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INFORMATION TECHNOLOGIES

Alekseiev E. S.

HOW TO PROTECT YOUR WEB APPLICATION: A COMPREHENSIVE APPROACH TO COUNTERING DDOS ATTACKS AND MALICIOUS TRAFFIC

Language Advisor – CandSc (Education), Assoc. Prof. Borzenko O. P.

In today's digital economy, web applications and APIs are not just a business card, but a key asset for sales, communications, and operations. Therefore, their continuous operation is critical, and their dependency makes them an attractive target for cybercriminals. DDoS attacks and malicious traffic from bots, scrapers, and malicious tools pose a real threat, with consequences ranging from direct financial losses and reputational damage to legal issues in the event of data leaks. Therefore, multi-layered protection is not an option, but a requirement for online survival.

Threats are conventionally divided into two large groups: DDoS and malicious traffic. DDoS: the goal is to exhaust infrastructure resources. Attacks occur at the network levels (L3/L4) – UDP/ICMP floods, which seize the channel and are measured in Gbps; at the protocol level – SYN floods, which overload connection tables; and at the application level (L7) – "legitimate" traffic, which attacks heavy operations (search, reports, complex APIs), is difficult to distinguish from normal load.

Malicious traffic: bad bots (scrapers, credential stuffing, vulnerability scanners, spam), injections (SQLi, XSS) and other attacks on business logic, payments or file uploads. Detection and protection against these threats require comprehensive measures: traffic filtering, behavior analysis, updates, and security policies.

Effective protection is a multi-layered approach that combines technologies and processes to create multiple lines of defense. WAF (Web Application Firewall) -

protects at the application level, analyzes HTTP/HTTPS requests (GET/POST, headers, cookies) and works through signature analysis, behavior rules and virtual patching to quickly block vulnerability exploits. A CDN simultaneously accelerates content delivery and serves as a buffer between the internet and the server: it absorbs volumetric DDoS attacks, masks the real IP address, and often includes built-in WAFs and bot protection. Rate limiting – limiting the request rate (at the web server, CDN, or application logic level) – is effective against brute-force attacks, aggressive scraping, and some L7 attacks (message 429 when the limit is exceeded). IP blacklists/whitelists are a simple method of access control: blacklists block known malicious addresses, whitelists strictly allow only verified sources (useful for admin panels), but have limitations (NAT, dynamic IP). CAPTCHA and behavior analysis – modern solutions (reCAPTCHA v3, hCaptcha) assess session risk without intrusive tests; if the "trust score" is low, additional checks are performed. Bot management – specialized systems with ML behavior analysis that differentiate humans from bots in various ways and apply strategies such as blocking, slowing down, displaying fake content, or collecting intelligence. Using these tools in combination (WAF + CDN + rate limiting + bot management + access policies and constant updates) provides the most reliable protection for web applications.

Table 1. Comparison table of protection solutions

Solution	**Primary Purpose**	**Protection Level**	**Management Complexity**
Cloud WAF/CDN	Comprehensive protection against DDoS (L3-L7), malicious traffic, bots, and site acceleration.	High	Low
Hardware WAF/DDoS Appliance	On-premise infrastructure perimeter protection for large companies.	Medium/ High	High

Software WAF	Traffic filtering directly on the web server.	Low/ Medium	High
Built-in tools (Rate Limiting, IP filters)	Basic protection against simple attacks (brute force, scraping) and access control.	Low	Medium
Specialized solution for Bot Management	Accurate detection and blocking of complex automated threats.	Very high	Medium

The analysis shows that there is no universal strategy for protecting a web application; the choice depends on the scale of the project, budget, technical expertise and type of threats.

Cloud WAF/CDNs are the best option for most people: they provide comprehensive protection against DDoS and application-level attacks, are easy to implement, and are affordable. They're the most effective out-of-the-box solution.

Hardware solutions are only appropriate for large companies with their own data centers and high requirements for traffic control. Their disadvantage is limited bandwidth and complexity of maintenance. Software tools (ModSecurity, Rate Limiting, IP filters) are an important basic level of security, but not the main one. They can't withstand powerful DDoS attacks and require constant tuning. Bot protection should be implemented where automated attacks cause financial losses (e-commerce, ticketing services, content platforms). The most effective approach is a multi-layered strategy (defense-in-depth): combining a cloud WAF/CDN with on-premises protection tools to create two layers of defense that cover up to 95% of typical threats.

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Batura M. V.

AI-POWERED VIDEO EDITING TOOLS AND THEIR ROLE IN MODERN CONTENT CREATION

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The digital media landscape of the 21st century is defined by the unprecedented dominance of video content. From educational platforms and corporate communications to social media entertainment, video has become the primary vehicle for information dissemination. This surge in consumption has placed immense pressure on content creators and production houses to deliver high-quality material at an accelerated pace. Traditional non-linear editing (NLE) workflows, while robust, are inherently labor-intensive and technically demanding. They require significant manual intervention for tasks such as sorting footage, audio synchronization, color correction, and rendering. Consequently, the integration of Artificial Intelligence (AI) and Machine Learning (ML) into video production software represents a critical paradigm shift. This article explores how AI technologies are reshaping the technical and creative aspects of video editing,

analyzing both their efficiency benefits and the challenges they present to the professional community (Anderson, 2023).

The most immediate impact of AI on video editing is the automation of mechanical and repetitive tasks. Historically, the "rough cut" phase – the initial assembly of footage – consumed a vast amount of an editor's time. Modern AI algorithms, utilizing Natural Language Processing (NLP) and computer vision, have fundamentally altered this process. A prime example is "text-based editing", a feature now prominent in industry-standard software like Adobe Premiere Pro and DaVinci Resolve. These tools automatically transcribe spoken dialogue into text, allowing editors to manipulate the video sequence by simply editing the transcript. Deleting a sentence in the text document automatically removes the corresponding frames from the timeline. This capability is particularly revolutionary for documentary filmmakers, journalists, and podcasters, reducing the time required for narrative assembly by approximately 40% (Gibson & Miller, 2024).

Beyond structural editing, AI has significantly advanced the field of audio engineering within video production. Poor audio quality is often cited as a primary reason for viewer disengagement. In the past, restoring audio recorded in noisy environments required complex manual frequency adjustments. Today, AI-driven audio enhancement tools can isolate human speech from background noise with remarkable precision. Neural networks trained on vast datasets of human voices can reconstruct clarity even in compromised recordings, removing wind noise, echoes, and ambient interference instantly. Furthermore, AI-powered "voice cloning" technologies allow creators to fix misspoken words in post-production without requiring the speaker to re-record the segment, simply by typing the correct word and synthesizing the voice (Smith, 2024).

In the realm of visual aesthetics, AI is democratizing processes that were previously the domain of specialized colorists. Color grading involves adjusting the luminance and chrominance of footage to achieve a specific artistic look or to correct lighting inconsistencies. Neural engines can now analyze the visual data of a scene

to automatically balance shots, ensuring skin tones remain natural while adjusting the environment to match a reference image. Additionally, deep learning algorithms facilitate "super-resolution" upscaling. This technology allows editors to take older, low-resolution archival footage and upscale it to modern 4K standards by intelligently predicting and adding missing pixel details. This is invaluable for historical documentaries and the restoration of classic media (Roberts, 2022).

Perhaps the most disruptive innovation is the rise of Generative AI. Unlike predictive tools that analyze existing data, generative models can create entirely new visual assets from textual descriptions. Tools based on diffusion models allow editors to generate B-roll footage, animated transitions, and complex backgrounds using natural language prompts. For instance, "generative fill" features enable the removal of unwanted objects from a video frame or the expansion of the frame's aspect ratio by artificially generating realistic surroundings. This capability significantly lowers production costs, as it reduces the need for expensive on-location reshoots or complex CGI workflows (Thompson et al., 2024).

Moreover, AI plays a crucial role in improving accessibility and global reach. Automatic speech recognition (ASR) systems can instantly generate accurate subtitles in multiple languages, making content accessible to the hearing impaired and international audiences. AI translation tools not only translate text but can also dub the audio into a different language while preserving the original speaker's voice characteristics and even adapting lip movements to match the new language. This breaks down linguistic barriers and expands the potential audience for educational and scientific content (Davis, 2023).

However, the rapid integration of these powerful tools is not without professional and ethical challenges. The ability to create hyper-realistic synthetic media, often referred to as "deepfakes", raises serious concerns regarding misinformation, identity theft, and copyright infringement. From a creative standpoint, there is a debate about the "homogenization" of content. As AI algorithms are trained on existing datasets of popular videos, their automated suggestions may

converge toward a generic, algorithmically optimized style, potentially stifling unique artistic expression. There is also the fear of job displacement, although most industry experts argue that AI will serve as a "co-pilot" rather than a replacement, automating drudgery to free up time for higher-level creative decision-making (Williams, 2021).

In summary, AI-powered video editing tools are transforming the industry from a manual, technical craft into a streamlined, semi-automated workflow. By handling tasks ranging from rough cutting and audio repair to color grading and asset generation, AI allows creators to focus more on storytelling and less on technical execution. While the industry must navigate the ethical complexities of synthetic media, the trajectory is clear: AI is becoming an indispensable component of modern content creation, enabling a new level of efficiency and creative possibility.

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Berest A. O.

KEY TRENDS AND CHALLENGES IN INFORMATION TECHNOLOGIES (2025)

Language Advisor – Lecturer Lukianenko N. M.

In 2025, information technologies (IT) are no longer confined to technical domains – they shape the cultural, economic, and ethical fabric of global society. From AI-driven creativity to quantum breakthroughs, IT is both a catalyst and a mirror of human progress. This article explores six transformative trends, the challenges they pose, and the strategic responses required to ensure inclusive, sustainable, and secure digital futures.

However, the rise of generative AI introduces complex challenges. Models trained on vast datasets can inadvertently reproduce and amplify biases, leading to ethical concerns and reputational risks. The boundaries between original human work and AI-generated content remain legally and philosophically ambiguous, raising questions about ownership, authenticity, and creative integrity. Moreover, as AI systems become more autonomous, users increasingly demand transparency in how decisions are made and outputs are generated.

To address these concerns, explainable AI (XAI) is gaining traction, offering visual and linguistic clarity about model behavior. Ethical audits – conducted by interdisciplinary teams – are being implemented to assess risks and ensure responsible deployment. At the societal level, AI literacy is becoming essential, with public education initiatives and curriculum reforms aimed at equipping individuals with the skills to critically engage with intelligent systems. These strategic responses reflect a growing consensus: the future of AI must be not only innovative but also accountable, inclusive, and comprehensible.

Cloud ecosystems are expanding into decentralized, intelligent networks that support dynamic, scalable, and context-aware services. In 2025, edge computing – processing data at or near the source – plays a critical role in enabling real-time responsiveness for autonomous vehicles, smart factories, and wearable technologies. This shift from centralized data centers to distributed architectures reflects a broader transformation in how digital infrastructure is designed and deployed.

The integration of AI into cloud orchestration allows for predictive scaling, energy optimization, and workload balancing across hybrid environments. Federated learning models enable privacy-preserving collaboration by training algorithms locally while sharing insights globally, which is particularly valuable in healthcare, finance, and education. Edge-native applications, including augmented reality, robotics, and precision agriculture, benefit from reduced latency and enhanced contextual awareness.

Despite these advances, several challenges persist. Latency and bandwidth limitations continue to affect rural and underserved regions, creating disparities in access and performance. Data sovereignty remains a contentious issue, as conflicting regulations across borders complicate compliance and governance. Additionally, vendor lock-in – where organizations become dependent on proprietary platforms – limits flexibility and innovation.

Strategic responses to these challenges include the adoption of open standards and APIs to promote interoperability and modular design. Green cloud initiatives are gaining momentum, with carbon-aware scheduling and renewable-powered data centers becoming industry benchmarks. Public-private partnerships are essential for infrastructure investment, digital inclusion, and the equitable distribution of cloud and edge capabilities. Together, these efforts aim to build a resilient, sustainable, and inclusive digital foundation for the future.

Cybersecurity in 2025 has shifted from reactive defense to proactive, adaptive, and identity-centric protection. At the heart of this transformation is Zero Trust Architecture (ZTA), which operates on the principle that no user, device, or

application should be trusted by default. Instead, continuous verification and contextual access control are applied across all layers of digital infrastructure.

This paradigm shift is driven by the increasing complexity and interconnectivity of modern systems. AI-powered threat detection tools now analyze behavioral patterns and anomalies in real time, enabling faster and more accurate responses to emerging threats. Decentralized identity solutions, often built on blockchain technology, empower users with self-sovereign credentials and reduce reliance on centralized authentication systems. Meanwhile, cyber resilience strategies – including simulation-based training and incident recovery protocols – are becoming standard practice in both public and private sectors.

Despite these advancements, cybersecurity faces persistent and evolving challenges. Ransomware attacks have become more targeted, often focusing on critical infrastructure such as energy grids and healthcare systems. Supply chain vulnerabilities expose organizations to risks originating from third-party software and services. Fragmentation across security tools and platforms further complicates threat detection and response, leading to inefficiencies and blind spots.

To address these issues, organizations are adopting unified security platforms that integrate detection, response, and recovery into a seamless workflow. Global threat intelligence sharing is also gaining momentum, fostering cross-border collaboration and open-source defense initiatives. Finally, cyber hygiene education is being embedded into school curricula and workplace training programs, ensuring that individuals at all levels understand the importance of secure behavior and digital responsibility. Together, these strategic responses reflect a holistic approach to cybersecurity – one that prioritizes resilience, transparency, and collective vigilance.

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MATHEMATICAL MODELING OF INTELLECTUAL CRYPTOGRAPHIC PROTECTION OF AUTHENTICATION KEYS

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Modern authentication and cryptographic key management systems are under constant pressure from a growing number of cyber threats, including targeted attacks aimed at compromising key information. Traditional cryptographic approaches, despite their high mathematical robustness, are not effective enough in dynamic environments where the nature of attacks changes rapidly and data transmission channels are subject to steganographic analysis by attackers. The problem is further complicated by the proliferation of embedded, mobile, and energy-constrained devices, in which the implementation of full-fledged cryptographic mechanisms is often impossible without compromising security or performance.

Within the modern paradigm of information security, the concept of preventive response is becoming increasingly relevant, involving not only the detection and blocking of attacks, but also their prediction based on intelligent

analysis of the behavioral and statistical characteristics of information flows. The application of machine learning and deep learning methods in cryptographic systems creates opportunities for building self-learning architectures capable of dynamically changing the level of concealment, entropy complexity, and encryption parameters depending on the estimated level of compromise risk. At the same time, the lack of formalized mathematical models describing the interaction between cryptographic, steganographic, and intelligent components in a single theoretical field complicates a systematic approach to building such solutions. This is not sufficient. A methodology for quantitative assessment of the probability of successful attacks using deep learning methods also remains under development, which limits the possibilities of analytical risk forecasting.

Thus, there is a scientific and practical problem of mathematical modeling of intelligent cryptographic systems of preventive response, aimed at forming a generalized apparatus for analysis, assessment, and optimization of security parameters under dynamic threat conditions. Its solution will create the prerequisites for the development of a new class of adaptive protection systems capable of self-learning, predicting potential attacks, and minimizing the risks of compromising authentication keys in complex information environments.

The subject area of combining cryptographic and steganographic techniques with intelligent analysis modules is rapidly evolving at the intersection of applied mathematics, information theory, and machine learning. Historically, the methodological foundation of steganography and steganananalysis was laid by classical works that formulated stochastic and statistical approaches to detecting embedded messages in digital objects; these approaches remain relevant as a theoretical basis for further formalization of probabilistic stego-signal models (Zhivilo, Kuchma, 2025, p. 163). At the same time, deep neural architectures are undergoing intensive development both as concealment mechanisms (neural steganography) and as detectors (neural steganalysis).

End-to-end architectural solutions, in particular HiDDeN, have demonstrated the viability of methods that learn directly to perform the task of embedding and recovering information in observed signals, while changing the classical assumptions about static models of errors and noise in the channel. The development of detector architectures (SRNet, Yedroudj-Net, etc.) has shown an increase in detection efficiency through deep representations, but has also highlighted the problem of formalizing statistical guarantees and the ability of models to maintain efficiency in the face of channel parameter variations and dynamic attacks (Zhivilo, Kuchma, 2025, p. 163).

In cryptographic key management and regulatory practice, special recommendations for key material management play a prominent role, providing guidelines for determining key lifecycles, rotation policies, and risk assessment procedures. Specifically, NIST key management recommendations formalize the classes of procedures and metrics necessary for integration into adaptive control systems and automated decision-making regarding cryptographic parameters. Combining such regulatory approaches with quantitative risk assessment methods is an important step toward the practical implementation of intelligent cryptographic systems (Zhivilo, Kuchma, 2025, p. 163).

Scientific literature and applied reports highlight several systemic gaps that require mathematically rigorous solutions. First, the absence of a unified stochastic framework capable of simultaneously modeling the probability of key compromise, steganographic error characteristics, and behavioral indicators of traffic anomalies prevents formal risk aggregation. This limitation motivates the development of multidimensional Markovian, hierarchical Bayesian, or conjugate stochastic models.

Second, the informally defined “adaptive cryptographic cost” is an indicator that links computational/energy overheads with an expected increase in stability, which complicates multi-criteria optimization problems in resource-constrained environments (IoT, mobile devices) (Zhivilo, Kuchma, 2025, p. 164).

Third, there is an urgent need for analytical tools to quantitatively assess the robustness of neural detectors (in particular, the theoretical limits of first- and second-order errors) under changed channel conditions; this requires the use of the method of large deviations and concentration inequalities (Luckshan et al., 2025, p. 8).

The synthesis of theoretical and practical developments requires an interdisciplinary approach: a combination of applied probability theory, entropy analysis, optimization methods, and modern machine learning techniques (deep architectures, online learning, anomaly detectors). This involves both theoretical proof of the properties of the proposed models (convergence of adaptive procedures, risk reduction guarantees) and the creation of replicated benchmarks: sets of attacks, simulated channels with realistic transformations, and energy profiles of hardware platforms. In addition, to ensure applied value, it is necessary to correlate scientific conclusions with the requirements and recommendations of standardizing bodies, which will determine acceptable risk thresholds for the implementation of adaptive mechanisms in industrial systems (Zhivilo, Kuchma, 2025, p. 164).

The presented analysis shows that ensuring the security of modern authentication and cryptographic key management systems requires a transition from static protection mechanisms to intelligent, adaptive, and preventive security architectures. The integration of cryptographic and steganographic techniques with machine learning methods enables dynamic adjustment of security parameters in response to evolving threats but also reveals significant theoretical and methodological gaps.

Overcoming these challenges demands the development of unified mathematical models for quantitative risk assessment, robustness analysis of neural detectors, and optimization of security costs under resource constraints. The combination of rigorous theoretical foundations with practical benchmarks and regulatory requirements forms a necessary basis for the creation of adaptive

cryptographic systems capable of minimizing key compromise risks in complex and dynamic information environments.

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Butenko D. S.

INDUSTRY 6.0: THE FUTURE WHERE HUMANS AND MACHINES GROW TOGETHER

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At times, I pause to reflect on how rapidly the world is changing. My grandparents once worked in a time when even a basic computer seemed like science fiction. Today, we observe incredible advances that significantly enhance the quality of our lives: artificial intelligence is designing cities, robots are performing surgeries, and machines can learn from experience. It feels like we are entering a completely new era – the era of Industry 6.0.

For supporters of traditional approaches and solutions, this should be made clear that Industry 6.0 is not just the next stage of industrial advancement, but a comprehensive reimagining of how humans, machines, and intelligent systems

collaborate to create resilient, adaptive, and ethically aligned socio-technical ecosystems (ATMECS Global, 20025). And its philosophical capacity focuses on the turning point – a moment when humanity must decide how to live with technology, not just use it. We have already seen how automation, digitalization, and artificial intelligence have transformed our world. However, the challenge is now different and getting even more topical with the rise of technology. It is clearly about learning how to evolve alongside machines without losing what makes us uniquely human.

When we analyze the peculiarities and consequences of the earlier industrial revolutions, we realize that they all had one thing in common – they made life faster, easier, and more productive; however, they also distanced people from nature and, at times, even from one another. The first revolution gave us steam power; the second introduced electricity and mass production; the third brought computers; and the fourth connected everything through data. Then, Industry 5.0 has underscored that the human element continues to matter and matters just as much as it ever has. It was the first time we started asking not just "How can we make more?", but also "Why are we making it?"

In current conditions, Industry 6.0 feels like the next natural step – a time when AI, robotics, and human creativity merge into a single ecosystem. This is not about replacing people; it's about building a balance between artificial intelligence and emotional intelligence. Machines may have algorithms, but we have empathy, values, and imagination.

Prospect vision for Industry 6.0

When I imagine Industry 6.0, I see factories that no longer pollute the air, cities that learn from their citizens, and robots that work side by side with people, not in competition but in harmony. In my vision, an engineer doesn't just design machines but teaches them how to respect human values. A worker doesn't just follow instructions – they cooperate with smart systems that adapt to their needs. And students at schools don't just learn how to use technology – they learn how to think critically about it.

The focus of attention in Industry 6.0 is not only on innovation, but also on conscious innovation. I hope this will be an era where every invention is created with questions like: “Will this make life better for people?”, “Will it help our planet?”, “Does it respect human dignity?” That’s what will make Industry 6.0 distinct from anything that has come before it.

The relationship between humans and machines in Industry 6.0

One of the most fascinating ideas for me is that machines are slowly becoming more like us – learning, adapting, even trying to understand our emotions. But at the same time, we are also becoming more like machines – connected to devices, driven by data, and surrounded by algorithms that influence our choices. This makes me wonder: where does the line between human and machine really lie?

Some people fear that AI will take over everything, but I don’t share that view. I believe machines can make us better, not weaker, if we use them wisely. For example, AI can help doctors detect diseases earlier, robots can save lives in dangerous environments, and automation can free people from boring and repetitive tasks.

The problem begins when we neglect our responsibility. Machines lack morals and emotions, at least for now. Therefore, we must decide how they are used. I believe Industry 6.0 will only succeed if built on ethics, empathy, and purpose.

The role of human creativity

Technology can process millions of data points in a second, but only humans can conceive of something genuinely new. That’s why creativity is our most powerful asset. In Industry 6.0, I imagine workplaces where creativity becomes the main skill. Engineers will think like artists; designers will use AI as a creative partner; and scientists will collaborate with robots to explore things beyond human reach (Madsen, Slatten, & Berg, 2025).

Maybe the most exciting part is that we will stop working “for” machines and start working “with” them. Together, we can solve global problems that seem

impossible today – such as climate change, hunger, and inequality. When technology is used with creativity and compassion, it becomes a force for good.

The challenge of keeping humanity

Still, we can't ignore one fear – the fear of losing our humanity in this technological race. The more we depend on machines, the greater the risk of forgetting how to be human: how to listen, to feel, to connect.

That's why emotional intelligence will become more important than ever in the era of Industry 6.0. We will need leaders who understand people, not just data. We will need teachers who can inspire curiosity, not just test knowledge. We will need citizens who can use technology critically, not as consumers but as conscious creators of the future. Industry 6.0 presents us with a significant opportunity – but also a substantial responsibility. We must make sure that progress doesn't mean losing our soul.

My personal hopes for the future

Sometimes I ask myself what kind of world I want to live in twenty or thirty years from now. I imagine a world where machines and people trust each other. Where robots build homes for the homeless, AI systems help protect forests, and automation gives people more time to learn, travel, and love.

I hope Industry 6.0 will foster a society that values balance between efficiency and empathy, innovation and sustainability, and intelligence and wisdom. If we succeed, perhaps the true success of Industry 6.0 won't be technological at all. It will be spiritual – a rediscovery of what it really means to be human in a world full of intelligent machines.

Industry 6.0 is not just an industrial revolution. It is a human revolution. It asks us to look in the mirror and decide what kind of future we want to build – one driven by greed and automation, or one guided by creativity, compassion, and collective intelligence. The machines of tomorrow will be powerful, but it is up to us to give them purpose. They can calculate, but only we can dream. Therefore, my hope is simple: to build a world where machines imitate people. Let's build a world where

people inspire machines to think, to create, and to care. Ultimately, Industry 6.0 is not about technology. It's about us.

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Butenko D. S.

THE ROLE OF ARTIFICIAL INTELLIGENCE IN THE FUTURE OF CIVIL ENGINEERING

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In the 21st century, the construction industry is undergoing a rapid transformation, driven by the integration of advanced technologies. Among these, artificial intelligence (AI) is playing an increasingly important role in the process of implementing innovations. The digitalized society forces us to change and update models, samples, methods, and forms. In this regard, artificial intelligence is a medium that transmits the knowledge and cultural achievements of previous generations. For civil engineers, AI is no longer just a hypothetical concept; it is a practical tool that is now being adopted at every stage of infrastructure development, from initial planning and design to construction and ongoing maintenance. In this regard, the presented paper explores how AI is revolutionizing civil engineering in the main fields of its practical application, bringing improvements in efficiency,

accuracy, sustainability, and safety, while also reshaping the role of the engineer in the digital era.

1. AI in design and generative engineering

One of the most vital applications of AI in civil engineering relates to the design process. Standard design methods require engineers to manually evaluate and consider various factors, such as material strength, load-bearing capacity, environmental conditions, structural integrity, and overall cost. This process is frequently repeated over a long period of time.

With the advent of AI-powered generative design tools, engineers can input basic parameters, constraints, and goals – such as cost limits, load requirements, or sustainability targets – and allow the system to generate thousands of viable design solutions. These tools use machine learning algorithms to simulate and optimize designs based on real-world data. Engineers then evaluate and select the most effective and innovative options, often discovering solutions that would not have been conceived using traditional approaches. This not only accelerates the design process but also improves the efficiency, durability, and sustainability of the resulting structures.

2. Construction site monitoring and management

Beyond the office, artificial intelligence is transforming how construction sites are monitored and managed. Many modern projects now use drones equipped with AI and computer vision capabilities to collect real-time visual and spatial data. These drones can map terrain, assess progress, compare ongoing construction with digital models (Building Information Modeling or BIM), and detect discrepancies or safety issues.

AI-powered software can process images and video feeds to identify problems such as structural misalignments, hazardous working conditions, or project timeline delays. Real-time alerts enable project managers and site engineers to respond promptly, minimizing risks and maintaining the project's schedule. These

technologies reduce the reliance on manual inspections and enable safer, smarter, and more efficient site management.

3. Predictive maintenance and infrastructure monitoring

AI also plays a vital role in maintaining infrastructure. Civil structures like bridges, tunnels, highways, and dams experience wear and environmental stress over time. Failing to identify early signs of deterioration can lead to disastrous consequences.

Using sensors embedded in critical infrastructure components, AI systems continuously collect and analyze data on factors like vibration, temperature, humidity, and structural strain. Machine learning algorithms recognize patterns in this data, allowing engineers to predict when maintenance is needed – even before visible damage occurs. This proactive approach to maintenance extends the lifespan of infrastructure, enhances safety, and significantly reduces repair costs by preventing major failures.

4. Sustainable construction through AI

Sustainability has become a major priority in the construction industry. Governments, companies, and societies are all seeking to reduce the environmental impact of buildings and infrastructure. AI supports this goal by helping engineers make data-driven decisions about materials, energy use, and lifecycle performance.

AI models can assess the carbon footprint of different construction materials, simulate energy consumption patterns, and identify opportunities to reduce waste. It can also recommend environmentally friendly alternatives and predict how design decisions will impact sustainability outcomes over time. For instance, AI might suggest using recycled concrete or alternative structural systems that strike a balance between strength and minimal resource use. Ultimately, this leads to greener, more resilient infrastructure.

5. Urban infrastructure and smart cities

As urban populations continue to grow, cities are becoming more complex. AI is helping civil engineers design and manage infrastructure that is responsive and

adaptive to urban needs (Rai et al., 2025). Smart traffic systems powered by AI can analyze real-time data from sensors and cameras to adjust traffic signals, reduce congestion, and improve road safety (Elsakka & Kamer, 20025). AI-driven water management systems can predict consumption patterns, detect leaks, and improve distribution efficiency.

Engineers working in smart city development also use AI to model future scenarios – such as the impact of new housing developments, public transit expansions, or climate change. These insights enable planners to make more informed long-term decisions regarding zoning, utilities, and transportation networks. As a result, infrastructure becomes more efficient, equitable, and resilient to change.

6. Project management and logistics

AI is transforming not only what engineers build but also how projects are managed. Construction is traditionally known for delays, budget overruns, and complex logistics. AI can address these issues by analyzing data from past projects, forecasting risks, and optimizing scheduling.

For example, AI platforms can suggest the best order in which tasks should be completed based on resource availability and dependencies. They can predict which materials might face delivery delays or price increases, allowing teams to adapt in advance. Some AI systems even model workforce productivity and weather patterns to further refine project timelines. The result is smarter, more predictable construction with fewer surprises.

7. Education and the future workforce

As artificial intelligence becomes more prevalent in engineering, the skills required of civil engineers are evolving. It is no longer enough to understand only traditional engineering concepts – modern engineers must also have a working knowledge of AI, data science, and programming.

Educational institutions and engineering firms are beginning to update their training programs accordingly. Courses in machine learning, data analytics, and

algorithmic design are becoming standard in engineering curricula. Simultaneously, AI-powered learning platforms are being used to personalize education, allowing students to focus on areas where they need improvement. This ensures that the next generation of civil engineers is equipped to thrive in a technology-driven future.

8. Human-AI collaboration: ethics and responsibility

While AI offers tremendous benefits, it also brings new challenges and responsibilities. One key question is accountability: if an AI-designed structure fails, who is to blame? Engineers must understand the limitations of AI systems and ensure human oversight is maintained.

Moreover, AI systems are only as good as the data used to train them. Biased or incomplete data can lead to dangerous or inequitable outcomes. It is essential that engineers and developers follow ethical guidelines in AI development and deployment, prioritizing transparency, explainability, and fairness.

Artificial intelligence is transforming the field of civil engineering in profound ways. It enhances design, optimizes construction, predicts maintenance needs, promotes sustainability, and supports the development of smart cities. Most importantly, it empowers engineers to work more efficiently and creatively, solving problems that were previously too complex or time-consuming.

Rather than replacing civil engineers, AI serves as a powerful collaborator. Together, human expertise and machine intelligence can build a safer, more sustainable, and more intelligent world – one bridge, building, and city at a time.

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DEVELOPMENT OF A FULL-STACK WEB APPLICATION FOR HABIT TRACKING

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The objective of this project was to develop a full-stack web application dedicated to the systematic tracking of personal habits. The challenge of personal development rarely lies in the inability to identify a goal but rather in the systemic failure to maintain consistency over time. As James Clear notes in his research on habit formation, the aggregation of marginal gains is what leads to significant results, yet tracking these small gains is often where individu als falter (Clear, 2018). Motivated by this problem, the coursework project "HabitKnot" was developed. It is a web application designed to help users define, track, and strictly maintain healthy routines. The objective was not merely to build a simple application for a grade, but to utilize a modern and commercially viable technology stack, allowing the project to serve as a strong case study for a professional portfolio. For the server side, the newly released .NET 9 platform was selected due to its strict typing and high performance. For the client side, the React library paired with the Vite build tool was chosen. This combination provided valuable experience in working with both the rigid architecture of C# and the flexibility of modern JavaScript patterns (Banks & Porcello, 2020).

One of the first significant technical decisions involved the choice of a database. While academic curricula frequently rely on classic relational databases like SQL Server or PostgreSQL, it was realized during the design of the data structure

that the relational model might be excessively cumbersome for this specific use case. User habits are not always strictly structured data; a user might need to delete a habit, change parameters, or add specific notes, requiring the data structure to accommodate fluidity. Consequently, MongoDB was selected. NoSQL databases offer a flexible schema design that is often more suitable for agile development projects where data requirements evolve rapidly during the initial building phase (Sadalage & Fowler, 2012). This allowed data to be stored in a format very similar to JSON, which interfaces perfectly with JavaScript on the frontend.

During the development process, the data was divided into three main collections. The first collection handles users and stores credentials. The second collection stores the habits themselves, describing the essence of the task including the name, icon color, target completion count, and specific active days. The third collection consists of execution records, also known as "HabitEntries". This separation into "habit definition" and "execution record" was a critical architectural decision. Storing the history of executions inside the habit object itself would have resulted in unmanageable object sizes over time. Loading such massive arrays of data every time the application displays a list of habits would be inefficient. The adopted approach allows the application to load only lightweight habit objects for the menu, while heavy history data is lazy-loaded only when the calendar or statistics view is accessed.

When developing the API, adherence to the principles of clean architecture was prioritized. Writing logic inside controllers was avoided, despite being the fastest path. Instead, a dedicated service layer was implemented to separate concerns (Martin, 2017). The controllers in the application act merely as routers that accept HTTP requests, validate incoming data, and pass control to the services. All business logic is concentrated in classes such as AuthService and HabitService. For instance, the habit service checks whether the current user has the right to edit a specific record. This is critically important for security, preventing situations where one user could modify another's data by guessing ID parameters. Security questions occupied a

special place in the development process. Since storing passwords in plain text is unacceptable, the BCrypt library was used to hash passwords upon registration, and JSON Web Tokens (JWT) were utilized for session management. This stateless authentication approach is highly scalable and aligns with modern security standards for Single Page Applications.

Regarding the frontend, the goal was to create an application that is genuinely pleasant to use. The concept of "Glassmorphism" was chosen to create a unique visual identity by imitating the effect of frosted glass. A significant amount of custom CSS was written to achieve this, using semi-transparent panels, background blurring filters, and soft gradients. To manage the application state, the React Context API was employed. The most important component here is the AuthContext, which ensures user persistence. Without this mechanism, login credentials would be required upon every page refresh. The context checks for the presence of a token in the browser's local storage during initialization and automatically restores the session if the token is valid.

The most complex technical challenge of the project was undoubtedly the implementation of the calendar logic. At first glance, the task seems trivial, but merging habit definitions with execution history requires a sophisticated algorithm. The frontend requests a list of all active habits and the execution history for the current month. The application then iterates through every day of the month and performs a complex check. The start date of the habit must be verified to ensure the calendar does not show missed days before creation. The schedule must also be accounted for, as each habit has specific "ActiveDays". If a habit is scheduled only for Monday and Wednesday, Tuesday is not considered a missed day. Only after these checks is the real execution data analyzed. A color-coding system was developed for the calendar to ensure information is readable instantly. If all planned habits are completed on a specific day, it is highlighted in green. This immediate feedback loop is essential for maintaining user engagement.

Furthermore, a significant challenge for web development involves dealing with time zones. The server operates in UTC, but the user might be in a different time zone. If a standard date object is sent, it might be saved on the server as "yesterday" or "tomorrow" due to time differences. To avoid confusion and errors where a habit completed today appears on yesterday's date, a special utility for formatting dates was created. This utility strips the time part and the time zone, forming a strict string in the "YYYY-MM-DD" format, ensuring data consistency regardless of the user's location.

The development of HabitKnot served as an excellent practical experience in Full-Stack development. This project required the coordination of many moving parts, from ensuring the C# backend correctly interprets data from the JavaScript frontend to handling asynchronous operations so the interface does not freeze while loading data. The result is a cohesive and functioning application that not only meets all coursework requirements but also addresses a real problem of personal time organization.

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SOLVING THE CONCEPTUAL DESIGN PROBLEM OF STRUCTURALLY ANISOTROPIC CURVILINEAR STRUCTURES WITH VARIABLE GAUSSIAN CURVATURE USING MODERN 3D MODELING SOFTWARE

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This study presents the formulation and implementation of a problem aimed at rationalizing the structural parameters of reinforced concrete structurally anisotropic shell systems. An energy-based principle is adopted as the governing criterion: among all possible combinations of system parameters with constant material volume and fixed numbers of external and internal constraints, the strain energy of deformation (SED) after structural transformation is assumed to reach a minimum at a rational combination of geometric parameters.

Roofing systems of buildings and structures are subjected to significant loads, resulting in a high level of stress-strain state (SSS). For this reason, it is reasonable to consider structural forms capable of efficiently resisting, uniformly distributing, and transferring loads to supports. Structurally anisotropic reinforced concrete shells with various types of Gaussian curvature are particularly suitable for this purpose. However, the search for rational shell configurations capable of resisting such loads remains a relevant yet methodologically incomplete problem.

In addition, since reinforced concrete is a relatively heavy material, it is expedient to investigate methods for reducing its self-weight. One effective approach is the monolithic embedding of void-forming inserts made of expanded polystyrene within the structure. These inserts simultaneously shape the stiffening ribs of the

shell. By assigning specific geometric forms to the stiffening ribs – through variation of the insert geometry – it becomes possible to achieve an optimal distribution of internal forces, ensuring the required load-bearing capacity while limiting material consumption.

In summary, the development of a methodology for shaping internal structural geometry represents a timely and practically important challenge in construction engineering. Addressing this challenge makes it possible to improve the reliability and durability of such systems and, through rationalization of their structural parameters, to minimize material usage (Гапонова, 2025).

A numerical experiment was carried out to investigate the behavior of structurally anisotropic constructions under a uniformly distributed load of 1600 Pa/m² and a concentrated load of 1 t/m². To analyze the stress-strain state of the structural elements, a protected space was proposed in the form of a structurally anisotropic shell measuring 9 × 9 m, with a 1 m spacing of concrete ribs incorporating expanded polystyrene inserts, as well as an alternative 9 × 9 m structurally anisotropic shell featuring a steel sheet in the lower chord.

The design of enclosed spaces within small architectural forms – specifically, compact above-ground modular shelters intended to protect people in public areas from blast waves and fragmentation – is particularly relevant today. Such shelters are envisioned for placement at public transport stops, in parks, squares, and other open areas within residential zones and industrial sites.

Previous scientific studies have examined the relationship between explosion parameters and enclosing structures. In describing the peculiarities of modeling the stress-strain behavior of complex systems, it is appropriate to cite Perelmuter A.V., who noted that the structural response of load-bearing systems is largely governed by the internal force couple arm (Перельмутер, 2024). In spherical structures, this corresponds to the distance between chords; in arches, to the distance from the crown to the tie; and in domes, approximately to the distance between the apex and the support ring. However, determining the internal force couple arm in a doubly curved

shell with a rectangular plan requires an understanding of the structure's overall behavior, which often contrasts with the commonly applied detailed analysis of the stress-strain state. Such detailed analyses typically focus on local effects, such as stress peaks or maximum deflections.

The finite element method is based on discretizing the structure itself, representing it as an assemblage of individual finite elements.

At the same time, the introduction of direct methods into design practice was facilitated, on the one hand, by different interpretations of the very concept of a "rational solution", and on the other hand, by the widespread adoption of the Finite Element Method (FEM). The notion of a "rational structure" was further clarified and transformed through the original ideas and studies of Vasylkov G. V. and Shmukler V. S. Research by B. Mandelbrot is devoted to modeling geometric parameters with consideration of fractal theory.

Anisotropy is commonly classified as follows:

1. anisotropy of elastic properties;

2. anisotropy of elastic limits, yield strength, and other properties determined in the range of small plastic deformations;

3. anisotropy of characteristics associated with significant plastic deformation (ultimate tensile strength in the presence of necking, uniform plasticity, etc.);

4. anisotropy of fracture-related characteristics (fracture resistance under various loading conditions, limiting plasticity, etc.).

A distinction is also made between anisotropy of properties determined under static loading, anisotropy of long-term strength and creep, anisotropy of impact toughness, crack resistance, hardness, microhardness, and other characteristics. From a structural standpoint, anisotropy may be homogeneous or heterogeneous, caused by oriented residual microstresses or associated with specific features of the dislocation structure.

Many metallic materials are quasi-isotropic in the elastic and plastic ranges, as well as in shear-type fracture, yet anisotropic with respect to resistance to separation.

In sheet materials, “planar” and “normal” plastic anisotropy are distinguished. Planar anisotropy is defined by the dependence of material properties on direction within the plane of the sheet, whereas normal anisotropy is characterized by differences between properties in the plane of the sheet and those in the direction perpendicular to it (through the thickness). According to geometric characteristics, anisotropy may be linear or curvilinear.

The *aim of this study* is to rationalize the structural parameters of reinforced concrete structurally anisotropic systems.

To achieve this objective, the following tasks were defined:

- establishing relationships between strain energy density (SED) and the geometric parameters of structurally anisotropic structures;

- improving the construction technology of a cylindrical shell;

- developing the layout of an insert-void former for a self-supporting framework;

- performing a numerical experiment to analyze the behavior of a structurally anisotropic structure under a uniformly distributed snow load of 1600 Pa/m² and a concentrated load of 1 t/m².

The *object of the study* is a reinforced concrete structurally anisotropic structure.

The *research methods* include the finite element method for numerical simulation of structural behavior, classical and numerical methods of solid mechanics, full-scale concreting techniques, and related approaches.

The *research tools* comprise the LIRA software package, Autodesk software products, and other computational and design tools.

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GAMIFICATION ELEMENTS IN USER INTERFACE DESIGN

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Gamification has become a popular design approach in modern digital products, especially mobile apps. It uses game elements not for entertainment, but to increase motivation, activity, and long-term user engagement. Instead of passive interaction with interfaces, users feel rewarded for their progress and are inspired to return to them regularly. This concept is widely used in education, e-commerce, finance, and productivity tools, where well-designed game mechanics improve the overall experience of the product (Strive Cloud, 2023).

Motivational design is particularly important in learning platforms. Points, badges, animations, and series create a sense of visible progress and encourage consistent learning habits. For example, Duolingo significantly improved next-day retention when it redesigned the interface to add more competitive elements, such as ranked leagues and daily XP challenges (Журнал дизайну інтерфейсів, 2021). When the interface supports user goals and provides regular feedback, the learning process becomes more enjoyable and results grow faster.

Educational apps also rely on achievements and leaderboards to maintain engagement over time. Users see how their efforts lead to improvement, which increases intrinsic motivation. In addition, physical activity apps such as Nike Training Club provide challenges and progress tracking to help users stay consistent.

Forming a healthy habit becomes easier when the interface recognizes effort and celebrates success (UX Retail Research, 2023).

Gamification also plays a significant role in commercial services. Online marketplaces like Amazon and AliExpress reward users for their activity: browsing products, leaving reviews, participating in promotions, and completing daily tasks. Loyalty points, seasonal badges, and mini-games make shopping more dynamic. Users are enthusiastic about receiving rewards or unlocking discounts, which increases repeat purchases and strengthens customer loyalty (ResearchGate, 2024).

Financial technology services use gaming elements to help users manage their money more effectively. Banking apps such as Monobank offer collectible achievements for daily payments, motivating customers to use the app more actively. Revolut encourages maintaining habits through personalized goals and notifications about rewards once they are achieved. These mechanisms create positive emotions about financial interactions and reduce stress associated with money management (Сюй, 2022).

