	X_{12} C_{12}	X_{13} C_{13}	…	X_{1n} C_{1n}	b_1	g_1
	…	…	…	…	…	…	…	…	
	Ps_k	u_k	X_{k1} C_{k1}	X_{k2} C_{k2}	X_{k3} C_{k3}	…	X_{kn} C_{kn}	b_k	
…	…	…	…	…	…	…	…	…	…
Gr_u	Ps_r	u_r	X_{r1} C_{r1}	X_{r2} C_{r2}	X_{r3} C_{r3}	…	X_{rn} C_{rn}	b_r	g_u
	…	…	…	…	…	…	…	…	
	Ps_m	u_m	X_{m1} C_{m1}	X_{m2} C_{m2}	X_{m3} C_{m3}	…	X_{mn} C_{mn}	b_m	
Expected cargo quantity			a_1	a_2	a_3	…	a_n		

Source: compiled by the author based on [10]

This cycle has the property of being closed, that is, it begins and ends in the same cell.

This allows for further calculations that depend on the structure of such a cycle and its corner elements.

Closed loop is a key condition for applying the value redistribution mechanism in the transport table.

The next step is to find the value of the parameter θ (theta), which plays the role of the magnitude of the change.

To maintain a balance between the available supply volumes and the demand volumes, it is necessary to alternately, in accordance with the established order, add or subtract the values of θ to those basic variables that are in the corners of the constructed cycle.

This happens according to the principle of alternating addition and subtraction: one variable increases, the next decreases, and so on, until the loop is completely traversed.

This sequence of actions allows for a correct update of the baseline plan without violating the conditions of the problem.

After making such changes, it is necessary to proceed to the stage of adjusting the values of all basic variables located inside the formed cycle.

This process involves updating the quantitative indicators in the corresponding cells of the table according to the previously calculated value of θ. This is necessary in order to ensure the consistency of all elements of the plan in accordance with the logic of the cyclical method.

In the event that, during the calculations, a situation is detected that violates the restrictions on the allowable amount of cargo for a certain group operating within the task, adjustments must be made.

Such violations indicate that the group has exceeded the permitted level of supply, and therefore it is necessary to reduce the volume of cargo distributed in accordance with these restrictions. This reduction is carried out within certain limits that allow returning to the permissible level without violating other conditions of the task.

After each stage of updating the plan, it is necessary to re-perform the potential calculation procedure.

This involves recalculating the values that determine the difference between the delivery costs and the estimates of the current plan. Calculating potentials allows you to check the optimality of the newly created plan and determine whether it requires further changes.

When all coefficients of the variables included in the objective function of the problem acquire negative values or do not improve the efficiency indicator, this means that the optimality condition has been achieved.

In this case, the solution to the problem is considered complete, and no further calculations are performed.

The current plan obtained at this stage of the algorithm will be considered optimal.

3. Numerical finding of plans for the transportation problem when grouping suppliers.

3.1. Finding a reference transportation plan when grouping suppliers.

Let the conditional parameters of the problem be given in the form of a table that reflects the distribution of cargo between suppliers and consumers under grouping conditions.

The tabular form of the problem representation contains all the necessary input data.

Suppliers are conditionally divided into several groups – for example, several elements in each group.

This structure allows for additional constraints at the level of combined sources of supply, which introduces a more complex distribution logic into the model.

One of the last columns of the table shows the quantities of cargo held in warehouses or other origin points.

Another column records the quantity of cargo that each group of suppliers can provide.

The bottom row of the table shows the expected cargo volume at the final consumption points. All of these indicators must be coordinated with each other to achieve balance.

The cells of the table, which are located at the intersection of the rows and columns representing the sources and destinations, contain the values of the transportation costs or costs in the upper right corner.

These values are used for further calculations. In the central part of each cell, the desired value will be placed – that is, the amount of cargo that must be transported along the corresponding route.

These values are the basis of the reference plan, which is formed in accordance with the input data of the task.

Step-by-step iterations of searching for a reference plan for the transport problem when grouping cargo suppliers are given in table 6–14.

Table 6

Input data of the transport task when grouping cargo suppliers

Grouping	Cargo suppliers	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
		Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
Gr_1	Ps_1	16	13	18	14	15	370	810
	Ps_2	15	17	14	18	16	570	
	Ps_3	17	14	16	13	18	320	
Gr_1	Ps_4	14	15	13	16	17	420	760
	Ps_5	17	16	15	14	14	470	
	Ps_6	13	18	17	16	13	220	
Expected cargo quantity		470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

Table 7

Finding a reference plan when grouping suppliers, iteration 1

Grouping	Cargo suppliers	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
		Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
Gr_1	Ps_1	370 16	0 13	0 18	0 14	0 15	370	810
	Ps_2	0 15	0 17	0 14	0 18	0 16	570	
	Ps_3	0 17	0 14	0 16	0 13	0 18	320	
Gr_1	Ps_4	0 14	0 15	0 13	0 16	0 17	420	760
	Ps_5	0 17	0 16	0 15	0 14	0 14	470	
	Ps_6	0 13	0 18	0 17	0 16	0 13	220	
Expected cargo quantity		470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

Table 8

Finding a reference plan when grouping suppliers, iteration 2

Grouping	Cargo suppliers	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
		Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
Gr_1	Ps_1	370^{16}	0^{13}	0^{18}	0^{14}	0^{15}	370	810
	Ps_2	100^{15}	0^{17}	0^{14}	0^{18}	0^{16}	570	
	Ps_3	0^{17}	0^{14}	0^{16}	0^{13}	0^{18}	320	
Gr_1	Ps_4	0^{14}	0^{15}	0^{13}	0^{16}	0^{17}	420	760
	Ps_5	0^{17}	0^{16}	0^{15}	0^{14}	0^{14}	470	
	Ps_6	0^{13}	0^{18}	0^{17}	0^{16}	0^{13}	220	
Expected cargo quantity		470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