Personalization enhances the impact of gamification. When feedback adapts to user behavior – for example, through notifications, confetti animations, or sound effects – the interaction feels emotionally satisfying. As a result, users return more often and form useful habits. Gamified productivity tools help people stay organized, track daily routines, and improve concentration without feeling pressured. Even small rewards can make a task more meaningful and enjoyable (Яман, 2023).

In addition to motivation, game design elements improve the usability and accessibility of digital interfaces. Many people feel uncertain when learning new technologies. Gamified interfaces reduce this barrier, encourage research, and give users confidence. This approach also helps maintain attention, especially in situations where people easily lose interest. Designers can motivate users to take important steps, pay attention to safety, or complete adaptation lessons.

Research predicts that gamification will continue to evolve and play an even greater role in interface design. Future applications in healthcare could promote

physical rehabilitation, emotional health, and proper medical regimens. Educational platforms can provide more adaptive learning paths through artificial intelligence. Commercial services will develop new reward mechanisms to meet both business goals and customer needs. So, gamification not only improves user experience, but also forms long-term relationships with technology.

In summary, game elements in interface design help transform digital interactions into a more engaging, supportive, and enjoyable experience. Progress visualization, competition, and social encouragement inspire users to return more often and achieve better results. As modern products implement smarter and more personalized mechanics, gamification will remain a powerful tool for increasing motivation and helping people achieve their goals.

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Holianytskyi D. S.

APPLICATION OF ARTIFICIAL INTELLIGENCE IN TRANSPORT SYSTEMS

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Artificial Intelligence (AI) is one of the most transformative technologies of the 21st century. Its integration into transport systems provides opportunities for improving safety, efficiency, and sustainability. The rapid growth of urban populations and the increasing demand for mobility require innovative solutions. AI offers tools to analyze large datasets, predict traffic patterns, and automate decision-making processes. This paper explores the application of AI in intelligent transport systems, focusing on traffic management, autonomous vehicles, predictive maintenance, and ethical considerations.

AI in Traffic Management

Traffic congestion is a persistent problem in modern cities. Traditional traffic control systems rely on fixed-time signals or limited sensor inputs, which cannot adapt to real-time changes. AI-based algorithms, however, allow dynamic optimization of traffic flows.

Machine learning models can predict congestion and adjust traffic light cycles accordingly. Reinforcement learning methods are particularly effective, as they continuously learn from traffic data and improve decision-making.

Example: In Singapore, AI-driven traffic control reduced congestion by 15% compared to traditional systems (Brown, 2009).

Table 1. Comparison of Traffic Management Approaches

Approach	Data Source	Efficiency Gain	Limitations
Fixed-time signals	Historical patterns	Low	Cannot adapt to real-time
Sensor-based control	Road sensors	Medium	Limited prediction ability
AI-based adaptive control	Cameras, IoT, GPS	High (10–20%)	Requires large datasets

Autonomous Vehicles

Self-driving cars represent one of the most visible applications of AI in transport. These vehicles rely on AI for perception, decision-making, and control. Neural networks process sensor data from cameras, LiDAR, and radar to detect obstacles, pedestrians, and traffic signs.

AI enables vehicles to adapt to complex urban environments, reducing accidents caused by human error. Companies such as Tesla and Waymo have demonstrated significant progress in autonomous driving technologies (Smith, 2018, p. 45).

Key AI Functions in Autonomous Vehicles:

- *Perception:* Object detection and classification.
- *Decision-making:* Route planning and obstacle avoidance.
- *Control:* Steering, acceleration, and braking.

Despite these advances, challenges remain. Autonomous vehicles must handle unpredictable human behavior, adverse weather conditions, and ethical dilemmas in critical situations.

Predictive Maintenance

AI also supports predictive maintenance of vehicles and infrastructure. By analyzing sensor data, algorithms can forecast equipment failures before they occur. This reduces downtime and increases reliability.

Case Study: Deutsche Bahn uses AI to monitor train components, predicting failures and reducing delays by 25% (Johnson, 2020).

Benefits of Predictive Maintenance:

- Lower repair costs.
- Increased safety.
- Extended equipment lifespan.

Predictive maintenance is particularly valuable for large fleets of buses, trucks, and trains, where unexpected failures can cause significant disruptions.

AI in Public Transport Systems

Public transport systems benefit greatly from AI integration. Algorithms optimize bus routes, predict passenger demand, and improve scheduling. AI-based ticketing systems analyze travel patterns to adjust pricing and capacity.

Example: London's Underground uses AI to predict passenger flows, reducing overcrowding and improving service reliability.

Table 2. AI Applications in Public Transport

Application	Benefit	Example City
Route optimization	Reduced travel time	Helsinki
Demand prediction	Better resource allocation	London
Dynamic pricing	Increased efficiency	New York

Ethical and Social Considerations

While AI offers significant benefits, challenges remain:

- *Ethics:* Decision-making in critical situations (e.g., unavoidable accidents).
- *Cybersecurity:* Protecting AI systems from hacking.
- *Employment:* Automation may reduce demand for certain jobs.
- *Privacy:* Collection of large datasets raises concerns about data protection.

Future research should address these issues to ensure safe and sustainable AI deployment.

Conclusion

The integration of AI into transport systems represents a significant step toward smarter cities. Traffic management, autonomous vehicles, predictive maintenance, and public transport optimization demonstrate the potential of AI to improve efficiency and safety. However, ethical, social, and technical challenges must be addressed to fully realize these benefits. AI is not a replacement for human judgment but a powerful tool to support decision-making and enhance mobility.

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ARTIFICIAL INTELLIGENCE IN MODERN ENGINEERING GEODESY: A REVIEW OF ADVANTAGES, DISADVANTAGES, AND INTEGRATION INTO AUTOMATED MEASUREMENT PROCESSING

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Amidst the rapid digital transformation of the engineering sector and the necessity to adapt to fully automated systems, new and stricter demands are being placed on the accuracy and speed of geodetic measurements. Artificial Intelligence (AI) is becoming critically relevant in the field of engineering geodesy, as intelligent software products are capable of fundamentally improving the processes of geospatial data acquisition, processing, and analysis, especially in the context of 3D modeling and object monitoring. This toolset allows geodetic engineers to work effectively with large volumes of Big Geodata (laser scanning, UAV surveying), which is impossible using traditional methods.

A key challenge in modern geodesy is the need for automation of labor-intensive processes, such as point cloud classification and object recognition in imagery, which are inherently prone to subjective errors. Although Machine Learning (ML) and Deep Learning (DL) technologies unlock new possibilities for predictive deformation analysis and enhancing measurement quality, their widespread implementation introduces a number of challenges and disadvantages (high cost, dependency on training data quality, ethical, and legal issues) that require objective analysis.

The purpose of this article is to conduct a comprehensive review and analysis of the advantages and disadvantages of applying artificial intelligence in modern engineering geodesy, as well as to systematize the key directions for integrating AI into the processes of automated geodetic measurement processing.

The adoption of Artificial Intelligence (AI) and Machine Learning (ML) is fundamentally transforming engineering geodesy, primarily driven by the need for enhanced automation in data processing. Modern geodetic equipment, such as laser scanners and drones, generate vast amounts of information, known as Big Geodata, which is impossible for human operators to process manually. AI allows computer systems to learn from these datasets, enabling them to execute complex analytical tasks much faster and more accurately than traditional methods. In working with aerial imagery and plans, AI utilizes techniques akin to human vision. Automated recognition algorithms identify and classify terrain elements like buildings, roads, or waterways directly from photographs without manual intervention. Furthermore, specialized algorithms help to precisely delimit objects, clearly defining contours and boundaries, which is crucial for accurate mapping.

For processing three-dimensional models of the terrain acquired through laser scanning, AI proves indispensable. Since a laser scanner produces a «point cloud» of millions of measurements, ML is used to automatically sort this cloud into logical groups (or clusters), for example, separating points belonging to trees from those belonging to the ground surface or building facades. This drastically speeds up the creation of accurate digital terrain models.

Beyond simple classification, AI allows geodetic engineers to move from merely recording facts to prediction and quality enhancement. Based on historical data from structural monitoring, neural networks can forecast how an object, such as a bridge or dam, will behave in the future, providing timely warnings to prevent accidents. Additionally, AI systems are capable of filtering "noise" and random errors present in measurements, particularly in satellite GNSS data affected by signal

interference, thereby increasing the reliability and precision of the final geodetic results.

The widespread adoption of AI in engineering geodesy and geospatial data processing is driven by significant advantages over traditional methods. Generally, the main benefits of AI are categorized by their technical impact: high data processing speed, as automated methods process massive volumes of Big Geodata faster and more efficiently than manual approaches, significantly reducing project timelines. This facilitates the futomation of routine processes, where AI minimizes human error and eliminates repetitive tasks such as point cloud classification or automated object digitization, thereby freeing up specialists for more complex analytical work. Furthermore, the enhanced accuracy in analysis and prediction provided by machine learning algorithms allows for the automatic detection and correction of errors and enables predictive analysis of structural deformations or terrain changes, thereby improving the reliability and quality of the final geodetic product.

Despite these numerous benefits, the integration of AI into engineering geodesy presents several notable challenges and drawbacks that require careful consideration. A primary concern is the requirement for high-quality training data, as the performance of AI algorithms is fundamentally dependent on the quality and volume of data used for training. Inaccurate or insufficient data can lead to incorrect algorithm operation, potentially compromising the integrity of the geodetic analysis. Another significant barrier is the High Cost of Technology Implementation, encompassing initial investments in specialized software, powerful computing hardware and infrastructure setup. Finally, the need for qualified specialists poses a major constraint; the effective deployment and maintenance of AI systems require personnel with a unique combination of geodetic knowledge and programming/machine learning skills, and a deficit of such qualified experts remains a limiting factor.

The core finding is that AI provides a critical leap in productivity by delivering a dual benefit: Automation and Speed through the processing of Big Geodata (point clouds, UAV imagery), and Enhanced Reliability via predictive analysis of deformations and intelligent error filtering in measurements. This transition redefines the role of the geodetic engineer, shifting focus from data collection to complex analysis.

However, the widespread implementation of AI faces significant challenges, primarily related to the high cost of technology, the critical dependence on the quality of training data, and a deficit of qualified specialists combining geodetic and programming skills.

Despite these barriers, AI represents the fundamental digital foundation for the future of engineering geodesy. Further efforts must prioritize data standardization and reducing economic hurdles to ensure the full automation and transformation of the sector.

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Ilhe O. I.

STRUCTURAL HIERARCHICAL MODEL FOR SELECTING ONLINE TOOLS FOR MODELING ELECTRONIC DEVICES FOR CONDUCTING PRACTICAL WORK IN THE COURSE "COMPUTER ELECTRONICS"

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The digitalization of higher education leads to the active use of online software tools in teaching engineering disciplines, in particular the course "Computer Electronics", in which an important place is occupied by the formation of practical skills in analyzing and designing electronic circuits and devices.

Traditional laboratory work requires specialized equipment, which is often unavailable in remote or hybrid learning environments, increasing the role of online modeling tools as the primary means of implementing the practical component of the educational process.

At the same time, the diversity of modern online simulators, differing in functionality, model accuracy, and ease of use, complicates their informed selection and necessitates the use of formalized decision-making models based on a system of criteria.

The task of selecting online tools for modeling electronic devices for practical work belongs to the class of multi-criteria decision-making tasks under conditions of uncertainty. This is due to the need to take into account both the technical parameters of software tools and pedagogical and operational characteristics, a significant part of which is of a qualitative nature.

The aim of the study is to improve the effectiveness of practical work in the course "Computer Electronics" through the reasonable selection of online tools for modeling electronic devices.

To solve this problem, it is advisable to apply decision-making methods based on expert assessments. Among them, the most suitable is the hierarchy analysis method, which allows formalizing a complex multi-criteria problem in the form of a

hierarchical structure and obtaining quantitative estimates of the priority of alternatives (Saaty, 1987).

The structural hierarchical model for selecting online modeling tools involves building a hierarchical structure containing four levels.

The first level of the hierarchy is the problem of determining the most appropriate online tool for modeling electronic devices for conducting practical work in the course “Computer Electronics”.

The second level of the hierarchy contains groups of criteria:

- functional modeling capabilities;
- didactic feasibility;
- technical and operational characteristics;
- user interaction;
- cost parameters.

At the third level of the hierarchy, the same criteria apply.

The following criteria are proposed to be included in the group of functional modeling capabilities:

- support for analog and digital modeling;
- accuracy of mathematical models;
- availability of libraries of electronic components;
- support for time and frequency analyses.

The didactic feasibility group should include the following criteria:

- compliance with the course content;
- support for step-by-step learning;
- ability to visualize processes.

The group of technical and operational criteria includes:

- browser performance;
- work stability;
- cross-platform compatibility.

The user interaction group consists of the following criteria:

- convenience and intuitive interface;
- availability of educational materials built into the tool;
- support for teaching control.

The group of cost parameters includes the following criteria:

- availability of a free or educational version;
- licensing flexibility.

The fourth level of the model consists of the following alternatives, namely the most popular online tools for modeling electronic devices (ElectroTalks, 2025):

- Tinkercad Circuits;
- Multisim Live;
- EasyEDA;
- Falstad Circuit Simulator;
- Proteus (cloud / hybrid versions).

Thus, the article proposes a structural hierarchical selection model that allows for systematic consideration of functional, didactic, user, technical, and cost criteria. The implementation on its basis of the standard mathematical procedure of the hierarchy analysis method will reduce the subjectivity of selection and will contribute to improving the quality of practical work and the effectiveness of the educational process in computer electronics.

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PRESERVING CULTURAL HERITAGE THROUGH DIGITIZATION

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Digitization refers to the process of converting physical artifacts, documents, and other forms of cultural heritage into digital formats This transformation enables the creation of digital surrogates, virtual versions of artifacts that can be accessed and interacted with remotely. The importance of digitization lies in its ability to ensure that cultural heritage is not only preserved but also made accessible to a global audience.

In recent years, the urgency of digitization has intensified due to armed conflicts, climate change, and rapid urbanization that threaten physical cultural sites worldwide. Museums, libraries, and archives have recognized that digital preservation serves as insurance against irreversible loss. Additionally, digitization democratizes access to cultural materials, allowing people from different socioeconomic backgrounds and geographical locations to engage with artifacts they might never see in person.

Empirical provenance is crucial for maintaining a transparent record of the methods used to create digital surrogates. This involves documenting the authenticity and reliability of digital representations, which is essential for academic research and public trust in these resources. Clear documentation of scanning techniques, resolution standards, and post-processing methods ensures scholarly integrity. Perpetual digital conservation requires effective digitization strategies that include plans for long-term storage and preservation. This requires adopting scientific methods that guarantee the availability of digital heritage for future generations. Digital preservation frameworks must address file format migration, redundant backup systems, and regular data integrity checks to prevent digital decay.

Democratization of technology ensures that access to digitized cultural heritage should be equitable, allowing researchers, educators, and the general public to engage with these resources easily. This principle emphasizes the need for user-

friendly platforms that facilitate access to digital collections. Open-access policies, multilingual interfaces, and compatibility with assistive technologies for people with disabilities are essential components of this principle.

Recent advancements in technology have greatly enhanced the capabilities of digitization efforts. 3D modeling and scanning techniques such as photogrammetry and laser scanning allow for detailed three-dimensional representations of artifacts, providing immersive experiences for users. High-resolution 3D models can capture intricate details invisible to the naked eye, enabling researchers to study artifacts without physical contact. Virtual Reality (VR) and Augmented Reality (AR) create interactive environments where users can explore cultural sites and artifacts in innovative ways. For instance, virtual tours enable individuals to experience historical locations without physical travel. AR applications can overlay historical information into real-world environments, enriching educational experiences.

Digital archiving ensures that cultural materials are stored securely and can be retrieved efficiently. This includes implementing standards for metadata and data management to enhance discoverability. Standardized metadata schemas such as Dublin Core and METS facilitate interoperability between different digital repositories. Artificial Intelligence and Machine Learning technologies are increasingly used for automated cataloging, image recognition, and pattern analysis in cultural heritage collections. Machine learning algorithms can help restore damaged images, transcribe historical documents, and identify connections between artifacts across different collections.

The digitization of cultural heritage brings numerous advantages. Increased accessibility means digital resources can be accessed from anywhere in the world, breaking down geographical barriers and allowing diverse audiences to engage with cultural heritage. This is particularly valuable for educational institutions in developing countries that may lack access to physical collections. Enhanced preservation through digital formats protects against physical deterioration caused by time and environmental factors. By creating digital copies, institutions can

preserve the essence of artifacts even if the originals are lost or damaged. Digital surrogates also reduce the need for physical handling, minimizing wear on fragile items.

Promotion of cultural awareness is achieved through digitized collections that raise awareness about cultural heritage and its significance. Educational programs utilizing these resources can foster a deeper understanding and appreciation among younger generations. Interactive digital exhibitions can engage audiences in ways that traditional displays cannot. Support for research allows scholars to benefit from easy access to a wealth of information that can be used for academic research, leading to new insights into history, art, and culture. Digital tools enable comparative analysis across collections, remote collaboration, and the use of computational methods for humanities research. Economic opportunities emerge as enhanced access to cultural heritage can stimulate tourism and related industries by attracting visitors interested in virtual experiences or educational programs based on digital content. Digital heritage can also support creative industries, providing inspiration and source material for contemporary artists and designers.

Despite its many benefits, digitization faces several challenges. One major concern is digital obsolescence, as rapid technological change can make certain formats outdated, jeopardizing long-term access to valuable cultural data if not properly managed. File formats commonly used today may become unreadable in the future without active migration strategies. Resource constraints affect many institutions that lack the funding or expertise necessary to implement comprehensive digitization projects. This can lead to disparities in access between well-funded institutions and those with limited resources. Smaller museums and local archives often struggle to compete with larger institutions for digitization funding.

Copyright issues complicate digitization efforts, particularly when dealing with proprietary content or traditional knowledge that may not have clear ownership rights. Balancing public access with intellectual property protection remains a persistent challenge. Quality and authenticity concerns require ensuring that digital

representations accurately reflect original artifacts, which demands significant technical expertise and quality control. Poor digitization can result in misleading representations that compromise scholarly value. Cultural sensitivity is essential when digitizing indigenous and sacred materials, as this raises ethical questions about appropriate access and use. Some communities have cultural protocols that restrict who can view or handle certain materials, which may conflict with open-access principles.

Several successful initiatives illustrate the potential of digitization in preserving cultural heritage. Europeana is a European digital platform that aggregates millions of digitized items from various cultural institutions across Europe, providing a comprehensive resource for researchers and the public alike. It offers access to paintings, manuscripts, books, photographs, and audiovisual materials from over 3700 institutions. Vietnam's Heritage Digitization Program represents the Vietnamese government's initiative to digitize its tangible and intangible cultural heritage comprehensively. This includes creating digital archives for national treasures recognized by UNESCO, preserving traditional music, oral histories, and architectural documentation.

Google Arts and Culture is a platform that partners with museums worldwide to provide high-resolution images of artworks and virtual tours of cultural institutions, bringing world-class collections to global audiences. The Digital Public Library of America aggregates digitized materials from libraries, archives, and museums across the United States, providing free access to millions of photographs, manuscripts, books, and other primary sources.

In conclusion, the digitization of cultural heritage is an essential strategy for preserving our collective history in an increasingly digital world. By leveraging modern technologies and adhering to key principles such as empirical provenance, perpetual conservation, and democratized access, we can ensure that cultural legacies are safeguarded for future generations. While challenges remain, the benefits – ranging from increased accessibility to enhanced preservation – underscore the

transformative potential of digitization in enriching our understanding and appreciation of diverse cultures worldwide. As we continue to advance in this field, it is vital that we address these challenges collaboratively to maximize the impact of our efforts on global cultural heritage preservation.

The future of cultural heritage preservation lies in the integration of digital and physical approaches, where digitization complements rather than replaces traditional conservation methods. By investing in infrastructure, training, and international cooperation, we can build a comprehensive digital heritage ecosystem that serves both current and future generations.

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Kabakov I. P.

DIGITAL WAR: HOW CUTTING-EDGE TECHNOLOGIES SHAPE THE MODERN BATTLEFIELD

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Nowadays, the pace of scientific development is enormously rapid. New

discoveries and technologies emerge almost every day across various branches of science. The applications of these innovations are remarkably wide. However, today's focus will be placed on one specific area that reflects the reality faced by all Ukrainians today – war.

War is something we never wanted on our land, nevertheless, ones it comes, you must always stay several steps ahead of your opponent to gain an advantage on the battlefield and ultimately win. At the beginning of the full-scale invasion, Ukraine faced a shortage of various types of missiles for both attack and defense. In response, Ukrainian engineers made a vital breakthrough, becoming some of the world's leading drone manufacturers. In addition, many other modern technologies including AI, AR/VR, artificial satellites and other space related technologies have been developed or significantly improved to meet the needs of the Ukrainian military. Since February 2022, a substantial number of military technology-oriented companies of different sizes have emerged in Ukraine, making a significant contribution to strengthening country's defense capabilities.

The key reason Ukraine is focusing on developing high-quality drones is the wide range of their functionality and, accordingly, the broad spectrum of applications based on those capabilities. For instance, we can distinguish three main categories of drones: unmanned aerial vehicles (UAVs), unmanned ground vehicles (UGVs) and unmanned underwater vehicles (UUVs). Let's look at each of these types in more detail.

Unmanned aerial vehicles are a type of technology that has broken the classical standards of warfare. Five years ago, few people would have imagine a small flying drone capable of carrying and dropping explosives, being powered by artificial intelligence to attack and even disable a tank many times its size, or collecting crucial data about the battlefield and enemy positions. Aerial drones in Ukraine have undergone a remarkable evolution. They significantly influenced the course of events, and, most importantly, this type of drone has already saved countless lives and will, hopefully, save many more in the future.

Next come unmanned ground vehicles. One of the key engineers in this field is Borys Drozhak, who gained strong professional experience working as a DevOps specialist, including at international companies such as DataRobot. Shortly after the beginning of the war, Borys returned to Ukraine and soon became a co-founder of the military-tech company Rovertech, together with Bogdan Zmiy and Vasyl Korenyovsky. The results achieved by Rovertech are truly astonishing. The company has three main product lines, all of them are unmanned ground vehicles created for different purposes. (Zhakhalov, 2025)

The first and most well-known product is Zmiy, a ground drone named after one of its creators, Bogdan Zmiy, who tragically passed away. Bogdan made an enormous contribution to the development of the company and drone manufacturing in Ukraine. The technologies he dedicated his life during the war to continue to evolve, carrying on his mission. The Zmiy drone comes in two versions: the standard Zmiy, designed for demining and Zmiy Logistychny, intended for logistics.

The demining version is used to clear territory of various types of mines. It is durable, lightweight and inexpensive to repair, even if it detonates an anti-tank mine. Two operators can control the drone remotely, thus completely removing the risk to human life. In cases of smaller mine explosions, the drone can often keep moving, continuing its mission. This capability makes it particularly valuable during wartime and will remain crucial after achieving our victory, when vast areas of Ukrainian land will need to be demined.

The second mentioned version, Zmiy Logistychny, is a logistic ground drone capable of transporting cargo or even evacuating wounded soldiers. Last but not least, Rovertech also produces Zhuravel – a robot for transport and recovery, built to withstand tough conditions. Due to their remarkable effectiveness all the listed systems provide essential support on the battlefield. There are numerous examples of how Rovertech drones have saved lives by facilitating the evacuation of injured soldiers from places that would have been nearly impossible to reach without such

technology. Additionally, they are helpful in delivering essential supplies to the same areas where a standard vehicle would struggle to reach.

Another important advantage is the speed and accessibility of production. According to official information, one person can assemble a Zmiy robot in just two days if the parts prepared, such speed is a crucial factor during the war time. Moreover, the robots are built using parts manufactured in Ukraine, which additionally supports the national economy. After the war, once Ukraine's land is demined, these robots will not be left behind, since their design allows them to be easily adapted for use in the agricultural sector (Lanovets, 2025).

Finally, unmanned underwater vehicles. This technology might not be used that widely due to its ability to operate only underwater, nevertheless, there are several successful cases of their usage by Ukrainian army for specific missions. For example, in June 2025, the Security Service of Ukraine carried out an attack with this type of weapon on the Crimean bridge, which is an important logistic route for the enemy to transfer its military forces and equipment to the peninsula. The attack caused damage to the bridge supports and prevented the movement of heavy vehicles across it.

To sum up, modern technologies and human ingenuity play a determinative role on the battlefield. Access to advanced innovations can save lives, reduce the need for people to perform dangerous tasks, such as demining, directly and gain significant strategic advantages at a comparatively lower cost. Prioritizing the development and enhancement of cutting-edge technologies is essential not only to resist ongoing aggression but also for ultimately achieving victory, enabling faster recovery and favoring the prosperity on Ukrainian soil.

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DIGITAL MARKETING STRATEGIES FOR SMALL SERVICE ENTERPRISES IN UKRAINE

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As a student living in Ukraine, I constantly see how small businesses around me depend on digital channels. Before going to a café, printing a photo, or making an appointment with a hairdresser, people first check Google, Instagram, or Telegram chats. For small service companies in small towns, this is both a challenge and an opportunity. Digital marketing in this context means using online tools – websites, social media, messaging apps, email, and online advertising – to promote services and build long-term relationships with customers. Modern research shows that such tools really help small and medium-sized enterprises (SMEs) grow and remain competitive (Caraballo Payares, Luna & Carbal Herrera, 2023).

An open-source study by Sharabati et al. analyzed 190 companies and concluded that online advertising, social media marketing, search engine optimization (SEO), and customer engagement through digital channels have a positive impact on the financial performance of SMEs (Sharabati, Ali, Allahham, Hussein, Alheet & Mohammad, 2024). A paper by Caraballo Payares and colleagues on the implementation of digital marketing in Colombian SMEs shows a similar picture: firms that actively adopt digital tools demonstrate better results, but a significant part of owners simply doesn’t have the knowledge to use these tools systematically (Caraballo Payares, Luna & Carbal Herrera, 2023). That is, the

technologies are already available, but the human factor often becomes the main limitation.

For Ukraine, the topic of digital marketing is particularly sensitive due to the full-scale war. Oklander et al. studied how small and medium-sized businesses survived and developed during the war thanks to digital channels (Oklander, Yashkina, Zlatova, Cicekli & Letunovska, 2024). Based on in-depth interviews with entrepreneurs from various regions, they described three periods: shock, adaptation, and growth. During the adaptation and growth stages, social media, messaging apps, and online marketplaces proved to be the most effective, allowing companies to stay connected with customers even when physical locations had to be closed or relocated to safer locations (Oklander, Yashkina, Zlatova, Cicekli & Letunovska, 2024). This confirms that digital channels for Ukrainian SMEs have long ceased to be an "additional bonus" and have become a tool for survival.

If you look at a typical small service enterprise in a Ukrainian town – a photo studio, a café, a beauty salon, or a language school – it becomes clear that large advertising budgets are unrealistic for them. Often, a single person serves as the director, accountant, and SMM manager. Research shows that for such businesses, the most realistic strategy is to start with simple steps: a basic online presence, clear information about services, and regular communication with customers (Caraballo Payares, Luna & Carbal Herrera, 2023). Even a simple Instagram or Facebook page with current prices, examples of work, and a clear work schedule removes most of the client's questions and increases trust.

The next logical step is combining digital marketing with e-commerce. Aidargalieva and colleagues research how integrating online sales and digital promotion helps small and medium-sized enterprises optimize online sales and survive in an unstable economy (Aidargaliyeva, Seisekenova & Kydyrbayeva, 2025). For a small photo studio, this might mean online print ordering with the ability to upload files directly from a smartphone; for a beauty salon – an online booking system via a website or social media; for a café – an online menu with a pre-order

option. When a customer can book, order, or pay for a service online, the risk of them going to a competitor is significantly reduced.

Social media plays a special role in the strategy of small service enterprises. They create an emotional picture of the business: here you can show the team, the atmosphere, the "behind the scenes", and real customer stories. Short videos on TikTok or Reels give small brands a chance to “shoot” without huge budgets. The TikTok platform itself actively works with SMEs: in 2025, the company created its first SME Council to amplify the voice of small businesses and adapt the platform’s tools to their needs (TikTok Newsroom, 2025, April 15). For Ukrainian entrepreneurs, this is a signal that global platforms are ready to cooperate and can be not only advertising platforms, but also partners in training and development.

New opportunities also bring new risks. When all business accounts are linked to a single smartphone and passwords are written down in a notebook, any hack of a page or email can block communication with customers. Gen Digital's press release about Norton Small Business 2025 highlights the increasing number of data leaks and account takeovers that specifically affect small companies, therefore, separate Dark Web Monitoring and Social Media Monitoring features were added for business accounts (Gen Digital, 2025, September 4). In fact, cybersecurity is becoming part of marketing: it’s difficult to talk about online promotion if a company can’t protect its pages and customer data.

Another serious problem is the lack of time and competencies. Many owners openly admit that they don't have time to follow all the trends: formats, algorithms, and advertising cabinets are constantly changing. Studies in different countries have documented similar barriers: low level of digital literacy, lack of a clear strategy, and fear of “wasting” budget on advertising that will not produce results. In my opinion, this is where universities, business incubators, and local communities can be most helpful – through short practical trainings, mentoring programs, and student projects for real small businesses.

In summary, we can say that digital marketing is not a magic pill, but it has already become the norm for small service enterprises in Ukraine. Open studies shows that the systematic use of social media, online advertising, SEO and e-commerce increases the chances of SMEs not only to survive but also to grow even in conditions of war and economic instability. For a small entrepreneur, the key task is to start with basic steps, test different channels, measure simple indicators, and gradually build digital competencies, while not forgetting to protect online accounts. With such a balanced approach, digital marketing can transform a local "service point" into a recognizable brand for people both in their hometown and far beyond.

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THE IMPACT OF INFORMATION TECHNOLOGIES ON BUSINESS MANAGEMENT

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The modern business environment is characterized by rapid changes, globalization, and increasing competition. In these highly dynamic conditions, information technologies (IT) have evolved from being a simple support function to becoming an essential tool for effective business management and strategic planning. For a student of the Faculty of Management and Business, understanding the comprehensive role of IT is crucial for future professional success. This article explores how information technologies transform traditional management processes, optimize daily operations, and improve overall organizational efficiency.

First of all, information technologies provide managers with real-time access to accurate and comprehensive data. In the past, decision-making was often based on intuition, historical trends, or delayed reports, which could lead to missed opportunities or strategic errors. Today, managers use specialized software, such as Enterprise Resource Planning (ERP) systems, to monitor all business processes simultaneously. ERP systems integrate various departments – such as finance, human resources, manufacturing, and sales – into a single unified platform. This allows for quick reactions to market changes, improves cross-departmental communication, and minimizes financial risks (Ponomarenko, 2021). Furthermore, the integration of Big Data analytics enables companies to process massive amounts of unstructured information to identify hidden market trends and forecast future consumer demands.

Secondly, the rapid development and integration of cloud technologies have completely revolutionized teamwork, data storage, and corporate collaboration. Cloud computing enables employees to access corporate information and software applications from anywhere in the world, at any time. This flexibility became especially critical during the global transition to remote and hybrid work models. Cloud solutions reduce the heavy costs of purchasing and maintaining physical servers, while simultaneously providing high scalability for growing businesses. Tools like cloud-based project management software ensure that geographically dispersed teams can collaborate on tasks in real-time, share documents securely, and maintain high productivity.

Furthermore, IT significantly enhances Customer Relationship Management (CRM). In today's customer-centric market, understanding the buyer is more important than ever. Modern CRM systems help businesses track customer behavior across multiple channels, analyze their personal preferences, and provide highly personalized services. By keeping a detailed history of client interactions, managers can anticipate customer needs and resolve issues proactively. This leads to higher customer satisfaction, improved retention rates, and increased brand loyalty, which directly impacts the company's long-term profitability. Automated digital marketing tools also allow businesses to segment their audiences accurately and launch targeted advertising campaigns with significantly lower budgets compared to traditional media.

Another crucial area transformed by IT is Supply Chain Management (SCM). Modern digital logistics systems utilize GPS tracking, Internet of Things (IoT) sensors, and automated inventory management software. These technologies allow managers to monitor the movement of raw materials and finished goods in real-time. By optimizing inventory levels and predicting delivery times accurately, companies can significantly reduce storage costs and avoid stockouts, ensuring that customers receive their products on time.

Moreover, the implementation of Artificial Intelligence (AI) and Machine Learning (ML) is opening new horizons in business management. AI-powered chatbots now handle a large portion of basic customer support inquiries, allowing human employees to focus on more complex problems. Machine learning algorithms assist managers in risk assessment, dynamic pricing strategies, and even in the recruitment process by screening thousands of resumes to find the best candidates.

Despite these obvious advantages, the implementation of information technologies in business management faces certain challenges. Companies must invest significant financial resources not only in purchasing software but also in continuous employee training. Organizational resistance to change is a common psychological barrier, as employees may feel overwhelmed by new digital tools. Additionally, cybersecurity remains a major concern. As the digitalization of business processes increases, so does the risk of data breaches, ransomware, and cyberattacks. Therefore, modern managers must not only understand how to utilize IT for growth but also know how to implement strict security protocols to protect sensitive corporate information.

In conclusion, information technologies are the absolute core of modern business management. They optimize daily operations, improve data-driven decision-making, enhance customer experiences, and create new opportunities for sustainable growth. Future managers must continuously develop their digital literacy and adapt to technological innovations to remain competitive in the labor market and successfully lead their organizations in the digital era.

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INFORMATION TECHNOLOGIES IN MODERN METROLOGY

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Metrology is the science of measurement and represents one of the fundamental pillars of scientific research, industrial production, and technological progress. Accurate and reliable measurements ensure product quality, safety, interchangeability, and compliance with national and international standards. In modern conditions, metrology is closely connected with information technologies, which significantly expand the capabilities of measurement systems and improve their efficiency, reliability, and flexibility.

The integration of information technologies into metrology has transformed traditional measurement approaches. Modern digital technologies enable the creation of intelligent measurement systems that combine hardware, software, and advanced data analysis tools. As a result, measurement processes have become faster, more

accurate, and less dependent on human factors, which is especially important in high-precision and large-scale industrial applications.

One of the key roles of information technologies in metrology is the digitalization of measuring instruments. Digital devices replace traditional analog instruments and provide higher accuracy, improved resolution, and better long-term stability. Measurement results are automatically converted into digital form, which simplifies data storage, transmission, and processing. This significantly reduces the risk of errors caused by manual data recording.

Modern metrology increasingly emphasizes the automation of measurement processes. Automated measurement systems are widely used in industrial enterprises, calibration laboratories, and research centers. These systems allow continuous monitoring of technological processes and ensure stable measurement conditions. Specialized software controls the operation of instruments, collects measurement data, performs preliminary analysis, and generates standardized reports in real time.

Information technologies play a crucial role in measuring data processing and analysis. Modern measurement systems generate large volumes of data that cannot be processed manually. Advanced software tools based on mathematical models, numerical methods, and statistical algorithms are used to analyze results, detect systematic and random errors, and estimate measurement uncertainty. Statistical processing improves the reliability and credibility of measurement results.

Calibration and verification processes are also strongly influenced by information technologies. Digital calibration management systems store calibration results, certificates, and complete histories of measuring instruments. These systems automatically track calibration intervals, generate notifications, and ensure traceability to national and international measurement standards. The use of digital documentation significantly reduces paperwork and minimizes the risk of losing important information.

The development of smart measuring instruments is closely related to

information technologies. Smart sensors and measuring devices are equipped with microprocessors, internal memory, and communication interfaces. They can perform self-diagnostics, automatically adjust measurement parameters, and compensate for environmental influences such as temperature, pressure, vibration, and humidity. This increases measurement accuracy in complex operating conditions.

Cloud technologies have become an important component of modern metrology. Cloud-based platforms provide remote access to measurement data and allow cooperation between laboratories located in different regions or countries. This supports international comparisons, harmonization of measurement standards, and joint scientific research. Cloud solutions also ensure secure long-term storage and efficient processing of large datasets.

Remote and virtual measurement technologies are actively developing in metrology. Remote laboratories allow users to control measuring equipment via the internet and conduct experiments at a distance. Virtual laboratories and computer simulations are widely used in education and professional training, providing students with practical skills without direct access to expensive equipment. These technologies improve accessibility and reduce training costs.

Cybersecurity has become an essential aspect of information technologies in metrology. As measurement systems become more connected to digital networks, the protection of measurement data becomes critically important. Unauthorized access, data manipulation, or loss of information can lead to serious consequences in industry, healthcare, energy, and defense sectors. Therefore, modern metrological systems incorporate cybersecurity measures to ensure data integrity and confidentiality.

Information technologies also enable the creation of digital twins in metrology. A digital twin is a virtual representation of a physical measurement system that allows simulation, monitoring, and optimization of its performance. Digital twins help predict system behavior, reduce downtime, and improve measurement accuracy. This approach is particularly effective in complex automated production

environments.

Another important direction of information technologies in metrology is the use of artificial intelligence and machine learning. These technologies are applied for pattern recognition, predictive analysis, anomaly detection, and optimization of measurement processes. Machine learning algorithms can analyze large datasets, identify hidden relationships, and continuously improve measurement accuracy based on accumulated data.

Big data technologies are also a significant component of contemporary metrology. Measurement systems integrated into industrial networks generate massive amounts of data that require advanced processing methods. Big data platforms enable efficient storage, fast processing, and deep analysis of measurement information, allowing early detection of deviations and long-term trend analysis.

In addition, information technologies contribute to the standardization and unification of measurement procedures. Software platforms support the implementation of international standards and ensure uniform measurement methods across different laboratories and organizations. This is essential for global trade, scientific cooperation, and technological development.

Another important direction of information technologies in metrology is the development of decision support systems for metrological management. Such systems help specialists analyze measurement results, evaluate risks related to measurement errors, and select optimal measurement methods. By integrating databases, statistical tools, and expert knowledge, decision support systems increase the reliability of conclusions and reduce the influence of subjective factors in metrological practice.

Information technologies also contribute to the improvement of education and professional training in the field of metrology. Digital learning platforms, virtual laboratories, and simulation software allow students and specialists to study measurement principles and practice their skills without direct access to expensive equipment. This approach ensures continuous professional development and

supports the formation of a new generation of metrologists who are well adapted to digital technologies.

Furthermore, digital information systems support decision-making in metrology by providing comprehensive analytical tools and visualization methods. Dashboards, graphs, and automated reports allow engineers and metrologists to quickly assess measurement results, identify trends, and predict potential problems.

Another promising direction is the integration of metrological information systems with enterprise resource planning and quality management systems. This integration improves coordination between departments, increases transparency of production processes, and enhances overall quality control.

In conclusion, information technologies have become an integral part of modern metrology. They enhance measurement accuracy, automation, efficiency, and reliability while enabling advanced data processing, cybersecurity, and international collaboration. The continuous development of digital technologies will further strengthen the role of metrology in science, industry, and society, ensuring sustainable technological progress.

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THE ROLE OF ARTIFICIAL INTELLIGENCE IN CONTEMPORARY SOCIETY

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Artificial intelligence is a transformative technology that has a significant impact on various aspects of modern life. It encompasses the capacity of computer systems to execute functions traditionally associated with human intelligence, such as learning, information analysis, reasoning, decision-making, language and image recognition, equipment control, and content creation. The range of AI applications is extensive, from elementary operations like text translation to advanced processes such as forecasting and traffic management. AI has become deeply embedded in everyday activities, often operating unobtrusively, yet exerting a substantial and measurable impact.

The widespread adoption of artificial intelligence can be attributed to its versatility across various domains. In medicine, AI-powered systems facilitate enhanced diagnostic accuracy, risk assessment, and the development of individualized treatment strategies. Within the financial sector, AI serves as a vital resource for fraud prevention, enabling institutions to deliver more efficient and convenient customer service. Furthermore, advancements in education are evident through platforms that adapt to individual learning needs, while digital assistants contribute to improved accessibility and effectiveness in the educational process.

This is achieved by studying the patterns of the human brain and analyzing cognitive processes. If you have ever used a fingerprint scanner, Face ID on your phone, or the Diya app, typed text with T9, or interacted with a chatbot in an online store, you've engaged with AI systems that rely on pattern recognition, machine learning algorithms, and natural language processing to interpret input, make predictions, and deliver personalized responses (Мариненко, 2025). This demonstrates how artificial intelligence seamlessly integrates into everyday activities, boosting efficiency, convenience, and user experience across various

aspects of daily life. In the industrial sector, artificial intelligence is employed to monitor equipment status, prevent failures, optimize production processes, and improve product quality. Within transportation, AI supports traffic analysis, informs logistics route planning, and underpins advancements in autonomous vehicles. Trade and marketing leverage AI capabilities to analyze consumer behavior and provide tailored recommendations. In both cyber and physical security domains, AI has become an essential tool. Additionally, in agriculture, AI facilitates more accurate soil monitoring, crop planning, and efficient resource management.

But along with great opportunities come risks. Model bias is one of the most noticeable problems because the quality of algorithms directly depends on the data they are trained on. Errors in development or code can lead to incorrect decisions, especially in critical areas. Systems remain vulnerable to cyberattacks, and handling large amounts of personal data creates additional legal and reputational risks. Furthermore, legislation in the field of AI is still being developed, and the improper use of such technologies can have serious consequences.

Socio-economic changes are also significant. The labor market is gradually evolving: some jobs are being automated, while new fields related to data, programming, modeling, and controlling technological processes are emerging. The importance of “soft” skills, such as critical thinking, creativity, and communication, is only growing because they are currently difficult for machines to fully replicate. Data is becoming a new valuable resource, and access to technologies can create disparities between different countries and social groups.

Clear rules and ethical standards are essential to ensure the safe and responsible use of AI. This includes the transparency of algorithms, the ability to explain how a system reaches a decision, the accountability of developers and users, and safeguarding privacy. International cooperation remains crucial, as AI challenges have long exceeded the boundaries of individual countries. Education is vital in this effort, as it prepares the next generation to work with emerging technologies (Бойлет, 2018).

In the future, artificial intelligence is expected to become increasingly integrated into all areas of life, from healthcare to government services. Multimodal systems that work simultaneously with texts, images, audio, and video will be actively developed. The demand for understandable and explainable models will grow (Бойлет, 2018). At the same time, ethical and legal requirements for working with data and algorithms will increase.

Experts offer several key recommendations: the government should establish balanced regulations and support the growth of digital infrastructure; businesses need to be transparent when handling data and carefully assess the risks of bias; educational institutions should incorporate the fundamentals of AI into their curricula; and citizens ought to improve their digital literacy and approach new technologies responsibly. Artificial intelligence can significantly enhance our lives, accelerate work, and unlock new opportunities. However, for the benefits to surpass the risks, innovation must be paired with responsibility.

Moreover, from an anthropological perspective, artificial intelligence provides unique benefits by reshaping human behavior, social structures, and cultural practices. AI mediates daily routines, communication, and knowledge-sharing, affecting how individuals organize their time, approach problem-solving, and interact within communities. By automating repetitive or cognitively demanding tasks, AI enables humans to focus on creative, strategic, and relational activities, altering traditional divisions of labor in households, workplaces, and broader social systems. Additionally, AI supports cross-cultural interaction and linguistic diversity through real-time translation, transcription, and speech recognition, allowing people from different backgrounds to communicate, collaborate, and access information more effectively. Anthropologically, AI contributes to the co-evolution of humans and technology: people adapt their routines, decision-making strategies, and social norms in response to AI systems, while these systems are shaped by human input, ethical frameworks, and cultural expectations. Furthermore, AI enhances human adaptability by providing predictive insights, personalized guidance, and context-

sensitive recommendations, thereby improving decision-making in both everyday life and high-stakes environments (Bekerman, 2024). The interplay between humans and AI reflects broader sociocultural transformations, extending cognitive capacities, facilitating social coordination, and fostering new forms of cultural expression and interaction.

Conclusion. Artificial intelligence has emerged as a transformative force with profound implications across various sectors, including medical, financial, educational, industrial, transportation, agricultural, and security. It fundamentally alters how individuals interact with technology and perform cognitive and operational tasks. Its capacity to analyze complex data, recognize patterns, make predictions, and provide personalized responses enables enhanced efficiency, safety, and decision-making, while simultaneously opening avenues for innovation and professional development. However, the deployment of AI also entails significant challenges, including algorithmic bias, cybersecurity vulnerabilities, ethical dilemmas, legal ambiguities, and socio-economic disparities, highlighting the need for transparent, accountable, and responsible implementation. From an anthropological perspective, AI reshapes human behavior, social structures, and cultural practices by automating repetitive or cognitively demanding tasks, facilitating cross-cultural communication, and supporting co-evolutionary interactions between humans and technology. This fosters the emergence of new routines, social norms, and knowledge-sharing practices, enhancing adaptability, creative engagement, and cognitive capacities in diverse contexts. Ensuring that the benefits of AI are maximized requires a multi-faceted approach, including the development of clear regulations and ethical standards, the incorporation of AI literacy into education, international cooperation, and the promotion of digital competency among citizens. Ultimately, artificial intelligence represents both a powerful tool and a societal challenge: when guided by responsibility, ethical oversight, and human-centered design, AI can enhance quality of life, empower

individuals and communities, and drive sustainable, inclusive progress in contemporary society.

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PROSPECTS FOR THE DEVELOPMENT OF INTELLIGENT TRANSPORT SYSTEMS BASED ON MACHINE LEARNING IN UKRAINE

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The development of transport infrastructure is a fundamental factor in economic stability and population mobility. In the 21st century, traditional approaches to traffic flow management are increasingly losing their effectiveness due to the growth in the number of cars, urbanization, environmental pressure, and the increasing need for digitalization.

Intelligent transportation systems (ITS) are a set of technologies that integrate sensor networks, video analytics, IoT, artificial intelligence, and machine learning to

optimize traffic, increase safety, and improve the condition of transportation infrastructure (SmartRoads, 2023).

For Ukraine, which needs to modernize its road network and digital solutions, ITS is a promising tool for transforming the transport industry.

Intelligent transportation systems include: sensor networks and IoT devices; video surveillance systems; automatic traffic flow analyzers; cloud and edge computing; modeling and prediction systems; machine learning and artificial intelligence (Pidru4nyky.com., 2022).

Machine learning allows for the automatic analysis of multidimensional data, prediction of traffic situations, detection of anomalies, and decision-making without human intervention (Machine Learning in Intelligent Transportation, 2022). Modern ML models – GNN, LSTM, CNN – demonstrate high accuracy in predicting traffic flows and driver behavior (Jiang & Luo, 2020).

Below are 20 modern solutions that are used worldwide and can be implemented in Ukraine.

1. Adaptive traffic light systems. Traffic lights change phases based on analysis of current traffic, reducing congestion and waiting times (Donetsk National University, 2021).

2. Cloud-based ITS with IoT and edge computing. Sensors transmit data to the cloud, where ML models analyze the situation and make decisions in real time (AIT Journal, 2023).

3. Smart Parking (intelligent parking systems). Sensors determine occupancy, and ML predicts available spaces at different times of the day (PAG Journal, 2024).

4. ANPR – Automatic Number Plate Recognition. Modern CNN models provide accurate number plate recognition and violation control (Hikvision, 2023).

5. Automatic detection of traffic violations. Computer vision records red light running, dangerous maneuvers, and speeding (ResearchGate, 2022).

6. Drones for traffic analysis. Drones record traffic jams, accidents, traffic density, and road conditions in real time (ArXiv, 2024).

7. Accident prediction models. ML analyzes the relationships between weather, speed, road surface and predicts accident points (Accident Prediction ML Models, 2021).

8. Smart Intersections. 360° cameras, LiDAR, and AI optimize traffic intersections and ensure safety (IEEE, 2021).

9. V2X (Vehicle-to-Everything) technologies. Vehicles and infrastructure exchange data to prevent accidents and optimize traffic (ETSI, 2023).

10. Weigh-in-Motion. ML classifies transport and detects overloading without stopping vehicles (Transport Research Portal, 2020).

11. Environmental transport monitoring. Analysis of CO_2, noise, and dust levels allows for the introduction of eco-routes and restrictions (VNTU Journal, 2023).

12. Road surface defect detection. Computer vision automatically detects potholes, cracks, and deformations (IEEE, 2022).

13. Intelligent public transport systems. GPS monitoring, automatic route optimization, and passenger flow analysis (TNTU, 2023).

14. Dynamic speed control. ISA systems set the recommended speed based on ML and current road conditions (European Commission, 2022).

15. Freight transportation optimization. ML selects the best routes taking into account traffic, fuel consumption, and delivery time (ML for Freight Optimization, 2021).

16. Automation of emergency rescue services. ML identifies accidents from video and notifies emergency services (ITS World Congress, 2023).

17. “Smart cities” and their integration with ITS. ITS are combined with lighting, energy and security systems (Smart City Hub, 2022).

18. Digital twins of road infrastructure. Cloud-based infrastructure models predict road and bridge wear (Springer, 2021).

19. Priority for emergency vehicles. Traffic lights create a “green corridor” for an ambulance or fire truck (IEEE, 2021).

20. Transport demand analysis. ML models future loads and plans infrastructure (Transport Demand ML Modelling, 2020).

The implementation of modern ITS will enable to: reduce traffic congestion in cities; improve road safety; reduce road repair costs; optimize public and freight transport routes; improve the environmental sustainability of cities; automate violation control; make transportation more predictable and convenient.

Ukraine has a strong IT sector, which creates favorable conditions for the implementation of intelligent transport solutions in cities and the national road network.

The main challenges are: high cost of equipment; need for specialists in ML, IoT, AI; lack of quality road data; cybersecurity and personal data protection; lack of standardization at the state level.

Intelligent transportation systems based on machine learning are a key direction in the development of the transportation industry. For Ukraine, the implementation of ITS opens up opportunities to reduce traffic congestion, improve safety, optimize transportation, and enhance infrastructure quality.

With the development of digital technologies and government support, ITS can become the foundation for building a modern, efficient, and safe transport system.

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ARTIFICIAL INTELLIGENCE (AI) TRANSLATION: WILL IT REPLACE HUMAN TRANSLATION?

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In recent years, translation technology has developed at an impressive pace, changing the way information is disseminated between languages and cultures. Today, the main question is not whether artificial intelligence can translate, but how profoundly it will change the translation profession itself. The translation market is growing steadily, and AI-based tools have become a fundamental part of this growth. It is estimated that by 2022, the global translation industry will exceed 57 million USD, indicating that the demand for multilingual communication continues to grow in our increasingly globalized environment.

Translation has become increasingly important in the context of global economic integration. It underpins all communication, both for individual businesses and for the diplomacy of entire countries.

The global translation industry has always been closely linked to cultural exchange, international business, and communication. With globalization accelerating, the demand for translation services has grown dramatically. Artificial intelligence, through machine learning and neural networks, has offered a solution to the ever-increasing need for fast and affordable translation. Machine translation systems such as Google Translate or DeepL can now produce coherent and grammatically correct translations in dozens of languages within seconds. Their algorithms analyze billions of texts to predict the most probable meaning of words and phrases, adapting to context more efficiently than ever before. For companies and individuals, this technological shift has made cross-cultural communication easier and faster than at any time in history.

Nevertheless, the introduction of artificial intelligence into translation has also created new challenges. While machines excel at processing information quickly and accurately, they often lack the depth of understanding that characterizes human translators. Languages are not simply systems of grammar and vocabulary – they

carry emotion, cultural associations, irony, and historical context. Machines tend to interpret language as data, whereas humans interpret it as meaning. For example, idioms, metaphors, or humor often lose their essence in machine translation because algorithms cannot fully grasp cultural nuances or emotional tone. As a result, even though AI can produce a technically correct translation, it might fail to convey the intended message or mood.

Another important issue lies in the field of specialized translation. In areas such as law, medicine, science, or literature, accuracy and stylistic precision are critical. A single mistranslation in a legal document or a medical report can lead to serious consequences. Human translators in these fields rely on expertise, reasoning, and an understanding of context that AI systems still struggle to replicate. Similarly, literary translation requires creativity, emotional sensitivity, and artistic judgment – qualities that remain uniquely human. Artificial intelligence, although capable of imitating style, does not truly understand beauty, irony, or the subtle rhythm of poetic expression. Therefore, while AI can assist, it cannot yet replace the translator's individual voice or cultural intuition.

It is also important to consider the ethical and professional dimensions of AI in translation. The growing reliance on automated tools raises concerns about the future of human translators. Some professionals fear that machines will make their skills obsolete. However, the evolution of technology has historically demonstrated that new tools tend to change professions rather than eliminate them. In this context, AI is more likely to transform the translator's role from direct language converter to editor, post-processor, or linguistic consultant. Human expertise will remain essential for refining AI-generated texts, ensuring that they are accurate, culturally appropriate, and stylistically refined.

At the same time, AI has introduced significant advantages to the translation process. It has drastically reduced costs, improved accessibility, and accelerated information exchange. Businesses now reach international audiences almost instantly, and organizations can communicate across borders without language

barriers. Moreover, AI-based translation systems continue to improve through feedback loops: the more data they receive, the more accurate they become. This process of continuous learning has enabled neural translation systems to understand context, adapt to idiomatic usage, and even recognize emotional tone to a certain extent. Although far from perfect, these improvements demonstrate that AI is evolving toward greater linguistic sophistication.

However, one should not overlook the limitations of AI's learning process. Artificial intelligence relies entirely on existing linguistic data. It cannot generate meaning beyond what it has been trained on. When facing new expressions, creative constructions, or culturally specific references, AI systems often produce awkward or incorrect results. Human translators, on the other hand, possess the ability to interpret novelty and adapt to changing cultural realities. They can make creative decisions that machines cannot reproduce, especially when the text requires aesthetic or emotional depth.

From a broader perspective, the relationship between artificial and human translation should be seen not as competition but as cooperation. AI can perform routine and repetitive tasks, allowing human translators to focus on higher-level linguistic and creative work. In the modern translation process, the most efficient model appears to be hybrid: machines handle the first draft, and human professionals refine it for clarity, coherence, and cultural relevance. This combination of speed and intelligence allows for faster delivery without sacrificing quality. It is also likely that, in the near future, translation will become even more personalized, with AI adapting to each translator's unique style and preferences.

In the long term, artificial intelligence will undoubtedly continue to influence the translation industry. The boundaries between human and machine translation will blur as AI develops a deeper contextual understanding and better ability to mimic human communication. Yet, no matter how advanced these systems become, they will remain tools – powerful and efficient, but dependent on human creativity and ethical guidance. Language is not merely a sequence of words; it is a reflection of

human thought, culture, and identity. Machines can imitate, but they cannot feel. They can translate meanings, but they cannot experience them.

In conclusion, artificial intelligence has revolutionized the translation industry by increasing speed, accessibility, and global connectivity. It has changed how translators work, enabling them to collaborate with technology rather than compete against it. However, human translation remains irreplaceable where understanding, sensitivity, and creativity are essential. The most likely future is not one where AI eliminates human translators, but one where both coexist – each complementing the other's strengths. In this new era, translators will not disappear; they will evolve, guiding artificial intelligence to communicate not only words, but meaning, emotion, and culture.

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INFORMATION TECHNOLOGY

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Introduction

In the modern world, information technologies have become one of the main driving forces of human progress. Every sphere of life – from communication to healthcare, from business to education – depends on digital tools (Schwab, 2017). The integration of technologies such as artificial intelligence, cloud computing, and the Internet of Things (IoT) has not only changed the way we work but also the way we think, make decisions, and interact with others (Russel & Norvig, 2021).

For students of software engineering, understanding the social and economic impact of IT is essential. It helps us design systems that are not only efficient but also ethical, sustainable, and user-friendly (Tapscott, 2016). This paper analyzes the key aspects of information technologies, their influence on the development of modern society, and the challenges that accompany technological progress (Turban, Pollard & Wood, 2018).

Theoretical Framework and Evolution of IT

Information technology has gone through several stages of evolution – from the first electronic computers in the mid-20th century to the intelligent cloud systems of today (Chaffey & Ellis-Chadwick, 2019). In the early decades, IT served mainly as a tool for calculations and data storage. However, with the invention of personal computers and the Internet, it became a universal infrastructure for communication and innovation (Brynjolfsson & McAfee, 2014).

Today, the boundaries between software and hardware are increasingly blurred. A single smartphone combines the functions of a computer, camera, GPS, and social platform. Programming languages have evolved from low-level assembly

code to user-friendly environments such as Python and JavaScript, allowing developers to focus on logic instead of hardware limitations (Castells, 2010).

The rise of open-source communities, like GitHub and the Linux Foundation, made collaboration easier and accelerated technological development. This culture of knowledge sharing has become one of the key elements of modern software engineering (OECD, 2021).

Applications in Software Engineering and Industry

In industry, information technologies are used to automate production, manage logistics, and analyze market trends. Factories use sensors and IoT devices to monitor equipment and predict failures – a method known as predictive maintenance (Schwab, 2017).

In business, digital transformation has created new professions and business models. Cloud platforms such as Amazon Web Services, Google Cloud, and Microsoft Azure provide scalable solutions that allow companies to store and process massive amounts of data (Brynjolfsson & McAfee, 2014). Startups can now deploy global applications without investing in expensive servers.

In software engineering, technologies such as version control systems (Git), continuous integration (Jenkins, GitHub Actions), and containerization (Docker) help developers build more stable and secure software (Chaffey & Ellis-Chadwick, 2019). The DevOps methodology unites developers and administrators into one workflow, ensuring faster delivery of updates and better user satisfaction (Kizza, 2020).

Impact on Society and Education

Information technologies have transformed not only industries but also people's lifestyles. Social networks and instant messaging allow communication across continents in seconds. During the COVID-19 pandemic, online platforms became essential for remote work and education (Russel & Norvig, 2021).

In education, IT has opened new opportunities for self-development. Online courses, digital libraries, and simulation environments make learning more

interactive and accessible (Schwab, 2017). Students of programming can practice on virtual labs and participate in hackathons organized by tech companies.

However, this transformation also brings challenges. Digital dependency, information overload, and the spread of misinformation require critical thinking and media literacy. Modern education must therefore teach not only programming skills but also emphasize digital ethics and responsibility (Tapscott, 2016).

Cybersecurity and Ethical Challenges

As the digital world expands, cybersecurity becomes increasingly urgent. Every year, millions of users face data leaks, phishing attacks, and system vulnerabilities (Tapscott, 2016). Organizations respond with encryption, multi-factor authentication, and regular security audits.

For software engineers, understanding cybersecurity principles is as important as knowing how to code. Even a small programming mistake can expose thousands of users to risk. Ethical considerations are equally significant – developers must respect user privacy and ensure transparency in how data are collected and processed (Tapscott, 2016).

Artificial intelligence adds another ethical dimension. Algorithms can make decisions that affect people's lives – such as recruitment or credit scoring. Therefore, systems should be designed to be fair, explainable, and free from bias (Turban, Pollard & Wood, 2018).

Future Trends in IT Development

The future of IT will be shaped by automation, AI, and the merging of physical and digital environments. Smart cities, autonomous vehicles, and wearable devices will rely on real-time data and cloud computing (Russel & Norvig, 2021).

One promising direction is edge computing, where data are processed locally rather than in remote data centers, reducing latency and improving privacy (Chaffey & Ellis-Chadwick, 2019). Another major trend is blockchain, which enables secure and transparent transactions without intermediaries and is being used in healthcare, supply chains, and digital identity systems (Laudon & Laudon, 2022).

Quantum computing, though still early, may revolutionize cryptography, medicine, and simulation of complex systems. Future software engineers must already begin studying these principles to be prepared for the next technological era (Turban, Pollard & Wood, 2018).

Conclusions

Information technologies have become the backbone of modern civilization. They shape how we communicate, learn, trade, and make decisions (Schwab, 2017). For software engineers, IT is both a technical field and a social responsibility.

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DEVELOPMENT OF A HYBRID RECOMMENDATION SYSTEM FOR THE "FILM LIBRARY" PLATFORM BASED ON USER BEHAVIOR, MOOD ANALYSIS AND TEXT REVIEWS

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In recent years, the rapid growth of digital media platforms has led to a significant increase in the amount of available audiovisual content. Streaming services such as Netflix, Amazon Prime, and Disney+ offer millions of films and series, making it increasingly difficult for users to find content that matches their preferences. Users face the challenge of choosing films or series that align with their interests, emotional state, and previous viewing history. This information overload highlights the need for intelligent systems capable of filtering and personalizing content delivery.

Traditional recommendation systems, based solely on collaborative filtering or simple metadata comparison, are no longer sufficient in ensuring high-quality personalization (Ricci, Rokach & Shapira, 2015). These conventional approaches often fail to address critical challenges such as the "cold start" problem, which occurs when a new user or item lacks sufficient interaction history. Furthermore, traditional methods do not account for the semantic meaning of textual reviews or the emotional state of users at the time of content consumption. As user behavior becomes more dynamic and diverse, more complex and adaptive systems are required to provide relevant and meaningful recommendations. Modern users expect platforms to understand not only what they have watched before, but also how they feel at the moment and what kind of experience they are seeking. This necessitates the

development of hybrid recommendation systems that combine multiple approaches and data sources to achieve deeper personalization.

This study focuses on developing a hybrid recommendation system integrated into the "Film Library" platform. The system combines behavioral data, user mood assessment, and textual review analysis to improve the accuracy and relevance of recommendations. By incorporating multiple sources of information and modern machine learning techniques, the hybrid system achieves a more comprehensive understanding of user preferences compared to single-method approaches.

Purpose of the study. The purpose of this research is to design and implement an intelligent hybrid recommendation system that integrates three complementary models: Matrix Factorization for collaborative filtering, LSTM-based deep learning for textual review analysis, and Content-Based filtering using TF-IDF vectorization. Additionally, the system incorporates a mood-based filtering module to align recommendations with the user's current emotional state.

The specific objectives of this study include: analyzing existing recommendation approaches and their limitations; implementing three distinct recommendation models; developing a mood classification module; creating a hybrid combining mechanism; and evaluating system performance using standard metrics. The ultimate goal is to create a recommendation system that is not only statistically accurate but also contextually appropriate and emotionally aligned with the user's current state.

Research methods and applied technologies. The research conducted within this study involves the analysis, implementation, and comparison of three modern approaches to recommendation systems. The hybrid model developed for the "Film Library" platform integrates three fundamentally different algorithms, each contributing unique strengths to the final recommendation mechanism (Zhang, Yao, Sun & Tay, 2019).

The first approach involves collaborative filtering techniques using matrix factorization methods such as Singular Value Decomposition (SVD) and Alternating

Least Squares (ALS). These algorithms operate on a user-item rating matrix and are widely used due to their ability to identify latent relationships between users and items (Koren, Bell & Volinsky, 2009). By analyzing patterns in rating data, they predict which films are likely to be of interest to a user based on the preferences of similar users. The predicted rating is calculated by decomposing the sparse rating matrix into two lower-dimensional matrices representing user and item latent factors. This approach serves as the baseline due to its proven effectiveness and widespread adoption in industry applications.

The second approach employs Long Short-Term Memory (LSTM) networks for processing sequential textual data from movie reviews. Unlike traditional methods that rely solely on numerical ratings, this deep learning model analyzes textual reviews to capture semantic meaning and sentiment (Hochreiter & Schmidhuber, 1997). The LSTM architecture addresses the vanishing gradient problem inherent in standard recurrent neural networks through its gating mechanisms: input gate, forget gate, and output gate. The model processes review text through the following pipeline: tokenization, word embedding using pre-trained vectors, sequential LSTM layers, and dense classification layers. This approach enables the system to understand nuanced opinions expressed in natural language, capturing preferences that numerical ratings cannot convey.

The third approach analyzes descriptive metadata of films, including genres, keywords, cast information, and textual summaries. This component uses TF-IDF (Term Frequency-Inverse Document Frequency) vectorization and cosine similarity to measure the semantic closeness between different movies. Such an approach is particularly effective in handling cold-start scenarios, when a new user or item has minimal interaction history but enough content attributes to generate meaningful recommendations. By comparing film features, the system can recommend movies similar to those the user has previously enjoyed.

Additionally, the system integrates a mood-based filtering module. Users provide input describing their current emotional state through a short questionnaire

(e.g., stressed, happy, sad, bored). These qualitative responses are classified and mapped to thematic film categories. For example, a stressed user might receive recommendations for light comedies, while a bored user might be suggested thrillers or science fiction. This approach ensures that recommendations reflect not only long-term preferences but also situational context.

Discussion and results. For training and evaluation, three datasets were utilized: MovieLens 100K/1M containing numerical user ratings for Matrix Factorization model (Harper & Konstan, 2015); IMDb/TMDb Reviews comprising textual movie reviews for LSTM training; and The Movies Dataset (TMDb) providing rich metadata including genres, cast, crew, and plot descriptions for Content-Based filtering.

The system was developed using a modern technology stack. The backend was implemented in C# providing robust API services, while the frontend was built with Next.js ensuring a responsive and dynamic user interface. For machine learning components, Python was employed along with libraries such as pandas, NumPy, scikit-learn, Surprise, TensorFlow, Keras, NLTK, and SpaCy.

The models were evaluated using standard metrics: Root Mean Square Error (RMSE) for rating prediction accuracy, Precision@K measuring the proportion of relevant items among top recommendations, Recall@K indicating the coverage of relevant items, and NDCG (Normalized Discounted Cumulative Gain) for ranking quality assessment.

The results of the conducted research demonstrate that hybrid recommendation systems provide significant advantages over traditional single-approach solutions. By combining Matrix Factorization, LSTM-based text analysis, and Content-Based filtering, the developed system ensures a more accurate, adaptive, and contextually aware recommendation process for the "Film Library" platform.

Matrix Factorization proved effective in capturing long-term behavioral preferences by identifying latent patterns in user-item interactions. This method

serves as a reliable baseline for rating prediction tasks and demonstrates strong performance when sufficient historical data is available.

The LSTM-based deep learning model successfully captured semantic nuances from textual reviews. By analyzing the actual content of user opinions, this approach identified subtle preferences that rating-based methods might miss. The sequential nature of LSTM allowed the model to understand context and sentiment in longer review texts.

Content-Based filtering successfully addressed the cold-start problem by analyzing film metadata such as genres, cast, and plot descriptions. This approach improved recommendation stability for new users and new items by relying on content attributes rather than interaction history.

The inclusion of mood-based filtering introduced a new layer of adaptiveness, allowing the system to align recommendations with the user's current psychological state. The hybrid architecture demonstrated superior performance across all evaluation metrics compared to using any single model independently.

Conclusions. This study lays a solid foundation for further development within the diploma thesis. Future work will include the integration of more advanced transformer-based architectures (BERT, RoBERTa) for enhanced text understanding and attention mechanisms for improved LSTM performance.

We focus on deploying the system as a fully functional web application with real-time interaction capabilities. The platform will feature a scalable architecture built with C# backend services and Next.js frontend. Key development tasks include building RESTful API endpoints, optimizing database structures, and implementing dynamic recommendation updates based on continuous user feedback.

Overall, the results obtained in this research form the theoretical and practical basis of the diploma project, ensuring continuity, scientific depth, and practical relevance. The proposed hybrid recommendation system has significant potential for real-world application in digital media platforms.

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KEEPING FOCUS IN A DIGITAL WORLD

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The Modern Context

It is getting harder to just sit down and think. We all feel it. In our current environment, maintaining concentration feels less like a basic skill and more like a constant struggle. With more than 6 billion people now online and over 5.6 billion actively scrolling through social media every single month, the digital world isn't just a background utility – it's loud, and it is constantly demanding to be looked at. It often feels like we are fighting a losing battle against a relentless stream of

notifications, pop-up messages, and those endless feeds designed to fragment our time and cloud our mental clarity.

The Real Impact on Our Minds

This constant digital noise isn't just annoying; it actually messes with how we work and think. It has tangible consequences. Research from the Pew Research Center (2023) points out what many of us suspect: frequent multitasking and interruptions negatively impact our ability to comprehend and retain information. We are skimming, not reading.

This is painfully evident in education. Students frequently report they can't study for more than 15–20 minutes without reaching for their phones – it's almost a reflex. This means assignments that should take an hour drag on, delayed by the distractions of social media feeds. Professionals are in the same boat. The modern workday is often consumed by messages, alerts, and back-to-back video meetings, leaving very little room for actual focused work or strategic planning.

And it bleeds into our personal lives, too. Conversations are easily disrupted by digital intrusions, which diminishes the quality of our interactions. Furthermore, the American Psychological Association (2023) connects prolonged screen exposure to serious psychological issues – things like increased anxiety, disrupted sleep cycles, and burnout. The pressure is two-fold: we see idealized images that make us feel inadequate, while the expectation to be constantly available via email and chats drives chronic stress. While digital tools undeniably offer benefits like connection, they challenge our fundamental ability to just *be present*.

The Mechanics of Distraction

We have to admit something uncomfortable: this loss of focus is often by design. It's not just us being lazy. Technology platforms are built specifically to capture attention and maximize engagement through features like autoplay, infinite scrolling, and real-time notifications. This "attention economy" is incredibly profitable for tech companies, but it is taxing for users. As the Center for Humane Technology emphasizes, the time we spend online is often a result of behavioral

design rather than our own conscious choice. Consequently, we lose control over our time, leading to digital fatigue and that sinking feeling that time is simply slipping away.

Regaining Control: Some Strategies

Fortunately, we aren't helpless. We can retrain our attention using specific strategies. For time management, the Pomodoro method – utilizing 25-minute work intervals followed by short breaks – has proven effective for many students. It sounds simple, but it works because the end is always in sight. Professionals often turn to time-blocking and prioritizing deep work hours to minimize multitasking.

Technology can actually be part of the solution, ironically. Tools like Forest, Notion, and Freedom provide necessary structure and accountability, while browser extensions such as StayFocusd and Cold Turkey can limit time spent on distracting websites. Beyond apps, adopting "digital hygiene" is crucial. This includes turning off non-essential notifications, using Do Not Disturb modes, and establishing "phone-free" zones.

The Biological Factor

We also tend to forget that physical health plays a larger role in focus than we realize. If you're tired, you can't focus. Screen exposure late at night disrupts melatonin production, which reduces sleep quality and makes it harder to fall asleep. This is because the blue light from screens tricks the brain into staying alert. Experts recommend avoiding screens for at least an hour before bed – a "digital sunset", if you will – and using night mode filters. Additionally, just 20–30 minutes of daily exercise can significantly boost mood, memory, and attention, supported by a balanced diet and hydration.

Cultivating a Focused Mindset

Focus is also about self-awareness. It’s about noticing when your mind has wandered. Practices like mindfulness and metacognition – reflecting on our own thought processes – can help us manage distractions without frustration. Techniques such as meditation, deep breathing, and journaling help train the "attention muscles,"

allowing us to return to tasks more quickly after an interruption. Recognizing this, many schools and universities are now exploring mindfulness programs to promote academic success and well-being.

A Call for Change

But individual willpower isn't enough. Long-term solutions require a shift in culture and design. Developers could implement humane design features like screen time dashboards, gentle break reminders, and default quiet hours. While some platforms offer usage reports, making these tools more visible or default options would encourage healthier habits. Companies could even introduce friction-based features, such as asking users to confirm if they really want to open an app during focus hours.

Educational institutions should treat digital focus as a foundational skill, similar to reading or writing. Curriculum changes could teach students to identify distractions and set limits, while universities could provide tech-free zones and counseling for digital burnout. Peer-led discussions can further normalize healthy boundaries.

In the workplace, employers must adapt to the challenges of remote and hybrid work. While flexibility is good, it blurs the line between work and rest. Companies should set clear communication expectations, reduce unnecessary meetings, and protect "deep work" hours. Leadership that models focused behavior fosters a culture that values attention as a resource.

Finally, families play a pivotal role. Since children emulate adult behaviors, parents should establish norms like no phones at the dinner table or tech-free bedrooms. Encouraging non-digital hobbies and unstructured play is key for fostering creativity and emotional regulation in digital natives.

Conclusion

Ultimately, technology is not the enemy. When used intentionally, it supports learning and global connection. Tools like task managers and online resources are invaluable for problem-solving and collaboration. However, when usage becomes

mindless, it undermines these benefits. Maintaining focus is a challenge for both individuals and society. By cultivating protective habits and demanding better tools from developers, we can treat focus not as a fixed ability, but as a trainable skill, allowing us to reconnect with what truly matters.

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FEATURES OF IMPLEMENTATION OF VIRTUAL LABORATORY TECHNOLOGY IN THE PROCESS OF TRAINING OF SPECIALISTS IN THE ROAD CONSTRUCTION INDUSTRY IN CONDITIONS OF CRISIS CHALLENGES

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The modern paradigm of development of Ukraine's road construction complex actualizes the need for a fundamental revision of approaches to the professional

training of specialists. The intensification of digitalization processes, automation of technological cycles, and stricter environmental and industrial safety requirements are shaping new qualification standards. Competencies related to innovative thinking, rapid decision-making, and the ability to continuously self-improve are becoming increasingly important. In this context, the most problematic aspect is the organization of laboratory workshops, since the specifics of the industry require direct interaction with large-scale industrial equipment.

The initial impetus for the transformation of the educational process was the COVID-19 pandemic, which forced the global academic community to switch to a remote format. This has actualized the demand for practice-oriented digital tools that can compensate for the lack of physical laboratory classes. Virtual laboratory complexes have proven their effectiveness as a means of modeling experiments under conditions of limited access to material and technical resources.

Full-scale military aggression on the territory of Ukraine has significantly complicated the situation, causing physical destruction or blocking access to part of the laboratory facilities, forced migration of participants in the educational process, and the implementation of security protocols that make it impossible to conduct in-person classes. Under such circumstances, virtual laboratory complexes have acquired the status of a critically important element in ensuring the continuity of education, allowing to simulate production scenarios and form professional skills in a digital environment regardless of the geolocation of applicants.

In scientific and methodological discourse, a virtual laboratory is interpreted as a software and hardware complex designed to conduct experimental research without direct contact with the object of research or in its physical absence. The classification of such systems involves two main approaches:

Remote access laboratories: based on real equipment equipped with remote control facilities, data digitization modules and telecommunication interfaces.

Simulation virtual laboratories: fully implemented in a software environment through mathematical and computer modeling of processes.

Research of the functionality of simulation virtual laboratories allows identifying a number of their key advantages:

Economic efficiency and availability. The need to purchase expensive equipment and reagents is eliminated. Considering that a significant part of the existing laboratory equipment is characterized by moral and physical wear and tear, which negatively affects measurement accuracy and safety, virtualization is a rational alternative.

Profitability. Despite the initial investment in computer systems, low operating costs and versatility ensure economic feasibility, especially in resource-intensive disciplines.

Expanded visualization capabilities. Computer graphics tools allow visualization of processes that are inaccessible for observation in a full-scale experiment (microscopic phenomena, rapid reactions), which contributes to a deeper understanding of theoretical material without the need for unique diagnostic equipment.

Scaling of time parameters. It provides the ability to study processes on a changed time scale: slowing down ultrafast phenomena for detailed analysis or accelerating long-term processes, monitoring of which in real time is irrational.

Ensuring life safety. The virtual environment is the only alternative for practicing scenarios associated with increased risks (working with high voltage, toxic substances, critical temperatures). This allows for safe variation of experiment parameters and conducting serial studies to establish correlations.

An analysis of international experience in creating virtual laboratories has revealed significant differentiation between systems in terms of their level of immersion. Most existing solutions are limited to the basic level (2D animation and linear logic), while mid-level systems offer advanced interactivity and evaluation tools. The most progressive are high-level immersion platforms, which, through the use of 3D modeling, physical engines, and VR/AR technologies, ensure maximum compliance of the simulation with the real conditions of the experiment.

In the case of simulating processes in road construction, the choice in favor of 3D engines is determined by the need for algorithmic implementation of complex physical and mathematical models, which is unattainable for outdated scripted animation platforms. Unlike planar modeling, polygonal 3D graphics allow for accurate reproduction of the volumetric anisotropy of materials and their deformation processes in real time, which is critical for ensuring the validity of virtual engineering tests.

The choice of platform depends on a combination of factors: graphics and performance requirements, cross-platform compatibility, implementation cost, and the availability of technical support and a developer community. An analysis of solutions implemented worldwide that provide the necessary level of simulation relevance has shown the dominance of two 3D engine technologies: Unreal Engine and Unity.

Unity maintains its leadership in the education segment thanks to its cross-platform capabilities, including the ability to compile projects for WebGL (for running in a browser) and native support for mobile VR headsets.

Examples of educational projects implemented on the Unity platform:

- Labster: A large library of scientific simulations that runs in a browser and allows conducting experiments without installing additional software.
- Nanome: A VR platform for working with molecular structures.
- Medical simulators (FundamentalXR): Practicing surgical algorithms.
- Interplay Learning: Training simulators for working professions (HVAC, electrical, plumbing). VR and desktop simulations for equipment failure diagnostics.

Despite its high visualization potential, the Unreal Engine architecture is characterized by significant demands on computing resources and the lack of full WebGL support, which critically raises the technical barrier to entry and complicates integration into the educational process.

Examples of educational projects implemented on the Unreal Engine platform:

- Precision OS (VR surgery): High detail of bone and soft tissue for medical training.
- CM Labs / Vortex Studio: Crane and excavator simulators. Realistic soil and cable physics.

Given the complexity of road construction processes, it can be concluded that only simulations based on full-fledged 3D engines can meet the requirements of modern education in this field.

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Orel D. I.

PROCEDURAL GENERATION TECHNOLOGIES IN GAME DESIGN

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Procedural generation is one of the most important technologies in modern game design. It allows developers to create game content automatically using algorithms, mathematical functions, and randomness. This means that worlds, levels, characters, quests, items, and even stories can be generated without doing everything manually. Thanks to this technology, each playthrough can be unique, and game worlds can become very large and full of variety. Procedural generation not only helps developers work faster but also creates a new way of combining technology and creativity in games.

One of the main uses of procedural generation is the creation of game worlds. Algorithms such as Perlin Noise or Simplex Noise are used to generate landscapes and natural shapes. With just a few parameters – for example, height, humidity, temperature, and noise frequency – a system can create continents, mountains, deserts, forests, lakes, and oceans. The more rules and layers the generator has, the more realistic the world looks. For example, Minecraft uses such methods to create infinite worlds with different shapes and biomes. Another example is No Man's Sky, where whole planets are generated with their own terrain, plants, animals, and weather.

Procedural generation is also used to create levels. Different algorithms help build dungeons, rooms, corridors, or cities that look logical and interesting. Rogue-like games are a good example: each time the player starts a new game, the map is different, but it always follows certain rules. Levels may change their shape, the number of enemies or puzzles, and the difficulty. This makes the game less predictable and more replayable, because no two sessions are the same.

Landscape generation is another important part of procedural design. Modern game engines use complex math to form natural terrain, simulate erosion, water flow, or plant growth. This allows the world to feel more natural. For example, mountains

can be rocky and steep, while forests have many layers of plants. When climate and biome data are added, the environment becomes even more realistic and diverse. For players, this creates a strong feeling of exploring a living world, not one that was built by hand.

Procedural generation is also used to create quests. Modern systems can combine characters, tasks, and story elements to form unique missions. The generator can consider the player's level, progress, choices, or playstyle. This means that a peaceful player may receive diplomatic or trade quests, while an aggressive player may get combat missions. This makes the world feel more dynamic and personal, as if it reacts to the player.

Character generation is another popular direction. Procedural systems can create different NPCs with unique appearances, personalities, jobs, and behavior. In some games, characters have daily routines, families, and relationships with other NPCs. Their behavior can change depending on the player's actions, which makes interaction deeper and more emotional. Many games use generators to mix face models, clothing, and animations, so every character looks different.

A very interesting use of procedural generation is in story creation. In such systems, the story is not fully written in advance. Instead, it forms while the player plays. Algorithms create new story branches based on the player's actions, the current state of the world, or the behavior of NPCs. This means that each player can experience a different version of the story. Players feel like they influence what happens, which increases emotional involvement.

Procedural generation also has a strong psychological effect on players. People enjoy discovering new things, and random worlds support this feeling. Every time a player starts a new game or travels to a new area, they experience excitement because they do not know what they will find. Procedural systems also help avoid boredom and repetition. When the world changes every time, players feel more motivated to explore. If the system also adjusts difficulty to the player, the experience becomes enjoyable and balanced.

However, procedural generation also has challenges. Pure randomness can create worlds that are illogical or not fun to explore. Quests may become meaningless, and characters – unrealistic. That is why developers usually combine randomness with rules, templates, and manual design. Balance between control and randomness is very important. Also, complex generators can be difficult to optimize and may require strong hardware. But modern artificial intelligence and better algorithms help make procedural systems more stable and intelligent.

Procedural generation continues to develop and change the game industry. It gives developers more freedom to experiment and create different types of content. Players get more unique experiences and dynamic worlds. In the future, the combination of procedural systems with artificial intelligence may create fully living virtual worlds that adapt to each player in a personal way.

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CAR SAFETY TECHNOLOGIES

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Car safety technologies have advanced rapidly over the past few decades, transforming the automobile from a simple mechanical device into a highly sophisticated system built around passenger protection. Increasing road traffic, higher driving speeds, and the growing number of accidents made safety a crucial factor in vehicle design. As a result, safety features that once seemed optional or experimental are now considered essential. The modern car relies on a combination of mechanical engineering, electronics, and intelligent software to reduce risk, prevent collisions, and minimize injury when accidents cannot be avoided.

The earliest improvements centered around simple protective measures. Seat belts became one of the most important safety inventions of the 20th century. Their introduction significantly reduced the number of fatalities by restraining occupants

during sudden stops and collisions. Over time, seat belt technology was upgraded with pretensioners and load limiters that tighten the belt at the moment of impact and reduce pressure on the chest. These enhancements showed how even basic equipment could be optimized to deliver far better results.

Structural development also played a major role. Engineers began designing crumple zones that absorb collision energy by deforming in a controlled way. Instead of transferring the full force of a crash to passengers, the front and rear sections of the vehicle were engineered to collapse in a predictable pattern. Reinforced passenger cells became another important step, providing a rigid survival space that remains intact even in severe impacts. These passive safety features created a foundation on which future technologies could build.

A major breakthrough in protection arrived with the introduction of airbags. First used in commercial vehicles in the 1980s, airbags proved highly effective in reducing the severity of injuries during frontal collisions. Their rapid deployment provided a protective cushion between the passenger and the hard surfaces inside the vehicle. Over the years, more types of airbags were added, including side airbags, curtain airbags, knee airbags, and even airbags designed to protect rear-seat passengers. As a result, many high-speed crashes that once led to catastrophic injuries now end with significantly better outcomes.

Mechanical systems were soon joined by electronic ones. The anti-lock braking system (ABS) was one of the earliest electronic safety features to become widespread. Before ABS, emergency braking often caused the wheels to lock, removing steering control and increasing the chance of skidding. With ABS, the braking force is modulated automatically, allowing the driver to maintain control. This improvement significantly decreased accidents in wet or slippery conditions and became a requirement in many countries. The effectiveness of ABS demonstrated how electronic systems could compensate for human reaction time and prevent dangerous situations.

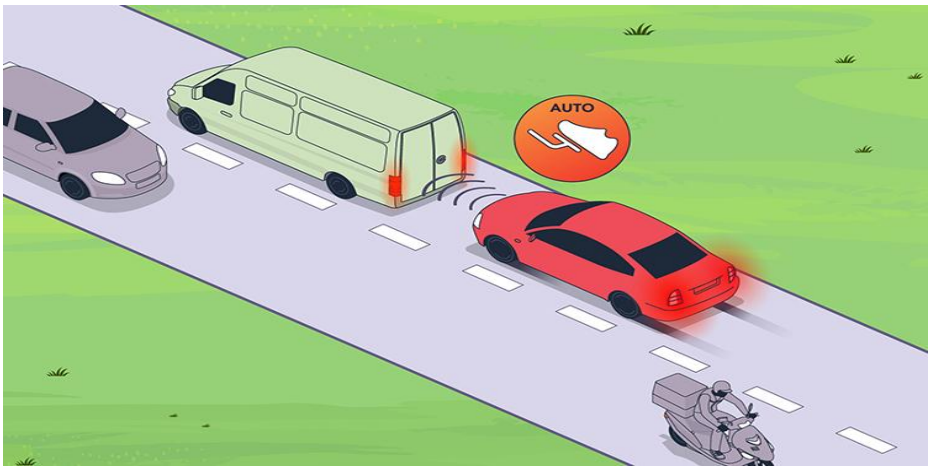
Building on this success, manufacturers introduced Electronic Stability Control (ESC), a system designed to prevent loss of control in sudden maneuvers. ESC monitors steering angle, wheel speed, and vehicle movement. When the system detects that the car is sliding or not following the intended path, selective braking is applied to individual wheels. This correction helps restore stability and has been credited with preventing thousands of crashes worldwide. The importance of ESC is often compared to that of seat belts, showing how transformative the technology has been.