Table 9

Finding a reference plan when grouping suppliers, iteration 3

Grouping	Cargo suppliers	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
		Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
Gr_1	Ps_1	370^{16}	0^{13}	0^{18}	0^{14}	0^{15}	370	810
	Ps_2	100^{15}	220^{17}	0^{14}	0^{18}	0^{16}	570	
	Ps_3	0^{17}	0^{14}	0^{16}	0^{13}	0^{18}	320	
Gr_1	Ps_4	0^{14}	0^{15}	0^{13}	0^{16}	0^{17}	420	760
	Ps_5	0^{17}	0^{16}	0^{15}	0^{14}	0^{14}	470	
	Ps_6	0^{13}	0^{18}	0^{17}	0^{16}	0^{13}	220	
Expected cargo quantity		470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

Table 10

Finding a reference plan when grouping suppliers, iteration 4

Grouping	Cargo suppliers	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
		Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
Gr_1	Ps_1	370 16	0 13	0 18	0 14	0 15	370	810
	Ps_2	100 15	220 17	120 14	0 18	0 16	570	
	Ps_3	0 17	0 14	0 16	0 13	0 18	320	
Gr_1	Ps_4	0 14	0 15	0 13	0 16	0 17	420	760
	Ps_5	0 17	0 16	0 15	0 14	0 14	470	
	Ps_6	0 13	0 18	0 17	0 16	0 13	220	
Expected cargo quantity		470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

Table 11

Finding a reference plan when grouping suppliers, iteration 5

Grouping	Cargo suppliers	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
		Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
Gr_1	Ps_1	370 16	0 13	0 18	0 14	0 15	370	810
	Ps_2	100 15	220 17	120 14	0 18	0 16	570	
	Ps_3	0 17	0 14	0 16	0 13	0 18	320	
Gr_1	Ps_4	0 14	0 15	150 13	0 16	0 17	420	760
	Ps_5	0 17	0 16	0 15	0 14	0 14	470	
	Ps_6	0 13	0 18	0 17	0 16	0 13	220	
Expected cargo quantity		470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

Table 12

Finding a reference plan when grouping suppliers, iteration 6

Grouping	Cargo suppliers	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
		Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
Gr_1	Ps_1	370 (16)	0 (13)	0 (18)	0 (14)	0 (15)	370	810
	Ps_2	100 (15)	220 (17)	120 (14)	0 (18)	0 (16)	570	
	Ps_3	0 (17)	0 (14)	0 (16)	0 (13)	0 (18)	320	
Gr_1	Ps_4	0 (14)	0 (15)	150 (13)	270 (16)	0 (17)	420	760
	Ps_5	0 (17)	0 (16)	0 (15)	0 (14)	0 (14)	470	
	Ps_6	0 (13)	0 (18)	0 (17)	0 (16)	0 (13)	220	
Expected cargo quantity		470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

Table 13

Finding a reference plan when grouping suppliers, iteration 7

Grouping	Cargo suppliers	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
		Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
		v_1 =	v_2 =	v_3 =	v_4 =	v_5 =		
Gr_1	Ps_1	370 (16)	0 (13)	0 (18)	0 (14)	0 (15)	370	810
	Ps_2	100 (15)	220 (17)	120 (14)	0 (18)	0 (16)	570	
	Ps_3	0 (17)	0 (14)	0 (16)	0 (13)	0 (18)	320	
Gr_1	Ps_4	0 (14)	0 (15)	150 (13)	270 (16)	0 (17)	420	760
	Ps_5	0 (17)	0 (16)	0 (15)	250 (14)	0 (14)	470	
	Ps_6	0 (13)	0 (18)	0 (17)	0 (16)	0 (13)	220	
Expected cargo quantity		470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

Table 14

Finding a reference plan when grouping suppliers, iteration 8

Grouping	Cargo suppliers	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
		Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
		$v_1 =$	$v_2 =$	$v_3 =$	$v_4 =$	$v_5 =$		
Gr_1	Ps_1	370 (16)	0 (13)	0 (18)	0 (14)	0 (15)	370	810
	Ps_2	100 (15)	220 (17)	120 (14)	0 (18)	0 (16)	570	
	Ps_3	0 (17)	0 (14)	0 (16)	0 (13)	0 (18)	320	
Gr_1	Ps_4	0 (14)	0 (15)	150 (13)	270 (16)	0 (17)	420	760
	Ps_5	0 (17)	0 (16)	0 (15)	250 (14)	90 (14)	470	
	Ps_6	0 (13)	0 (18)	0 (17)	0 (16)	0 (13)	220	
Expected cargo quantity		470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

From the last table, we calculate the objective function from the found reference plan:

$$F_{Gr} = 370 \cdot 16 + 100 \cdot 15 + 220 \cdot 17 + 120 \cdot 14 + 150 \cdot 13 +$$
$$+ 270 \cdot 16 + 250 \cdot 14 + 90 \cdot 13 = 23780 \text{c.u.} \quad (3)$$

3.2.Finding the optimal road transportation plan when grouping cargo suppliers.

We compile an extended table and apply the algorithm proposed above. Step-by-step iterations of the search for the optimal plan are given in table 15–37.