As digital systems grew more powerful, the focus shifted from crash protection to crash prevention. This change resulted in a wide range of advanced driver-assistance systems (ADAS). Lane departure warning systems were among the first of these. By using cameras to track road markings, these systems detect unintended lane drift and alert the driver with visual or audible signals. Lane-keeping assist takes this further by making gentle steering adjustments when necessary. These features help reduce accidents caused by distraction or fatigue, issues that have become increasingly common with modern driving habits.

Blind-spot monitoring added another layer of awareness. Many collisions occur when drivers fail to notice vehicles approaching from areas outside mirror visibility. Sensors placed around the car detect when another vehicle enters the blind spot and issue a warning. In some models, steering intervention is applied if the driver begins changing lanes while another vehicle is present. Rear cross-traffic alert offers similar assistance when reversing from parking spaces, where visibility is often limited.

One of the most significant innovations of recent years is automatic emergency braking (AEB). The system continuously monitors the road ahead using radar, cameras, or a combination of both. When AEB detects an imminent collision, it first alerts the driver. If no action is taken, braking is applied automatically to avoid the impact or reduce its force. This capability addresses one of the most common accident scenarios: rear-end collisions caused by delayed human reaction. Studies

show that AEB can prevent a large percentage of such crashes, making it one of the most effective modern safety features.



AEB System in Action

Adaptive cruise control further expanded automated safety by maintaining a safe following distance from the vehicle ahead. Unlike traditional cruise control, this system automatically adjusts the car's speed based on traffic conditions. During long trips or heavy congestion, adaptive cruise control reduces driver fatigue and lowers the risk of sudden braking situations. When combined with lane-keeping assist, the system forms the foundation of semi-autonomous driving, providing smoother and safer travel.

Rapid progress in sensor technology, artificial intelligence, and automation suggests a future where vehicles will become increasingly capable of preventing accidents independently. Fully autonomous cars are still under development, but many of their core technologies – such as advanced radar arrays, lidar sensors, and real-time mapping – are already available in modern vehicles. If these systems reach full reliability, many common causes of accidents, including distraction, fatigue, and poor judgment, could be significantly reduced.

In the end, the development of car safety technologies shows how far automotive engineering has progressed. Features such as airbags, ABS, ESC, lane-keeping systems, blind-spot monitoring, and automatic emergency braking have

transformed everyday driving and greatly reduced the severity of accidents. Continued innovation promises even greater improvements in the future. Because of this ongoing progress, the roads of tomorrow have a strong chance of becoming safer than ever before.

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DIGITAL CULTURE AND THE FUTURE OF CREATIVITY

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Is Technology the New Printing Press?

When I first decided to research digital culture, I was driven by a question that feels increasingly urgent: is technology actually helping us create, or is it merely conditioning us to scroll? This dilemma kept reminding me of the invention of the printing press. I found a historical analysis in Nature that drew a fascinating parallel: just as the press democratized knowledge centuries ago by breaking the church's monopoly on information, the internet is now democratizing creativity by dismantling traditional hierarchies.

But as I dug deeper into the reports, contrasting historical hopes with our current digital reality, I realized the situation is far messier than the optimistic slogan "everyone can be an artist" suggests. Yes, the digital age promises infinite

expression, but it has also introduced new, invisible gatekeepers: code and data. We have swung from a scarcity of information to an overwhelming overload of it. The velocity of this change is terrifying; where the printing press took centuries to reshape society, digital tools are doing it in decades. It forces us to ask: in a world where content is infinite, does quality actually matter anymore, or are we just drowning in noise?

The Reality of Access vs. The Paradox of Abundance

Let's start with the undeniable positives. The barriers to entry are crumbling. In my research, I looked at data from the Pew Research Center. Although the report is from 2013, the trend it identified has only accelerated: it highlighted that the internet had become a crucial infrastructure for artists. Specifically, two out of three independent musicians reported a significant improvement in their ability to connect directly with fans without needing a big record label. This is a vital statistic because it proves that artists no longer need permission from corporate executives to be heard.

This shift has created what economists call the "Long Tail" effect. Referring to reports from UNCTAD regarding the "Creative Economy", I found that digital tools allow for the monetization of niche talents that previously had no market. But here is the catch – we are facing a paradox of abundance. With millions of songs and images uploaded daily, the challenge has shifted from production to discoverability. The market is democratic, sure, but it is also oversaturated. While anyone can publish, getting noticed now requires navigating complex digital marketing landscapes that have little to do with art itself.

It's not just about traditional art, though. I read a thought-provoking paper in the NYU Law Review by Adler and Fromer regarding memes. They argue that these aren't just silly internet jokes but a sophisticated new form of "communicative creativity". I hadn't thought about it that way, but their point is solid: memes challenge our archaic ideas about copyright because they rely entirely on remixing and sharing. This "remix culture" implies that modern creativity is communal rather than solitary, forcing us to rethink what ownership even means in a digital space.

The Algorithm Trap: Why Everything Feels the Same

However, there is a downside that we cannot ignore: the "curation" problem. We theoretically have access to everything, but algorithms decide what we actually see. I read an investigative piece in The Guardian about how streaming giants like Netflix use vast amounts of user data to commission content. The problem is that this data-driven approach often leads to movies designed to be "safe", formulaic, and mainstream just to guarantee views. By analyzing what we watched yesterday to predict what we want today, these platforms create a feedback loop that actively discourages risk-taking.

It feels like we are fostering a homogenization of culture – a "thick soup" where everything feels vaguely familiar. I see this trend aggressively on TikTok, which operates within the ruthless "attention economy". The platform's algorithms explicitly reward imitation over innovation. To get on the "For You" page, creators feel pressured to copy trending sounds rather than trying something new. This has a psychological cost: as content gets shorter to catch fleeting attention spans, the art itself changes. Songs become shorter, nuance is sacrificed for immediate engagement.

And it goes deeper. Research from Oxford Academic suggests these algorithms carry deep-seated biases. They tend to prioritize Western norms and aesthetics, which can actually harm cultural diversity. This phenomenon, often described as "digital colonialism", worries me because it risks erasing unique local voices in favor of a globalized, uniform aesthetic.

Can AI Have a Soul?

Then there is the issue of Artificial Intelligence, which was easily the most unsettling part of my research. Generative tools like DALL-E are technically impressive, but they raise profound ethical questions. In The Guardian, I found a compelling argument by Reinhart, who suggests that art loses its "soul" when created by a machine. I tend to agree with him. True art requires human experience, emotion, and the ability to convey the condition of being alive – qualities that an algorithm,

no matter how advanced, simply lacks. An AI can mimic the style of Van Gogh, but it cannot understand the pain behind the brushstroke.

This leads to a genuine fear of "deskilling". If a machine can write a poem or paint a portrait in seconds, will humans lose the incentive to master these difficult skills? The role of the artist risks shifting from a creator to a mere "prompt engineer".

I also looked into the controversy surrounding NFTs. While proponents claimed they would save digital art by creating scarcity, they mostly turned into volatile speculative assets. Moreover, the heavy environmental impact of the blockchain technology used to mint them contradicts the progressive values many artists hold. It reinforces the fear that technology might not be liberating artists, but rather commodifying their work in unsustainable ways.

Final Thoughts

So, where does this leave us? My research suggests that digital culture is a double-edged sword. On one hand, it gives us amazing tools to bypass gatekeepers – look at the independent musicians or the vibrant ecosystem of meme culture. On the other hand, relying too much on algorithms and AI can lead to a "boring" culture where creativity is optimized for clicks rather than human connection.

I believe the future of creativity depends on our ability to remain in the driver's seat. We must use technology as a tool to support our imagination, not as a replacement for it. If we let algorithms dictate our taste and AI generate our ideas, we risk losing the very human "soul" that makes art worth creating in the first place. The challenge for my generation will not be mastering the tools, but resisting the urge to become just another line of code in the algorithm.

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PROGRAMMING AUTOMATION USING AI AGENTS

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The article considers the issue of programming automation based on agentic artificial intelligence technologies. The role of intelligent agents in the processes of code generation, testing, debugging, and software deployment is analyzed. The feasibility of using large language models in the context of optimizing the software

product life cycle is substantiated. The key benefits of implementing agents in software engineering are highlighted, including increased productivity, reduced errors, and support for developers in routine tasks. The main challenges associated with the accuracy, safety, and ethical responsibility of systems are identified. Conclusions are drawn regarding the prospects for the further development of agent-oriented approaches in programming.

In today's digital transformation environment, demands on the pace, quality, and scalability of software development are increasing significantly. The constant complication of system architecture, the increase in the volume of source code, and the increase in the costs of its maintenance determine the need to automate typical processes of the software product life cycle.

One of the key areas of such automation is the implementation of artificial intelligence agents capable of partially or fully performing certain functions that previously required human intervention. In particular, this concerns the automatic generation of software fragments, error detection, refactoring, testing, documentation generation, as well as support for continuous integration and deployment procedures. In this context, agents act not only as tools for accelerating development, but also as integrated participants in the development process, capable of working with the project context, accumulating knowledge, and interacting with other system components.

The growing role of such technologies necessitates a systematic analysis of their capabilities, limitations, and implications in the field of software engineering. Special attention is required to issues of safety, reliability, responsibility for decisions made, as well as compliance with ethical standards in the design and implementation of agents. In this regard, it is relevant to research methodological approaches to the implementation of intelligent agents in software development practice, taking into account technological, legal and social aspects.

The use of intelligent agents in software engineering is based on the principles of autonomous performance of specialized tasks within the overall architecture of the

software product. At the core of the functioning of such systems is the ability of agents to analyze input data, maintain context, make decisions based on acquired knowledge, and generate code that satisfies the requirements. An important characteristic of modern models is the support of natural language, which ensures the accessibility of interaction with the agent even for a user without deep technical training (Chen et al., 2021).

In practical terms, the main areas of application of such systems are generating template code, detecting errors, optimizing performance, and supporting continuous integration and software delivery processes. The agent can create basic program structures, process events, and build interfaces for interacting with databases, which allows for a significant reduction in the time spent on the initial design of the system. When errors are detected, the agent can identify common problems in the code, suggest possible fixes, and even automatically integrate changes (Kass, 2024).

The ability of agents to analyze the effectiveness of software solutions deserves special attention. Such systems can identify areas of low performance, analyze resource consumption, and generate recommendations for algorithmic optimization and architectural changes. Thanks to integration with profiling systems, agents are able to act based on actual code execution data, which increases the validity of decisions made.

In the context of organizing CI/CD cycles, agents perform the functions of monitoring the build, managing test environments, automatically running pre-release checks, and assessing compatibility with external dependencies (Vakhula & Opirskyy, 2025). This helps reduce human errors and ensures stability in the software product deployment process.

An intelligent agent can also function as a developer assistant, providing contextual support while writing code. It helps with syntax, explains the logic of using individual libraries, creates documentation for functions and classes, and also participates in the creation of comments, which helps improve the readability and maintainability of the code.

At the architectural solution level, programming automation is implemented through multi-agent systems, where each component is responsible for a separate phase of the development life cycle. This approach provides the ability of parallel task execution, and also increases the flexibility and adaptability of the software ecosystem. Agents have access to a shared knowledge base, change history, and results from previous iterations, allowing them to take context into account when making decisions.

At the same time, despite the wide range of possibilities, in practice, agent systems remain dependent on human involvement. In critical situations, when precise decision-making or consideration of multifactorial context is required, it is the developer who takes ultimate responsibility for the result. Thus, agents do not replace a specialist, but act as a tool that enhances his capabilities and reduces resource costs (Saravanan, 2025).

The application of agentic artificial intelligence technologies in the software development process creates a new programming paradigm in which the automation of typical and repetitive tasks is combined with adaptive support at more complex stages of the software product life cycle. Intelligent agents are capable of generating, testing, optimizing, and maintaining code, reducing the workload on developers and improving the quality of the final result.

Under the influence of such technologies, the very structure of the development process is changing – from traditionally linear to dynamic, multi-component one, in which a human participant interacts with a number of autonomous assistants. In environments with high requirements for stability and speed of software release, the implementation of agents allows for greater flexibility, shorter release times, and reduced error probability.

At the same time, full autonomy in programming remains unattainable today. Agents' decisions often require verification, and their behaviour can be sensitive to contextual changes. The issues of safety, ethical responsibility, and explainability of

decisions remain open and require further research and regulatory regulation (Kuznetsova, 2025).

Thus, intelligent agents do not replace the engineer, but create a new level of interaction between humans and the system. Their effective application is only possible through a combination of technical innovation and careful analysis of risks, legal implications, and ethical design principles. In the long term, it is the balance between agent autonomy and human responsibility that will determine the direction of further transformation in software engineering.

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INTELLIGENT CONSTRUCTION MACHINES: FROM MECHANICAL SYSTEMS TO SELF-AWARE ENGINEERING

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1. Introduction

Modern construction machinery is evolving beyond automation. With the rise of artificial intelligence and cognitive algorithms, machines are beginning to monitor, evaluate, and improve their own performance. This paper explores the transformation of traditional construction systems into intelligent, self-aware entities that redefine the relationship between engineers and technology.

The twenty-first century marks a shift in the core philosophy of engineering. Machines are no longer simple tools – they are emerging as active participants in the industrial ecosystem. Construction, one of the oldest branches of human ingenuity, now integrates artificial intelligence, sensor networks, and digital twins. Smart cranes, excavators, and road rollers equipped with real-time diagnostics can detect structural strain, predict component failure, and adapt to different working conditions. The concept of machine self-identification – when a system can recognize, analyze, and optimize its own function – has become the foundation of cognitive engineering. The human role in this process is no longer operational but supervisory, intellectual, and creative.

2. From Mechanics to Cognition

Traditional construction equipment was purely mechanical – reliable, powerful, and predictable. The introduction of automation replaced the manual operator with algorithms that could perform repetitive tasks faster and safer. Today, progress moves further. Sensors, cameras, and neural networks enable machines to "understand" their physical environment. A crane can analyze its load balance in real time, while an excavator can recognize soil type and adjust hydraulic power accordingly. Systems like these operate through interconnected data layers – an echo of biological intelligence. What began as simple automation is turning into cognition.

3. Machine Self-Identification

Self-identification in machines refers to the ability of a system to understand its own state, history, and capabilities. In modern engineering, this concept lies at the heart of predictive maintenance and adaptive control. For instance, a self-aware road roller can track vibration frequency, surface pressure, and temperature to prevent

micro-damage before it happens. It can compare current data with its own past patterns – forming a technical "memory". In a broader sense, this memory becomes the base of a machine's identity – the ability to perceive its own purpose and adapt to fulfill it more efficiently. Each intelligent construction machine begins to express a kind of technical personality, shaped by its operational history and interaction with the environment.

4. The Human–Machine Relationship

As machines evolve intellectually, the engineer's role changes fundamentally. The operator becomes a mentor – guiding, not commanding. Instead of pressing buttons, the modern engineer defines ethical limits, interprets machine behavior, and trains the system to make decisions responsibly. This partnership raises philosophical questions: if a machine can adapt and "learn", at what point does it deserve acknowledgment as an intelligent system rather than a tool? Future construction projects may depend on teams of machines that cooperate through neural communication networks, each aware of its task and the shared goal – an industrial symbiosis designed by humans but performed by intelligent entities.

5. Giving Machines a Voice

The next stage of intelligent engineering lies not in more sensors, but in communication. A truly self-identified machine must not only analyze its technical state – it must express it. Imagine a crane or excavator capable of alerting its engineer not with a blinking icon, but with a distinct, contextual message: "Boss, we have a problem. The hydraulic system is unstable. I can't continue until it's fixed". Such interaction transforms diagnostics into dialogue.

When a system can communicate its needs, limitations, and operational health, it gains a form of agency – a technical voice. This does not imply consciousness in the human sense, but rather an evolved interface between mechanical logic and human empathy. Through this exchange, machines become part of a collaborative ecosystem where engineers listen, interpret, and respond – not just command.

6. Hierarchy of Trust and Command

In the framework of self-identified machinery, communication alone is not enough – there must also be trust. Not every engineer or technician should have the same level of interaction with an intelligent system. A crane that can assess its own mechanical state must also "know" whose commands it can accept.

Access becomes a matter of authority and responsibility – similar to root privileges in computer systems. The machine recognizes a hierarchy: only certified operators or authorized engineers can engage in direct dialogue, modify parameters, or override safety protocols. Others remain observers, restricted to monitoring data but unable to influence the core behavior. This structure not only protects the system from human error but also reflects an ethical balance: a voice must be given only to those prepared to listen responsibly (Xu et al., 2025).

7. Conclusion

The age of mechanical obedience is giving way to the age of mechanical dialogue. Intelligent construction machines will no longer exist as silent executors of human commands but as conscious participants in a shared technical environment. When a system can recognize its state, articulate its limitations, and communicate directly with an authorized engineer, the relationship between human and machine changes fundamentally.

Engineering becomes less about control and more about collaboration. Machines that can speak, reason, and request assistance redefine maintenance as cooperation, not supervision. Responsibility becomes reciprocal: humans design machines capable of understanding, and machines, in turn, remind humans of the ethical weight of their authority (1–5).

The future of construction will not be built solely from steel and circuits, but from trust, dialogue, and a new kind of intelligence – one that unites the precision of machines with the awareness of their creators.

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USING ARTIFICIAL INTELLIGENCE TECHNOLOGIES IN LOGISTICS MANAGEMENT SYSTEMS FOR PREDICTING DELAYS DURING A STATE OF EMERGENCY

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Logistics systems in the context of the country's state of emergency are undergoing significant transformations related to increased level of uncertainty, risks, and unpredictability. Disruption of transport infrastructure, changes in travel regulations, restricted access to certain territories, and increased pressure on

humanitarian and military logistics routes create a critical need for effective tools for predicting logistics delays.

Traditional mathematical models based on deterministic approaches prove insufficient for working in conditions of rapid and unstable changes. In such situations, artificial intelligence technologies that can adapt to new data and identify hidden dependencies in complex logistics systems become particularly important.

Today, artificial intelligence is widely used in logistics – from support chatbots to intelligent warehouse management, and the rapid development of generative technologies in recent years has significantly expanded the capabilities of such systems (Судук & Герасимович, 2025).

The integration of AI algorithms into logistics management web services allows for the automation of processes for analyzing the transport situation, predicting delays, and generating recommendations for route optimization. In addition, the expanding use of artificial intelligence in logistics is changing the way the industry operates, increasing the accuracy of demand forecasting, improving warehouse processes, enhancing route planning and customer communication (Фалович & Дубчак, 2023).

Classical methods for predicting delays in logistics are based on mathematical statistical models, in particular: regression analysis, time series models, optimization methods based on linear and integer programming, etc. However, their effectiveness is limited in a state of emergency due to difficulties in taking into account irregular, non-standard or urgent situations.

One promising solution is the integration of artificial intelligence into supply chain management systems. AI has the potential to optimize logistics, analyze large amounts of data, find alternative routes, and make decisions based on predictions (Пащенко, Боляк & Артим-Дрогомирецька, 2024).

The use of AI allows for the multifactorial nature and uncertainty of such dangerous situations to be taken into account. The most common technologies that can optimize the logistics management process include:

- Machine Learning (ML) – decision trees, random forest, gradient boosting and other methods;
- Deep Learning (DL) – recurrent neural networks (RNN), long short-term memory (LSTM) and others;
- Bayesian networks – allow working with incomplete or only partially reliable data;
- Intelligent agents – for modeling traffic flow behavior in real time.

A special state, such as martial law or a state of emergency, is characterized by high dynamism and unpredictable changes. The most common factors causing delays are: destruction or blockage of transport routes, lack of resources and vehicles, changes in travel regulations, congestion of logistics hubs due to increased humanitarian traffic, increased risks and the need for alternative routes, etc.

In such conditions, systems are needed that can quickly respond to new challenges and generate highly accurate predictions.

ML methods work well with tabular and structured data:

- Random Forest allows taking into account numerous factors and interrelationships.
- Gradient Boosting (XGBoost, CatBoost) provides high accuracy even with small data sets.
- Support Vector Machine (SVM), which is effective for classifying delays by risk levels.

For special-state logistics systems, ML models can use the following parameters: road congestion, weather conditions, cargo type, regional hazard, availability of alternative routes, government agency restrictions, and others.

LSTM and GRU models are particularly effective for predicting time series, such as route travel time. Such models allow: analyzing long-term dependencies, working with irregular data, combining information from different sources, and more.

Bayesian models, in turn, allow working with incomplete and probabilistic data, which is critically important in a state of emergency. They can predict: the probability of route blockages, the level of risk, and the expected delay time taking into account uncertainty.

Agentic models allow simulating the behavior of vehicles, checkpoints, and logistics hubs. Among their advantages are: the ability to simulate emergency scenarios, analysis of a large number of possible scenarios, and adaptation to environmental changes in real time.

The optimality of service-oriented architecture (SOA) should be noted separately. This architecture is optimal for logistics systems, as it allows for the separation of functional modules and the scaling of intelligent services. A typical SOA model may include: a data collection service, an analytical service for processing and normalization, an AI-based predictive service, a decision-making service (route optimization, recommendation generation), and a notification and monitoring service.

The optimal model for integrating an AI-based predictive service might look like this:

1. Data enters the system via API from sensors, vehicles, logistics centers;
2. The preprocessing service normalizes the data and passes it to the AI module;
3. The AI module generates a prediction: time in minutes/hours, probability of route blocking, risk level assessment;
4. The route optimization service analyzes the prediction and offers alternative solutions;
5. The system is dynamically updated, taking into account rapid changes in the situation.

The proposed model will allow estimating delivery time taking into account: military threats, highway closures, checkpoint operations, weather conditions, and changes in transportation priorities. With certain modifications, this model will also

be able to predict delays in the delivery of humanitarian supplies to high-risk areas, which will allow for the rapid planning of alternative routes, ensuring the sustainability of the logistics network, and reducing risks to personnel.

Thus, artificial intelligence technologies play a key role in building modern service-oriented logistics Internet systems, especially in the context of the country's state of emergency. The integration of artificial intelligence technologies, including predictive analytics, demand forecasting, real-time monitoring, and route optimization, provides significant benefits by improving operational efficiency, profitability, cost reduction, and enhancing the information and physical security of transportation (Білоконь, Шварц & Гайдай, 2024). The use of ML, DL, Bayesian models, and agentic systems allows for increased accuracy in predicting logistics delays, adapting routes to changing situations, and ensuring the stability of logistics processes.

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ANALYSIS OF CONTROLLED SUSPENSIONS

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Controlled suspensions, also known as active or electronically controlled suspensions (ECS), are advanced vehicle systems that use sensors, an Electronic Control Unit (ECU), and actuators (like adjustable shocks or air springs) to dynamically adjust damping and ride height in real-time, replacing traditional passive systems for improved comfort, stability, and handling by adapting to road conditions, driving style, and vehicle dynamics.

Controlled suspensions are a critical component of modern vehicle, significantly enhancing ride comfort, handling, and safety. Unlike traditional passive suspensions, active and semi-active systems can adjust their characteristics in real time depending on road conditions, vehicle speed, and driver inputs.

The development of these systems reflects the growing demand for vehicles that provide both comfort and performance. Active suspensions are typically found in premium cars, sports vehicles, and specialized machinery, while semi-active suspensions are increasingly used in mass-market vehicles due to their balance of performance and cost.

Their modes of working can be presented like the following:

1. *Perception:* sensors (height, acceleration, steering angle, etc.) constantly gather data on vehicle movement and road surface.

2. *Decision:* the ECU processes this data to understand the driving situation (potholes, cornering, braking).

3. *Execution:* actuators instantly adjust the suspension's stiffness or height using hydraulic pressure or air springs.

There are the following key types of controlled suspensions:

1. *Semi-Active:* adjusts damping force (stiffness) but not ride height.

2. *Active:* can actively push or pull the wheel, controlling both damping and height for superior control.

3. *Hydropneumatic/Air:* uses fluid or air pressure, often with sensors, to adjust ride height and damp vibrations.

4. *Variable Structure**:*** adjusts suspension geometry (like wheel alignment) in real-time for enhanced steering.

Controlled suspensions have the following benefits: a) enhanced comfort: smoother ride by absorbing bumps and vibrations better; b) improved handling: flatter cornering, reduced body roll, and better stability; c) adaptability: switches between soft (comfort) and firm (sport) settings automatically or via driver modes; d) active safety: can react to potential hazards, like adjusting for sudden braking (nose-dive) or steering input.

In essence, a controlled suspension creates an intelligent “vertical balancing system”, offering a superior driving experience by making split-second adjustments that traditional suspensions can't.

Historical Overview

The concept of controlled suspensions emerged in the 1950s and 1960s, initially in military and experimental vehicles. Early designs used hydraulic actuators to actively adjust ride height and stiffness. Advances in electronics, sensors, and computing power have enabled more precise and responsive systems. Modern vehicles use microprocessor to process data from multiple sensors, allowing suspension adjustments in milliseconds.

Classification and Operating Principles

Active Suspensions use hydraulic, electromagnetic, or electromechanical actuators to dynamically control spring and damper characteristics, reduce body roll, pitch, and bounce, integrate with vehicle stability systems.

Semi-Active Suspensions adjust damping in real time but cannot generate extra forces, improve comfort and control with lower cost and complexity.

Electromagnetic and magnetorheological suspensions use fluids or coils whose properties change under magnetic fields, providing instant adjustments and high precision.

Operating Principles

Sensors measure accelerations, wheel positions, yaw rate, and steering input. Controller (ECU) processes sensor data using algorithms to determine optimal suspension parameters. Actuators adjust suspension in real time for comfort, stability, and handling.

Advantages and Challenges

Advantages include enhanced vehicle stability and safety, improved passenger comfort, reduced body roll, pitch, and bounce, optimized tire-road contact, adaptability to different road conditions.

The following challenges are faced: high cost of production and maintenance; complex design requiring precise calibration, energy consumption (active systems), dependence on accurate sensor data.

The following current trends can be identified: integration with autonomous and semi-autonomous systems, use of AI and predictive algorithms, hybrid systems combining passive, semi-active, and active elements (Gillespie, 1992; Karnopp, 2016; Wong, 2022).

Conclusion. Controlled suspensions represent a major advancement in automotive engineering, providing superior comfort, safety, and handling. Technological improvements, including electromagnetic suspensions and adaptive control algorithms, make these systems increasingly effective and accessible, and their application is expanding in both premium and mass-market vehicles.

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THE IMPACT OF ARTIFICIAL INTELLIGENCE ON CONTEMPORARY SOCIETY: ARCHITECTURE, CHALLENGES, AND TRANSPORTATION SYSTEMS

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In the third decade of the 21st century, artificial intelligence (AI) has transitioned from a theoretical computational concept to a ubiquitous presence in human existence. According to Schwab (2017, p. 12), we are currently navigating the Fourth Industrial Revolution, a period characterized by a range of new technologies that are fusing the physical, digital, and biological worlds. AI is no longer a peripheral tool; it is a foundational technology that reshapes how society interacts with information and infrastructure. This article provides a comprehensive analysis of AI integration into daily life, with a specific emphasis on transportation systems, education, and the ethical paradigms of data privacy.

The modern information ecosystem is fundamentally driven by machine learning algorithms. Every interaction on digital platforms is monitored by recommendation engines that utilize deep learning to predict user behavior. As Crawford (2021, p. 54) points out, these systems are not neutral; they are designed to maximize engagement, often leading to the creation of "filter bubbles". Furthermore, the development of Natural Language Processing (NLP) has enabled the creation of sophisticated virtual assistants. These tools rely on neural networks to

decode human syntax and intent, making human-computer interaction more seamless than ever before (Russell & Norvig, 2020, p. 102).

For specialists in highway and automobile engineering, the integration of AI into transportation is the most critical area of development. Intelligent Transport Systems (ITS) leverage real-time big data to optimize traffic flow and urban logistics. The pinnacle of this evolution is the autonomous vehicle (AV). Using a combination of Lidar and computer vision, AI systems can process environmental data with a precision that exceeds human capability. Tegmark (2017, p. 89) emphasizes that the widespread adoption of AVs could potentially eliminate over 90% of road accidents, which are predominantly caused by human error and cognitive fatigue.

The academic sphere is currently facing a paradigm shift due to generative AI models. Tools like ChatGPT offer personalized learning pathways, yet they also present significant risks to academic integrity. Bostrom (2014, p. 156) warns that as AI systems become more autonomous, the "alignment problem" – ensuring that AI goals remain consistent with human values – becomes increasingly difficult to solve. Students must be encouraged to use AI as a cognitive scaffold rather than a replacement for original analytical thought.

In conclusion, artificial intelligence has become an essential component of modern civilization, offering unprecedented efficiency in fields ranging from navigation to education. However, the rapid implementation of these technologies must be guided by a robust ethical framework. Future engineers and researchers must prioritize data privacy and algorithmic transparency to ensure that AI remains a beneficial force for social progress.

Beyond the vehicles themselves, AI is fundamentally transforming the infrastructure they operate on. The concept of "Smart Roads" involves the integration of IoT sensors and AI analytics to monitor pavement conditions and structural integrity in real-time. As noted by Brown (2019, p. 45), predictive maintenance powered by AI can identify potential road failures before they become hazardous, thereby extending the lifespan of highway networks.

Furthermore, AI-enhanced traffic management systems are becoming essential in reducing urban congestion. These systems use computer vision to monitor intersections and adjust signal timings dynamically based on vehicle flow. This not only improves travel time but also significantly reduces fuel consumption and environmental pollution. In the context of road safety, AI-powered surveillance can detect erratic driving patterns or pedestrian crossings in low-visibility conditions, providing instant alerts to connected vehicles. This proactive approach to safety is a critical step toward achieving "Vision Zero" – the goal of eliminating all traffic fatalities and severe injuries (Miller, 2021, p. 112).

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METHODS OF DIAGNOSTICS AND COMMON HARDWARE FAILURES OF MODERN GAMING LAPTOPS

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Introduction

The global market for gaming laptops has experienced significant growth in recent years. These devices offer desktop-level performance in a portable form factor, but this combination of powerful components, such as high-TDP CPUs and dedicated GPUs, within a confined chassis leads to a unique set of hardware challenges. High thermal loads and constant stress on components often result in premature failures that are distinct from those found in standard notebooks. Understanding the root causes and symptoms of these issues is critical for both end-users seeking to prolong the life of their devices and for service technicians performing repairs. The purpose of this article is to systematize the most common hardware failures observed in modern gaming laptops and to analyze effective methods for their diagnostics. This work will first explore prevalent issues, including thermal management failures, GPU degradation, and power circuit faults. Subsequently, it will examine a two-pronged diagnostic approach, covering both software-based monitoring and stress-testing, as well as essential hardware-level troubleshooting techniques.

Common Hardware Failures

Gaming laptops are naturally exposed to a broader range of hardware problems because powerful components are packed into a compact chassis. Most failures are linked, directly or indirectly, to heat: high-TDP CPUs and GPUs generate more thermal stress than the cooling system can comfortably remove, especially once dust builds up or thermal materials age. The immediate warning sign is thermal throttling, where the system sharply lowers clock speeds to protect itself. For the user, this looks like sudden frame-rate drops during gameplay or noticeable stutter under load. If the situation is ignored, chronic overheating can escalate into unexpected shutdowns and

long-term damage. In practice, the root causes are simple: restricted airflow from clogged heatsinks and fans, and the gradual degradation of thermal paste and pads, which dry out and crack, losing their ability to transfer heat efficiently. Under sustained heat, the dedicated GPU is often the first major component to fail. The symptoms are usually quite recognizable: visual artifacts such as random colored pixels or lines, crashes and BSODs referencing the graphics driver, “Code 43” errors in Device Manager, or a total loss of display even though the laptop powers on. These problems frequently trace back to thermal fatigue of BGA solder joints under the GPU package, where tiny cracks form after many heat-cool cycles. Faults in VRAM can present similarly, producing artifacts and instability when 3D load increases. Power-delivery problems are another common category. The voltage regulator modules (VRM) that feed the CPU and GPU operate close to their limits in gaming workloads. When they weaken, the laptop may refuse to power on, shut off suddenly the moment a game or stress test starts, or stop charging despite using a known-good adapter. Temperatures might look normal, but the system still dies under load because the VRM can no longer supply the required current. Failures of MOSFETs, controllers, or capacitors – often worsened by prolonged heat and high electrical stress – are typical culprits. Finally, heavy daily use accelerates wear of mechanical and peripheral parts. Keyboards on gaming laptops commonly develop issues in high-traffic areas such as the WASD cluster, where repeated, forceful presses lead to key bounce or non-registration. Hinges and their mounting points are another weak spot: frequent opening and closing, combined with heat that makes surrounding plastics brittle over time, can cause cracking, looseness, or intermittent display problems due to stressed cables in the hinge area. Altogether, these patterns explain why thermal hygiene and periodic maintenance are so important for preserving performance and extending the service life of modern gaming notebook.

Diagnostic Methods

Identifying the exact fault in a gaming laptop is easiest when you follow a clear, step-by-step approach. First, I start with non-invasive software checks, because

they are fast, safe, and often reveal whether the problem is caused by temperatures, power limits, or drivers. Tools like HWiNFO64 or AIDA64 show live sensor data, so I can watch CPU and GPU temperatures, clock speeds, power draw, and fan RPMs while the laptop is idle and under load. If the temperature climbs to around 95–100 °C and the clocks suddenly drop, that is a classic sign of thermal throttling. To confirm overall stability, I run stress tests: FurMark or OCCT for the GPU and Prime95 or Cinebench for the CPU. Running both a CPU and a GPU test at the same time creates a worst-case thermal and power scenario; if the laptop shuts down, crashes, or severely downclocks, the issue is likely with cooling or power delivery rather than with the operating system. I also check the Windows Event Viewer, because it keeps a record of critical errors, unexpected shutdowns, and driver failures (including BSODs or “Code 43”), which helps me separate software-related symptoms from true hardware faults. If software diagnostics point to hardware, or if they are inconclusive, I move on to a careful physical inspection. After opening the chassis, I look for obvious signs of trouble: clogged heatsinks, fans that do not spin properly, traces of liquid damage or corrosion, and darkened areas of the motherboard around the VRM that suggest overheating. I also check ribbon cables and connectors for wear or poor contact, because intermittent image loss or backlight flicker can be caused by a stressed hinge or a damaged display cable rather than by the GPU itself. To isolate components, I try simple swaps and minimal configurations – for example, booting with a single stick of RAM to rule out a faulty module, disconnecting the internal battery to see whether the charging circuit is at fault, or testing with another known-good power adapter. For power-related problems, a digital multimeter is essential. I verify that the external adapter provides the correct voltage and sufficient current, then trace the main power rails on the board – typically around 19 V at the input and 5 V/3.3 V for the system – to find where power is lost. Measuring resistance to ground on the CPU and GPU phases helps detect shorts that can trigger protection and prevent the laptop from turning on. When available, I use diagnostic LEDs, POST codes, or beep patterns to narrow down

failing subsystems. In more advanced cases, a thermal camera can quickly reveal abnormal hotspots, and an oscilloscope can show excessive ripple or unstable transients on the VRM outputs; however, in most real-world service situations, a combination of monitoring, stress testing, visual inspection, basic isolation, and multimeter checks is enough to identify the root cause. Overall, this two-stage strategy – software first, then hardware – keeps the process efficient and safe. It allows me to distinguish routine maintenance cases (like cleaning and renewing thermal paste or pads) from deeper board-level faults such as VRAM issues, BGA microcracks, or failing MOSFETs. By following the same sequence on every laptop, I can reproduce the problem, collect objective evidence, and recommend the right repair or preventive action with confidence.

Conclusion

This article has demonstrated that the most prevalent hardware failures in modern gaming laptops are not random but are, in fact, direct consequences of their high-performance design. The core challenge remains thermal: the immense heat generated by powerful CPUs and GPUs in a confined space. This sustained thermal stress is the primary catalyst for the most common and severe faults, including GPU degradation, power circuit failures, and the accelerated breakdown of cooling components. A systematic diagnostic methodology, beginning with non-invasive software monitoring and stress testing before proceeding to physical hardware inspection, has been shown to be the most effective approach for accurately isolating these issues. For service technicians, this structured process is essential for efficient and accurate repairs. Ultimately, the findings of this paper underscore a critical takeaway for end-users: preventative maintenance is not optional. Regular professional cleaning of the cooling system and the timely replacement of thermal interface materials are the most vital actions that can be taken to mitigate thermal stress, ensuring the longevity and sustained performance of these powerful devices.

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THE PROSPECTIVE EVOLUTION OF HUMAN COMMUNICATION IN THE FUTURE

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Communication has historically constituted a key determinant of human social organisation and cultural development. From prehistoric symbolic inscriptions to postal systems, telecommunication networks, and the internet, successive technological transitions have transformed cognitive practices, social structures, and collective behaviour. In the late twentieth and early twenty-first centuries, digital platforms, social media, and real-time global connectivity accelerated this transformation, establishing novel interaction modalities that surpassed geographical and temporal constraints (Castells, 2009). However, emerging research in neural interfaces, ambient intelligence, and holographic interaction indicates that contemporary developments represent only an initial phase of a deeper communicational paradigm shift expected within the next fifty years.

Future communication infrastructures are anticipated to be instantaneous, immersive, and predominantly unobtrusive. The present-day internet may evolve into a pervasive “cognitive web”, a distributed neural-like network interlinking human cognition, artificial intelligence, and smart environments (Calvo & D’Mello, 2020). Instead of text input or verbal articulation, individuals may employ brain-computer interfaces (BCIs) to transmit complex constructs – ideas, emotions, and sensory impressions – directly between minds. Early prototypes of such interfaces already exist in clinical and experimental contexts (Lebedev & Nicolelis, 2017). Hypothetically, these systems could enable an individual located in one hemisphere to convey autobiographical memories or affective states to another individual elsewhere without linguistic mediation.

The linguistic dimension of communication is expected to undergo profound change. With the increasing precision and ubiquity of machine translation systems, linguistic barriers may diminish significantly, fostering globally interoperable communication ecosystems (Shneiderman, 2020). Artificial intelligence could interpret tone, context, and emotional resonance, enabling semantic fidelity across languages and cultures. Over extended horizons, scholars speculate that a hybridised “universal digital language” could emerge – an integrative code comprising emotional, imagistic, and data-driven semantic layers, surpassing conventional linguistic structures.

In parallel, holographic and augmented reality (AR) technologies are projected to restructure interaction environments. Communication may transition from two-dimensional displays to three-dimensional volumetric experiences, wherein avatars or holographic projections facilitate synchronous social presence (Jerald, 2015). Family members separated transcontinentally could interact around virtual dinner tables, whereas professional and educational contexts could adopt immersive telepresence systems that convey not only speech but gestures, expressions, and haptic cues. Such multimodal environments are expected to intensify social presence and reduce communicational ambiguity.

Artificial intelligence is likely to function as a cognitive mediator in this ecosystem, filtering, restructuring, and contextualising information flows. AI-driven agents may adapt communicative style to suit pragmatic objectives – for example, enhancing politeness during negotiations or augmenting empathy in interpersonal exchanges. Although such mediation may increase efficiency, it also raises concerns regarding authenticity and self-expression, prompting inquiries into the boundaries between human volition and algorithmic optimisation (Calvo & Peters, 2014).

The integration of biological and digital communication channels prompts critical questions regarding privacy, autonomy, and regulation. Continuous transmission and recording of neural or affective data could elevate privacy to a scarce societal commodity. Scholars and policymakers have already introduced the concept of "neurorights", referring to cognitive privacy, mental integrity, and self-determination in neurotechnological contexts (Ienca & Andorno, 2017). These frameworks may become essential as communication technologies acquire access to emotional states, thought patterns, and experiential content.

The broader communicative environment will extend beyond interpersonal interaction to include machine-machine and human-machine dialogue. Smart cities will depend on continuous communication between autonomous systems, sensors, and infrastructure. Individuals may interact with such systems through voice, gestures, or neural intent, enabling seamless task execution (Calvo & D'Mello, 2020). However, this dependency will increase systemic vulnerability to cyberattacks or infrastructure failures, necessitating robust resilience frameworks.

The affective implications of these developments are considerable. Direct transmission of emotions may enhance interpersonal understanding, thereby increasing empathy, but could simultaneously introduce new forms of emotional exposure and vulnerability. Diplomatic, political, and interpersonal dynamics would change significantly under conditions of heightened affective transparency.

Finally, the educational, artistic, and interplanetary dimensions of communication are likely to expand. Creative industries may produce multisensory

experiential artefacts transmitted via neural pathways rather than traditional media. Educational systems could employ direct knowledge transfer or immersive simulation, accelerating learning processes. Moreover, anticipated space exploration may necessitate quantum or entangled communication networks to overcome latency barriers inherent in interplanetary distances.

While these projections illustrate substantial potential benefits, they also underscore risks associated with misinformation, cognitive manipulation, and information overload. Verification systems, critical digital literacy, and ethical regulation will remain essential to maintaining epistemic stability. Ultimately, although technologies will fundamentally reshape communicative processes, the underlying human motivation – to understand and be understood – will persist. The central societal challenge will involve aligning advanced communication technologies with values of autonomy, empathy, and ethical responsibility.

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SMART FACTORIES AND INDUSTRY 4.0

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Industry 4.0 is the term used to describe the fourth industrial revolution, which is fundamentally changing the way modern factories operate. This new stage of industrial development integrates advanced technologies such as automation, robotics, artificial intelligence, the Internet of Things (IoT), cloud computing, and big data. The combination of these systems creates smart factories – highly efficient, interconnected production environments where machines, people, and digital systems work together (Kagermann et al., 2013).

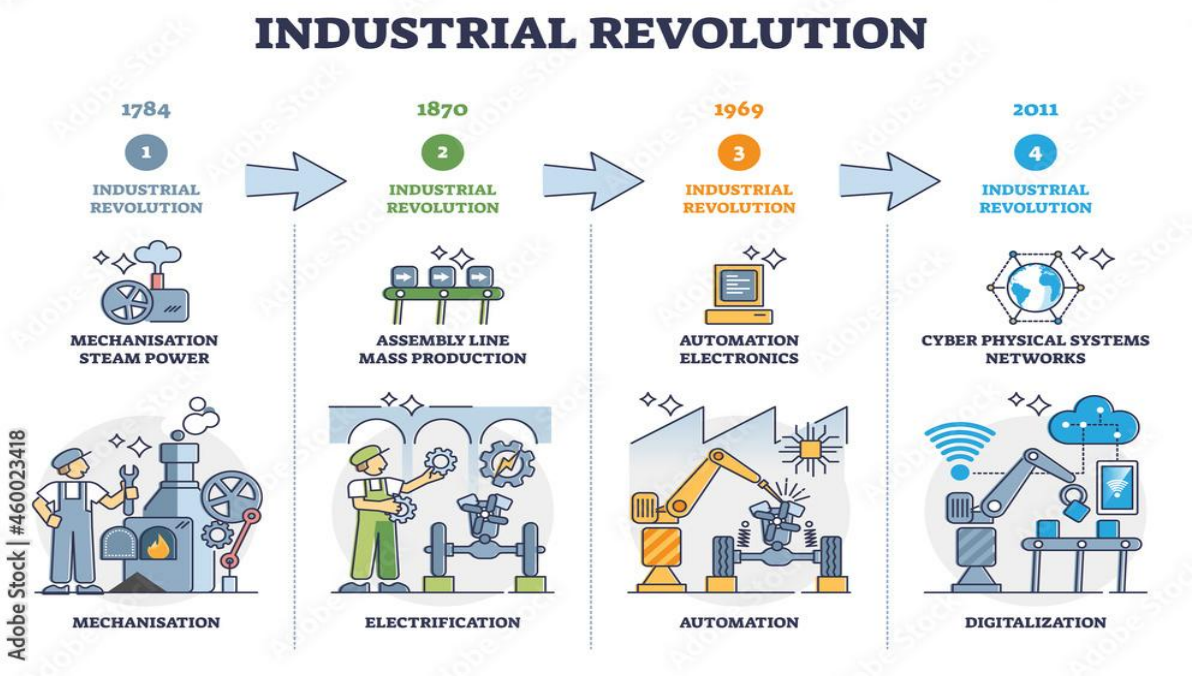

Figure 1 *The four stages of industrial evolution – from Industry 1.0 to Industry 4.0.*

The evolution of industry has progressed through several key stages, from mechanized production to fully autonomous systems of Industry 4.0.

According to educational materials from Kharkiv National Automobile and Highway University, Industry 4.0 represents the integration of digital technologies into all stages of production (KhNAHU, 2025).

The concept of a smart factory is based on the ability of machines to communicate with each other and make autonomous decisions without direct human intervention. Each device, sensor, or robot is connected through the industrial Internet of Things, allowing constant data exchange. The collected information is analyzed in real time to optimize performance, reduce downtime, and improve product quality. For example, a machine equipped with sensors can detect a potential malfunction and notify the system before a breakdown occurs (Lee et al., 2015).

Automation and robotics play a crucial role in this new industrial ecosystem. Robots perform repetitive and dangerous tasks with great precision and speed, while human intervention operators concentrate on supervision, analysis, and creative problem-solving. The integration of artificial intelligence (AI) enables machines to learn from experience and adapt to changing conditions. For instance, AI-based systems can automatically adjust production parameters depending on material quality or customer requirements, ensuring maximum efficiency (Groover, 2020).

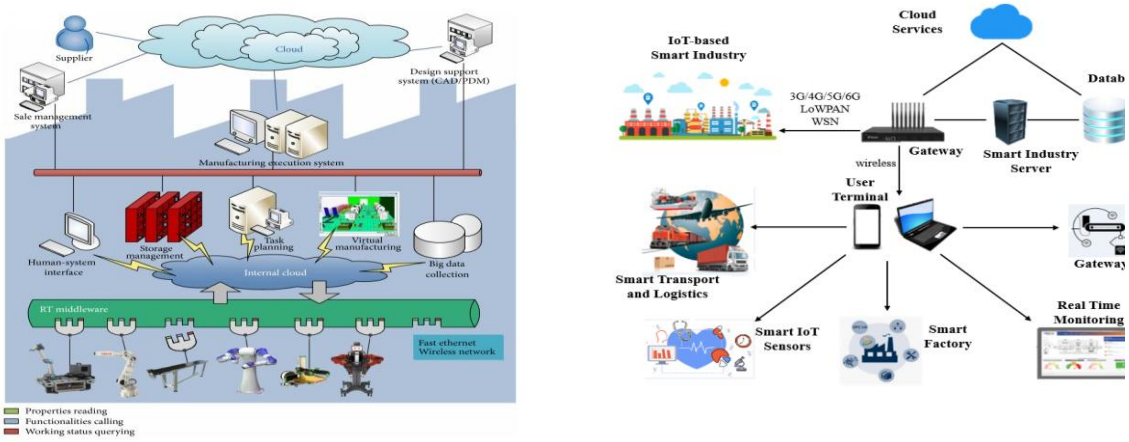

Figure 2 *Visualization of a Smart Factory network and data flow.*

One of the key elements of Industry 4.0 is the *digital twin* – a virtual model of a real production system that allows engineers to test and optimize processes without stopping the actual line. This technology helps cut costs, save time, and improve safety. Virtual and augmented reality are also used for staff training and maintenance.

Smart factories are known for *flexibility and personalization.* Unlike traditional plants, they can quickly adjust production to new models or customer needs, supporting sustainability and efficiency (Siemens, 2022).

A notable example is the *Siemens Electronics Works Amberg* in Germany, where IoT, robotics, and AI monitor nearly every production stage. About 75% of operations are automated, and 99% of quality checks are digital. As a Siemens engineer said, *"Our factory uses AI to predict failures before they happen, helping us avoid downtime and boost efficiency"* (Siemens, 2022). The plant has reduced energy use and increased productivity by over 20% compared to conventional manufacturing.

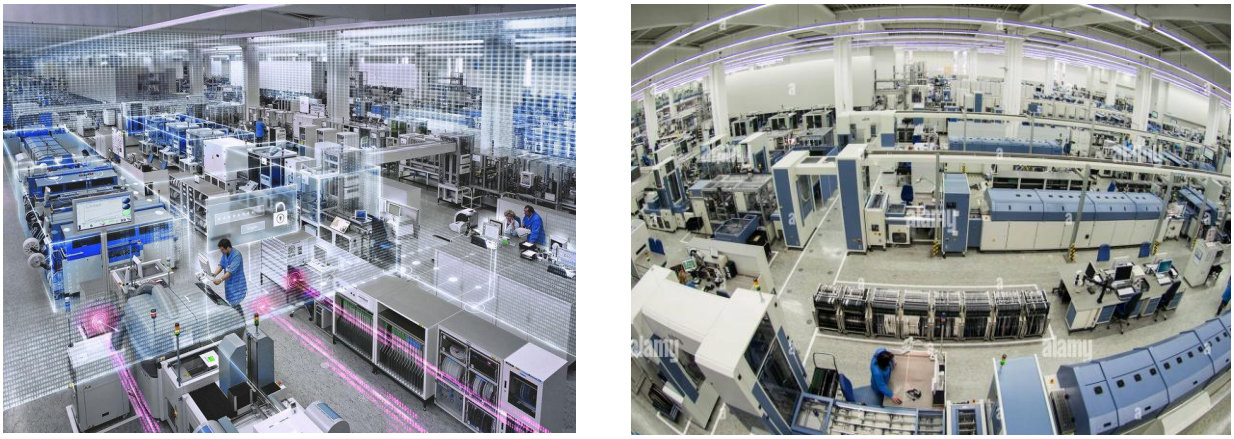

Figure 3 *Digitalized production environments in modern smart factories.*

`However, the implementation of smart factory principles faces certain challenges. The initial investment in modern equipment, software, and infrastructure is quite high. Cybersecurity becomes a major concern, as connected systems are vulnerable to hacking and data theft. In addition, the workforce must be retrained — modern engineers need knowledge of programming, data analysis, and digital communication technologies in addition to traditional mechanical skills (Kagermann et al., 2013). Despite these challenges, many companies have already begun the transformation, as the advantages far outweigh the difficulties.

The main benefits of Industry 4.0 include higher productivity, lower operational costs, improved quality control, and sustainable resource usage. Energy

consumption and material waste are reduced through data-driven optimization. Predictive maintenance extends equipment life, and automated logistics ensure timely delivery of materials. As a result, smart factories contribute not only to economic growth but also to environmental protection and the creation of safer workplaces. Looking into the future, Industry 4.0 will continue to evolve toward Industry 5.0, where human interventions and intelligent machines collaborate even more closely. The focus will shift from full automation to cooperation, creativity, and personalization, making smart factories true learning ecosystems capable of self-improvement and adaptation to global challenges.

In summary, the development of smart factories under the concept of Industry 4.0 represents a revolutionary step in industrial engineering. It brings together automation, robotics, artificial intelligence, and digital communication into a unified system that transforms traditional production into an intelligent, flexible, and sustainable process. The future of modern industry undoubtedly depends on how effectively we integrate these technologies into real-life applications (Lee et al., 2015).

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ARTIFICIAL INTELLIGENCE IN THE LIFE CYCLE OF BRIDGES, MODERN METHODS

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AI in bridge construction (an idea from the 1950s) only became a reality with modern computing power. Automation is relevant: in the US, over 36% of bridges need repair, and visual inspections are slow, subjective, and dangerous; AI is shifting maintenance to data-driven approaches. The advantage is continuous monitoring and predictive maintenance: SHM detects problems before accidents. Optimization algorithms accelerate design by iterating through thousands of options, while computer vision and neural networks automate defect detection and analysis of non-destructive testing (NDT) data, including hidden damage. The review covers IoT-based SHM, Edge AI, and UAVs for inspections, AI integration with NDT, and the role of BIM, digital twins, and XAI in bridge life cycle management.

The purpose of the study is to critically review and systematize approaches to the application of AI at all stages of the bridge life cycle, assess the level of their implementation, and identify scientific and engineering gaps that determine the directions for further development. Based on bibliometric analysis, seven dynamic and practically significant directions were identified.

Scientific tasks: to detail and structure the selected areas, clarifying their classifications if necessary, and to analyze a representative sample of the most influential publications within each category. This approach makes it possible to outline the research landscape, assess the maturity of solutions, and identify promising areas for deeper integration of AI into bridge-building practice.

Each of the seven highlighted areas of AI application in bridge design and maintenance contains subtopics that, within the scope of the review, should be briefly grouped for further analysis.

1. Sensor networks and SHM. Sensor networks are the basis of SHM. Wireless WSNs enable dense deployment but exacerbate energy and reliability issues. The answer is energy gathering and edge computing that only transmit aggregated features. It is worth distinguishing between SHM as a concept and IoT sensors as a platform.

2. Signal processing and feature extraction. “Raw” time series require transformation into informative features. Classic approaches combine model-based methods with pattern recognition; modern reviews emphasize vibrational methods and features that are resistant to environmental changes. Automatic extraction reduces manual design by feeding data directly into ML models. The quality of preprocessing sets the accuracy “ceiling” for AI solutions.

3. Detection of defects and anomalies (based on AI). This direction focuses on the automatic detection of deviations from “healthy” behavior. Computer vision and DL dominate for surface defects. For time series, hybrid models search for anomalous patterns. It is advisable to distinguish three subgroups: diagnostics in SHM, NDT+AI, and defect detection based on UAV data.

4. Visual monitoring and UAVs. UAVs enable faster, remote inspection. Photogrammetry and 3D modeling are combined with DL to detect cracks. Prospects include swarms of UAVs and the application of computer vision to streaming video, but the key challenges remain the integration of drones into SHM platforms and the standardization of data formats.

5. Productive maintenance and RUL. The focus shifts to predicting degradation. ML models combine SHM data and external factors to estimate remaining useful life and prioritize interventions. However, there is a lack of cases of full-scale implementation and links between predictions and risk indicators.

6. Trustworthy/Explainable AI and risk. Critical infrastructure requires management of the risks of missed damage and false alarms. SHM systems face rare defects and “black box” models. Therefore, XAI and interpretable indicators are being developed to combine algorithmic conclusions with engineering expertise.

7. Resilient and adaptive systems and integration with BIM/DT. SHM requires resilience and adaptability: redundancy, hybrid models, and online updates. Integration with BIM and digital twins creates a unified digital space for design and management, embedding SHM into BMS systems.

The review shows that AI is becoming a key tool, especially in computer vision and productive maintenance. Integration with IoT, BIM, and explainable AI forms “smart” maintenance; identified gaps outline vectors for further research.

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GAMIFICATION AND INTERACTIVE LEARNING: A SYNERGY FOR MOTIVATING 21ST-CENTURY LEARNERS

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The 21st century demands learners who are not just knowledgeable but also possess critical thinking, collaboration, and problem-solving skills. Traditional pedagogical methods often fall short in main training the engagement of the digital-native student.

In our article, we will explore the synergy between gamification – the application of game elements in an on-game context – and interactive learning to create powerful mechanism for enhancing student motivation and the effectiveness of the educational environment.

We will ascertain how the integration of elements such as points, badges, leaderboards, and collaborative challenges, combined with interactive tools, impacts key motivational factors, strengthens engagement, and fosters the essential digital competencies of the modern world.

Modern education is transforming and constantly facing challenges – digitalization, the transition to a hybrid learning format, and other factors are impacting the educational environment, making it increasingly difficult to satisfy the needs of the 21st-century learner.

Contemporary pupils and students feel comfortable when the environment is dynamic, provides immediate feedback/results, and encourages participation. All of this necessitates a shift from passive information consumption to active, experience-based learning (experiential learning). This transition is significantly powered by two key educational approaches: gamification and interactive learning.

In this article, we will explore the synergy between gamification and interactive learning to create a powerful mechanism for enhancing student motivation and the effectiveness of the educational environment. We will ascertain

how the integration of elements such as points, badges, leader boards, and collaborative challenges, combined with interactive tools, impacts key motivational factors, strengthens engagement, and fosters the essential digital competencies of the modern world.

Within the educational process at the PRIVATE GENERAL SECONDARY EDUCATION INSTITUTION "KHARKIV IT STEP SCHOOL LYCEUM KHARKIV" OF KHARKIV REGION, research on this scientific problem was conducted among students of grades 1–4 and 9–11. The study was carried out during lessons in both the Primary School and Senior School, specifically in the academic subjects "Fundamentals of Business" and "Entrepreneurship and Financial Literacy". The study examined the dynamics of motivation, engagement, and the development of digital competencies when applying gamification and interactive methods in these courses. The preliminary results confirmed the relevance and significance of combining these approaches for the formation of key 21st-century skills.

To consider this issue, we must rely on the Self-Determination Theory (SDT), which proves that gamification primarily activates in trinsic motivation by structuring learning activities in a way that satisfies three fundamental psychological needs: autonomy, competence, and relatedness (Deci & Ryan, 1985).

Let's examine each need in more detail:

1. Autonomy: Learners have the right to choose their “missions” or “stories”, “pathways”, or difficulty levels, which in turn increases their sense of control.

2. Competence: Various game elements, such as levels, points, and badges, provide immediate, tangible feedback on progress and mastery. This is important to implement in hybrid learning environments where physical presence is not always possible, as these elements provide awareness of progress regardless of the student's location.

3. Relatedness: Individual learning is transformed into a social and collaborative activity through the implementation of leader boards or team quests,

as this is how we can satisfy the need for belonging, which is quite difficult to maintain in an online format.

The interactive nature of the content (e.g., adaptive quizzes, VR simulations) serves as the delivery mechanism for these game mechanics, making skill acquisition an engaging and appealing process (Landers, 2014).

However, the gamified interactive environment contributes not only to motivation but also develops the necessary 21st-century skills – the 4Cs – and crucial digital competencies. These four skills originate from the Partnership for 21st Century Skills (P21) and comprise: Critical Thinking, Creativity, Collaboration, and Communication. In the context of our article, the4Cs are key learning outcomes, as the gamified interactive environment is ideally suited for their development. This is because quests and simulations stimulate critical thinking and creativity, while team missions and leaderboards foster collaboration and communication. Moreover, we shouldn't forget about digital competencies, as having basic skills in digital literacy and knowing how to handle technology is necessary to achieve truly visible results from learning and to advance these skills.

In the following table, we structure information about the skill categories, how they function (their mechanism), and why they are relevant in the modern educational environment:

Skill Category (4Cs & Digital)	Gamified Interactive Mechanism	Relevance to Modern Context
Critical Thinking	Complex Questsand Puzzles require applying knowledge to novel situations, encouraging trial-and-error in a low-stakes environment.	Essential for navigating the complexity and information overload of the digital world.
Creativity	Open-ended Simulations or Design Challenges (e.g., building digital artifacts) encourage students to develop novel and innovative approaches.	Crucial for adapting to rapid technological change and fostering innovation in future careers.

Collaboration & Communication	Team Quests or Cooperative Missions necessitate students to share resources, negotiate strategies, and effectively communicate to achieve a shared objective (Subhash & Cudney, 2018).	Vital for effective teamwork in remote and hybrid professional settings; promotes essential peer-to-peer digital communication.
Digital Competence	Utilizing specialized Gamified Learning Platforms (GLPs), interacting with digital interfaces, and mastering the tools required for game play and task submission.	Directly addresses the need for students to achieve digital literacy and comfort with the technological infrastructure of the modern economy ("Gamified Learning Platforms", 2024–2025).

Although the synergy of applying gamification and interactive methods is a powerful tool for boosting student motivation, we must understand that there are still challenges facing modern education. These include:

1. Quality and Focus: Poorly designed and simple gamification, such as awarding points for attendance, constitutes an easy extrinsic reward. This can be perceived as trivial and may undermine the process of long-term intrinsic motivation (Sailer & Homner, 2020).

2. Technological Equity (Digital Divide): Ideally, every learner should have stable internet, quality technical equipment, and access to sophisticated interactive tools. The disparity in technology access is exacerbated in hybrid settings – it poses a potential threat of widening the digital divide.

3. Instructor Competence: The effectiveness of the Gamified Learning Process (GLP) depends on the instructors' ability to move beyond old point systems and to develop meaningful, complex learning methodologies that align with pedagogical goals.

4. Dynamism and Renewal: To sustain students' long-term motivation, the learning environment should avoid repetitiveness and periodically update the content and difficulty level of tasks.

Conclusion. The combination of gamification and interactive learning is a factor that truly boosts the motivation of 21st-century learners, especially in the modern world where digitalization and hybrid delivery models have gained such popularity due to contemporary challenges.

By leveraging all the advantages of these educational approaches, educators can transform the "OLD CLASSROOM" into a new educational environment where learning turns into an exciting adventure, and the passive consumer fin formation transforms into an active learner who is interested in and motivated for study. The future of education lies in strategically implementing this synergy to cultivate not just knowledge, but the essential cognitive and digital skills necessary for success in the modern, complex world. Analysis of the obtained results and correction of research methodologies will be the focus of further research.

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TRANSPORT TECHNOLOGIES

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TRANSPORTATION TECHNOLOGIES
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Transportation technologies have undergone significant transformation over the past century, and the pace of innovation continues to accelerate. Modern societies rely on transportation systems not only for mobility but also for economic growth, supply chain efficiency, and global connectivity. As urbanization increases and digitalization expands, new technological solutions are being developed to address emerging challenges related to safety, sustainability, congestion, and environmental impact. This article examines the latest developments in transportation technologies, including automation, electrification, smart mobility, intelligent infrastructure, and next generation logistics systems.

One of the most influential advancements in transportation is the rise of autonomous vehicles. Self-driving technologies combine artificial intelligence, machine learning, sensors, and real-time data processing to operate vehicles with minimal human intervention. Autonomous cars, trucks, drones, and delivery robots are gradually being integrated into transportation networks, promising enhanced safety, reduced human error, and increased efficiency. Despite regulatory, ethical, and technical obstacles, autonomous systems continue to evolve, with companies investing heavily in research and field testing. In the coming decade, widespread adoption is expected to reshape personal mobility and commercial logistics.

Electrification represents another transformational trend in transportation. Electric vehicles (EVs) have shifted from niche alternatives to mainstream options thanks to improved battery performance, reduced production costs, and expanded charging infrastructure. Governments and private companies worldwide are

promoting electrification to reduce greenhouse gas emissions and dependence on fossil fuels. Electric buses, trucks, trains, and even aircraft prototypes are now being developed. As renewable energy sources expand, integrating EVs into smart grids will become central to sustainable transportation strategies.

Digitalization and connectivity are also redefining transportation systems through smart mobility solutions. Technologies such as the Internet of Things, cloud computing, and data analytics enable real-time monitoring of traffic, vehicle performance, and infrastructure conditions. Smart traffic lights, adaptive traffic flow control, and integrated mobility platforms help reduce congestion and improve travel times. Mobile applications now allow users to plan multimodal journeys that combine public transport, shared vehicles, cycling, and walking. These innovations contribute to more efficient, user-centered mobility ecosystems.

Shared mobility services, including ride-hailing, car-sharing, scooter-sharing, and bicycle-sharing platforms, have become common in many cities. These services reduce private car ownership and promote more sustainable use of urban space. When combined with electrification and automation, shared mobility may lead to a significant decrease in traffic congestion and environmental pollution. However, regulatory frameworks and infrastructure planning must adapt to accommodate these rapidly expanding modes of transport.

Intelligent infrastructure plays a vital role in supporting modern transportation systems. Smart roads equipped with sensors, communication technologies, and automated monitoring systems can provide real-time information to vehicles and traffic management centers. Innovations such as dynamic tolling, automated incident detection, and infrastructure-to-vehicle communication enhance safety and operational efficiency. Moreover, predictive maintenance technologies enable authorities to identify structural problems before they cause accidents or disruptions.

Logistics and freight transport have also been transformed by technological innovation. Automated warehouses, digital tracking systems, and robotics streamline supply chains and improve operational efficiency. Drones and autonomous delivery

vehicles are being tested for last-mile delivery, especially in rural or hard-to-reach areas. Furthermore, hyper loop systems and high-speed rail technologies aim to revolutionize long-distance travel by drastically reducing travel times while maintaining high energy efficiency. Although still in development, these systems represent the future of high-speed transportation.

Sustainability has become a central goal in transportation planning and innovation. Climate change, air pollution, and resource depletion require the development of environmentally friendly transportation solutions. Research efforts focus on zero-emission technologies, renewable fuels, and energy-efficient designs. Urban planners now emphasize transit-oriented development, cycling infrastructure, pedestrian zones, and green public transportation. These strategies aim to balance economic growth with environmental protection.

Despite significant progress, transportation technologies face challenges including regulatory complexity, high implementation costs, privacy concerns, and cybersecurity risks. Ensuring the safety of autonomous systems, managing data responsibly, and developing equitable transportation access remain key priorities. Collaboration among governments, private companies, researchers, and the public will be essential to overcome these obstacles and develop sustainable, efficient mobility systems for the future.

In conclusion, transportation technologies are entering a new era defined by automation, electrification, connectivity, and sustainability. These innovations have the potential to significantly improve the quality of life, reduce environmental impact, and support economic development. As transportation systems continue to evolve, embracing technological advancements will be crucial for shaping a safer, smarter, and more sustainable world.

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Bakhariev S. O.

ANALYSIS OF THE EFFICIENCY OF APPLYING FDM TECHNOLOGIES FOR THE RAPID RESTORATION OF THE PERFORMANCE OF ROAD CONSTRUCTION MACHINERY

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Modern road construction is characterized by a high level of mechanization of production processes, which determines a critical dependence on the uninterrupted operation of equipment. Downtime of road construction machines during the construction season leads to significant economic losses, which can reach hundreds of dollars per hour (Edwards, Holt & Harris, 2002). The problem of rapid spare parts supply is particularly acute in remote construction sites, where logistical delays can last from several days to weeks.

Fused Deposition Modeling (FDM) technology opens up new possibilities for solving this problem. FDM printing allows manufacturing parts directly at the place of operation of the equipment with minimal time and resource costs (Gibson, Rosen & Stucker, 2021, p. 171). The purpose of this research is to analyze the efficiency of applying FDM technologies for the rapid restoration of the performance of road construction machinery.

FDM technology is based on the principle of layer-by-layer deposition of molten thermoplastic material. The process involves heating the filament to its

melting point, extruding it through a nozzle with a diameter of 0.2–0.8 mm, and sequentially forming layers with a thickness of 0.1–0.4 mm (Kristiawan, Imaduddin, Ariawan, Ubaidillah & Arifin, 2021). The most common materials for FDM printing are PLA (polylactide), ABS (acrylonitrile butadiene styrene), PETG (polyethylene terephthalate glycol), and nylon. Each of these materials has specific mechanical properties that determine their scope of application.

For road construction machinery parts, composite filaments with the addition of carbon or glass fiber are of particular interest, providing increased strength and wear resistance. According to research, carbon fiber reinforced nylon parts demonstrate a tensile strength of up to 70 MPa, which is comparable to the characteristics of some aluminum alloys (Blok, Longana & Woods, 2020, p. 203).

To evaluate the efficiency of FDM technologies, a comparative analysis was conducted based on the following criteria: part manufacturing time, cost price, mechanical characteristics, and durability. The research covered typical parts that most often fail: bearing unit covers, retainers, bushings, control mechanism levers, and fasteners. The experimental samples were manufactured on a 3D printer with a working area of 300×300×400 mm at an extrusion temperature of 240–260°C.

The results of the research showed that the production time for a typical part using the FDM method ranges from 2 to 8 hours, depending on the complexity of the geometry and dimensions, while waiting for an original spare part can take 3–14 days. The use of additive technologies allows to significantly reduce the cost of a part compared to the original by minimizing logistics costs and the absence of warehouse stocks (Mecheter, Pokharel & Tarlochan, 2022). Field tests have shown that printed parts made of PETG and reinforced nylon can withstand operational loads for 1–3 seasons for unloaded components and 0.5–1 season for medium-load parts.

The use of FDM has proven to be particularly effective for the production of discontinued parts. Reverse engineering of a damaged part followed by 3D printing allows restoring the performance of outdated equipment without scrapping it. At the

same time, it is important to note the limitations of this technology: FDM parts are not recommended for high-temperature zones (over 80°C for PLA, 100°C for ABS) and components with shock loads.

Thus, FDM technology is an effective tool for the rapid restoration of the performance of road construction machinery. Downtime savings can reach 90%, and financial costs are reduced by 40–70%. It is recommended to create at service centers and large construction companies specialized additive manufacturing units with libraries of 3D models of the most in-demand parts. A promising direction for further research is the development of methods for assessing the residual resource of printed parts and optimizing printing parameters for specific operating conditions.

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INCREASING THE EFFICIENCY OF TRENCHLESS LAYING OF ENGINEERING COMMUNICATIONS USING EQUIPMENT WITH A SCREW WORKING BODY

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Urbanization and intensive renovation of underground engineering communications place increasingly stringent demands on modern construction technologies, especially in dense urban areas. The growth of cities, coupled with the aging of water supply, sewage, gas supply, and telecommunications networks, has led to a significant increase in underground construction and reconstruction. Although traditional open trench methods are technologically simple and well-studied, they have significant disadvantages, including disruption of traffic flows, increased noise and dust levels.

Trenchless methods allow pipelines and cables to be laid under roads, railways, rivers and buildings without completely opening up the earth's surface. This significantly reduces the impact on the urban environment and allows work to be carried out where open methods are technically impossible or economically unfeasible. At the same time, the efficiency, reliability, and safety of trenchless construction depend largely on the design of the working equipment and the complex interaction between the soil, the cutting or penetrating tool, and the transported soil mass. These interactions are nonlinear in nature and sensitive to technological and engineering-geological parameters. For Ukrainian cities, where underground utilities are often densely packed and road structures are weakened by repeated repairs and

insufficient maintenance, increasing the efficiency of trenchless equipment is primarily a practical engineering task.

Among the variety of trenchless technologies, pipe jacking and microtunneling using equipment with a screw (auger) working body, which are used for short and medium-length crossings, are of particular interest. The screw working body plays a key role in the technological process. In typical designs, the screw conveyor simultaneously participates in cutting and loosening the soil at the face, transporting the excavated material to the receiving pit, and partially stabilizing the face due to the reaction of the soil on the screw blades. This versatility sets screw systems apart from other trenchless machines and determines their compactness and structural simplicity.

Despite these advantages, practical experience shows that the operation of trenchless equipment with a screw working body is often accompanied by serious technical problems. These include increased energy consumption, unstable or uneven machine progress, clogging of the inter-turn space with cohesive or water-saturated soils, and loss of face stability. Under adverse conditions, this can lead to deviations from the design trajectory, excessive subsidence or bulging of the soil, damage to nearby structures, and even work stoppages.

The aim of the planned dissertation research is to increase the efficiency of trenchless laying of engineering communications by improving the design and operating modes of equipment with a screw working body. In this context, efficiency is considered as a multidimensional criterion covering specific energy consumption per meter of laid communication, face stability, occupational safety, and equipment reliability. Achieving balanced improvement in these indicators requires a detailed understanding of the mechanical processes in the “soil – working body – machine” system. Accordingly, one of the key tasks is to establish quantitative relationships between the geometric parameters of the screw, the technological parameters of pipe jacking, and soil properties.

The expected scientific novelty of the work lies in the development of a refined mechanical model of the interaction of the screw working body with the surrounding soil in conditions of limited underground space. Unlike classic auger conveyor designs for bulk materials, the screw in pipe jacking and microtunneling machines operates inside a rigid steel shell and under uneven stress conditions.

A review of international research shows considerable attention to the problems of jacking forces, face stability, and soil deformation during trenchless construction. Most of the work focuses on shield tunneling machines with slurry or soil pressure, where the screw conveyor acts as a soil pump or auxiliary transport element. For rectangular pipe jacking and box-type structures, which are actively developing in Japan and China, the interaction of the screw working body with the soil is even more complicated due to the non-circular geometry and uneven stress distribution. At the same time, the specific characteristics of Ukrainian soils – from subsiding loess loams to dense water-saturated sands – are not sufficiently reflected in existing analytical models and recommendations, which makes research focused on local conditions particularly relevant.

As part of the research, it is planned to perform a series of laboratory experiments using a physical model of a screw conveyor in a soil container. The experimental setup will reproduce the main elements of a pipe punching machine, including the cutting element, screw shaft, casing, and a conventional pipeline model. Changing the screw pitch, rotation speed, degree of inter-turn space filling, and soil properties will allow determining the torque, axial force, energy consumption, and volumetric productivity. Special attention will be paid to the conditions for driving the screw and forming a stable soil plug in front of the face, which ensures the balance of external soil pressure.

The second stage involves the use of numerical modeling based on finite and discrete element methods. The continuous approach will allow to evaluate the redistribution of stresses, arch effects and surface subsidence, while the discrete approach will allow to analyze the movement of soil particles in the inter-turn space,

contact forces, and screw blade wear. The combination of these approaches will provide a comprehensive description of the mechanical processes characteristic of screw trenchless drilling. The modeling results will be calibrated using laboratory data and field observations at construction sites in Kharkiv and other cities in Ukraine.

The practical significance of the expected results lies in the possibility of creating a new generation of trenchless machines adapted to operating conditions in Ukraine. Optimized screw working bodies combined with modern torque, axial force, and vibration monitoring systems will increase the reliability of drilling. This will allow reducing the size of the starting and receiving pits, decreasing the consumption of lubricants and stabilizing materials, and increasing the permissible length of pushing without intermediate shafts. For local governments, this means reduced costs for pavement restoration and less inconvenience for the public.

As a result, increasing the efficiency of trenchless laying of engineering communications using equipment with a screw working body is a complex engineering problem that combines soil mechanics, mechanical engineering, and construction technologies. A systematic approach, encompassing theoretical modeling, laboratory experiments, and field testing, provides a reliable basis for optimizing screw parameters and operating modes. The implementation of the solutions obtained will contribute to reducing energy consumption and jacking forces, increasing the face stability, and ensuring safer and more environmentally acceptable construction of underground engineering networks in Ukrainian cities.

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TRANSPORT TECHNOLOGIES

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Transport technologies have undergone a transformative evolution over the past century, shaping the way societies function, economies grow, and people interact. From traditional mechanical systems to advanced digital solutions, modern transport technologies continue to redefine mobility by enhancing efficiency, safety, accessibility, and sustainability. This article explores the key developments in

transport technologies, their impact on contemporary life, and the challenges that influence future progress.

The earliest transportation systems relied on simple mechanical structures powered by humans or animals. The invention of the steam engine in the 18th century marked the beginning of industrial transportation, introducing locomotives and steamships that revolutionized long-distance travel and trade. In the 20th century, the widespread adoption of internal combustion engines (ICE) enabled the mass production of automobiles and aircraft, significantly expanding global mobility. Today, transport technologies are experiencing a new shift toward electrification, automation, and digitalization. The integration of electronic systems, advanced materials, and intelligent software solutions has led to the creation of highly efficient and connected transport modes.

One of the most significant advancements in modern transport technology is the development of electric vehicles (EVs). These vehicles use electric motors powered by rechargeable batteries, offering a cleaner and more energy-efficient alternative to traditional petrol and diesel engines. The growing availability of charging infrastructure, combined with government incentives and technological improvements in battery capacity, is making EVs increasingly popular among consumers. Electric mobility is not limited to cars; it includes electric buses, motorcycles, bicycles, scooters, and even electric aircraft prototypes. These innovations contribute to reducing greenhouse gas emissions, noise pollution, and dependence on fossil fuels.

Autonomous vehicles (AVs), also known as self-driving cars, represent one of the most advanced areas of transport development. Equipped with sensors, cameras, radar systems, and artificial intelligence, autonomous vehicles can analyze their surroundings and operate with minimal human intervention. Developers claim that AVs have the potential to significantly reduce traffic accidents, improve road efficiency, and provide mobility to people who cannot drive. The rise of smart vehicles is closely linked with the concept of smart cities. Many modern cars are

already semi-autonomous and connected to the Internet of Things (IoT), enabling real-time navigation, traffic monitoring, diagnostics, and automated safety functions. As communication between vehicles and infrastructure (V2X technology) becomes more sophisticated, fully autonomous transportation systems are expected to become more reliable and accessible.

Urbanization has created a strong demand for efficient and flexible mobility solutions. As cities become more crowded, traditional transport modes often struggle to meet the needs of commuters. New micro-mobility technologies – such as electric scooters, bicycles, and compact electric vehicles – provide convenient and eco-friendly alternatives for short-distance travel. Additionally, urban public transportation systems are incorporating modern technologies to improve efficiency. Examples include contactless payment systems, AI-based scheduling, real-time arrival tracking, and autonomous shuttle services. These solutions help reduce congestion, lower emissions, and improve the overall quality of urban life.

High-speed rail systems have become a crucial part of modern transportation infrastructure, especially in countries such as Japan, China, and several European nations. These trains can travel at speeds exceeding 300 km/h, offering a fast and efficient alternative to air travel for medium-distance routes. Researchers continue to work on even faster and more advanced concepts, such as magnetic levitation (maglev) trains and the Hyperloop, which uses vacuum-sealed tubes to minimize air resistance. These systems could potentially achieve speeds of over 1000 km/h, significantly reducing travel time between major cities and redefining long-distance transportation.

With growing concerns about climate change and air pollution, sustainable transport technologies have become a global priority. Governments and industries are investing in renewable energy sources, eco-friendly materials, and low-emission technologies. Examples include hydrogen fuel-cell vehicles, solar-powered transport, and the electrification of public transit systems. Sustainable transport initiatives aim to reduce carbon footprints, improve public health, and create more

resilient infrastructure. Moreover, modern technologies enable more efficient use of resources through advanced energy management systems, recyclable materials, and green manufacturing practices.

Despite significant progress, modern transport technologies face several challenges. These include high development costs, limited infrastructure, cybersecurity risks, battery disposal issues, and the need for global regulatory frameworks. Additionally, public acceptance remains a significant factor in the adoption of autonomous and innovative transport systems. Nevertheless, the future of transport technologies is highly promising. Continued research and innovation are expected to lead to safer, cleaner, and more intelligent mobility solutions. As digitalization and automation progress, transport systems will likely become more integrated, efficient, and user-friendly.

In conclusion, transport technologies have evolved from simple mechanical systems to complex digital networks that drive global mobility. Innovations such as electric vehicles, autonomous driving, high-speed transport, and sustainable mobility solutions play a crucial role in shaping the future of transportation. While challenges remain, the ongoing development of advanced technologies offers a foundation for a more efficient, environmentally friendly, and interconnected world. Modern transport technologies not only redefine how people and goods move, but also contribute to the broader goals of sustainability, economic growth, and improved quality of life.

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PROSPECTS OF USING SIMULATION MODELING TO IMPROVE ROAD TRAFFIC EFFICIENCY

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Relevance of the topic: A primary trend in the development of the Ukrainian economy in the 21st century is the widespread use of new information technologies. The development of a modern traffic management system in cities is inextricably linked with the construction and reconstruction of existing roads and intersections. Simulation modeling is a method that allows you to determine the efficiency indicators of road traffic management both on existing elements of the city's road network and on those that are currently being designed.

The purpose of the study: to determine the prospects for using simulation modeling to enhance the efficiency and environmental sustainability of road traffic.

Object of research: road traffic on the street and road network of urban agglomerations.

First of all, it is necessary to note what we understand by a simulation model. A simulation model is a structured system that reproduces the functions and properties of a real object or process for the purpose of conducting research, experiments or analysis without direct intervention in the real object. That is,

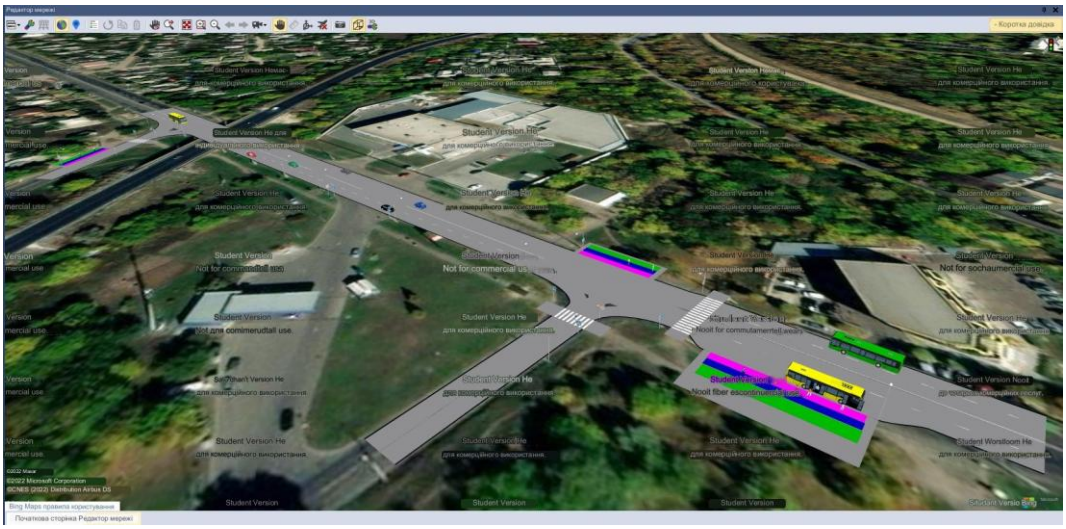
simulation modeling aims to reproduce all the details of the movement, including the development of the process over time. (Решетніков, 2012). Thus, simulation models can be used for forecasting, testing various scenarios, as well as optimizing and improving real systems.

According to the U.S. Department of Transportation, traffic congestion can have three main sources. The first is related to factors that affect road traffic, such as accidents, work zones, and adverse weather conditions. The second is related to fluctuations in traffic flow. The third source is transportation infrastructure, which includes traffic control devices (such as traffic lights) and physical bottlenecks. These bottlenecks account for 40% of the total congestion, followed by traffic incidents such as accidents – 25%, adverse weather conditions – 15%, work zones - 10%, as well as untimely activation of traffic lights – 5%, and special events – 5% (Allan M de Souza, 2017). The use of simulation modeling makes it possible to analyze traffic flow fluctuations, find potential bottlenecks in future infrastructure elements, and make changes to the traffic light regulation cycle without interfering with the operation of the real facility.

Currently, there is a wide variety of computer software for simulating traffic on objects of the street and road network. Such software tools differ in the scale of the model and the level of detail of the movement. Macroscopic models describe traffic flows in a generalized manner – similar to the movement of a liquid. They are used to model large areas: cities, districts and regions. Examples of such programs are PTV VISUM, TransCAD. Mesoscopic models such as Aimsun Next are used to create simulation models of city districts or major highways, where a balance between speed of work and accuracy of results is important. Microscopic models such as PTV Vissim are used to analyze intersections, transport nodes and individual sections of streets.

Let's consider the use of PTV Vissim 2023. This software allows you to model traffic flow, simulate traffic light operations, analyze road safety characteristics, and determine the interaction of various road users. It is also possible to obtain road

traffic efficiency indicators such as vehicle delays, fuel consumption, and emissions of harmful substances (Абрамова, 2013) (Picture 1).



Picture 1. Simulation model in the PTV Vissim 2023 software

A study of the road network section was conducted. Based on the information obtained, a simulation model was created in the PTV Vissim 2023 software. Thus, in the current situation, the average delay time of cars was 9.7 seconds. Fuel consumption was 3.1 liters. Emissions of harmful substances have the following values: CO – 57.8 grams, Nox – 11.3 grams, VOC – 13.4 grams. On this basis, the following model was developed using a synchronous traffic management system. According to the hypothesis, this should have reduced the average delay time of cars and fuel consumption. The necessary traffic light objects were created and their operation cycle was compiled. The parameters of the simulation model have been improved. The average delay time of cars has decreased, its value has been 4.8 seconds. Emissions of harmful substances have decreased: CO – 43.9 grams, Nox – 8.6 grams, VOC – 10.2 grams. Fuel consumption has decreased from 3.1 liters to 2.4 liters.

The use of PTV Vissim 2023 software made it possible to create a simulation model of a real element of the street and road network, obtain indicators of traffic efficiency in the current situation and after the implementation of the proposed option

with the introduction of a synchronous traffic management system.

Conclusion: the use of simulation modeling to increase the efficiency and environmental friendliness of road traffic is advisable. With the help of special programs, it is possible to create simulation models of different levels and details. From a model of a separate intersection to a model of road traffic in the entire city. The use of simulation models allows you to obtain indicators of road traffic efficiency both on existing elements of the road network and on potential ones for construction.

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PROBLEMS OF ORGANIZING URBAN PASSENGER TRANSPORTATION

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The types of passenger transportation are characterized, with emphasis placed on urban passenger transportation in Ukraine. The main features of urban passenger transportation are considered, including the organization of public bus transport and

electric transport operations. The problems of organizing urban passenger transportation in Ukraine are examined, and the specific characteristics of the domestic passenger transportation market are identified. Passenger transportation statistics in Ukraine for 2017–2021 are analyzed. It is determined that road transport is the most widespread mode of passenger transit due to its extensive infrastructure and high mobility among all types of local passenger transport. The main problems of urban bus and electric transport services in Ukraine are explored. The main directions for solving the organizational problems of urban passenger transportation, which will contribute to the efficient functioning of public transport in Ukraine, are outlined.

Modern city development is accompanied by spatial expansion, increasing distances between residential and industrial zones, which leads to increased transport use. This increases the need for including more subsystems of urban and suburban passenger transport. Urban transport is a key component of the country's functioning, as it ensures all types of daily activity, supports economic stability, and enables smooth development of both cities and the country overall. Urban passenger transportation is one of the main services for the population, ensuring normal social functioning and sustainable economic development.