From the last table, we calculate the objective function from the found optimal plan:

$$F_{Gr} = 220 \cdot 13 + 150 \cdot 14 + 440 \cdot 15 + 30 \cdot 14 + 270 \cdot 13 +$$
$$+ 120 \cdot 16 + 250 \cdot 14 + 90 \cdot 13 = 22080 \text{c.u.} \quad (4)$$

Table 15

Finding a reference plan when grouping suppliers, iteration 1

Grouping	Cargo suppliers	Potentials	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
			Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
			–	–	–	–	–		
Gr_1	Ps_1	–	16	13	18	14	15	370	810
	Ps_2	–	15	17	14	18	16	570	
	Ps_3	–	17	14	16	13	18	320	
Gr_1	Ps_4	–	14	15	13	16	17	420	760
	Ps_5	–	17	16	15	14	14	470	
	Ps_6	–	13	18	17	16	13	220	
Expected cargo quantity			470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

Table 16

Finding a reference plan when grouping suppliers, iteration 2

Grouping	Cargo suppliers	Potentials	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
			Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
			–	–	–	–	–		
Gr_1	Ps_1	–	370^{16}	0^{13}	0^{18}	0^{14}	0^{15}	370	810
	Ps_2	–	100^{15}	220^{17}	120^{14}	0^{18}	0^{16}	570	
	Ps_3	–	0^{17}	0^{14}	0^{16}	0^{13}	0^{18}	320	
Gr_1	Ps_4	–	0^{14}	0^{15}	150^{13}	270^{16}	0^{17}	420	760
	Ps_5	–	0^{17}	0^{16}	0^{15}	250^{14}	0^{14}	470	
	Ps_6	–	0^{13}	0^{18}	0^{17}	0^{16}	90^{13}	220	
Expected cargo quantity			470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

Table 17

Finding a reference plan when grouping suppliers, iteration 3

Grouping	Cargo suppliers	Potentials	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
			Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
			10	12	9	12	10		
Gr_1	Ps_1	6	370 ^{16}	0 ^{13}	0 ^{18}	0 ^{14}	0 ^{15}	370	810
	Ps_2	5	100 ^{15}	220 ^{17}	120 ^{14}	0 ^{18}	0 ^{16}	570	
	Ps_3	1	0 ^{17}	0 ^{14}	0 ^{16}	0 ^{13}	0 ^{18}	320	
Gr_1	Ps_4	4	0 ^{14}	0 ^{15}	150 ^{13}	270 ^{16}	0 ^{17}	420	760
	Ps_5	2	0 ^{17}	0 ^{16}	0 ^{15}	250 ^{14}	0 ^{14}	470	
	Ps_6	3	0 ^{13}	0 ^{18}	0 ^{17}	0 ^{16}	90 ^{13}	220	
Expected cargo quantity			470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

Table 18

Finding a reference plan when grouping suppliers, iteration 4

Grouping	Cargo suppliers	Potentials	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
			Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
			10	12	9	12	10		
Gr_1	Ps_1	6	370 ^{16}	0 + ^{13}	0 ^{18}	0 ^{14}	0 ^{15}	370	810
	Ps_2	5	100 ^{15}	220 ^{17}	120 ^{14}	0 ^{18}	0 ^{16}	570	
	Ps_3	1	0 ^{17}	0 ^{14}	0 ^{16}	0 ^{13}	0 ^{18}	320	
Gr_1	Ps_4	4	0 ^{14}	0 ^{15}	150 ^{13}	270 ^{16}	0 ^{17}	420	760
	Ps_5	2	0 ^{17}	0 ^{16}	0 ^{15}	250 ^{14}	0 ^{14}	470	
	Ps_6	3	0 ^{13}	0 ^{18}	0 ^{17}	0 ^{16}	90 ^{13}	220	
Expected cargo quantity			470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

Table 19

Finding a reference plan when grouping suppliers, iteration 5

Grouping	Cargo suppliers	Potentials	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
			Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
			10	12	9	12	10		
Gr_1	Ps_1	6	370 – [16]	0 + [13]	0 [18]	0 [14]	0 [15]	370	810
	Ps_2	5	100 + [15]	220 – [17]	120 [14]	0 [18]	0 [16]	570	
	Ps_3	1	0 [17]	0 [14]	0 [16]	0 [13]	0 [18]	320	
Gr_1	Ps_4	4	0 [14]	0 [15]	150 [13]	270 [16]	0 [17]	420	760
	Ps_5	2	0 [17]	0 [16]	0 [15]	250 [14]	0 [14]	470	
	Ps_6	3	0 [13]	0 [18]	0 [17]	0 [16]	90 [13]	220	
Expected cargo quantity			470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

Table 20

Finding a reference plan when grouping suppliers, iteration 6

Grouping	Cargo suppliers	Potentials	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
			Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
			10	12	9	12	10		
Gr_1	Ps_1	6	150 [16]	220 [13]	0 [18]	0 [14]	0 [15]	370	810
	Ps_2	5	320 [15]	0 [17]	120 [14]	0 [18]	0 [16]	570	
	Ps_3	1	0 [17]	0 [14]	0 [16]	0 [13]	0 [18]	320	
Gr_1	Ps_4	4	0 [14]	0 [15]	150 [13]	270 [16]	0 [17]	420	760
	Ps_5	2	0 [17]	0 [16]	0 [15]	250 [14]	0 [14]	470	
	Ps_6	3	0 [13]	0 [18]	0 [17]	0 [16]	90 [13]	220	
Expected cargo quantity			470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

Table 21

Finding a reference plan when grouping suppliers, iteration 7

Grouping	Cargo suppliers	Potentials	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
			Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
Gr_1	Ps_1		150 ^{16}	220 ^{13}	0 ^{18}	0 ^{14}	0 ^{15}	370	810
	Ps_2		320 ^{15}	0 ^{17}	120 ^{14}	0 ^{18}	0 ^{16}	570	
	Ps_3		0 ^{17}	0 ^{14}	0 ^{16}	0 ^{13}	0 ^{18}	320	
Gr_1	Ps_4		0 ^{14}	0 ^{15}	150 ^{13}	270 ^{16}	0 ^{17}	420	760
	Ps_5		0 ^{17}	0 ^{16}	0 ^{15}	250 ^{14}	0 ^{14}	470	
	Ps_6		0 ^{13}	0 ^{18}	0 ^{17}	0 ^{16}	90 ^{13}	220	
Expected cargo quantity			470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

Table 22

Finding a reference plan when grouping suppliers, iteration 8

Grouping	Cargo suppliers	Potentials	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
			Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
			11	8	10	13	11		
Gr_1	Ps_1	5	150 ^{16}	220 ^{13}	0 ^{18}	0 ^{14}	0 ^{15}	370	810
	Ps_2	4	320 ^{15}	0 ^{17}	120 ^{14}	0 ^{18}	0 ^{16}	570	
	Ps_3	0	0 ^{17}	0 ^{14}	0 ^{16}	0 ^{13}	0 ^{18}	320	
Gr_1	Ps_4	3	0 ^{14}	0 ^{15}	150 ^{13}	270 ^{16}	0 ^{17}	420	760
	Ps_5	1	0 ^{17}	0 ^{16}	0 ^{15}	250 ^{14}	0 ^{14}	470	
	Ps_6	2	0 ^{13}	0 ^{18}	0 ^{17}	0 ^{16}	90 ^{13}	220	
Expected cargo quantity			470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

Table 23

Finding a reference plan when grouping suppliers, iteration 9

Grouping	Cargo suppliers	Potentials	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
			Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
			11	8	10	13	11		
Gr_1	Ps_1	5	150 ^{16}	220 ^{13}	0 ^{18}	0 + ^{14}	0 ^{15}	370	810
	Ps_2	4	320 ^{15}	0 ^{17}	120 ^{14}	0 ^{18}	0 ^{16}	570	
	Ps_3	0	0 ^{17}	0 ^{14}	0 ^{16}	0 ^{13}	0 ^{18}	320	
Gr_1	Ps_4	3	0 ^{14}	0 ^{15}	150 ^{13}	270 ^{16}	0 ^{17}	420	760
	Ps_5	1	0 ^{17}	0 ^{16}	0 ^{15}	250 ^{14}	0 ^{14}	470	
	Ps_6	2	0 ^{13}	0 ^{18}	0 ^{17}	0 ^{16}	90 ^{13}	220	
Expected cargo quantity			470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

Table 24

Finding a reference plan when grouping suppliers, iteration 10

Grouping	Cargo suppliers	Potentials	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
			Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
			11	8	10	13	11		
Gr_1	Ps_1	5	150 + ^{16}	220 ^{13}	0 ^{18}	0 + ^{14}	0 ^{15}	370	810
	Ps_2	4	320 + ^{15}	0 ^{17}	120 + ^{14}	0 ^{18}	0 ^{16}	570	
	Ps_3	0	0 ^{17}	0 ^{14}	0 ^{16}	0 ^{13}	0 ^{18}	320	
Gr_1	Ps_4	3	0 ^{14}	0 ^{15}	150 + ^{13}	270 + ^{16}	0 ^{17}	420	760
	Ps_5	1	0 ^{17}	0 ^{16}	0 ^{15}	250 ^{14}	0 ^{14}	470	
	Ps_6	2	0 ^{13}	0 ^{18}	0 ^{17}	0 ^{16}	90 ^{13}	220	
Expected cargo quantity			470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

Table 25

Finding a reference plan when grouping suppliers, iteration 11

Grouping	Cargo suppliers	Potentials	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
			Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
			11	8	10	13	11		
Gr_1	Ps_1	5	30 ^{16}	220 ^{13}	0 ^{18}	120 ^{14}	0 ^{15}	370	810
	Ps_2	4	440 ^{15}	0 ^{17}	0 ^{14}	0 ^{18}	0 ^{16}	570	
	Ps_3	0	0 ^{17}	0 ^{14}	0 ^{16}	0 ^{13}	0 ^{18}	320	
Gr_1	Ps_4	3	0 ^{14}	0 ^{15}	270 ^{13}	150 ^{16}	0 ^{17}	420	760
	Ps_5	1	0 ^{17}	0 ^{16}	0 ^{15}	250 ^{14}	0 ^{14}	470	
	Ps_6	2	0 ^{13}	0 ^{18}	0 ^{17}	0 ^{16}	90 ^{13}	220	
Expected cargo quantity			470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

Table 26

Finding a reference plan when grouping suppliers, iteration 12

Grouping	Cargo suppliers	Potentials	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
			Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
Gr_1	Ps_1		30 ^{16}	220 ^{13}	0 ^{18}	120 ^{14}	0 ^{15}	370	810
	Ps_2		440 ^{15}	0 ^{17}	0 ^{14}	0 ^{18}	0 ^{16}	570	
	Ps_3		0 ^{17}	0 ^{14}	0 ^{16}	0 ^{13}	0 ^{18}	320	
Gr_1	Ps_4		0 ^{14}	0 ^{15}	270 ^{13}	150 ^{16}	0 ^{17}	420	760
	Ps_5		0 ^{17}	0 ^{16}	0 ^{15}	250 ^{14}	0 ^{14}	470	
	Ps_6		0 ^{13}	0 ^{18}	0 ^{17}	0 ^{16}	90 ^{13}	220	
Expected cargo quantity			470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

Table 27

Finding a reference plan when grouping suppliers, iteration 13

Grouping	Cargo suppliers	Potentials	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
			Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
			15	12	10	13	11		
Gr_1	Ps_1	1	30 16	220 13	0 18	120 14	0 15	370	810
	Ps_2	0	440 15	0 17	0 14	0 18	0 16	570	
	Ps_3	0	0 17	0 14	0 16	0 13	0 18	320	
Gr_1	Ps_4	3	0 14	0 15	270 13	150 16	0 17	420	760
	Ps_5	1	0 17	0 16	0 15	250 14	0 14	470	
	Ps_6	2	0 13	0 18	0 17	0 16	90 13	220	
Expected cargo quantity			470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

Table 28

Finding a reference plan when grouping suppliers, iteration 14

Grouping	Cargo suppliers	Potentials	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
			Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
			15	12	10	13	11		
Gr_1	Ps_1	1	30 16	220 13	0 18	120 14	0 15	370	810
	Ps_2	0	440 15	0 17	0 14	0 18	0 16	570	
	Ps_3	0	0 17	0 14	0 16	0 13	0 18	320	
Gr_1	Ps_4	3	0 + 14	0 15	270 13	150 16	0 17	420	760
	Ps_5	1	0 17	0 16	0 15	250 14	0 14	470	
	Ps_6	2	0 13	0 18	0 17	0 16	90 13	220	
Expected cargo quantity			470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