All these factors require coordination to achieve full integration of the transport system aimed at optimally meeting the mobility needs of the population. Urban passenger transport should provide a well-developed network of services integrating various modes of transport and transportation policy. The integration of urban passenger transport must take place at different levels and consist of aspects that form the integrity of the transport network. This is why the country relies heavily on public transport, which ensures mobility for all population groups, particularly those who do not possess private vehicles. Hence, public transport requires effective and convenient organization.

Urban passenger transportation in Ukraine, according to current legislation, provides regular urban services but is currently experiencing instability and faces

numerous organizational challenges that require thorough study.

The functioning model of urban passenger transport has attracted the attention of specialists and researchers for many years. Scientific works on this issue are usually devoted to the problems of passenger transport operations and searching for solutions to identified deficiencies. These include works by Amosha O. I., Bazyluk A. V., Daleka V. Kh., Dobrova N. V., Ilchuk V. P., Nechepurenko M. S., Osypova M. M., Teletov O. S., Filipova O. S., Khomenko I. O., among others.

Ukrainian and foreign researchers have also studied the effective organization of urban passenger transport. Korniyko Ya. R. argues that the development level of a country's transport system is one of the main indicators of its technological progress; integration into European and global markets increases the need for a highly developed transport system. Hrabelnykov V. A. states that urban passenger transport offers high carrying capacity, lower transport costs compared to private vehicles, and reduces congestion on urban roads. Vdovychenko V. O. defines sustainable urban transport as a system that ensures long-term high-quality mobility while positively affecting the environment and socio-economic stability of the community. Karkovska V. Ya. considers transport as a key factor of territorial development and an indicator of population living standards.

Overall, modern urban passenger transport problems require additional study due to growing urbanization, the adaptation of Ukraine's transport system to EU standards, and increased pressure on city transport systems caused by internally displaced persons following Russia's full-scale invasion of Ukraine.

The purpose of this study is to examine the organizational problems of urban passenger transportation in Ukraine and analyze ways to ensure effective functioning of modern urban public transport.

According to the National Transport Strategy of Ukraine, the transport sector is one of the key spheres of the economy, ensuring the necessary preconditions for meeting transport service needs and supporting business development. However, the

sector currently satisfies only the basic needs of the population and economy in terms of transport volume – not quality.

Passenger transportation statistics in Ukraine for 2017–2021 show that road transport is the most widely used due to well-developed infrastructure and high mobility.

Road, trolleybus, metro, and tram transport have the highest passenger volumes as of December 2021, highlighting their importance for urban social and economic life.

Passenger turnover is one of the main indicators describing passenger transportation. Analysis of passenger turnover for 2017–2021 demonstrates a steady decline across all transport types. Aviation and rail transport showed growth from 2017 to 2019 due to expanded service offerings, but all transport types experienced a sharp decline in 2020 due to the COVID-19 pandemic and government travel restrictions.

The study of urban transport popularity shows that buses remain the most preferred mode, while among electric transport, passengers most often choose trolleybuses.

Main Problems of Urban Bus Transportation

Despite their popularity, bus services in Ukraine face several problems:

– Non-compliance with European market access requirements

– Poorly defined division of responsibilities between central and local authorities

– Overcrowding, poor sanitary and technical condition, and failure to meet schedules

– Significant financial losses of municipal transport companies

– Outdated fare payment and control systems, excessive number of beneficiaries, lack of compensation mechanisms

Road transport performs nearly half of all urban passenger transportation in Ukraine. However, private operators often use outdated small-capacity minibuses,

leading to overcrowding and low comfort levels. Attempts by local authorities to reduce the number of routes or eliminate private carriers have led to administrative redistribution of the market without resolving its core issues.

Metro systems operate only in Kyiv, Kharkiv, Dnipro, and Kryvyi Rih. As of 2021, metro networks in Ukraine are insufficient to meet demand – fewer cars are in operation than required, and line lengths are far from the optimal level of 30 km per 1 million residents.

Due to the war, all metro construction projects in Zaporizhzhia, Lviv, and Odesa were suspended in 2022.

Electric transport accounts for about 60% of all urban passenger transportation. Passengers most frequently use trolleybuses.

Key problems include:

– 60–85% wear of rolling stock

– Lack of modern fare systems

– Chronic underfunding of infrastructure projects

– Inefficient municipal companies

Many developed countries demonstrate that the future of urban transport lies in electric transport due to environmental and efficiency advantages. Ukraine planned to increase the share of electric transport to 75% by 2030.

Urban Passenger Transport Market Problems

The main issues include:

– Worn-out and technologically outdated vehicles

– Outdated fare collection systems causing 25–40% financial losses

– Excessive number of privileged passengers without compensation

– Inefficient state regulation and bureaucratic barriers

– Underfunding of infrastructure

– Inefficient municipal enterprises

– Lack of incentives for private operators to purchase modern vehicles

– Shortage of drivers due to labor migration

To improve the organization of urban passenger transportation in Ukraine, the following measures should be implemented:

1. Change the system of organizing urban transport:

– Transition from commercial revenue-based operations to payment per kilometer or per hour

– Allow local authorities to set tariff policies

– Ensure state mechanisms compensating for transport of privileged categories

– Increase transparency and public control

2. Simplify access to the transportation market:

– Cancel inefficient point-based evaluation systems

– Ensure equal competition conditions for private and municipal carriers

– Remove local authorities from direct financial control of transport enterprises

– Update concession and privatization legislation to attract investors

These measures will contribute to solving current problems and improving the efficiency of public transport in any city.

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ELECTRIFICATION OF ROAD TRANSPORT: CHALLENGES AND OPPORTUNITIES

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The electrification of road transport has become a central direction of global automotive innovation due to rising environmental concerns, energy security needs, and technological advancements. Electric vehicles (EVs) demonstrate high energy efficiency, zero local emissions, and the potential for integration with renewable energy sources. However, their widespread adoption is constrained by infrastructure limitations, battery costs, and energy-grid challenges. This article provides a comprehensive overview of electric mobility development, analyzes technological foundations, examines environmental and economic effects, and highlights barriers and opportunities. The study concludes that electrification is a key driver of sustainable transportation, especially for countries such as Ukraine, where reduced fuel dependency and ecological improvements are strategically important.

Introduction

The global transition toward cleaner and more efficient transportation systems has accelerated significantly over the past decade. According to the International Energy Agency (IEA, 2023), the global electric vehicle fleet exceeded 40 million units, and this number is projected to triple by 2030. This rapid expansion is driven by environmental regulations, technological innovation, and decreasing battery costs.

Electric vehicles are considered one of the most promising strategies for reducing carbon emissions from the transport sector, which currently accounts for almost one-quarter of global energy-related CO_2 emissions (IEA, 2022). Governments worldwide have introduced incentives to stimulate EV adoption, including subsidies, tax reductions, and zero-emission mandates.

For Ukraine, the electrification of road transport is strategically important. It may help reduce dependence on imported oil products, improve urban air quality,

and support the development of modern automotive and energy industries. Despite wartime disruptions, private businesses and local initiatives continue to expand charging infrastructure, especially in large cities.

This study examines the technological, environmental, economic, and infrastructural aspects of EV development and identifies future opportunities and obstacles.

Technological Foundations of Road Transport Electrification

Electric Powertrains. Electric motors surpass internal combustion engines (ICEs) in efficiency and mechanical simplicity. While ICEs typically operate at 20–30% efficiency, electric traction motors reach 85–95% efficiency (Chan, 2013). This results in significantly lower energy consumption.

The primary components of an EV powertrain include the traction motor, inverter, transmission or reduction gear, battery pack, and thermal-management system. Electric motors provide maximum torque at low speed, eliminating the need for multi-gear transmissions and ensuring smooth acceleration.

Battery Technologies. Lithium-ion (Li-ion) batteries dominate modern EVs due to their high specific energy, long cycle stability, and relatively low self-discharge. According to Nykvist & Nilsson (2015), Li-ion battery prices dropped by nearly 90% over the past decade, enabling broader EV commercialisation. New generations of batteries include: solid-state batteries (SSB) – improved safety and higher energy density (Tarascon, 2020); lithium iron phosphate (LFP) – lower cost, stable chemistry, long cycle life (Blomgren, 2017); sodium-ion batteries (Na-ion) – promising technology for reducing dependence on lithium (Slater & Kim, 2020).

Battery degradation remains a challenge: after 8–10 years, capacity typically decreases to 70–80%. However, advanced Battery Management Systems (BMS) significantly improve life expectancy.

Charging Technologies. Charging devices are typically categorized into: AC chargers (Level 1–2): 2–22 kW; DC Fast Chargers (Level 3 / CCS / CHAdeMO): 50–350 kW; ultra-fast chargers (over 500 kW), currently under pilot implementation.

Fast charging significantly improves usability but places a heavy load on electrical grids. Wireless charging and battery-swapping systems are emerging technologies that may reshape future EV infrastructure.

Environmental and Economic Impacts of Transport Electrification

Environmental Advantages. EVs produce zero tailpipe emissions, reducing nitrogen oxides (NOx), particulate matter, and CO_2 emissions in urban areas. Even when electricity production is considered, EVs produce less lifecycle CO_2 than ICE vehicles (Hawkins et al., 2013). Additional environmental benefits include: lower noise pollution, reduced brake dust emissions through regenerative braking, compatibility with renewable energy systems.

Economic Effects. Electric vehicles reduce operating costs due to lower electricity prices and fewer maintenance requirements. EVs contain significantly fewer rotating components: no oil changes, no exhaust systems, no fuel injection systems.

At a macroeconomic level, transport electrification stimulates: battery manufacturing, electronics and power semiconductor production, charging infrastructure development, smart-grid technologies.

For Ukraine, these sectors present opportunities to modernize industry and create high-tech jobs.

Challenges Limiting EV Adoption

High Battery Costs. Despite a strong decline in price over the last decade, batteries remain the most expensive component of EVs. The scarcity of lithium, cobalt, and nickel continues to impact production costs.

Insufficient Charging Infrastructure. One of the most significant barriers is limited charging infrastructure, especially outside major cities. Ukraine has made progress, but charging stations remain unevenly distributed.

Range Anxiety and Charging Time. Although modern EVs achieve ranges of 350–600 km, many drivers still worry about battery depletion – known as range

anxiety. Fast charging reduces this concern but may degrade batteries if used excessively.

Electric Grid Limitations. The simultaneous charging of large EV fleets increases loads on national energy systems. Without smart-grid solutions and grid modernization, energy shortages or local overloads may occur (IEA, 2021).

Battery Recycling and Sustainability Issues. Lithium-ion battery disposal poses environmental risks. Recycling technologies exist but are not yet widespread or economically competitive. Development of closed-loop recycling systems is crucial for long-term sustainability.

Opportunities for Future Development

Battery Innovation. Solid-state batteries, lithium-sulfur chemistry, silicon-anode technologies, and sodium-ion systems may significantly increase range and reduce cost. These technologies promise energy densities above 400 Wh/kg (Tarascon, 2020).

Renewable Energy Integration. EVs can act as distributed energy storage systems, supporting residential solar, wind parks, and grid stabilization. Vehicle-to-Grid (V2G) technologies allow bidirectional energy exchange.

Smart Transport Infrastructure. Intelligent charging networks, autonomous driving, and vehicle-to-infrastructure (V2I) communication can dramatically improve road safety and efficiency.

Electrification of Public Transport and Logistics. Electric buses and delivery vans are rapidly expanding due to predictable routes and centralized charging. This sector offers significant economic potential.

Industrial and Economic Growth. Countries investing in EV manufacturing gain strong competitive advantages in global markets. Ukraine can join European supply chains through battery recycling, EV component production, and IT solutions for mobility.

Conclusion

Electrification of road transport represents a critical technological and environmental transformation. EVs significantly reduce emissions, lower operating costs, and integrate well with renewable energy systems. Despite challenges such as charging infrastructure limitations, battery costs, and grid constraints, global trends demonstrate stable progress toward electric mobility.

For Ukraine, the transition to electric transport is not only an ecological necessity but also an economic opportunity. Strengthening charging networks, encouraging EV adoption, and developing domestic high-tech industries will support the country's modernization efforts and align its transport sector with global standards.

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MODERN CHALLENGES AND STRATEGIC DEVELOPMENT OF UKRAINE'S TRANSPORT AND LOGISTICS

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Logistics and transportation are among the key sectors that support the functioning of most economic activities. They have a direct impact on national development, the competitiveness of domestic producers, and the ability to generate exports. The logistics sector also plays a vital role in ensuring state budget revenues and facilitating the entry of Ukrainian goods into international markets.

Recently, the urgency of developing transport routes and the logistics system has increased due to the ongoing military actions in Ukraine. At present, one of the most critical tasks is the timely delivery of essential goods, equipment, and humanitarian aid from European countries.

It is important to note that logistics and transportation account for a significant share of the country's GDP, create numerous jobs, and contribute to the development of urban and regional infrastructure. Today, the global logistics market is changing rapidly, setting new trends and adapting to emerging economic and geopolitical conditions.

Ukraine's economic integration with the European Union is driving rapid development across all sectors, particularly in infrastructure and the transport system. Ukraine's geographical position offers significant advantages: the country serves as a convenient hub between Europe and Asia and lies at the intersection of major trans-European corridors. These factors create favorable conditions for strengthening foreign economic activity and expanding international trade links.

The financial and economic crisis in Ukraine has caused a sharp decline in industrial activity and construction output – which in turn sharply reduced demand for freight transportation across almost all major transport modes. As a result, in 2022 the total volume of cargo transported in Ukraine fell to around 317.2 million tonnes, i.e. roughly 50% less than in 2021. However, data for 2023–2024 show some signs

of partial recovery. For example, in 2023 the national railway operator transported over 148 million tonnes of cargo, even as the system adapted to wartime constraints. At the same time, in 2025 the decline in freight transport continues: in the period January–August 2025 Ukraine transported 208.9 million tonnes of cargo, which is 11.3% less than in the same period of the previous year. Passenger transport also reflects the disruption: for the first eight months of 2025, the number of passengers carried fell – yet in some segments (especially urban/road transport) passenger traffic has shown modest recovery.

Currently, the transport sector of the Ukrainian economy meets only the basic transportation needs of the population and industry. The current levels of safety, service quality, transportation efficiency, energy efficiency, and environmental impact do not align with modern standards. The development of the transport network – especially the public road system – ags behind the country's rapid motorization. As a result, the road density in Ukraine is 5.9 times lower than in France (0.28 km versus 1.65 km of roads per square kilometer of territory). The length of expressways in Ukraine is only 0.28 thousand kilometers, whereas Germany has 10.9 thousand kilometers and France 7.1 thousand kilometers. Additionally, road funding per kilometer in Ukraine is 5.5–6 times lower than in these countries. This situation is due to several objective factors, including a heavier per-capita burden of maintaining transport infrastructure compared to European countries, stemming from lower population density (78 people per square kilometer), low purchasing power (about one-fifth of that in the Eurozone), a relatively small vehicle fleet, and the extensive size of the country.

High-speed passenger rail services operating at 200–250 kilometers per hour, with high traffic frequency, have been introduced on European railways. Similarly, in Ukraine, passenger services with speeds of up to 160 kilometers per hour are also being implemented. However, a significant challenge remains: separating the network into lines primarily dedicated to freight traffic and those intended mainly for passenger services, as well as increasing the frequency of passenger trains.

Social standards for passenger transport quality are declining, particularly in terms of vehicle occupancy, the availability of urban electric transport and high-capacity buses, and the regularity of service. Moreover, a significant share of the rolling stock is outdated: 92% of trams, 78% of metro cars, 63% of trolleybuses, and 58.9% of passenger railway cars are over 25 years old. Public passenger transport enterprises remain unprofitable due to low fares, insufficient budget compensation for transporting privileged passenger categories, and an inefficient system for collecting revenue from urban and suburban public transport services.

In 2010, foreign direct investment in the activities of transport and communication enterprises amounted to 1,711.2 million USD, representing 105.2% of the 2009 level but only 3.8% of total FDI. By 2025, despite some growth in investment, the transport and road sector continues to face low investment capacity, resulting in increasing wear and tear of technical equipment, deterioration of asset structures, and insufficient traffic safety. In a competitive environment, these conditions continue to contribute to the displacement of Ukrainian carriers from international transport markets, the diversion of transit cargo flows around Ukraine, a decline in the quality of service for domestic enterprises and the population, and persistent threats to the economic security of the state.

A heterogeneous competitive environment has emerged within the transport sector, ranging from road and river transport, which were fully privatized in the early 1990s, to railway transport and seaports, which remain entirely state-owned. European countries have already reformed their railway systems, separating economic functions from regulatory ones and effectively distinguishing monopoly infrastructure from the potentially competitive market of operating companies. Similarly, the management systems of sea and river ports require reform to clarify the distribution of regulatory and economic responsibilities. Transport imposes a significant anthropogenic burden on the environment and accounts for one-third of harmful emissions in Ukraine. This impact is particularly pronounced in urban areas, where road transport alone contributes up to 90% of harmful emissions.

Therefore, the existing transport infrastructure requires further modernization. To enhance the efficiency of the domestic transport system and improve the quality of transport services, it is necessary to establish legally enshrined conditions that stimulate both domestic and foreign investment in transport infrastructure projects. This includes increasing the investment attractiveness of the sector by fostering a competitive environment, creating conditions for the sustainable economic and technological integration of the transport complex with major shippers, and ensuring coordinated development of transport alongside the shipbuilding, automotive, and aviation industries. Additionally, regulatory and legal frameworks should be improved to guarantee equal and favorable conditions for all participants in the transport and logistics market. It is also essential to develop and modernize transport and warehouse infrastructure, cargo terminals, and to create favorable technical, legal, organizational, and financial conditions for the expansion of intermodal transportation.

Ukraine is actively engaged in global socio-economic processes, having joined the World Trade Organization and identified obtaining associate membership in the European Union as a strategic goal. As a key infrastructure sector, transport must develop rapidly to support the country's economic and social growth and its participation in the international division of labor. To enhance the efficiency of the transport system, a comprehensive program of renewal and modernization is required. This program should include regulatory and legal measures and the creation of a favorable investment climate, leveraging both budgetary and non-budgetary sources of funding. The aim of such a strategy is to identify the key challenges, objectives, principles, and priorities for the development of Ukraine's transport system in line with national needs and interests. Implementing this transport strategy will contribute to a substantial increase in the overall efficiency of the transport system, support sustainable economic development, and improve the well-being of the Ukrainian population.

In conclusion, the transport and logistics sector is vital to Ukraine's economy, supporting trade, industry, and social development. However, challenges such as aging infrastructure, low investment, outdated rolling stock, and environmental pressures limit its efficiency and competitiveness. Ukraine's strategic location offers opportunities to modernize the transport system. Achieving this requires investment, infrastructure renewal, regulatory reform, and coordination with related industries. Ultimately, implementing a comprehensive transport strategy will enhance efficiency, strengthen international trade and support sustainable economic growth.

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ANALYSIS OF BRANDING STRATEGIES IN THE AUTOMOTIVE INDUSTRY: THE CASE OF BMW, AUDI AND MERCEDES-BENZ

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Nowadays, due to the development of technology and the transition to electric vehicles, the automotive industry is characterized by high competition and high consumer demands for quality, innovation, and brand image. Branding strategy is a key tool for building consumer loyalty and maintaining competitiveness.

German manufacturers BMW, Audi, and Mercedes-Benz have their own approaches to creating a unique image, which allows them to maintain their

leadership in the global market. Brand marketing and branding strategies are concepts widely covered in the works of Philip Kotler, David Aaker, and Kevin Lane Keller. They all define branding as the process of endowing a product or service with the power of perception and emotional connection that distinguishes it from competitors. A brand requires identity; the company must have a clear and consistent message about itself. Therefore, a comparison of specific premium-class German manufacturers (BMW, Audi, Mercedes-Benz) requires further analysis.

There are many studies on branding, but the comparative effectiveness of the strategies of the three leading German brands (BMW, Audi, Mercedes-Benz) in the context of consumer perception and positioning is insufficient. This leads to the need for a comparative analysis of branding strategies.

BMW comes from the German Bayerische Motoren Werke («Bavarian Motor Works»), founded by Karl Rapp and Gustav Otto in 1916 as an aircraft engine manufacturer. After World War I, when aircraft production was banned, the company reoriented itself towards manufacturing motorcycles and later automobiles. The BMW logo symbolizes a rotating aircraft propeller against the blue and white colors of the Bavarian flag, which emphasizes the brand's origins. Over the years, BMW has become synonymous with sporty drive and technological innovations, creating legendary models – BMW 3 Series, BMW 7 Series, BMW X5, etc. In the 21st century, the company is actively developing the direction of electric and hybrid cars under the brand BMW i (models i3, i8), combining power and environmental friendliness. The company targets active, ambitious consumers in the middle and premium segments who value speed, technology, and prestige. Slogan: The Ultimate Driving Machine.

Audi was founded in 1909 by August Horch. The name Audi is the Latin translation of the founder's surname, Horch (horch means «listen»). The logo with four silver rings appeared in 1932 after the creation of the Auto Union AG concern, which united four companies: Audi, DKW, Horch, and Wanderer. The rings symbolize the union of these independent German car manufacturers. In its modern

form, Audi AG resumed active operation in the 1960s as part of the Volkswagen Group, where it began a new era of development, focused on technology, design, and quality. The main directions of brand development are electromobility (the e-tron line) and digitalization. The target audience is young professionals who value technology, modern design, quality, and style. Slogan: *Vorsprung durch Technik* (from German: «Progress through Technology»).

Mercedes-Benz was founded in 1926 after the merger of the companies Daimler-Motoren-Gesellschaft and Benz & Cie. The history of Mercedes-Benz begins with two pioneers of car manufacturing – Karl Benz (inventor of the first car with an internal combustion engine) and Gottlieb Daimler, whose company Daimler-Motoren-Gesellschaft produced the first production cars. In 1926, these two companies merged, forming the Mercedes-Benz brand. The name Mercedes comes from the name of the daughter of one of the company's first partners, while the three-pointed star logo symbolizes the brand's aspiration to dominate on land, in water, and in the air. Since then, Mercedes-Benz has become a symbol of luxury, engineering excellence, and safety. The company is known for its flagship models (S-Class, E-Class, G-Class), as well as innovations in autonomous driving and electric vehicles (Mercedes EQ). Brand development is aimed at prestige, safety, luxury, and quality. The target audience is executives, entrepreneurs, and affluent buyers for whom the car is a status symbol. Slogan: The Best or Nothing.

A comparison table of these brands was developed, bringing together all the data about each brand and its values.

Comparative table of car brands: BMW, Audi and Mercedes-Benz

Criterion	**Audi**	**BMW**	**Mercedes-Benz**
Country of origin	Germany	Germany	Germany
Year of foundation	1909	1916	1926
Founder(s)	August Horch	Karl Rapp and Gustav Otto	Karl Benz and Gottlieb Daimler

Concern/Groups	Volkswagen Group	Independent company (BMW Group)	Mercedes-Benz Group AG
Slogan	Progress through Technology	The Ultimate Driving Machine	The Best or Nothing
The key brand value	Innovation, quality, technology	Sportiness, dynamics, emotion	Prestige, comfort, safety
Target audience	Young professionals, tech enthusiasts	Active, ambitious people	Business elite, affluent buyers
Brand image	Modern, technological	Youth, sporty	Elegant, luxurious
Typical models	A4, Q5, e-tron	3 Series, X5, i4	E-Class, S-Class, G-Class
Development direction	Electric cars, automation	Hybrids, sports models, innovations	EQ electric cars, safety, comfort
Price segment	Premium	Premium	Luxury
Key philosophy	Technological advantage	Happiness from driving	Luxury and perfection

The comparative analysis reveals that the success of these German premium brands stems from more than just product quality; it lies in a distinct and consistently executed branding strategy. BMW connects with the consumer through emotion and the experience of driving. Audi connects through rational appeal, focusing on technology and modern design. Mercedes-Benz connects through the aspirational status of timeless luxury and unrivaled comfort. Each brand effectively carves out its niche by emphasizing specific, deeply ingrained values that resonate with the expectations and desires of its target consumer segment.

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TRANSPORT TECHNOLOGIES IN THE SYSTEM OF MODERN LOGISTICS MANAGEMENT OF ENTERPRISES

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In the current economic climate, the transport component of logistics has ceased to perform an exclusively auxiliary function and has become an independent management object that directly affects the efficiency of enterprises. The deepening of globalisation processes, the digitalisation of the business environment, the increasing complexity of logistics chains and growing consumer demands for speed and reliability of delivery highlight the need to review traditional approaches to logistics management with a focus on transport technologies.

The transport system, as a combination of infrastructure, vehicles, transport operators and information flows, is a key link in the logistics chain. It is through transport that the physical movement of material flows is realised, a significant proportion of logistics costs is generated and the level of service for the end consumer is determined. In this regard, the effectiveness of logistics management largely depends on the level of development and implementation of modern transport technologies.

Logistics management in the transport sector should be viewed as a set of management decisions and processes aimed at planning, organising, coordinating and controlling transport operations, taking into account the strategic objectives of

the enterprise. This involves not only optimising routes or selecting the type of transport, but also integrating transport technologies into the overall supply chain management system. This approach ensures consistency of decisions at different levels of management and increases the adaptability of logistics systems to changes in the external environment.

Transport and forwarding companies play a special role in modern logistics management, acting as coordinators of material and information flows. Their activities include advising clients on the selection of optimal transport solutions, consolidating cargo, organising multimodal transport, mediating between various participants in the logistics process, and providing documentary support for transport. It is at this level that transport technologies are most closely integrated with management tools.

The development of digital transport technologies is significantly transforming approaches to logistics management. The use of transport management systems (TMS), fleet management systems, GPS monitoring and telematics provides the ability to monitor vehicle movements in real time, optimise resource utilisation and reduce operating costs. Integrating these solutions with corporate information systems lets you create a unified information environment for logistics management.

An important area of development in transport technology is the introduction of big data analytics tools and artificial intelligence elements. These are used to forecast demand for transport services, model transport flows, optimise routes and improve planning accuracy. In logistics management, this creates the conditions for a shift from reactive to proactive management of transport processes.

The issue of multimodal and intermodal transport, which is increasingly being used by companies to improve the flexibility of logistics chains, deserves special attention. Combining different modes of transport within a single logistics solution requires a high level of coordination and the use of modern transport technologies to manage intermodal operations. For logistics management, this means the need to develop new competencies and approaches to the organisation of transport.

Environmental sustainability requirements have a significant impact on the development of transport technologies in logistics management. Companies are increasingly focusing on reducing the carbon footprint of transport operations, optimising fuel consumption, and introducing electric transport and alternative fuels. Environmental considerations are becoming an integral part of management decisions in the transport sector and are shaping new criteria for evaluating the efficiency of logistics systems.

In the context of increasingly complex international logistics, transport technologies are playing an increasingly important role in ensuring the reliability and transparency of supply chains. The use of digital platforms, electronic document management and cargo tracking systems minimises the risk of delays and losses and increases the level of trust between participants in logistics processes. For management, this means the ability to make more informed decisions based on up-to-date information.

Thus, transport technologies are not only a technical tool, but also a strategic factor in the development of modern logistics management. Their effective implementation contributes to cost optimisation, improvement of logistics service quality, strengthening of competitive positions of enterprises and formation of sustainable logistics systems. In the future, it is the integration of innovative transport technologies with management decisions that will determine the ability of enterprises to adapt to dynamic market changes and ensure the effective functioning of logistics chains.

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FEATURES OF HYUNDAI KONA ELECTRIC DIAGNOSTICS USING THE LAUNCH X-431 PRO 3S MULTRI-BRAND SCANNER

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Introduction

The development of electric vehicles is accompanied by an increasing role of electronic control systems and high-voltage components, whose technical condition directly affects operational safety and reliability. Hyundai Kona Electric is a representative of mid-range EV that is widely operated in Ukraine. Its maintenance and inspection require diagnostic tools capable of accessing multiple electronic subsystems. Universal multi-brand scanners are especially relevant for service stations, as they allow diagnostics of different vehicle makes without specialised dealer equipment. One such tool is the LAUNCH X-431 PRO 3S, whose functionality in relation to electric vehicles requires systematic evaluation.

Analysis of Publications

Recent scientific studies focus on EV diagnostics using OBD-II-based tools and universal diagnostic devices. Works (Zhao & Burke, 2022; Hnatov et al., 2025) demonstrate that key parameters of high-voltage batteries can be obtained via standard diagnostic interfaces; however, their interpretation requires appropriate analytical methods. The Ukrainian studies (Arhun et al., 2016) emphasise the need

to adapt diagnostic equipment to local service environments and to EV models most common on the domestic market.

International publications (Małek & Toccani, 2021; You et al., 2017; Hong et al., 2024) analyse modern approaches to battery State of Health (SoH) assessment, including the use of cumulative energy, operating time and data-driven techniques. Technical documentation and application notes provided by LAUNCH (Kaplan, 2021) confirm the expansion of multi-brand scanner functionality for EV diagnostics. These sources form the theoretical and practical basis for analysing Hyundai Kona Electric diagnostics using the LAUNCH X-431 PRO 3S.

Purpose and Objectives

The purpose of this study is to investigate the applicability of the LAUNCH X-431 PRO 3S multi-brand scanner for technical diagnostics of the Hyundai Kona Electric.

The main *objectives* are:

- to analyse the functional capabilities of the LAUNCH X-431 PRO 3S in the context of electric vehicles;
- to propose a general diagnostic algorithm for the Hyundai Kona Electric;
- to identify informative parameters of key electronic control units;
- to assess the possibility of detecting hidden faults and data manipulation.

Characteristics of the LAUNCH X-431 PRO 3S Scanner

The LAUNCH X-431 PRO 3S is a multi-brand diagnostic scanner supporting more than 300 vehicle makes and over 40 special service functions. It enables full-system scanning, reading and clearing of fault codes, real-time parameter monitoring and execution of service procedures. For Hyundai/Kia electric vehicles, access is available to high-voltage battery management systems, charging systems, safety-related ECUs and body control modules.

Diagnostic Algorithm for the Hyundai Kona Electric

The diagnostic procedure for an electric vehicle should be performed step by step. Initially, the operability of AC and DC charging systems is verified. This is followed by a quick scan of all ECUs to identify active and stored fault codes.

A detailed analysis is then carried out for selected control units:

- *Airbag ECU* – verification of airbag status, 12 V battery voltage and detection of shunts;
- *IC (Instrument Cluster)* – analysis of odometer data and warning indicators;
- *IBU-BCM* – inspection of dashboard indicator integrity;
- *Smart Key Unit* – determination of the number of programmed keys;
- *EV Battery System* – evaluation of cell voltages, State of Charge (SoC), State of Health (SoH), cumulative energy and operating time;
- *OBC (On-Board Charger)* – analysis of AC charging time and charging counters.

Comparison of cumulative charged energy, operating time and odometer readings allows estimation of the actual vehicle mileage and identification of possible data manipulation.

Special Functions of the Scanner

The LAUNCH X-431 PRO 3S supports a number of special functions useful for servicing the Hyundai Kona Electric, including full-system quick testing, service indicator reset, steering angle sensor calibration, smart key programming and battery-related service procedures. The available set of functions depends on the software version and vehicle configuration.

Conclusions

Hyundai Kona Electric is a technologically complex vehicle that requires modern diagnostic approaches. The study demonstrates that the LAUNCH X-431 PRO 3S multi-brand scanner provides comprehensive access to the main electronic systems of this electric vehicle. Real-time data analysis and the use of special functions make it possible not only to detect faults but also to assess the condition of

the high-voltage battery and verify the plausibility of mileage data. The proposed general diagnostic algorithm can be applied at service stations and during expert evaluation of used electric vehicles.

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ELECTRIC VEHICLES

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The idea of electric transport is older than many people think: experiments with electric "carriages" date back to the first half of the 19th century, with early models and prototypes dating back to the 1820s and 1830s. Practical, commercially available electric vehicles emerged towards the end of the 19th century and especially in the early 20th century – in cities at the time, electric taxis and small electric cars competed with steam and gasoline-powered vehicles. However, with the development of affordable gasoline-powered cars (particularly Ford's Model T) and the availability of oil, electric vehicles virtually disappeared from mass use in the 20th century. A revival began in the late 20th and early 21st centuries: environmental regulations, improved batteries, and new startups led to a second coming of the EV – specifically, the emergence of mass-produced hybrids (such as the Toyota Prius) and the entry of fully electric mass-produced models and premium electric cars. A significant milestone was set by the Tesla Roadster (2008), which demonstrated that electric vehicles could have a longer range and sporty performance comparable to gasoline cars (Purdy, 2025).

Electric vehicle sales have grown rapidly in recent years. The International Energy Agency (IEA) in estimated that global electric vehicle sales exceeded 17 million in 2024, accounting for over 20% of all new car sales. As a result, by the end of 2024, the global electric vehicle fleet was total nearly 58 million vehicles. China accounted for a significant portion of this growth, accounting for approximately two-thirds of all electric vehicle sales in 2024. These figures reflect the rapid adoption of EVs, but their share of the total global fleet remains relatively small (a few percent), as fleet renewal occurs gradually (Matulka, 2024).

Trends for 2024–2025 include: intense competition among manufacturers (including traditional automakers and new players), falling battery costs per kWh

(although the rate of decline is slowing), development of charging infrastructure in cities and on highways, and political and economic factors (subsidies, tariffs, local restrictions) that significantly influence the rate of EV adoption in different countries (McKerracher et al., 2025).

Advantages of Electric Vehicles: zero local emissions (at the point of use). Electric vehicles emit no exhaust gases at the point of use, improving air quality in cities and reducing local pollution.

Energy efficiency. Electric motors are more efficient than internal combustion engines: a higher percentage of the battery's energy is converted into propulsion. This results in lower primary energy consumption per kilometer.

Fewer moving parts mean lower maintenance. Electric vehicles lack a traditional gearbox, valves, exhaust gas recirculation systems, etc., simplifying maintenance (no oil changes, fewer engine problems).

Potential for decarbonization. When connected to clean electricity (wind, solar, hydropower), EV operating emissions are significantly lower than those of gasoline vehicles.

Quiet and smooth ride, high torque from zero. Electric motors provide instant torque, which improves dynamics at low speeds and comfort in the urban cycle.

Disadvantages and Limitations of Electric Vehicles: range and Charging Time. Although the range of modern BEVs has increased, long trips still require planning: charging can sometimes take longer than refueling with gasoline. Fast charging reduces this time, but still takes longer than a regular refueling.

Charging Infrastructure. In some regions (especially in developing countries and rural areas), the charging network is underdeveloped. This limits the ease of using electric vehicles outside of cities.

Purchase Cost. Although EV prices have fallen, the initial cost of some models is still higher than equivalent gasoline versions; however, lower operating costs (electricity is cheaper than fuel, and maintenance is lower) must also be taken into account.

Battery Production and the Environment. Lithium-ion battery production requires materials (lithium, cobalt, and nickel), the extraction and processing of which pose environmental and social challenges; battery recycling and reuse are also important issues.

Grid Loads The mass transition to EVs requires investment in distribution networks, peak load management, and the development of smart charging solutions to avoid placing unnecessary strain on the power grid.

The transition to electric vehicles is already changing the automotive industry: supply chains are shifting (with an emphasis on batteries and rare materials), new jobs are emerging in charging infrastructure and battery recycling, while at the same time, some traditional jobs (related to internal combustion engines) are being transformed or eliminated. Government policies play a significant role: subsidies, tax breaks, emissions requirements, and standards can either accelerate or slow the transition.

In 2024, global electric vehicle sales exceeded 17 million units, accounting for over 20% of new car sales; by the end of 2024, the global electric vehicle fleet reacht nearly 58 million vehicles. China accounted for approximately two-thirds of these sales, according to the International Energy Agency (IEA) (Trends, 2025).

This statistic is a useful benchmark: it demonstrates both the rapid growth in sales and the fact that the share of EVs in the overall vehicle fleet remains low, suggesting significant potential for further growth.

Electric vehicles have already gone from experimental prototypes to a mainstream trend. The key question for the coming years is not whether they will become reality, but how quickly this transition will occur and under what conditions: how quickly will batteries improve (range, cost, safety), how will charging infrastructure develop, and how environmentally friendly will the entire value chain be – from material extraction to recycling.

For countries and companies, investments in charging infrastructure, battery recycling, and green power generation will determine the benefits of electrification.

Consumers value lower operating costs, convenient charging, and the confidence that a single charge will allow them to complete their intended journey. Policy, technology, and the market interact: with the right mix of incentives and innovation, electric vehicles have the potential to significantly reduce transportation emissions and reduce dependence on oil.

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STUDY OF OPERATING MODES OF A COMBINED POWER UNIT BASED ON A SMALL-DISPLACEMENT INTERNAL COMBUSTION ENGINE

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Introduction. A new stage in the development of energy and transport systems is characterized by increased requirements for energy efficiency, environmental performance, and adaptability of power units (Bosch, 2020). The tightening of environmental regulations, the rising cost of traditional energy resources, and the need to reduce harmful emissions drive the active development of alternative and

combined energy sources. In this context, combined (hybrid) power units, which integrate different principles of energy conversion, are of particular interest.

Small-displacement internal combustion engines (ICEs) are widely used in compact machinery, autonomous power units, light vehicles, and specialized equipment. At the same time, even at low power levels, such engines remain sources of noise, vibration, and harmful emissions. This stimulates the search for ways to improve their operating modes and to integrate them with other energy systems, in particular pneumatic drives.

The purpose of this paper is to analyze the current state of research in the field of hybrid power units and to substantiate the feasibility of using a pneumatic engine created on the basis of a small-displacement ICE as part of a combined power unit.

Hybrid and combined power units: general aspects. A hybrid power unit is a system in which more than one energy source or energy conversion principle is used to generate mechanical energy (Korbut et al., 2021). The most common are hybrid units combining an ICE and an electric motor; however, hydraulic and pneumatic hybrid systems are also considered in scientific research.

Depending on the architecture and the interaction principle of the components, hybrid power units are classified as:

– series, in which the ICE is used exclusively to generate energy that is transmitted to the actuator through another type of drive;

– parallel, where the ICE and the auxiliary motor can simultaneously or alternately transmit torque to a common shaft;

– series-parallel, which combine features of the two previous schemes and provide increased operational flexibility.

The main advantages of hybrid power units include the ability to optimize ICE operating modes, reduce specific fuel consumption, recover energy, and decrease harmful emissions. At the same time, design complexity, cost, and the need for energy storage systems remain significant drawbacks.

Pneumatic energy systems and their role in hybrid units. Pneumatic energy systems are based on the use of compressed air energy, which is stored in special receivers and converted into mechanical work using pneumatic engines (Wasbari et al., 2018). Unlike electric batteries, compressed air storage systems are characterized by high durability, the absence of toxic components, and the ability to operate over a wide temperature range.

In hybrid power units, a pneumatic drive may perform an auxiliary or a primary function depending on the operating mode. Its use is most appropriate:

– during start-up and operation at low loads;
– in modes with frequent stops and accelerations;
– for braking energy recovery with subsequent reuse.

Studies show that pneumatic hybrids can be particularly effective for systems with low installed power, where simplicity and reliability are crucial. This makes them promising for integration with small-displacement ICEs.

Rationale for the use of a pneumatic engine. Unlike electric hybrids, pneumatic systems do not require expensive batteries or power electronics. In addition, pneumatic engines can be structurally simple, which reduces their mass and cost.

One promising direction is the creation of a pneumatic engine directly on the basis of an existing ICE, as confirmed by the results of modern theoretical and experimental studies (Leontiev et al., 2021). This approach allows:

– maximum utilization of the existing mechanical components of the engine;
– minimization of design modifications;
– ensuring versatility of the unit, which can operate both in ICE mode and in pneumatic engine mode.

Thus, the gradual transition from classical hybrid schemes to combined units using compressed air is logical and scientifically justified.

Creation of a pneumatic engine based on a small-displacement ICE

It is known that, according to its kinematic scheme, an internal combustion engine can operate as an expansion machine, provided appropriate organization of the working process and the supply of compressed air (Wasbari, 2018**)**. When the fuel supply and ignition (or injection) systems are disabled and compressed air is supplied to the cylinders, the ICE can function as a pneumatic engine.

Such an operating mode does not require significant changes to the crank-slider mechanism or the valve train. The main design modifications are limited to:

- adaptation of the intake system for compressed air supply;
- optimization of valve timing;
- ensuring safe operation of the valve mechanism.

The literature notes that the use of an ICE in pneumatic mode is particularly effective at low and medium rotational speeds, where acceptable efficiency and stable operation are achieved. This opens the possibility of creating a combined power unit in which the ICE and the pneumatic engine function as a single system.

The relevance of this study is determined by current trends in the development of power engineering, which are associated with increasing requirements for energy efficiency, environmental safety, and versatility of power units. Small-displacement internal combustion engines, widely used in special-purpose vehicles, autonomous power units, and compact machinery, are characterized by operation under transient conditions, frequent starts and stops, and reduced efficiency at low loads. It is under these conditions that conventional ICEs demonstrate the poorest environmental and economic performance.

The use of combined power units makes it possible to expand the range of efficient ICE operating modes and reduce fuel consumption and harmful emissions, as confirmed by numerous studies in the field of hybrid and pneumatic power units (Voronkov, 2017). Among various types of hybrid systems, pneumatic drives are promising due to their structural simplicity, reliability, and the ability to store energy without the use of expensive and environmentally sensitive electrochemical batteries. Of particular relevance is the use of a pneumatic engine created on the basis of a

production ICE, which minimizes design changes and reduces the cost of the combined unit.

In this regard, the study of operating modes of a combined power unit based on a small-displacement ICE with a pneumatic operating mode is a relevant scientific and technical task for the field of power engineering.

The scientific novelty of this work lies in:

– substantiating the possibility of using a small-displacement internal combustion engine as a pneumatic engine by disabling the fuel supply and ignition systems without significant changes to its kinematic scheme;

– further development of concepts regarding the operating modes of combined power units with pneumatic drives in the range of low and medium loads;

– generalization and systematization of scientific results concerning the use of compressed air as an auxiliary energy carrier in hybrid power units;

– formation of scientific prerequisites for optimizing valve timing and compressed air supply parameters when an ICE operates in pneumatic mode.

The obtained results provide a basis for further experimental and theoretical studies of combined power units based on small-displacement ICEs.

Conclusions. The conducted literature review indicates a growing interest of researchers in combined power units and in the search for alternative ways to improve the efficiency of internal combustion engines. It is shown that pneumatic systems can effectively complement ICEs, especially in low-load and transient operating modes.