Table 29

Finding a reference plan when grouping suppliers, iteration 15

Grouping	Cargo suppliers	Potentials	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
			Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
			15	12	10	13	11		
Gr_1	Ps_1	1	30 – ^{16}	220 ^{13}	0 ^{18}	120 + ^{14}	0 ^{15}	370	810
	Ps_2	0	440 ^{15}	0 ^{17}	0 ^{14}	0 ^{18}	0 ^{16}	570	
	Ps_3	0	0 ^{17}	0 ^{14}	0 ^{16}	0 ^{13}	0 ^{18}	320	
Gr_1	Ps_4	3	0 + ^{14}	0 ^{15}	270 ^{13}	150 – ^{16}	0 ^{17}	420	760
	Ps_5	1	0 ^{17}	0 ^{16}	0 ^{15}	250 ^{14}	0 ^{14}	470	
	Ps_6	2	0 ^{13}	0 ^{18}	0 ^{17}	0 ^{16}	90 ^{13}	220	
Expected cargo quantity			470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

Table 30

Finding a reference plan when grouping suppliers, iteration 16

Grouping	Cargo suppliers	Potentials	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
			Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
			15	12	10	13	11		
Gr_1	Ps_1	1	0 ^{16}	220 ^{13}	0 ^{18}	150 ^{14}	0 ^{15}	370	810
	Ps_2	0	440 ^{15}	0 ^{17}	0 ^{14}	0 ^{18}	0 ^{16}	570	
	Ps_3	0	0 ^{17}	0 ^{14}	0 ^{16}	0 ^{13}	0 ^{18}	320	
Gr_1	Ps_4	3	30 ^{14}	0 ^{15}	270 ^{13}	120 ^{16}	0 ^{17}	420	760
	Ps_5	1	0 ^{17}	0 ^{16}	0 ^{15}	250 ^{14}	0 ^{14}	470	
	Ps_6	2	0 ^{13}	0 ^{18}	0 ^{17}	0 ^{16}	90 ^{13}	220	
Expected cargo quantity			470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

Table 31

Finding a reference plan when grouping suppliers, iteration 17

Grouping	Cargo suppliers	Potentials	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
			Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
Gr_1	Ps_1		0 [16]	220 [13]	0 [18]	150 [14]	0 [15]	370	810
	Ps_2		440 [15]	0 [17]	0 [14]	0 [18]	0 [16]	570	
	Ps_3		0 [17]	0 [14]	0 [16]	0 [13]	0 [18]	320	
Gr_1	Ps_4		30 [14]	0 [15]	270 [13]	120 [16]	0 [17]	420	760
	Ps_5		0 [17]	0 [16]	0 [15]	250 [14]	0 [14]	470	
	Ps_6		0 [13]	0 [18]	0 [17]	0 [16]	90 [13]	220	
Expected cargo quantity			470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

Table 32

Finding a reference plan when grouping suppliers, iteration 18

Grouping	Cargo suppliers	Potentials	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
			Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
			15	16	14	17	11		
Gr_1	Ps_1	-3	0 [16]	220 [13]	0 [18]	150 [14]	0 [15]	370	810
	Ps_2	0	440 [15]	0 [17]	0 [14]	0 [18]	0 [16]	570	
	Ps_3	0	0 [17]	0 [14]	0 [16]	0 [13]	0 [18]	320	
Gr_1	Ps_4	-1	30 [14]	0 [15]	270 [13]	120 [16]	0 [17]	420	760
	Ps_5	-3	0 [17]	0 [16]	0 [15]	250 [14]	0 [14]	470	
	Ps_6	2	0 [13]	0 [18]	0 [17]	0 [16]	90 [13]	220	
Expected cargo quantity			470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

Table 33

Finding a reference plan when grouping suppliers, iteration 19

Grouping	Cargo suppliers	Potentials	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
			Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
			15	16	14	17	11		
Gr_1	Ps_1	-3	0 ^{16}	220 ^{13}	0 ^{18}	150 ^{14}	0 ^{15}	370	810
	Ps_2	0	440 ^{15}	0 ^{17}	0 ^{14}	0 ^{18}	0 ^{16}	570	
	Ps_3	0	0 ^{17}	0 ^{14}	0 ^{16}	0 ^{13}	0 ^{18}	320	
Gr_1	Ps_4	-1	30 ^{14}	0 ^{15}	270 ^{13}	120 ^{16}	0 ^{17}	420	760
	Ps_5	-3	0 ^{17}	0 ^{16}	0 ^{15}	250 ^{14}	0 ^{14}	470	
	Ps_6	2	0 + ^{13}	0 ^{18}	0 ^{17}	0 ^{16}	90 ^{13}	220	
Expected cargo quantity			470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

Table 34

Finding a reference plan when grouping suppliers, iteration 20

Grouping	Cargo suppliers	Potentials	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
			Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
			15	16	14	17	11		
Gr_1	Ps_1	-3	0 ^{16}	220 ^{13}	0 ^{18}	150 ^{14}	0 ^{15}	370	810
	Ps_2	0	440 ^{15}	0 ^{17}	0 ^{14}	0 ^{18}	0 ^{16}	570	
	Ps_3	0	0 ^{17}	0 ^{14}	0 ^{16}	0 ^{13}	0 ^{18}	320	
Gr_1	Ps_4	-1	30 + ^{14}	0 + ^{15}	270 ^{13}	120 ^{16}	0 ^{17}	420	760
	Ps_5	-3	0 ^{17}	0 ^{16}	0 ^{15}	250 ^{14}	0 ^{14}	470	
	Ps_6	2	0 + ^{13}	0 + ^{18}	0 ^{17}	0 ^{16}	90 ^{13}	220	
Expected cargo quantity			470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

Table 35

Finding a reference plan when grouping suppliers, iteration 21

Grouping	Cargo suppliers	Potentials	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
			Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
			15	16	14	17	11		
Gr_1	Ps_1	-3	0 ^{16}	220 ^{13}	0 ^{18}	150 ^{14}	0 ^{15}	370	810
	Ps_2	0	440 ^{15}	0 ^{17}	0 ^{14}	0 ^{18}	0 ^{16}	570	
	Ps_3	0	0 ^{17}	0 ^{14}	0 ^{16}	0 ^{13}	0 ^{18}	320	
Gr_1	Ps_4	-1	30 ^{14}	0 ^{15}	270 ^{13}	120 ^{16}	0 ^{17}	420	760
	Ps_5	-3	0 ^{17}	0 ^{16}	0 ^{15}	250 ^{14}	0 ^{14}	470	
	Ps_6	2	0 ^{13}	0 ^{18}	0 ^{17}	0 ^{16}	90 ^{13}	220	
Expected cargo quantity			470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

Table 36

Finding a reference plan when grouping suppliers, iteration 22

Grouping	Cargo suppliers	Potentials	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
			Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
Gr_1	Ps_1		0 ^{16}	220 ^{13}	0 ^{18}	150 ^{14}	0 ^{15}	370	810
	Ps_2		440 ^{15}	0 ^{17}	0 ^{14}	0 ^{18}	0 ^{16}	570	
	Ps_3		0 ^{17}	0 ^{14}	0 ^{16}	0 ^{13}	0 ^{18}	320	
Gr_1	Ps_4		30 ^{14}	0 ^{15}	270 ^{13}	120 ^{16}	0 ^{17}	420	760
	Ps_5		0 ^{17}	0 ^{16}	0 ^{15}	250 ^{14}	0 ^{14}	470	
	Ps_6		0 ^{13}	0 ^{18}	0 ^{17}	0 ^{16}	90 ^{13}	220	
Expected cargo quantity			470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

Table 37

Finding a reference plan when grouping suppliers, iteration 23

Grouping	Cargo suppliers	Potentials	Cargo consumers					Quantity of cargo in warehouses	Cargo quantity by group
			Sp_1	Sp_2	Sp_3	Sp_4	Sp_5		
			11	12	10	13	11		
Gr_1	Ps_1	1	0 [16]	220 [13]	0 [18]	150 [14]	0 [15]	370	810
	Ps_2	4	440 [15]	0 [17]	0 [14]	0 [18]	0 [16]	570	
	Ps_3	0	0 [17]	0 [14]	0 [16]	0 [13]	0 [18]	320	
Gr_1	Ps_4	3	30 [14]	0 [15]	270 [13]	120 [16]	0 [17]	420	760
	Ps_5	1	0 [17]	0 [16]	0 [15]	250 [14]	0 [14]	470	
	Ps_6	2	0 [13]	0 [18]	0 [17]	0 [16]	90 [13]	220	
Expected cargo quantity			470	220	270	520	620	2370	1620

Source: compiled by the author based on [10]

Thus, as a result of the numerical experiment conducted on the basis of specific initial data, the proposed approach to finding both the reference (i.e., the initial permissible) and the optimal road transportation plan within the modified transport problem, which takes into account the specifics of the grouping of cargo suppliers, was implemented and tested. For this, a clearly defined methodology was used, which included preliminary preparation of a tabular representation of the initial data, structuring of supply sources into groups with fixed restrictions on the total cargo, as well as step-by-step application of the adapted potential algorithm, which allowed, taking into account all the specified parameters, to form an appropriate transportation plan.

During the numerical calculation, the basic plan was sequentially constructed using classical methods (taking into account the features of the new model), with the subsequent transition to the search for an optimal solution. In this case, both classical restrictions on the volumes of supply and demand and additional restrictions imposed on the group structures of sources were taken into account. The algorithm that formed the basis of the calculation allowed adjusting the current values of transportation taking into account closed cycles, as well as determining the admissibility of each subsequent step based on the calculation of potentials and corresponding estimates.

Conclusions. Thus, the work considered the problem of optimizing transportation in the conditions of grouping of cargo suppliers, which allowed to form a new approach to building effective resource allocation plans in logistics systems. Based on the analysis of the classical formulation of the transport problem and taking into account the specifics of modern transportation processes, a model was proposed that covers the features of group organization of supply sources.

By building a model in which individual suppliers are grouped together with common constraints, it was possible to adapt traditional methods of solving transport problems to conditions that more accurately reflect real logistics processes. This approach allows not only to increase the accuracy of mathematical modeling, but also to reduce the risks of overloading individual transportation directions, ensuring the balance of the transport network.

Within the framework of the conducted research, an approach to modeling the transport problem was formulated and substantiated, taking into account the grouping of cargo suppliers, which allowed to deepen the classical formulation of the transportation problem and adapt it to more complex logistical situations encountered in practice. The main attention was paid to building a mathematical model that covers not only the relationship between sources and consumption points, but also takes into account the structure of associations of suppliers into groups, each of which has certain restrictions on the total volume of cargo that can be sent to the transport system.

Thanks to a thorough analysis of the theoretical foundations of the transport problem and modification of existing algorithms, a generalized method was created that allows for effective finding of admissible and optimal transportation plans within the new structure of the problem. In the process of work, the criteria for optimality of the plan in the presence of additional group constraints were refined, which ensured the mathematical correctness of the new approach and made it possible to preserve the integrity of the logic of the classical transport problem. The use of the potential method in combination with the introduction of mechanisms for controlling group constraints allowed adapting known algorithms to the conditions of the new formulation.

The constructed model provides an automated procedure for checking the admissibility of solutions from the point of view of not only the balance of supply and demand, but also the total limits on cargo within each group of suppliers. This significantly expands the scope of the transport problem and allows solving transportation planning problems in large logistics systems where suppliers have common resource constraints or operate within a single administrative or geographical space.

The study also implemented a numerical procedure for constructing a reference plan taking into account the structural grouping of sources, and showed how classical elements of the transport table – such as potentials, θ values, closed loops – are modified and applied in the conditions of the new model. This allowed us to demonstrate in practice the effectiveness of the developed approach and verify its operability under different configurations of the source data.