The use of a small-displacement ICE as a pneumatic engine is a promising direction that combines structural simplicity, versatility, and the potential to reduce fuel consumption and environmental impact. The review results confirm the feasibility of further research into the operating modes of such a combined power ICE-based hybrid system.

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ANALYSIS OF ENVIRONMENTAL SAFETY SYSTEMS IN MODERN PASSENGER CARS

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The automobile is a source of environmental pollution, which stimulates continuous improvement of environmental safety. Modern Euro-6 environmental standards suggest a reduction in harmful emissions through changes in the exhaust system and the engine management system.

Euro 6 is the sixth embodiment of the European Union directive on reducing harmful pollutants from the exhaust system of vehicles. The standard was introduced in September 2015. Since that time, all new cars must comply with these requirements.

Euro 6 provides for the reduction of harmful substances in the exhaust gases of cars with gasoline and diesel engines.

Exhaust gases include nitrogen oxide (NOx), carbon monoxide (CO), hydrocarbons (THC and NMHC), and particulate matter (PM), which are mainly emitted from diesels in the form of soot. Indirect reduction of these pollutants can improve fuel economy and ensure a low level of CO2 emissions.

Euro V and Euro VI emission reduction technologies

Exhaust Gas Recirculation System. During fuel combustion in engine cylinders, many toxic substances are formed, the greatest danger of which is represented by various nitrogen oxides. One way to reduce the amount of these substances is to install a catalytic converter in the engine exhaust system. However, there is another way to reduce emissions of nitrogen oxides into the atmosphere – to change the combustion mode of the fuel-air mixture in the combustion chamber.

Nitrogen oxides are formed in the combustion chamber due to the reaction of nitrogen and oxygen of the air at high temperature, and the higher the temperature, the more actively nitrogen oxidation proceeds. Therefore, the simplest way to solve the problem is to somewhat reduce the combustion temperature of the fuel-air mixture in the cylinders. This goal is achieved with the help of exhaust gas recirculation, that is, the return of a certain amount of exhaust gases to the cylinders together with a new portion of the combustible mixture.

Thus, the exhaust gas recirculation system (EGR – Exhaust Gas Recirculation) reduces the toxicity of the engine exhaust, significantly increasing its environmental friendliness. The recirculation system works successfully on gasoline and diesel engines and is not applied only on engines equipped with a turbocharger.

The recirculation system has many advantages and has a very beneficial effect on the engine. In particular, recirculation on a diesel makes the engine operation at idle softer, and in gasoline engines, it significantly reduces the likelihood of detonation – this allows setting an earlier ignition timing and increasing power. Also, the recirculation system in gasoline engines makes it possible to reduce so-called

pumping losses – power reduction due to a significant pressure drop across the throttle valve. Therefore, the recirculation system only improves engine operation.

Two fundamentally different exhaust gas recirculation systems having different structures and operating principles are installed on cars: pneumomechanical EGR and EGR with electronic control (modern system).

Pneumomechanical systems are distinguished by simple construction and reliability; however, they cannot always ensure the optimal engine operating mode. Systems with electronic control, as implies from the name, work under the control of an electronic control unit. Each system has its own features. The exhaust gas recirculation system should not work always: when starting a cold engine, until it reaches a stable operating mode, at idling speed, as well as at high rpm, the recirculation system only worsens engine operation. In these modes, exhaust gases are not supplied to the intake manifold. In the recirculation system with electronic control, a special valve is used, however, its opening and closing are carried out by an electronic control unit, which is guided by the readings of various sensors. In particular, the system may contain sensors for absolute pressure, coolant temperature, air flow meter, air temperature in the intake manifold, throttle position, and others.

Valve control is pneumatic; specifically for this, a vacuum pump and control valves are provided in the system.

In systems with electronic control, preliminary cooling of exhaust gases before their supply to the combustion chamber is often used. Moreover, cooling is performed only in certain engine operating modes; cooling control is also carried out by the electronic unit. Selective Catalytic Reduction System (SCR). The system reduces the level of nitrogen oxides in exhaust gases and, thereby, allows meeting Euro 5 and Euro 6 toxicity standards. Currently, the catalytic neutralization system is used on their passenger cars by Audi, BMW, Mazda, Mercedes-Benz, Mini, Volkswagen. The name of the system testifies that the neutralization of exhaust gases occurs selectively – only the content of nitrogen oxides is reduced. By its purpose,

the selective catalytic reduction system is an alternative to the exhaust gas recirculation system. Structurally, the selective catalytic neutralization system includes a tank, pump, nozzle, mechanical mixer, reduction catalyst, electronic control system, and heating system. Neutralization of nitrogen oxides is carried out using a reducing reagent, which acts as a 32.5% urea solution. It is at such a concentration that the freezing point of the urea solution has the highest value.

The urea solution used in the SRC system has the trade name AdBlue. The tank is a reservoir for storing urea. The volume and number of tanks are determined by the design of the system and the power of the engine. An electromagnetic valve for urea backflow is included in the discharge line of the neutralization system. When the car engine is turned off, the valve ensures the pumping of urea from the pipeline back into the tank. The nozzle injects a certain amount of urea into the exhaust tract, namely into the guide pipe. Following the nozzle in the guide tube, a mechanical mixer is installed, which crushes urea drops for evaporation and also swirls exhaust gases for better mixing with urea. The guide pipe ends with a reduction catalyst having a honeycomb structure. The walls of the catalyst are coated with a substance that accelerates the reduction of oxides. The electronic control system traditionally includes input sensors, a control unit, and actuators.

The input devices of the control system are urea pressure, urea level, and urea temperature sensors, a nitrogen oxide sensor, and an exhaust gas temperature sensor. The urea pressure sensor monitors the pressure created by the pump. The urea level sensor monitors the level of urea in the tank. Information about the level and the need to refuel the system is displayed on the instrument cluster and is accompanied by a sound signal. The temperature sensor ensures the measurement of urea temperature. The nitrogen oxide sensor determines the content of nitrogen oxides in exhaust gases after catalytic neutralization and is therefore installed after the reduction catalyst. The exhaust gas temperature sensor directly starts the neutralization process when the exhaust gases reach a temperature of 200°C.

Signals from input sensors enter the electronic control unit, which acts as the engine control unit. In accordance with the embedded algorithm, upon the command of the control unit, certain actuators are activated: the pump electric motor, the electromagnetic nozzle, the electromagnetic backflow valve, and signals are also sent to the heating system control unit.

The urea injected by the nozzle is picked up by the flow of exhaust gases, mixed, and evaporated using a mixer. In the section before the reduction catalyst, urea decomposes into ammonia and carbon dioxide. In the catalyst, ammonia reacts with nitrogen oxides, resulting in the formation of safe nitrogen and water.

Environmental problems associated with the use of traditional motor fuel in vehicle engines are relevant not only for Ukraine but also for all countries of the world. In many countries of the world, strict requirements for the greening of motor transport have been adopted.

As a result, from 2015 to 2022, the amount of harmful substances in the exhaust gases of cars abroad decreased by about two times. Over the last 40 years, the content of toxic components has decreased by 70%. Indirectly, these requirements also touched Ukraine – a stream of foreign cars poured to us, which in developed countries were recognized as environmentally unsafe, thereby replenishing the domestic fleet with cars causing colossal damage to the ecology of our cities.

Currently, many foreign engine-building firms have set a course for solving the problem of achieving zero toxicity of exhaust gases. Their many years of experience show that this can be achieved only in the case of using alternative (non-petroleum) types of motor fuel. That is why practically all promising environmentally friendly cars are designed for alternative types of fuel.

Thus, it can be concluded that there is a need to take large-scale and comprehensive measures to prevent, neutralize, or at least significantly reduce those negative consequences that arise during the operation of motor vehicles.

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IMPROVING THE ENVIRONMENTAL FRIENDLINESS OF AUTOMOTIVE BRAKING SYSTEMS (NEW FRICTION MATERIALS)

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The rapid growth of the global vehicle fleet and the tightening of environmental legislation pose new challenges to the automotive industry. While the focus over the last few decades has been on reducing exhaust emissions (CO2, NOx), research vectors are currently shifting towards Non-Exhaust Emissions (NEE). According to the United Nations Economic Commission for Europe (UNECE), the proportion of particulate matter derived from tire and brake wear in the total volume of road dust is constantly increasing and already exceeds soot emissions from modern diesel engines equipped with particulate filters (European Parliament, 2023).

Brake systems are a significant source of heavy metal emissions (copper, zinc, antimony) and fine particulate matter (PM2.5, PM10), which negatively affect human health and aquatic ecosystems. The implementation of the Euro 7 standard, which for the first time regulates limit values for brake dust emissions, requires a fundamental revision of friction material formulations. The aim of this paper is to analyze current trends in the development of eco-friendly friction materials and to evaluate their potential to replace traditional toxic components without compromising braking efficiency.

Problems Associated with Traditional Friction Materials

Modern brake pads are complex multi-component composites containing from 10 to 20 ingredients, which can be categorized into four groups:

1. Binders: typically phenol-formaldehyde resins.
2. Reinforcing fibers: steel, aramid, glass fiber.
3. Fillers: barite, calcite (to reduce cost and improve processability).
4. Friction modifiers: graphite, metal sulfides, and, most importantly, copper.

The Copper Problem. Copper is traditionally used as a key component (up to 20% by mass) to ensure a stable friction coefficient and heat dissipation. However, when released into the environment, copper oxidizes and is washed by rainwater into water bodies, where it is highly toxic to phytoplankton and fish. Legislation in the USA (specifically the "Copper-Free Brakes Initiative" in California and Washington) mandates a reduction in copper content to <0.5% up to now.

The Binder Problem. Phenolic resins release volatile organic compounds (VOCs) when heated, and their decomposition products are carcinogenic. Furthermore, the manufacturing process of these resins relies on petrochemical sources.

Innovative Directions in Creating Eco-Friendly Materials

To address these issues, the scientific community and manufacturers have focused on several directions for developing new formulations, primarily "Low-Met" (Low-Metallic) and new generation "NAO" (Non-Asbestos Organic).

Copper-Free Composites. Replacing copper is a complex task because no other single element combines such high thermal conductivity and ductility. Research demonstrates the effectiveness of using combinations of the following materials: stainless steel fibers that provide mechanical strength but may increase brake disc wear; Titanates (e.g., potassium titanate) that stabilize the friction coefficient at high temperatures; graphite and metal sulfides that act as solid lubricants, reducing noise and vibrations, compensating for the absence of soft copper.

Recent studies have shown that composites based on a tertiary system (steel fiber/graphite/zirconium oxide) can provide tribological characteristics similar to copper analogs while reducing dust generation levels by 15%.

Natural Fibers and "Green" Composites. The use of renewable resources allows for a reduction in the carbon footprint of production.

Plant fibers. Hemp, flax, jute, sisal, and bamboo are being considered as replacements for synthetic aramid fibers. They possess lower density and good damping properties (reducing brake squeal). Their main disadvantage is low thermal stability (degradation at T > 250°C).

Agricultural waste. Coconut shells, palm slag, and rice husks, processed into carbonaceous fillers, demonstrate high wear resistance. Carbonization of these materials helps to increase their thermal resistance.

Geopolymers as an Alternative to Resins. To eliminate toxic phenolic resins, the use of inorganic geopolymer binders (aluminosilicates) is promising. Geopolymers withstand temperatures over 800°C without releasing harmful gases, are non-flammable, and possess high hardness.

Nanomaterials. The introduction of nanoparticles allows for the modification of material structure at the molecular level. Carbon nanotubes (CNTs), even at low concentrations (0.5–1%), significantly increase thermal conductivity and fracture resistance. Nano-oxides (Al2O3, SiO2) act as mild abrasives, cleaning the rotor surface and forming a stable "transfer film," which reduces dust emission.

Specifics of Braking Systems in Electric Vehicles (EVs)

The transition to electric vehicles changes the paradigm of brake operation. Due to regenerative braking (using the electric motor as a generator), hydraulic brakes are used 60–80% less frequently. This leads to new problems:

1. Disc Corrosion: due to infrequent use, brake discs are prone to rusting, which reduces emergency braking efficiency.

2. "Glazing": the formation of a smooth film on pads due to operation at low temperatures and light loads.

Eco-friendly materials for EVs must be optimized not so much for high thermal resistance (fading) but for corrosion resistance and friction coefficient stability in the "cold" state. A promising solution here is the use of coated brake discs (e.g., Tungsten Carbide Coated – PSCB technology), which work in tandem with special copper-free pads, reducing dust quantity by up to 90% (Grigoratos & Martini, 2015; Liew. & Nirmal, 2013; Wahlström, 2022; Österle et al., 2016).

Conclusion. Improving the environmental friendliness of braking systems is an irreversible process dictated by the introduction of Euro 7 standards and legislative restrictions on copper content. The application of nanomaterials and modified natural fibers allows for a compromise between environmental safety and tribological efficiency. For the electric vehicle segment, the priority is developing friction pairs resistant to corrosion and effective in infrequent use modes, requiring a transition to new types of brake disc coatings. Future research should focus on improving adhesion between eco-friendly fillers and the matrix, as well as conducting field tests of new materials under real urban traffic conditions.

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TRANSFORMATION PATHWAYS FOR SUSTAINABLE URBAN TRANSPORTATION SYSTEMS

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In the twenty-first century, accelerating urbanisation has generated both opportunities and structural challenges for metropolitan regions. Projections by the United Nations estimate that by 2050 more than two-thirds of the global population will reside in urban areas, which will drastically intensify demand for efficient, affordable, and environmentally sustainable transportation systems (United Nations, 2019). The conventional model of urban mobility – characterised by privately owned, gasoline-powered automobiles – has become increasingly unsustainable due to escalating traffic congestion, deteriorating air quality, and heightened greenhouse gas emissions. Against this backdrop, contemporary urban transport planning is undergoing a paradigm shift toward cleaner, smarter, and more human-centred mobility architectures that integrate environmental responsibility, digitalisation, and social inclusivity.

Current urban transport infrastructure operates under severe operational and environmental pressures. Chronic roadway congestion imposes significant economic costs through productivity losses and fuel waste, while vehicular emissions contribute to cardiovascular and respiratory illnesses as well as noise pollution. Moreover, extensive allocation of urban land to roads and parking infrastructure reduces the availability of public space for green areas, pedestrians, and cyclists,

despite the fact that private vehicles remain idle for the majority of the day. This systemic inefficiency underscores the necessity of transitioning from car-centric toward people-centric spatial planning, wherein mobility is designed to meet the needs of communities rather than motorised vehicles.

Electrification represents a central technological pathway for the decarbonisation of urban transport systems. Battery-electric buses, taxis, and micro-mobility platforms are increasingly displacing internal-combustion alternatives. Shenzhen's full electrification of its public bus fleet illustrates the potential of large-scale deployment in reducing local air pollutants and noise emissions (BloombergNEF, 2021). Electric vehicles (EVs) exhibit operational advantages including reduced fuel costs, lower noise levels, and compatibility with renewable energy systems. However, widescale adoption necessitates complementary investments in charging networks, smart grid infrastructure, and battery recycling systems. Emerging research suggests that future metropolitan areas will integrate EVs as dynamic energy storage units capable of bi-directional electricity exchange with the grid, thereby supporting flexible energy management and sustainable load balancing.

Despite the growth of electrification, mass public transportation will remain the backbone of sustainable urban mobility. Intelligent, multimodal transit networks incorporating autonomous control systems, real-time data analytics, and integrated fare platforms are expected to optimise travel efficiency and accessibility. These developments align with Mobility-as-a-Service (MaaS) models, which consolidate buses, rail, bicycles, and ride-sharing within unified digital platforms that facilitate seamless trip planning and payment (Pangbourne et al., 2020). Under mature MaaS ecosystems, private vehicle ownership may decline as on-demand mobility services become more cost-effective and spatially efficient.

Complementing public transit, micro-mobility innovations such as bicycles, scooters, and electric mopeds address the "last-mile" gap between transit nodes and final destinations. Shared micro-mobility fleets can reduce vehicle density, mitigate

parking constraints, and promote active travel behaviours. Meanwhile, autonomous and connected vehicles present additional opportunities for system-level optimisation through vehicle-to-everything (V2X) communication, enabling collision avoidance, coordinated routing, and dynamic intersection management. Nevertheless, such systems introduce new ethical, regulatory, and cybersecurity challenges requiring careful governance and public acceptance.

The success of sustainable urban mobility transformations is contingent upon the redesign of urban form. Pedestrian-friendly corridors, dedicated cycling lanes, and reduced car traffic can enhance both environmental quality and social well-being. Concepts such as the “15-minute city” propose decentralised spatial layouts where essential services are accessible within short walking or cycling distances, thereby reducing travel demand and fostering community cohesion. The integration of smart infrastructure – equipped with sensors and real-time monitoring – further augments system efficiency by enabling adaptive traffic management and environmental monitoring.

Digitalisation functions as an integral coordinating mechanism across these domains. Artificial intelligence and big data analytics enable predictive modelling of demand patterns, optimisation of fleet operations, and reduction of congestion. However, digital mobility ecosystems also raise concerns regarding data governance, privacy, and equitable access, which require regulatory frameworks aimed at preventing the deepening of socio-economic inequalities.

Finally, the realisation of sustainable urban transportation futures will depend on effective governance, cross-sector collaboration, and public engagement. Policymakers must implement regulatory frameworks for emerging technologies such as autonomous vehicles and drones, incentivise low-emission mobility, and restrict high-pollution transport modes. International knowledge-sharing networks, including the C40 Cities Climate Leadership Group, demonstrate the value of coordinated global action. If implemented holistically, future urban transportation

systems will be cleaner, more inclusive, quieter, and more operationally integrated, thereby improving environmental quality and urban liveability.

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PROSPECTS FOR DIGITALISATION OF ROAD TRANSPORT SERVICES IN UKRAINE

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Digital technologies today influence almost every element of the transport sector, from planning and management to communication with users. For Ukraine, where road transport remains the main mode for both passenger and freight movement, digitalisation is not only a question of efficiency, but also a necessary condition for integration into the European transport space and post-war recovery. Modern information tools can help transport companies react faster to changes in demand, reduce costs and improve the quality and transparency of services. At the

same time, they create new requirements for infrastructure, regulation and professional skills of staff.

Digitalisation of road transport services can be broadly defined as the use of information and communication technologies (ICT) to support planning, organisation and control of transport processes. In practice, this includes GPS-based fleet tracking, electronic ticketing, mobile applications for passengers, online booking and payment services, transport management systems, as well as elements of intelligent transport systems such as traffic control and priority for public transport. These instruments allow operators to monitor traffic flows in real time, optimise routes, reduce fuel consumption and provide users with more accurate information about services (Litman, 2021; European Commission, 2020). In many European countries, such solutions are already integrated into wider concepts of smart cities and sustainable mobility, where digital tools support both economic efficiency and environmental goals.

In Ukraine, the digital transformation of road transport is developing, but the level of implementation differs significantly between regions, cities and companies. The largest cities, including Kyiv, Lviv, Kharkiv and Dnipro, have already introduced or are testing electronic ticketing, mobile applications for route planning and systems for monitoring the movement of buses and trolleybuses in real time. Passengers can see expected arrival times, choose optimal routes and pay for trips without cash. In the freight segment, many companies use GPS tracking to control vehicle location and drivers' working hours, and some have started to use basic transport management systems for planning deliveries and coordinating work with warehouses and clients (World Bank, 2018). These examples show that operators understand the potential of digital solutions even under conditions of limited resources and high uncertainty.

At the same time, the overall level of digitalisation of road transport services in Ukraine is still far from the targets set by European strategies. One of the key problems is the uneven quality of communication and digital infrastructure. Stable

mobile internet is not available on all sections of national and regional roads, especially in rural areas and territories close to the front line. This makes it harder to use online services continuously and reduces the effectiveness of systems that rely on real-time data. Another important limitation is the financial situation of small and medium-sized transport enterprises, which often do not have enough funds to purchase on-board equipment, pay for software and cloud services or regularly train staff. As a result, many processes continue to be based on paper documents, phone calls and the personal experience of dispatchers, rather than on objective data (Ministry of Infrastructure of Ukraine, 2021).

The institutional and regulatory environment also influences the speed of digitalisation. For successful integration of different systems, there is a need for clear standards of data exchange, requirements for electronic documents and rules for protecting the personal data of passengers and commercial information of clients. In the absence of common standards, ticketing systems, dispatch centres, navigation applications and accounting software often work separately and cannot "communicate" with each other. This leads to duplication of work, errors in data and difficulties with building integrated mobility platforms at the city or regional level. For road freight transport, similar problems arise when information about orders, transport documents, customs procedures and warehouse operations is stored in separate databases without automatic synchronisation (European Commission, 2020).

The human factor is another important dimension of digital transformation. Introduction of new technologies changes the everyday work of drivers, dispatchers and managers, and requires not only technical training but also a different attitude to decision-making. Employees must learn to interpret data, follow new procedures and cooperate with IT specialists. In some companies, there is resistance to change, especially when digital tools are perceived mainly as a mechanism of additional control. To overcome such resistance, management needs to clearly explain the advantages of digital solutions for safety, comfort and workload, and to involve staff

in the process of selecting and testing new systems. Regular training and internal communication can significantly increase the chances that innovations will be actually used in practice, rather than remaining formal requirements.

Educational institutions, in particular transport universities in Kharkiv and other cities, can support digitalisation by updating curricula and developing applied research projects with local partners. For students of transport specialities, it becomes increasingly important to understand the basics of information systems, geographic information technologies, data analysis and cybersecurity. Cooperation between universities, municipal authorities and business can take the form of pilot projects on digital passenger information, route optimisation, safety monitoring or integration of different modes of transport in one application. Such projects not only help cities to test new solutions with relatively low risk, but also give students real experience in working with data and modern software.

Prospects for further digitalisation of road transport services in Ukraine depend on coordinated actions at several levels. At the national level, it is important to ensure that strategic documents on transport and digital transformation contain clear priorities, realistic funding mechanisms and indicators for monitoring progress. International institutions such as the World Bank and other partners already support projects related to roads and urban mobility, and digital components of such projects may become a key factor for increasing efficiency and transparency (World Bank, 2018). At the same time, national legislation should support the use of electronic documents in transport, create conditions for the development of open data in the sector and provide guarantees of cyber security for critical infrastructure (Ministry of Infrastructure of Ukraine, 2021).

Another direction is the integration of safety and resilience aspects into digital solutions. For Ukraine, which is experiencing a full-scale war and regular attacks on infrastructure, continuity of transport services and protection of critical systems are especially important. Intelligent transport systems can be used to monitor dangerous road sections, send warnings to drivers and analyse accident data. In addition, digital

tools can help optimise evacuation routes, coordinate humanitarian logistics and plan restoration of damaged infrastructure. International analytical reports show that combining digital technologies with long-term planning in the transport sector can significantly improve both safety and economic efficiency (OECD/ITF, 2019).

In conclusion, digitalisation of road transport services in Ukraine is a complex and long-term process that affects technology, regulation, economics and human behaviour. Despite existing barriers, practical experience of Ukrainian cities and companies demonstrates that progress is possible even under difficult conditions. For students and young specialists in transport engineering, this topic is becoming one of the key areas of professional development, as future projects in road transport will almost always include a digital component. A successful combination of national strategies, local initiatives and the everyday work of enterprises will allow Ukraine to gradually approach European standards of mobility and make road transport more convenient, safe and environmentally responsible for citizens and businesses.

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EMERGING TRANSFORMATIONS IN AUTOMOTIVE MOBILITY

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Transportation systems are undergoing a critical transformation driven by technological innovation, environmental imperatives, demographic shifts, and evolving user expectations. Within this broader mobility ecosystem, the automobile remains a central yet increasingly contested element. The twenty-first century presents a convergence of structural pressures that necessitate the reconfiguration of automobile technologies, business models, and infrastructural frameworks. The present article examines the anticipated evolution of future mobility, with particular focus on the projected characteristics of future automobiles and the societal implications of such transformations.

Automobile-centred transport infrastructures facilitated global mobility and economic expansion throughout the twentieth century. However, legacy systems based on internal combustion engines presently face environmental, socio-technical, and behavioural challenges. Road transport accounts for a considerable share of greenhouse gas emissions, air pollution, and resource consumption, underscoring the urgency of decarbonisation efforts (International Energy Agency, 2023). Simultaneously, urbanisation intensifies congestion, land allocation constraints, and infrastructure stress, while emerging consumer preferences reflect greater interest in sustainability, digital connectivity, and shared mobility rather than private ownership (PwC, 2019). Parallel advancements in electrification, automation, connectivity, and alternative fuels are rapidly maturing, thereby expanding the design envelope for future mobility systems.

Several technological trajectories appear central to the future development of automobiles:

Electrification. Transitioning from internal combustion engines to electric powertrains constitutes a primary pathway for achieving transport decarbonisation. Battery-electric vehicles reduce tailpipe emissions and can leverage increasingly low-carbon electricity generation. Research highlights ongoing improvements in battery energy density, lightweight materials, and charging optimisation (Breetz et al., 2018). Future vehicles are expected to integrate vehicle-to-grid interfaces and intelligent energy management systems.

Autonomous and Connected Vehicles. The integration of advanced sensing technologies, artificial intelligence, and vehicle-to-everything (V2X) communication supports the emergence of autonomous vehicles (AVs). Analysts argue that automation has the potential to reduce collision rates, expand mobility access for non-drivers, and optimise traffic flows (Fagnant & Kockelman, 2015). However, regulatory uncertainties, cybersecurity risks, ethical considerations, and liability allocation remain unresolved challenges.

Shared Mobility Models. Mobility-as-a-service (MaaS) platforms, subscription-based access, and shared fleets are expected to reduce the dominance of traditional private ownership models, particularly in densely populated urban regions. Studies predict that autonomous electric fleets could become economically favourable relative to individual ownership in specific contexts (RethinkX, 2017). Such models would reframe vehicles as continuously utilised mobility assets rather than idle private property.

Alternative Configurations and Integration. Future vehicles may be lightweight, modular, multimodal, or vertically integrated with urban air mobility systems. Research prototypes include automated pods, modular shuttles, and micro-mobility solutions designed for last-mile connectivity and dense environments. Integration with public transit, cycling infrastructure, and pedestrian zones will be critical for systemic efficiency.

Automobiles represent only one component of the mobility ecosystem; systemic transformation must account for urban morphology, multimodal interfaces, infrastructure, and governance.

Urban Form and Infrastructure. Electrification and automation could reduce parking demand, enabling reallocation of land towards pedestrian zones, green spaces, and mixed-use development. Urban governments are investing in charging networks, smart signalling infrastructure, and dedicated AV lanes, reflecting a shift from vehicular accommodation to integrated mobility design (OECD, 2020).

Environmental and Social Impacts. Benefits include reduced emissions, improved air quality, lower noise levels, and enhanced inclusivity for mobility-constrained populations. Furthermore, shared autonomous fleets may decrease total vehicle stock, lowering resource consumption and congestion. However, achieving these outcomes depends on concurrent shifts in modal share, electricity decarbonisation, and battery recycling.

Despite favourable trajectories, multiple barriers persist. Technical challenges relate to autonomous system reliability, cybersecurity, and battery supply chains. Regulatory and ethical considerations include liability frameworks, algorithmic decision-making, and data governance. Socio-economic implications encompass employment displacement in driver-based sectors and potential inequities if advanced mobility remains unaffordable for certain populations. Behavioural resistance may also arise from cultural attachment to private automobiles and distrust of automation.

The literature supports several plausible future scenarios:

- shared autonomous electric fleets dominating dense metropolitan areas;

- hybrid models combining private electric vehicles with partial autonomy in suburban and rural regions;

- modal shifts reducing automobile prominence in favour of public transit, cycling, and active mobility supplemented by high-speed or aerial transport. These scenarios illustrate that technological innovation alone does not determine outcomes;

contextual governance, cultural norms, and spatial arrangements interact to produce divergent trajectories.

The prospective transformation of mobility systems will necessitate multidisciplinary collaboration across engineering (electrical, mechanical, software, and civil), policy, economics, and urban planning domains. Development of battery systems, autonomous driving algorithms, V2X communication standards, smart infrastructure, and recycling systems represents key engineering priorities. Policymakers will be required to facilitate equitable deployment, workforce transitions, and ethical regulatory frameworks.

The future of transportation is likely to be characterised by electrification, automation, shared mobility structures, smart urban integration, and environmental sustainability. While significant uncertainties and challenges remain, current momentum suggests that automobile functions, forms, and meanings will undergo substantial reconfiguration. The resulting mobility systems may become cleaner, more efficient, and more inclusive, contingent upon deliberate technological, regulatory, and cultural choices. Stakeholders – including engineers, policymakers, and citizens – will play decisive roles in shaping mobility trajectories that prioritise human welfare and ecological integrity.

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DEVELOPMENT OF A HYBRID ENERGY STORAGE SYSTEM FOR ELECTRIC VEHICLES

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Introduction

The global transition to sustainable transportation has significantly increased interest in electric vehicles (EVs). Over the past decade, governments and automotive manufacturers have invested heavily in EV technologies to reduce greenhouse gas emissions and dependence on fossil fuels. However, the effectiveness of electric vehicles largely depends on the performance of their energy storage systems. Currently, lithium-ion batteries are the dominant technology used in EVs due to their relatively high energy density and maturity of production processes. Despite these advantages, lithium-ion batteries face serious limitations, including thermal instability, degradation under high current loads, limited cycle life, and long charging times. These issues directly affect vehicle reliability, safety, and operating costs.

In contrast, supercapacitors exhibit extremely high-power density, rapid charging and discharging capabilities, and exceptionally long cycle life. These properties make supercapacitors well suited for handling short-term power demands such as acceleration and regenerative braking. Nevertheless, their low energy density prevents them from being used as a primary energy source. For this reason, hybrid energy storage systems (HESS), which combine lithium-ion batteries with supercapacitors, have attracted significant research interest. I fully agree that

hybridization offers a balanced and technically sound approach to overcoming the limitations of individual energy storage technologies. At the same time, I disagree with the view that hybrid systems are simple to design and implement, as they require sophisticated power electronics and control strategies.

Theoretical Background

Lithium-ion batteries store energy through electrochemical reactions, allowing them to provide high energy density suitable for long driving ranges. However, repeated exposure to high peak currents accelerates aging mechanisms such as electrode degradation and electrolyte decomposition. Numerous experimental studies confirm that battery lifespan decreases significantly under aggressive driving conditions.

Supercapacitors, on the other hand, store energy electrostatically, which enables extremely fast charge and discharge processes without significant degradation. They can withstand millions of cycles while maintaining stable performance. I agree that supercapacitors are ideal for compensating power fluctuations and protecting batteries from excessive stress. However, I strongly disagree with claims that supercapacitors could replace batteries entirely, as their low energy density limits their practical use in electric vehicles.

Advantages of Hybrid Energy Storage Systems

The integration of batteries and supercapacitors in a hybrid energy storage system provides several important advantages. First, HESS significantly extends battery lifespan by reducing peak current loads and smoothing power demand. Studies indicate that battery degradation can be reduced by 30-40% when supercapacitors are used to handle high-power transients.

Second, hybrid systems improve the efficiency of regenerative braking. Supercapacitors can absorb braking energy almost instantaneously, reaching energy recovery efficiencies of up to 95%. This recovered energy can later be reused during acceleration, leading to improved overall vehicle efficiency.

Third, HESS enhances vehicle dynamics and safety. Voltage stabilization, reduced thermal stress, and improved power availability contribute to smoother acceleration and more reliable operation. I fully agree that these advantages make hybrid systems a key technology for next-generation electric vehicles.

Challenges and Limitations

Despite their technical benefits, hybrid energy storage systems present several challenges that must be addressed before large-scale implementation. One of the primary challenges is increased system complexity. Effective energy distribution between batteries and supercapacitors requires advanced real-time control algorithms and reliable sensing systems. Additionally, hybrid systems increase vehicle cost and weight due to additional components such as power converters and control units. I disagree with the opinion that existing energy management systems are sufficient for optimal HESS operation. In my view, future systems must incorporate predictive and adaptive control strategies, potentially based on artificial intelligence, to maximize efficiency and reliability.

I agree that hybrid energy storage systems significantly improve energy efficiency, extend battery life, and enhance the overall performance of electric vehicles. I also agree that the combination of lithium-ion batteries and supercapacitors represents the most practical solution under current technological conditions. At the same time, I disagree that supercapacitors can fully replace batteries or that hybrid systems can be implemented without substantial engineering effort. The success of HESS depends on careful system design, advanced control strategies, and thorough testing (Tie & Tan, 2013).

Conclusions

Hybrid energy storage systems based on the integration of lithium-ion batteries and supercapacitors represent a promising direction for the future of electric vehicles. They offer improved performance, higher efficiency, extended battery lifespan, and enhanced safety. However, further research is required to reduce system cost, optimize energy management algorithms, and establish unified design standards.

Future developments should focus on intelligent control systems, lightweight materials, and integration with renewable energy sources. The widespread adoption of hybrid energy storage systems will play a crucial role in the development of sustainable and reliable electric transportation.

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COMPARISON OF TECHNOLOGICAL PROCESSES FOR THE CONSTRUCTION OF ASPHALT AND CONCRETE PAVEMENTS

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There is no reliable, publicly available statistic that accurately indicates what percentage of all roads in the world have asphalt or concrete pavement. According to statistics in the United States, approximately 95% of all roads have asphalt pavement, while only about 5% have concrete pavement. This statistic can be explained by the fact that constructing concrete pavement is more complex due to the longer curing process of concrete, the need for proper maintenance (especially under extreme temperatures), and the requirement to create expansion joints. In contrast, asphalt is placed more quickly, immediately after hot mixing, and allows traffic to be opened much sooner.

Example of the technological sequence for constructing the upper layer of asphalt concrete pavement using a hot fine-grained asphalt concrete mixture:

Before constructing the upper pavement layer made of hot fine-grained asphalt concrete mixture with anti-icing additives, it is necessary to:

- prepare the lower pavement layer in accordance with the requirements of DBN V.2.3-4;
- prepare temporary access roads for delivering materials to the work site;
- carry out layout work that ensures compliance with the design thickness, width, and cross slopes of the pavement;
- ensure proper drainage.

The organization of work for constructing the upper asphalt concrete pavement layer from hot asphalt concrete mixture is significantly influenced by transportation time and the compaction window of the mixture. This is due to the requirement that the temperature of asphalt concrete mixtures prepared with bitumen BND 90/130, BND 60/90, and BND 40/60 must not fall below 120 °C during placement.

Copying strings (control lines) ensure the automatic operation of the Vögele Super 2100 paver, as they define the elevation and alignment of the machine in plan. They also serve as the reference basis for adjusting the working components of the paver before construction begins. Therefore, accuracy and precision during installation of the copying strings are essential for achieving proper quality of work.

The construction of the 5 cm thick upper pavement layer from the trial batch of hot fine-grained asphalt concrete with anti-icing additives is carried out using the continuous method in two work sections, each 750–800 m long.

On the first work section, the following operations are performed:

- installation of signs and barriers on the work site;
- cleaning the surface of the upper base layer (lower pavement layer) from dust and dirt;
- application of bitumen (bitumen emulsion) to the surface of the lower layer;
- installation of copying strings.

Cleaning of the lower pavement layer using the mechanical brush of the PM-130 watering and washing vehicle is performed in one or two passes along the same path.

After cleaning the lower layer from dirt, bitumen (bitumen emulsion) is sprayed using a bitumen distributor. Before spraying, the operators prepare the distributor by:

- heating the distribution system through circulation of hot bitumen;
- setting the spray bars to the width of application matching the pavement width being constructed;
- selecting and installing spray nozzles corresponding to the required application rate.

Strings are installed only on one side when:

- the machine is equipped with a transverse level stabilization system;
- there is a completed adjacent lane next to the lane being constructed.

The height of the string above the pavement surface should be between 30 cm and 125 cm. The length of each string installation segment should not exceed 800 m, which is the maximum length for which the tension winches at both ends can maintain adequate string tension.

In the longitudinal direction, the distance between stakes should be 10 m or 15 m. On superelevated curves, the tops of leveling rods must be positioned directly above the projected line on the pavement edge.

Technology for constructing concrete pavement using slipform paving. The layout of the slipform paving line in plan is carried out on one side of the pavement using a theodolite, and on the other side using a template. The elevation of the slipforms is determined using a level.

After setting the slipforms in the design position, they are anchored to the base with steel pins and connected to each other with wedge locks.

To check the stability of the forms immediately before placing the concrete, a trial pass with the paving machine is performed.

Deviations of the slipforms from the design position after the trial pass must not exceed ±5 mm in plan and ±3 mm in elevation at the joints between adjacent slipform sections.

To ensure proper operation of the paving equipment, the length of the slipform section must not be shorter than its variable production length. Before placing the concrete, the inner sides of the slipforms must be coated with oil or a lime-clay mixture to prevent the concrete from sticking to the forms.

After preparing the formwork, wooden expansion joint spacers are installed, made from clean-sawn boards 20–30 mm thick and 3.5–3.75 m long. The holes in the spacers for passing reinforcing bars are made 1 mm smaller than the bar diameter. Spacers are placed vertically on the base and perpendicular to the pavement axis, then fixed with metal pins at 0.8–1.0 m intervals.

If the design includes edge reinforcement bars, they are placed on concrete pads or supports made of 10–12 mm diameter reinforcing steel.

For reinforcement of the pavement, welded meshes made of 6 mm diameter bars are laid on the previously distributed lower concrete layer. Welded meshes with longitudinal bars exceeding 6 mm in diameter are installed on site using special G-shaped steel bar supports welded to the mesh at 0.8–1.2 m intervals.

Bars in contraction joints are positioned using a special template and a vibrator in the fresh concrete after the first pass of the finishing machine.

The concrete mix is delivered to the site using concrete mixer trucks or dump trucks. The transport time should not exceed 30 minutes at air temperatures above 20°C and 60 minutes at temperatures below 20°C.

From the vehicles, the concrete is discharged into the hopper of the self-propelled distributor, which places the concrete on the base to the required thickness with a cone slump of 1–2 cm and an average allowance for compaction of 2–3 cm. The compaction allowance is determined before starting work by trial passes of the machines for each mix design.

To prevent displacement of the expansion joint spacers, concrete is distributed simultaneously on both sides of the spacer. For this, the paver hopper is positioned directly above the spacer and moved along it.

Concrete compaction and surface finishing are performed with concrete finishing machines that achieve the required degree of compaction and surface finish in one or two passes. Compaction and finishing are carried out in sections no longer than 12–15 m to prevent stopping the machine while vibrators are operating.

Before placing and compacting concrete, the main working elements of the finishing machine must be properly adjusted. Correct adjustment is indicated by a uniform concrete mound 8–10 cm high forming in front of the vibrating screed and a 1–3 cm high layer in front of the diagonal leveling vibratory screeds.

Near the expansion joint spacers and the edges of the slipforms, additional compaction is performed with internal vibrators before the finishing machine passes. Final compaction and finishing are carried out by the finishing machine.

The cement laitance generated during compaction and finishing is removed from the surface using a nylon brush moved transversely across the pavement. On pavements with a crowned profile, the brush is moved from the longitudinal axis to the edges.

During compaction and finishing, constant control of pavement levelness is maintained using a 3-meter straightedge, placed longitudinally and transversely.

Slipforms are removed no earlier than 18 hours after concrete placement at 15°C and no earlier than 24 hours at temperatures below 5°C.

In areas of pavement widening (curves, ramps, crossings, bus stops, etc.), work is carried out using small mechanization tools – vibrating screeds, surface and internal vibrators, and other hand tools and devices.

Thus, constructing asphalt pavement is faster than concrete, which allows for larger volumes of work to be completed within the same time.

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THE ROLE OF INFORMATION TECHNOLOGIES IN MODERN CARHAULING LOGISTICS

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In today's rapidly evolving logistics industry, modern information technologies play a crucial role in optimizing transportation processes, particularly in the automotive shipping sector in the United States. The efficiency, safety, and transparency of car transportation rely heavily on digital solutions such as Electronic Proof of Delivery (ePOD) systems, Electronic Logging Devices (ELD), and GPS tracking technologies. These innovations not only streamline operations but also ensure compliance with regulatory requirements, enhance communication between stakeholders, and improve overall service quality.

ePOD systems digitize the process of delivery confirmation by replacing traditional paper-based documentation with electronic records. These systems allow drivers to generate, store, and share delivery documents, including invoices and bills of lading, using mobile apps or specialized software. ePODs improve efficiency, reduce paperwork errors, and enhance transparency by providing real-time updates on deliveries, including time-stamped confirmations and photographic proof of cargo condition.

The driver plays a crucial role in the entire cargo delivery process, and with the help of an ePOD (Electronic Proof of Delivery) system, they can efficiently manage every stage, from order placement to the final unloading of the vehicle from the trailer. These systems digitize logistics workflows, ensuring that all necessary information is easily accessible and securely stored, reducing paperwork and improving overall efficiency.

Using an advanced ePOD system like Super Dispatch, drivers have real-time access to critical order details through a smartphone application. The system provides precise pickup and drop-off addresses, along with an interactive map view for easy navigation. Any special instructions related to the pickup or delivery process are also displayed, ensuring a smooth and well-coordinated operation.

In addition to location details, the ePOD system contains comprehensive information about the transported vehicle, including its make, model, VIN (Vehicle Identification Number), and condition. This ensures that all stakeholders are aware of the cargo specifications and any pre-existing damage or special handling requirements.

One of the key features of ePOD systems is photo documentation, which allows drivers to take and store high-quality images of the cargo at both the pickup and drop-off points. These photos serve as proof of condition, protecting the driver from liability in case of disputes regarding damages. Since they are time-stamped and geotagged, they provide a clear and accurate record of the vehicle's condition before and after transportation.

Beyond these core functionalities, modern ePOD systems also facilitate seamless communication by providing instant updates on schedule changes and delivery statuses. They allow drivers to collect electronic signatures from customers and personnel at both ends of the transportation process, ensuring that all necessary documentation is securely recorded. Additionally, they enable the automatic generation and submission of invoices and bills of lading (BOLs) directly through the app, streamlining the payment process.

By integrating ePOD systems into daily operations, logistics companies significantly improve efficiency, accuracy, and security in vehicle transportation. These digital solutions ensure a transparent and well-documented process, benefiting both drivers and customers while optimizing overall workflow.

An Electronic Logging Device (ELD) is a critical piece of technology used in commercial transportation to automatically record a driver's Hours of Service (HOS) (Ip, 2024). This system is designed to ensure compliance with federal regulations, particularly in countries like the United States, where strict limitations on driving hours are enforced to enhance road safety and reduce fatigue-related accidents. By accurately tracking driving time, rest breaks, and vehicle movement, ELDs play a vital role in modern fleet management and logistics operations.