Thus, the solution of the transport problem in the context of grouping cargo suppliers is not only theoretically justified, but also practically significant. The use of such an approach allows achieving more flexible management of logistics flows, especially in cases where the supply is centrally coordinated or requires taking into account interdependencies between individual suppliers. The proposed model opens up prospects for further development in the direction of multi-criteria optimization, taking into account time intervals, as well as in the context of building dynamic adaptive transportation management systems.

It is also worth emphasizing that the use of the grouping model allows for improved transportation planning in conditions of limited vehicle resources or heterogeneity of consumer demand. This creates a basis for the application of the model in real economic conditions – both at the level of individual enterprises and at the interregional level of logistics networks. The practical implementation of such a model, taking into account modern information technologies, can serve as the basis for the creation of intelligent decision-making support systems in the field of freight transportation.

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3.4. ARTIFICIAL INTELLIGENCE AS A DRIVING FORCE FOR SMALL BUSINESS DEVELOPMENT AND A TOOL FOR TAX REPORTING

Introduction. Ukrainian small and medium-sized businesses (SMEs) are looking for ways to overcome the problem of competitiveness to enter foreign markets. And recent events in the world demonstrate significant changes in global trade, moreover, the world economy is on the verge of a major reformatting, which is associated with the policy of the new US administration. It is unlikely that globalization is threatened by anything that can be classified as collapse or destruction, but the algorithms and structure of markets will definitely change. On the one hand, these changes carry great dangers for business. On the other hand, it is during the period of great changes that you can get the same chance and be on the wave of success. Artificial intelligence (AI) can help solve such a task, with the help of which calculations are performed and solutions are simulated, which are quite difficult for a person to perform for many reasons. The main one is the lack of access to databases on the scale of the world information network. Therefore, the expertise of AI in this sense can hardly be overestimated. Another significant problem that small and medium-sized enterprises permanently solve is the management of reporting and the taxation system, which requires high competencies and efficiency. And this task should also facilitate the application of AI.

What do Ukrainian representatives of small and medium-sized businesses see as difficulties? First of all, it is an extremely complex system of regulatory relations, which is constantly changing and has signs of fiscalization, rather than stimulation and assistance in business development. The resources of SMEs are also small to attract complex technological solutions and highly professional specialists. And entrepreneurs are forced to balance between the costs of solving these problems and high penalties that can simply destroy business, and instantly. Therefore, the introduction of artificial intelligence (AI) looks like a promising solution to the problem of optimizing the regulatory system and tax reporting in SMEs. The only question is how AI will be able to comply with legal and regulatory requirements and how exactly to test its effectiveness.

Scientists are actively researching the role of AI in the formation of tax reporting and optimization of taxation of SMEs. For example, O. Bilyk and O. Panasyuk in their work prove that the integration of AI into the processes of accounting and financial reporting by automating machine learning algorithms for compliance with the legislation significantly reduced the time and effort for the formation of tax reporting, increased operational efficiency [1, p. 362]. Other scientists – A. Koshil [2, p. 341] and I. Zhiglei [3, p. 98] proved that the use of AI in work with tax reporting significantly increased the level of compliance with the legislation and reduced the number of operational errors. That is, the optimization of automated accounting systems through the integration of AI significantly increases the efficiency of SMEs in this sector. But there are also problematic issues. Some scientists have found that AI algorithms are related to a specific jurisdiction of the enterprise. And if an SME plans to work in the markets of other countries, that is, in another jurisdiction, then AI can produce erroneous data and results. The latest meta-analysis by N. Rogova revealed such discrepancies that concerned not only different jurisdictions, but also business structures [4, p. 111]. That is, this indicates a very wide scale of variability, which requires clearer and more contextual work with AI. The integration of AI into the business processes of a particular enterprise should begin with a lot of work on teaching artificial intelligence all the nuances of SME activities.

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Interestingly, there are still discussions around the ethics of using AI in the tax reporting system. For example, I. Yurieva and P. Khomin warn against the use of AI in tax activities to make decisions on the results of SMEs' activities, where algorithmic bias and interpretation of contradictory legislative norms by tax authorities may appear [5, p. 495]. And, undoubtedly, another important argument for Ukrainian small businesses is the availability of the latest digital technologies. R. Augustine's research showed that against the background of the rapid introduction of AI by large businesses, small and medium-sized businesses are lagging far behind, having a shortage of both resources and qualified personnel [6, p. 42].

Summary of the main results of the study. The purpose of this article is to identify the algorithms that AI can use to optimize the formation of tax reporting for SMEs. The main task is to understand and identify how AI can improve the operational efficiency of small and medium-sized enterprises.

Taxation of SMEs is the regular collection of taxes on the income, profits and activities of such enterprises for the benefit of the state and local communities. The business taxation system is quite complex in Ukraine. Small businesses pay a single tax for certain categories or income tax, personal income tax (PIT), social contributions, VAT, various local taxes and fees. All these taxes and fees form the basis of tax reporting, which can be monthly, quarterly and annual. Despite the fact that the volume of reporting for SMEs is much lower than for large businesses, this area of the SME's operational activities is quite complex, given the resource opportunities. And although small businesses can use outsourcing for tax reporting. Very often, entrepreneurs refuse such a decision, because these are quite expensive services, and secondly, they are very often of poor quality, which leads to fines and unpredictable costs. Work with taxes and reporting is of key importance for SMEs, which forms the basis for managerial decision-making. From the point of view of representativeness, such reporting positions the enterprise in the market and demonstrates its investment potential, which is important for those SMEs that plan foreign economic activity. Especially important in this sense is the reporting of the financial results of the enterprise. Form No. 4 – statement of financial results and equity – informs about income and expenses, demonstrates the profitability, solvency and liquidity of SMEs. That is, these are the main indicators by which the owners and managers of the enterprise control and make decisions. But there are also non-financial reports that are no less important for evaluating the company's activities. They are formed by analytical indicators on operational, marketing, personnel activities, strategic development. For example, these are sales reports, performance indicators (KPIs), inventory reports, customer portfolios and reviews, logistics maps. All this information is used to make important decisions about the development and operation of SMEs. Thanks to these reports, business owners identify trends, patterns and opportunities, and can adjust their strategy and tactics accordingly to stimulate growth and increase competitiveness [7, p. 73].

The integration of AI to optimize tax activities and generate reporting for SMEs should involve quite a lot of functions and technical solutions that should simplify and increase the efficiency of the enterprise, which is related to taxation. It makes sense to involve AI in the analysis of operational activities and all financial indicators of the enterprise. Thanks to this analysis, AI algorithms are able to form projects of managerial decisions that can become the basis for the formation of a strategy for cost saving, tax optimization, enterprise development and, tactically, its adjustment. Traditionally, these tasks were performed by personnel, whose qualifications are not always sufficient to build optimal strategies. And the question is not even in qualifications, but in the ability of a person to accurately process large amounts of information in a short period of time. It should be noted that the efficiency and effectiveness of using AI directly depends on the ability of the operational worker (working with AI algorithms) to train and form task contexts for AI. If you do not pay attention to this work, then mistakes will occur. AI is like a new employee who needs time to learn the business, its algorithms, and become effective. AI algorithms can detect trends, correlations, and anomalies in financial data, allowing small businesses to make data-driven decisions to optimize their tax outcomes, and in real time, which allows SMEs to at least minimize the risks of penalties [8].

It should be noted that developers of artificial intelligence technologies have already offered solutions specifically for small and medium-sized businesses, integrated into existing reporting platforms. These systems offer a synthesis of data analysis, voice analyzers, and forecasting systems and methods that are related to tax formation, tax planning, and expenditure formation. Accounting software platforms with integrated AI can effectively categorize enterprise expenses, analyze transactions, generate financial reports, calculate salaries and bonuses with taxes, inform about legislative changes and innovations and implement them in reporting. All this greatly facilitates the work of specialized personnel and increases the efficiency of managerial decisions [9, p. 92]. However, in addition to the advantages and advantages of AI integration, there are also certain caveats and disadvantages that should be carefully considered before starting to work with artificial intelligence. The researchers highlight one of the significant caveats, which is algorithmic biases and inaccurate calculations and conclusions of AI, which is related to the data used to train AI. This leads to erroneous conclusions, decisions, and recommendations. Such a deformation arises as a result of a large amount of information related to the complexity of the tax system itself, filled with different profiles of enterprises and contradictions in the legislative and regulatory framework. SME entrepreneurs may lack the experience and digital skills to assess the effectiveness of AI. Skepticism as a barrier to integration into their business can also be associated with significant costs for SMEs at the initial stage of applying the latest digital technologies. In addition, data privacy, security, and compliance issues may hinder the implementation of AI-based tax optimization solutions, especially for businesses operating in highly regulated industries or jurisdictions [10, p. 129]. Thus, artificial intelligence is able to optimize the work of SMEs with reporting, but it is necessary to carefully weigh all the pros and cons, even if they are temporary (table 1).

Table 1

Pros and cons of integrating AI into the reporting and taxation system for SMEs

Pros	Cons
AI can automate repetitive reporting tasks, saving time and reducing human error	AI systems can access confidential business information, raising concerns about data security among owners
Artificial intelligence algorithms are able to analyze data with high accuracy, which provides the basis for more accurate reports and insights	Implementing AI technologies involves high upfront costs for SMEs in software, training, and infrastructure
AI can quickly process large amounts of data, providing real-time information for decision-making	Overreliance on artificial intelligence in reporting processes can lead to a loss of human control and reduce data understanding
AI can tailor reports to specific business needs, providing personalized insights for better decision-making	Small businesses may lack the technical expertise or resources to effectively implement and support AI systems
AI reporting solutions can scale to meet business needs, accommodating growth without significant additional resources	Artificial intelligence algorithms may unintentionally introduce bias or discrimination into reporting processes which could lead to ethical issues
Small businesses that integrate artificial intelligence for reporting can gain a competitive advantage through the use of advanced analytics and predictive capabilities	Integrating an AI reporting system with existing infrastructure and processes can be complex and time-consuming for SMEs
Data generated through artificial intelligence can drive better decision-making by providing more detailed analysis and predictive analytics.	Employees may resist the implementation of AI technology for fear of losing their jobs or changing their role in the reporting process.

Developed by the authors based on [11]

Digitalization of SMEs should become a prerequisite for the development and formation of Ukrainian entrepreneurship that masters (or plans) foreign markets. The integration of AI into the processes of generating SME reporting is certainly a significant competitive advantage that affects the efficiency of the enterprise as a whole. Recommendations for the implementation of AI in the financial and accounting reporting system can be formed as follows:

1) each SME owner should invest in digital education, both its own and its staff, including mastering the work with artificial intelligence;

2) integrate AI into the system of analysis of tax, customs and regulatory legislation in order to timely adapt and make prompt decisions to protect businesses from penalties and useless and unpredictable costs;

3) adapt AI solutions to the needs of your own business: create user-friendly interfaces, reporting models, predictive models, and personalized chats;

4) to form a reliable data privacy protection system when generating reports using AI or algorithms for analysis and forecasts of SME development strategies – encryption, access control, backups, anonymization;

5) establish cooperation with specialized specialists of the tax and customs service, who can help in debugging the work of AI and interpreting data, results and algorithms;

6) work out the integration of reporting and taxation tools with existing platforms already used by SMEs, such as APIs for seamless data exchange and compatibility with financial systems.

Conclusions. Such modern tools as artificial intelligence, if properly used and professionally integrated into business processes, can greatly facilitate both the work of employees and decision-making by the business owner. AI as a tool for strengthening the efficiency of the enterprise and an auxiliary factor in the formation of the development strategy and presentation of SMEs in foreign markets is becoming a mandatory digital technology for small and medium-sized businesses in Ukraine.

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