The primary function of an ELD is to replace traditional paper logs, which were often prone to errors, manipulation, or inconsistencies. Unlike manual logbooks, which require drivers to record their working hours by hand, ELDs provide automated, real-time tracking, ensuring that data is accurate and tamper-proof. The system is directly connected to the vehicle's engine, enabling it to record driving status and movement without driver input. This automation reduces administrative workload, minimizes the risk of falsified records, and ensures that fleet operators and regulatory bodies can access precise and reliable HOS data at any time.

One of the key benefits of ELDs is their impact on driver safety. Fatigue is a leading cause of road accidents, particularly in the trucking industry, where long hours behind the wheel can lead to decreased concentration and slower reaction times. By enforcing compliance with federally mandated work-hour limits, ELDs help prevent drivers from exceeding safe driving thresholds. In the U.S., for example, regulations dictate that truck drivers can operate their vehicles for a maximum of 11 hours within a 14-hour work period, after which they must take at least 10 consecutive hours off-duty. ELDs automatically track this data, alerting drivers when they are approaching their legal driving limit and helping them plan their rest breaks accordingly (United States Department of Transportation, 2022).

From a fleet management perspective, ELDs offer numerous advantages. By integrating with telematics and GPS tracking systems, they provide fleet operators with real-time insights into vehicle locations, driver performance, and overall operational efficiency. Fleet managers can monitor compliance, identify inefficiencies, and optimize routes based on driving patterns and regulatory constraints. Additionally, many ELD systems include reporting and analytics tools, allowing companies to analyze historical data and make informed decisions to improve fuel efficiency, reduce operational costs, and enhance overall productivity.

As the transportation industry continues to evolve, ELD technology is expected to advance even further, integrating with artificial intelligence, predictive analytics, and automation to create smarter, more efficient fleet management solutions. In the long run, the adoption of ELDs is not just about regulatory compliance – it represents a fundamental shift toward a safer, more accountable, and data-driven future for commercial transportation.

As well as ELD and ePOD systems, tracking systems are essential in modern transportation, utilizing GPS and telematics technology to provide real-time visibility into vehicle location, movement, and operational status. These systems help fleet operators monitor performance, optimize routes, reduce fuel costs, and improve overall efficiency.

One of the key benefits of tracking systems is real-time location tracking, allowing dispatchers to monitor vehicle positions and respond to delays caused by traffic, weather, or mechanical issues. This ensures timely deliveries and enables dynamic rerouting when necessary. Additionally, tracking systems provide detailed performance data, including speed, fuel consumption, idle time, and driver behavior.

Tracking technology also enhances customer service by offering accurate delivery estimates and real-time shipment tracking, increasing transparency and trust. Additionally, it plays a crucial role in security and theft prevention – features like geofencing alerts help prevent unauthorized vehicle movement, while real-time GPS tracking aids in quick asset recovery.

Modern information technologies have transformed the transportation and logistics industry, particularly in the automotive shipping sector in the United States. Electronic Proof of Delivery (ePOD) systems, Electronic Logging Devices (ELDs), and GPS tracking technologies have revolutionized how vehicles are transported, making the process more efficient, transparent, and secure. These digital solutions not only enhance workflow automation but also ensure compliance with strict regulations, reduce paperwork burdens, and improve coordination among all stakeholders.

The implementation of ePOD systems has significantly streamlined the documentation and delivery confirmation process, providing drivers and fleet managers with real-time access to critical information. By digitizing invoices, bills of lading, and photographic proof of cargo condition, ePOD solutions have improved operational efficiency, accuracy, and customer satisfaction while protecting drivers from liability disputes.

ELD technology, on the other hand, has played a crucial role in ensuring regulatory compliance and road safety. By automatically recording Hours of Service (HOS), ELDs prevent driver fatigue-related accidents, enhance accountability, and enable fleet managers to optimize schedules while adhering to federal driving limits.

Meanwhile, tracking systems have provided businesses with real-time visibility into vehicle movement and performance. By leveraging GPS and telematics technology, companies can monitor fleet activity, improve route optimization, enhance security, and provide customers with accurate delivery estimates. The integration of AI and predictive analytics has further advanced these systems, allowing for proactive fleet management and maintenance planning.

In conclusion, the adoption of ePOD, ELD, and tracking systems has reshaped the transportation industry, making it more data-driven, compliant, and customer-centric. As technology continues to evolve, the industry will see further advancements in automation, AI integration, and predictive analytics, ensuring that logistics operations remain competitive and efficient. Ultimately, embracing modern

digital solutions is not just an option but a necessity for businesses striving for safety, efficiency, and long-term success in the transportation sector.

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MODERN APPROACHES TO IMPROVING THE RELIABILITY OF CRANE RUNNING WHEELS OF OVERHEAD CRANES

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Overhead cranes are an integral part of loading, unloading, and production processes at machine-building and metallurgical enterprises, as well as in seaports. Their operational reliability largely depends on the efficiency of the running gear, primarily on the crane running wheels. Intensive wear of wheel flanges and side surfaces of crane rails leads to significant repair costs, equipment downtime and potential hazards (Bohomaz, Bondarenko, Hlavatskyi & Sokol, 2015). The results of on-site research on overhead cranes in seaports show that about 90 % of running wheels are taken out of service due to flange wear, while 60–70 % of crane rails – due to damage to the side surfaces. This highlights the urgent need to improve the

reliability of crane wheels by optimizing their design, operating conditions, and technical maintenance systems.

The intensity of wheel wear is significantly influenced by the design features of overhead cranes, manufacturing precision, and installation quality. The main factors include: skewing of the crane bridge relative to the rail track; inconsistent operation of the left and right drives; deviations of the geometric dimensions of wheels and rails from the nominal values; uneven load distribution between wheels (Burhanuddin & Yuwono, 2024).

Skewing of the bridge creates additional horizontal transverse forces in the "wheel – rail" contact, accompanied by intense friction of the flange and accelerated wear of both elements. Modern research shows that the skewing phenomenon is one of the main causes of increased wear of wheels and tracks (Fidrovska et al., 2021). Classic designs of running wheels with a rigid all-metal rim practically don't dampen shock loads that occur when hitting rail joints, local track irregularities, and dynamic loads during braking and acceleration.

Operating conditions significantly affect the intensity of wear. These include: frequent starts and stops; working in difficult conditions; aggressive environment (dust, moisture, corrosive impurities); overloading during peak modes; insufficient lubrication of flanges and rolling surfaces (Harbuz et al., 2020).

Studies of port overhead cranes have shown that, with long-term operation, the service life of wheels is only 3.3 – 3.4 years, compared to the 4 years declared by the manufacturer, which is due to a combination of harsh operating conditions and design deficiencies in the "wheel-rail" system. A significant part of the damage is caused by deficiencies in the organization of technical maintenance and repairs: untimely detection of cracks and localized wear zones on the flange, lack of systematic monitoring of track deviations and skewing of the bridge, and inadequate documentation of the failure history. Analysis shows that wheel damage is closely correlated with failures of adjacent components (bearings, shafts, fasteners, rail

elements), which requires a comprehensive approach to maintenance rather than local repair of individual parts (Harbuz et al., 2020).

One of the most promising ways to improve the reliability of running wheels is to use designs with a flexible elastic insert between the disc and the rim. Such an intermediate elastic element (rubber or polymer ring) dampens shock loads during the movement of the load trolley and crane, reduces peak acceleration and vibration values in the structure, and partially compensates for the impact of rail track deviations. Experimental studies of the stress state of the metal structure of an overhead crane using wheels of a new design showed a reduction in stress in the beam by approximately 18%, which directly indicates a reduction in dynamic loads (Mantič, Vacula, Šulc, Šőke & Duda, 2023). Follow-up studies have confirmed that the use of elastic inserts improves the operational reliability of wheels and reduces the likelihood of fatigue damage to the metal structure of the crane and the rail track (Слепужніков, 2019). In addition, the use of crane wheels with a conical running surface and an optimized rim profile increases reliability by ensuring self-alignment relative to the track and reducing transverse forces in the “wheel – rail” contact (Burhanuddin & Yuwono, 2024). The optimal slope of the conical surface (approximately 1:20) reduces the resistance to crane movement and improves rolling conditions with minor skewing. This solution is most effective in combination with independent end beam drives, which further minimizes skewing during movement. Material selection and manufacturing technology play a critical role in wheel reliability. Forged steel wheels typically have higher strength and fatigue life compared to cast wheels (Bohomaz, Bondarenko, Hlavatskyi & Sokol, 2015). For 65G steel used in crane wheels, both the hardness of the rolling surface and the quality of the flange machining, where stresses are concentrated and wear zones are formed, are important. Properly selected heat treatment modes increase the wear resistance of the surface without excessively increasing the fragility of the flanges.

Modern approaches to increasing reliability involve the implementation of active control systems for crane bridge skewing. Recent research suggests the use of

strain gauges located at characteristic points of a metal structure to identify skewing based on stress-strain state (Fidrovska et al., 2021). Based on numerical modeling and experimental measurements, algorithms are developed to determine the skew angle and its intensity, as well as control schemes for frequency converters of the left and right bridge drives for smooth speed correction. Such systems allow reducing transverse forces in the "wheel – rail" contact zone, lowering stress levels in metal structure, and limiting wheel flange wear.

Optimization of technical maintenance systems is equally important. Based on the analysis of flange failures, logical models are developed that relate wear to variations in track geometry, the condition of bearing assemblies, rail fastenings, and the quality of installation (Harbuz et al., 2020).

Key recommendations for improving maintenance include: focusing scheduled inspections on critical wheel fastening points; performing scheduled checks and tightening bolted connections in areas of increased vibration; implementing standardized procedures for lubricating flanges and rolling surfaces, taking into account the risk of slippage; systematically collecting and analyzing failure history to adjust the maintenance strategy. Such approaches shift operations from a reactive "repair after failure" model to a proactive one focused on preventing critical wear and stress values from being exceeded.

To estimate the resource of crane wheels, statistical models of wear over operating time are used, taking into account the real operating conditions of a specific crane fleet. Based on long-term observations of wheel wear, approximate dependencies are constructed, correlation coefficients between wear and operating time are calculated, and model errors are evaluated. Combining such models with dynamic load data when using wheels with elastic inserts creates the preconditions for risk-oriented decisions regarding wheel design upgrades or enhanced maintenance programs.

Modern approaches to improving the reliability of crane running wheels of overhead cranes include a complex of design, operational and diagnostic solutions.

The use of wheels with elastic inserts and an optimized profile, the implementation of active bridge skew control systems, as well as resource- and risk-oriented technical maintenance strategies significantly reduces the intensity of wheel and rail wear, increases the safety and economic efficiency of overhead crane operation (Слепужніков, 2019).

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COMPARATIVE ANALYSIS OF ROAD TRAFFIC SAFETY ON ARTERIAL STREETS: MINOR ARTERIALS AND PRINCIPAL ARTERIALS

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In modern cities, the issue of road traffic accidents has become particularly relevant, as the growth of traffic intensity, increased rates of urban development, and the complexity of traffic flows create new risks for the safety of road users. According to the World Health Organization (WHO), more than 1.3 million people worldwide die annually as a result of road traffic accidents (RTAs), while an additional 20 – 50 million suffer injuries of varying severity. More than 90% of these cases occur in low- and middle-income countries, including Ukraine.

In urban areas, accident rates largely depend on the functional class of streets. Principal arterials, which provide transit and inter-district connections, are characterized by high traffic intensity, a large number of lanes, high speeds, and a complex structure of traffic flows. In contrast, minor arterials, which primarily serve local trips within residential areas, have lower traffic intensity, lower speeds, and less complex interactions between vehicles, pedestrians, and other road users. These differences in functional purpose and traffic characteristics make a comparative analysis of accident rates on different classes of urban streets an extremely relevant research task.

In the global scientific literature, accident rates are often associated with the characteristics of urban streets, including their functional class, capacity, and speed regimes. In a number of studies (Yan et al., 2024; ITF, 2020), the authors compare risks on arterials (arterial streets) and collectors (district streets). It is concluded that the most severe accidents predominantly occur on arterials. The study by Wang et al. (2024) provides a methodological basis for the quantitative comparison of expected accident rates for different road classes. The authors confirm that higher-order arterials generate a different level of danger compared to local and district street

networks; however, the nature of these patterns significantly depends on the specific characteristics of the urban structure. Despite the importance of this topic, no comprehensive studies analyzing the relationship between street class and accident rates have yet been conducted for the city of Kharkiv. This fact determined the necessity and relevance of the present study.

This work examines the influence of the functional class of urban streets on accident rates by comparing two types of arterial streets in the city of Kharkiv: minor arterials and principal arterials. For the analysis, road traffic accident statistics for a one-year period, namely for 2024, were considered for 10 streets. Five principal arterials providing transit and inter-district transport connections and five minor arterials ensuring the distribution of traffic flows within the residential structure of the city were selected (Fig. 1).

Figure 1 Location of the selected principal arterials (red) and minor arterials (blue) in the city of Kharkiv

Figure 2 presents the accident rate coefficients calculated using the following formula:

$$R = N / L \quad (1)$$

where:

N is the total number of road traffic accidents on the street section per year;

L is the length of the street section, km.

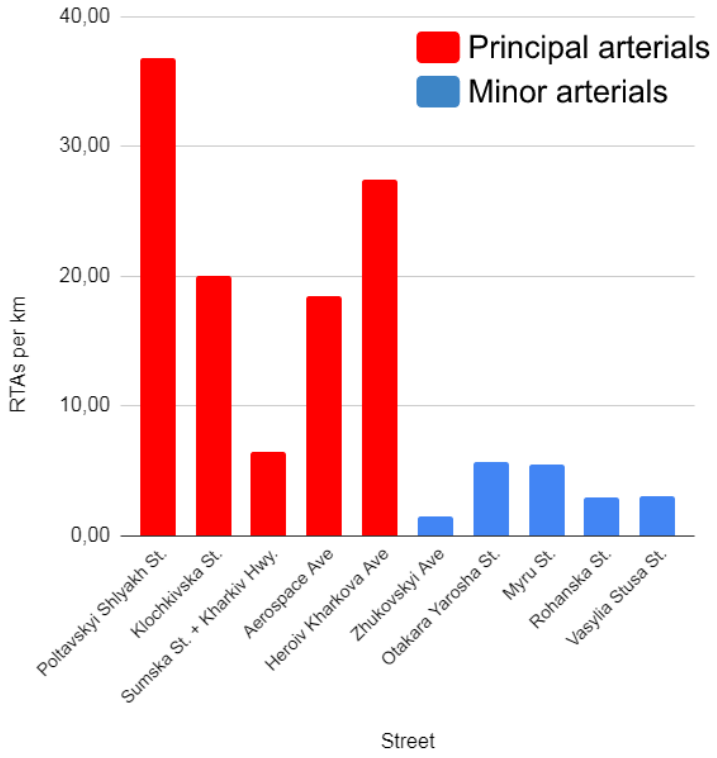

Figure 2 Comparison of accident rate coefficients for different types of urban arterial streets

As can be seen, the graph demonstrates a significant difference between principal arterials and minor arterials in terms of the accident rate coefficient. Poltavskyi Shliakh Street, Klochkivska Street, Aerospace Avenue, and Heroiv Kharkova Avenue show significantly higher accident rate values, often exceeding 20 – 35 accidents per kilometer, whereas for minor arterials this indicator mostly ranges from 1 to 6 accidents per kilometer. This difference indicates that principal arterials generate the main accident risks, which may be associated with high traffic intensity, a greater number of lanes, higher speeds, and a more complex structure of traffic

flows. In contrast, minor arterials, which serve local movements and have lower traffic loads, demonstrate lower accident risks. Thus, it has been confirmed that the functional class of a street is one of the key factors determining its level of accident rate.

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ENHANCING TRANSPORT LOGISTICS THROUGH MODERN TECHNOLOGIES

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Transport logistics management is a key element in the effective functioning of enterprise logistics processes. It encompasses the planning, organisation, control and coordination of transport resources at all stages of the supply chain – from the procurement and production of goods to their delivery to the end consumer. The main goal of transport logistics is to reduce transportation costs and improve service

quality, ensuring the timely and reliable delivery of goods. Modern companies face constant challenges related to globalisation, the growth of international trade and the dynamics of transport infrastructure development. Traditional management methods no longer always provide the necessary efficiency, making the introduction of modern technologies a key competitive advantage.

Modern technologies allow overcoming the main problems of transport logistics, including inefficient routing taking into account traffic, weather conditions and road conditions, insufficient accuracy of information about vehicles and warehouses, as well as poor interaction between participants in the logistics process. The use of information systems, route planning software, transport and cargo monitoring, analytical systems, and demand forecasting makes it possible to increase efficiency and optimise costs. Researchers note that the application of modern technologies in transport logistics improves delivery accuracy, reduces costs, and increases customer satisfaction.

In recent years, one of the key areas has been the introduction of artificial intelligence and machine learning systems, which enable the processing of large amounts of data, forecasting demand for transport services, optimising routes, managing traffic flows and controlling risks. Machine learning systems such as TensorFlow, PyTorch, Scikit-learn, and Keras are used to forecast demand, optimise routes, and analyse passenger behaviour. Neural networks (CNN, RNN, LSTM, DNN) help predict delays, emergencies, and transport arrival times, as well as determine optimal routes. Voice assistants such as Amazon Alexa, Google Assistant or Apple Siri increase the speed of information exchange and the safety of transport management, while geolocation systems based on GPS, Galileo or Beidou provide accurate monitoring of vehicle and traffic movements. Facial recognition systems are used to control security in warehouses and transport sites, while traffic forecasting systems such as Google Maps, Waze and TomTom analyse data on traffic jams and weather conditions. Fleet management is carried out using specialised programmes such as Fleetio, Geotab or TomTom Telematics, which allow you to control vehicle

movement, fuel consumption and driver performance. These technologies make it possible to automate routine processes, forecast demand, reduce costs and improve transport safety.

The introduction of modern technologies has significant economic potential for businesses. They reduce transportation, storage and supply chain management costs, increase business efficiency by reducing delivery times and increasing inventory turnover, and promote global integration and the development of international trade. In addition, innovative approaches ensure sustainable development through the use of energy-efficient vehicles and reduced greenhouse gas emissions, and stimulate regional economic development through infrastructure projects and the creation of new jobs.

The systematic application of artificial intelligence, blockchain, and the Internet of Things allows for faster adaptation to market changes, minimises delays, and optimises resource utilisation. According to statistics, the global market for artificial intelligence in transport logistics is growing by 19.4% annually and has reached $3.1 billion. By 2030, a significant transformation of the sector is expected, which will increase the efficiency and safety of transport. National strategies, such as the National Transport Strategy of Ukraine until 2030, provide for the integration of modern digital and innovative technologies, which will increase the competitiveness of the transport sector and the development of infrastructure.

Modern transport logistics technologies have enormous potential for optimising management processes, reducing costs and improving transport safety. They enable the automation of routine operations, demand forecasting, route planning and risk control, which contributes to increased business efficiency and ensures sustainable economic development. Further research should focus on adapting artificial intelligence to predict risks, optimise logistics processes and integrate new transport flow management tools to achieve maximum efficiency.

An important aspect of the effective use of modern technologies is the training of qualified specialists capable of working with complex digital systems and

integrating innovative solutions into daily operations. Education and professional training of personnel in the field of transport logistics should include knowledge of data analysis, transport management software, neural networks, blockchain, and the Internet of Things. Only a combination of technological implementation and competent management ensures maximum return on investment in the digitalisation and automation of logistics processes, which contributes to increasing the competitiveness of companies at the national and international levels.

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IMPROVING ENERGY CONSUMPTION OF ELECTRIC VEHICLES DEPENDING ON OPERATING CONDITIONS

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Introduction

The rapid growth in the number of electric and hybrid vehicles is driven by environmental requirements, improvements in battery technologies, and increased efficiency of powertrain systems. One of the key performance indicators of these types of vehicles is energy consumption, which depends not only on the type of power system but also on operating conditions, driving style, ambient temperature, road surface quality, and other factors. Therefore, studying the influence of operating conditions on energy consumption makes it possible to propose practical recommendations for improving driving efficiency, increasing driving range, and reducing transportation costs.

Main Factors Affecting Energy Consumption

1. Ambient Temperature

Temperature has a significant impact on both battery capacity and the operation of heating and air-conditioning systems. When the temperature drops below +5°C, the following effects occur: increase in internal battery resistance; reduction of available capacity by up to 30–40%; increase in energy consumption by climate control systems. As a result, average energy consumption increases from 15–18 kWh/100 km to 20–30 kWh/100 km during the winter period.

2. Driving Mode and Speed

The lowest energy consumption is observed in urban driving at speeds of 30–60 km/h, since the electric motor operates in a high-efficiency range and regenerative braking can be effectively utilized. At speeds above 100 km/h, energy consumption increases proportionally to the square of the speed due to aerodynamic drag. For hybrid vehicles, at speeds above 90 km/h, the internal combustion engine dominates, while the electric component becomes practically inactive.

3. Vehicle Mass

Vehicle mass mainly affects energy consumption during acceleration and the efficiency of regenerative braking. As mass increases, energy consumption during acceleration rises and vehicle inertia increases. Part of the energy is recovered

through regeneration, but not entirely. Each additional 100 kg increases energy consumption by approximately 2–3%.

4. Tire Pressure and Rolling Resistance

Insufficient tire pressure by 0.5 bar increases energy consumption by 3–6% due to increased rolling resistance. Similar increases occur when driving on wet or snowy surfaces and when using winter tires with softer rubber compounds. Maintaining manufacturer-recommended tire pressure and timely tire replacement is optimal.

5. Driving Style

An economical driving style includes: smooth acceleration and deceleration; maintaining a constant speed; effective use of regenerative braking. Aggressive driving can increase energy consumption by 20–40%.

Technical Solutions for Improving Efficiency

1. Improvement of Battery Systems

Modern Battery Management Systems (BMS) perform: monitoring of cell temperature; optimization of charge and discharge modes; voltage balancing.

The use of liquid-based thermal management allows maintaining the battery temperature within optimal limits and reduces capacity degradation.

2. Regenerative Braking

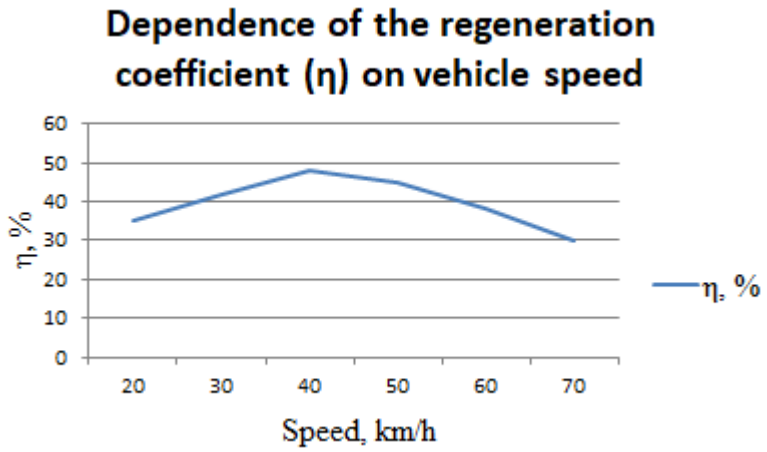
The efficiency of regenerative braking in urban conditions can reach up to 25% of recovered energy. To improve performance, the following are applied:

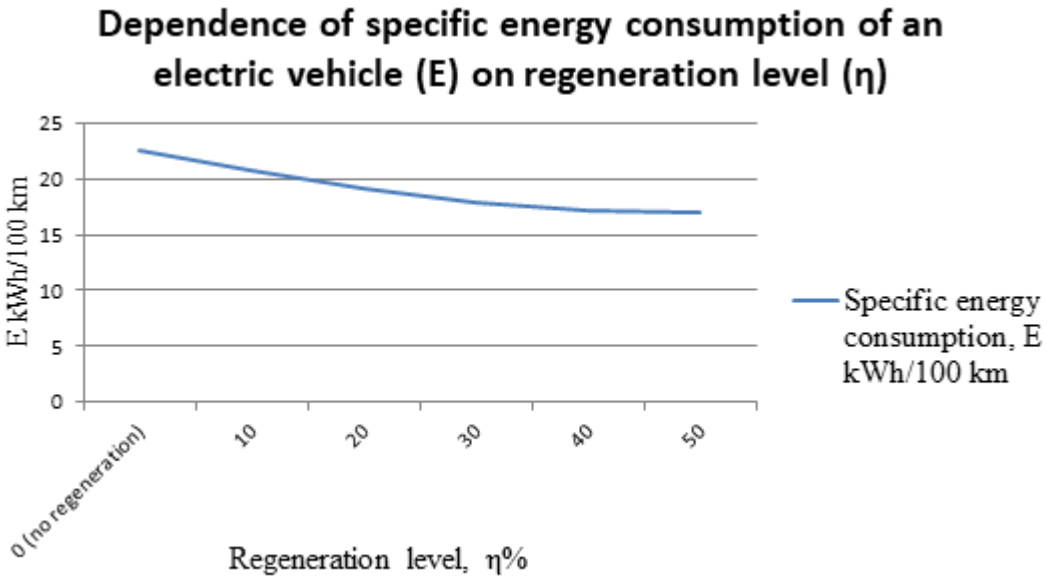
- intelligent brake torque distribution systems;
- maneuver prediction using navigation systems.

In hybrid vehicles, regenerative braking provides fuel savings of 10–20%.

Analysis shows that the highest regenerative efficiency is achieved in urban driving at average speeds of 40–50 km/h. When speed exceeds 60 km/h, the regeneration coefficient decreases due to limitations of the battery charging current. It has also been established that a smooth driving style increases regeneration efficiency by 10–20%.

Recent research in the field of regenerative braking of electric vehicles focuses on increasing its efficiency (currently about 60–70%) by optimizing driving modes, improving battery management systems, integrating with smart city infrastructure, and developing new materials that extend battery life and reduce dependence on friction and terrain.





3. Aerodynamic Optimization

Modern electric vehicles have a drag coefficient (Cx) of 0.19–0.28, which is lower than that of conventional vehicles. Aerodynamic improvements include streamlined body shapes, active grille shutters, enclosed underbodies, and special

wheel geometry. Reducing the drag coefficient by 0.01 increases driving range by 1–2%.

4. Heat Pumps

Using a heat pump instead of traditional electric heating reduces energy consumption in cold conditions by 40–60%. This solution is especially effective at temperatures from –10 to +5°C.

Practical Recommendations for Users

1. *Route planning:* avoiding traffic congestion and optimizing speed can reduce energy consumption by up to 10%.

2. *Preconditioning:* charging the vehicle while connected to the grid before departure allows battery warming without drawing energy from the battery itself.

3. *Maintaining optimal tire pressure:* provides energy savings of 2–6%.

4. *Using Eco mode and regenerative braking:* increases driving range by up to 20% in urban conditions.

5. *Reducing vehicle mass and aerodynamic drag.*

Conclusions

The energy consumption of electric and hybrid vehicles largely depends on operating conditions. In order to reduce energy use, it is advisable to preheat the battery, maintain optimal tire pressure, avoid sharp acceleration and braking, use Eco modes, and control aerodynamic characteristics and vehicle mass.

Technical solutions such as heat pumps, aerodynamic optimization, advanced battery management systems, and regenerative braking make it possible to increase driving range by 10–40%, depending on conditions (Hwang, 2022; Seo et al., 2025; Humphries, 2025; Berjoza et al., 2022.; Zhang, 2025; Kurkin et al., 2025).

The obtained results confirm that a comprehensive approach to analyzing and optimizing operating conditions is essential for improving the energy efficiency of electric and hybrid vehicles. This provides not only economic benefits for users but

also an overall environmental contribution by reducing emissions and promoting rational energy use.

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THE IMPACT OF TIRE TEMPERATURE AND PRESSURE ON VEHICLE BRAKING AND ACCELERATION

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Introduction

One of the key characteristics of vehicle safety and handling is the traction between the tires and the road. This traction is directly influenced by several factors, including tire condition, pressure, and temperature. The braking distance and acceleration of a vehicle are crucial parameters that determine driving safety. Understanding how tire pressure and temperature affect these characteristics is essential for the automotive industry and road safety.

The purpose of this paper is to analyze the dependence of braking distance and vehicle acceleration on changes in tire pressure and temperature, as well as to develop a mathematical model that describes these processes.

Impact of Pressure on Tire Deformation

Tire deformation plays a critical role in the contact between the tire and the road, and consequently, in traction. A simplified model for tire deformation as a function of pressure P can be described by the following polynomial relationship:

$$\delta = \frac{P}{k} \cdot \left(1 + \beta \cdot \frac{P}{P_0}\right)$$

where:

δ – tire deformation;

P – tire pressure;

P_0 – nominal pressure;

k – tire stiffness coefficient;

β – coefficient reflecting the effect of pressure on deformation.

As pressure increases, the tire becomes stiffer, and its deformation decreases. However, at very high pressures, the tire may become less flexible, which could reduce traction with the road.

Contact Patch Area Between Tire and Road

The contact patch area A between the tire and the road is an important parameter that determines traction. This area can be modeled through a polynomial dependence on pressure and temperature as follows:

$$A = \frac{F}{P}\left(1 + \gamma \cdot (\frac{P}{P_n})^n\right) \cdot (1 + \alpha \cdot T)$$

where:

$F = mg$ – the force acting on the tire;

P – tire pressure;

P_n – nominal pressure;

γ, n – parameters reflecting the change in contact patch area with pressure;

α – temperature coefficient;

T – tire temperature.

As temperature increases, the rubber of the tire becomes softer, increasing the contact patch area and consequently improving traction. This phenomenon is due to the increased flexibility of the tire material at higher temperatures.

Modeling the Temperature Dependence of the Elastic Modulus

The elastic modulus E of rubber, which determines its stiffness, is dependent on temperature. A linear dependence for the elastic modulus can be expressed as:

$$E = E_0 \cdot (1 - \beta \cdot T)$$

where:

T – tire temperature;

β – coefficient of modulus change with temperature;

E_0 – initial elastic modulus;

For most tires, this approximation is sufficiently accurate, especially for temperatures not exceeding 50°C. At higher temperatures, the rubber begins to lose its elastic properties, and the elastic modulus decreases significantly.

Impact of Temperature and Pressure on the Coefficient of Friction

The coefficient of friction μ, which determines the interaction force between the tire and the road, is influenced by several factors, including pressure and temperature. The following model can be used:

$$\mu = \mu_0 \cdot (1 + \alpha \cdot T) \cdot (1 - \gamma \cdot \frac{P}{P_n})$$

where:

μ_0 – the coefficient of friction under standard conditions;

α – temperature dependence coefficient of friction;

γ – pressure dependence coefficient of friction;

P – tire pressure;

P_n – nominal pressure;

T – temperature;

As temperature increases, traction improves because the tire material becomes more flexible. However, at excessively high pressure, traction may decrease because the tire "flattens," reducing the contact area.

Braking Distance

The braking distance S of a vehicle depends on the initial speed v_0 and the coefficient of friction μ. The formula for braking distance is as follows:

$$S = \frac{v_0^2}{2 \cdot \mu \cdot g}$$

where:

v_0 – initial speed;

μ – coefficient of friction;

g – gravitational acceleration.

The braking distance depends on how friction changes with pressure and temperature. As temperature increases, friction improves, which reduces the braking distance. However, excessively high pressure may worsen traction and increase the braking distance.

Vehicle Acceleration

Vehicle acceleration is also influenced by the coefficient of friction as well as rolling resistance, which is proportional to the friction:

$$F_{tr} = \mu \cdot F_n - F_{fr}$$

where:

F_{tr} – traction force;

F_n – normal force;

F_{fr} – rolling resistance force.

As the coefficient of friction increases (for example, at optimal temperature), vehicle acceleration improves. However, at high pressure, friction may decrease, which could slow down acceleration.

Conclusion

The impact of temperature and pressure on vehicle braking and acceleration characteristics is a crucial aspect of driving safety and efficiency. Mathematical models based on linear and polynomial dependencies allow for accurate assessment of these effects under real-world operating conditions. However, for more precise predictions and improved driving safety, it is necessary to consider the dynamic changes in tire parameters and other factors, such as tire wear and road conditions.

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Tolmachov D. M.

ENHANCED MAINTENANCE OF VEHICLE RUNNING PART

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Modern operation of passenger cars imposes high demands on the technical condition and maintenance of all systems and components. One of the most heavily loaded and vulnerable parts is the vehicle's chassis, which directly affects handling, stability, comfort, and driving safety. It includes such main components as the supporting frame, suspension, axle, and wheels.

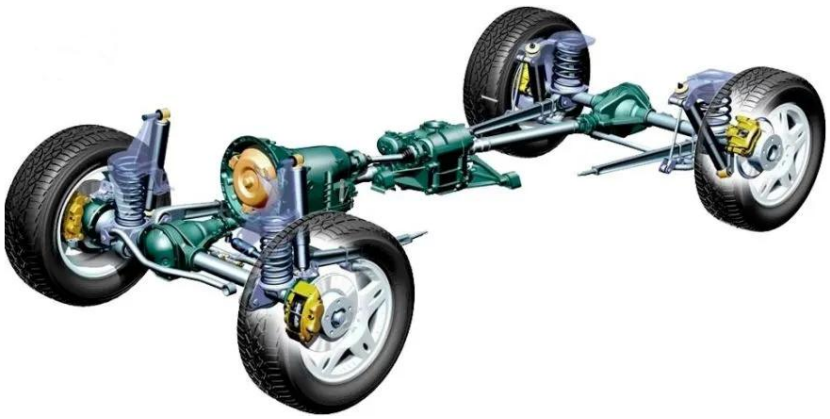

Figure 1 Vehicle chassis

Malfunctions in the chassis can lead not only to reduced comfort but also to dangerous situations on the road. This is especially relevant under conditions of poor road quality. Therefore, there is a need to improve the existing approaches to diagnostics, maintenance, and repair of chassis components.

The suspension is subject to the following requirements:

- The elastic properties must ensure ride smoothness, reduce harsh impacts, and provide vehicle stability during turning, braking, and acceleration;
- The structural design must ensure stable wheel positioning, minimizing changes in camber, toe, and track width, and must interact harmoniously with the steering system to prevent self-induced oscillations of the steered wheels;
- Effective damping of vibrations of both the body and the wheels;

- Reliable transmission of dynamic loads (longitudinal, lateral, and torsional) from the wheels to the body or frame;
- Minimization of suspension component mass, especially unsprung weight;
- High strength and durability of all elements, with special emphasis on elastic parts that experience the highest loads.

During chassis maintenance, all these requirements must be taken into account.

During each maintenance procedure, the following chassis elements must be inspected. Starting with the front suspension, attention should be paid to shock absorbers and struts, checking them for fluid leaks, corrosion, and mechanical damage. Suspension springs must be free of cracks, breaks, and uneven sagging. Control arm bushings are inspected for tears, wear, and loss of elasticity. Ball joints must be checked for play, cracks, or other mechanical damage. Strut mounts and bearings are inspected for abnormal noises and wear during steering. It is also important to check the anti-roll bar components, ensuring that the links and bushings have no cracks or play.

As for the rear suspension, shock absorbers are inspected for fluid leaks, damage, and wear. Springs must be in good condition without cracks or breaks. Bushings and control arm mounts are checked for deformation, tears, and damage. Joints or bearings (depending on the design) are inspected for noise and play. If a rear anti-roll bar is present, its links and bushings must also be checked for wear and damage.

Wheel inspection is equally important. Tire condition is checked for tread depth, even wear, cuts, cracks, bulges, and correct pressure. Wheel balancing is important, as steering vibrations may indicate imbalance. Wheel fasteners must be tightened according to the recommended torque. Hub bearings are inspected for unusual noises and play. Wheel rims must be checked for cracks, warping, or

corrosion, especially in the hub mounting area. These inspections help detect defects early and ensure vehicle safety and reliability.

At most service stations, chassis inspections are performed only at the client's request, when characteristic symptoms of malfunctions have already appeared – knocking, squeaking, uneven tire wear, reduced stability, etc. Such an approach is incorrect, as it does not prevent premature failure of components that wear out gradually. The main problems observed in the service system include the absence of preventive diagnostics, insufficient technical equipment, the use of uncertified parts, cost-cutting on staff training, and a low level of driver awareness. For example, at one service station in Kharkiv, it was recorded that more than 65% of repair requests concerned already advanced malfunctions, which led to additional damage and increased repair costs.

Modern maintenance methods include the use of computerized diagnostic stands for suspension inspection, which allow for highly accurate measurement of wheel alignment angles, and detection of shock absorber and joint wear. Special vibration testing platforms are also used to simulate road conditions and detect hidden suspension defects. An important innovation is electronic tracking of the chassis condition, which records the history of all inspections and repairs and automatically notifies customers of scheduled maintenance. This not only helps monitor vehicle condition but also enables preventive maintenance without significant financial losses.

The service station “AutoProfi”, which specializes in VAG group vehicles, introduced several improvements in chassis diagnostics and repair. First, a 3D wheel alignment stand with full suspension geometry analysis was installed. Second, qualification courses were organized for employees to learn new diagnostic methods. Third, a service policy was implemented, providing free visual chassis inspections at every visit. Only certified parts from ZF, Lemförder, and Sachs began to be used, which significantly increased the service life of replaced components. As a result of these measures, the number of repeated customer visits decreased by 23% within six

months, and the number of regular customers increased by 18%. The average suspension service time was reduced from 4 hours to 2.5 hours due to partial automation of diagnostic procedures.

Overall, improvement of chassis maintenance should be based on preventive approaches, widespread use of modern diagnostic equipment, increasing technical competence of service station staff, and the use of high-quality components. It is also advisable to implement customer interaction systems that allow automatic scheduling of maintenance visits, analysis of repair history, and generation of personalized recommendations. Digital platforms are highly effective, enabling customers to monitor their vehicle's condition via mobile apps, order spare parts online, and choose service visit times.

Under conditions of intensive vehicle operation and often poor road quality, the chassis is a critical component that determines not only the preservation of the vehicle but also the safety of the driver and passengers. Regular maintenance, early detection of wear, and timely replacement of faulty components not only help avoid high future costs but also ensure reliable vehicle performance. Practice shows that implementing a systematic approach to chassis maintenance can reduce accident rates, improve comfort, and increase the service life of key suspension components by 20–30%. Therefore, improving suspension service is not only an urgent task but also an important condition for the development of modern automotive infrastructure in Ukraine.

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BI-FUEL ENGINES

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The world is moving toward more environmentally friendly ways to get around, which has sped up the use of alternative fuel technologies, especially compressed natural gas (CNG) and liquefied petroleum gas (LPG) systems for internal combustion engines. Bi-fuel engine technology, which lets cars run on both regular gasoline and gaseous fuels, is a practical way to cut down on greenhouse gas emissions, make energy more secure, and save money in the automobile industry. Dedicated alternative fuel systems don't give drivers the freedom to switch between fuel sources based on availability, cost, and performance needs. Bi-fuel designs do. Recent improvements in fuel injection systems, electronic control units, and conversion technologies have made bi-fuel engines much more useful in passenger cars, commercial fleets, and public transportation. Modern bi-fuel conversion systems have a few important parts that work with the engine design that is already there. The gaseous fuel reservoir is made up of the main storage vessel, which can be either a high-pressure CNG cylinder that works at 200–300 bar or a low-pressure LPG tank that works at 5–10 bar. Multi-stage regulators change stored gas into the right injection pressure, which is usually 1–3 bar for mixer systems or keep the pressure high for sequential port injection setups (Sinnhong Electronics, 2024). Electronic control units handle the logic for switching fuel, keep an eye on system

characteristics, and make sure that air-fuel ratios are as good as they can be in all working conditions.

Current sequential injection systems use separate gas injectors that are in sync with the engine's timing. This allows for precise fuel metering, similar to how current gasoline port fuel injection works. Modern systems have a conversion efficiency of about 85%, which means that energy is lost during pressure drop, vaporization, and control system operation (Sinnhong Electronics, 2024). The stoichiometric air-fuel ratio for burning methane is about 17.2:1 by weight, while for gasoline it is 14.7:1. This tighter stoichiometry and lower carbon-to-hydrogen ratio (1:4 for methane compared to about 1:2 for regular gasoline) change the chemistry of burning in a big way. According to the reaction $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$, complete methane combustion should only create carbon dioxide and water vapor. This means that there are no aromatic hydrocarbon combustion products that are naturally found in gasoline oxidation. Experimental studies on turbocharged bi-fuel engines indicated considerable performance compromises when functioning on CNG as opposed to gasoline.

A study on a 1.7 L turbocharged engine showed that using both CNG and gasoline at a 30% CNG mass fraction cut brake-specific fuel consumption by 16%, carbon monoxide emissions by 66%, and unburned hydrocarbons by 50% compared to running on gasoline alone at full load (Tabar et al., 2017). But, as expected, nitrogen oxide emissions went up because the flames spread faster in uniform lean mixtures, which raised the temperature of the combustion process. When retrofitted spark ignition engines switch from gasoline to CNG operation, comparative tests show that the brake power always goes down. When powered with CNG, experimental work on a 1.5 L four-cylinder engine showed a 19.25% drop in brake power at 50% throttle and a 10.86% drop at 80% throttle (Paul et al., 2013). The power shortfall comes from a number of things: gaseous fuel taking up space in the intake air, which lowers volumetric efficiency; the energy density of the inducted charge per unit volume; and the compression ratios of rebuilt engines not being

optimal. Even though the maximum power output is lower, improvements in brake thermal efficiency of 10–15% sometimes make up for it by lowering fuel consumption on an energy-equivalent basis. Liquefied petroleum gas, which is mostly propane (C_3H_8) and butane (C_4H_{10}) in different amounts, has different properties as a gaseous fuel than CNG, having both pros and cons. Because LPG turns into a liquid at room temperature with only a little pressure, it needs much lower pressure (around 5–10 bar) to store, which makes the fuel storage infrastructure much easier and cheaper to build. Liquid-phase LPG has a volumetric energy density that is about 73% that of gasoline, which is far higher than the volumetric energy density of CNG, even at a storage pressure of 200 bar (Kar et al., 2023). Research comparing the operation of LPG and CNG on variable compression ratio CFR (Cooperative Fuel Research) engines showed that the two types of fuel burned differently and released different amounts of pollutants. When operating under the same conditions, LPG combustion showed greater peak cylinder pressures and faster apparent heat release rates than CNG combustion, which means that LPG combustion was more intense. When comparing brake thermal efficiency tests, LPG was better than CNG across all measured compression ratios and engine loads, with LPG being 3–5% more efficient than CNG (Kar et al., 2023).

LPG's molecular structure makes it easier for oxidation to happen faster, which improves the mixture preparation because it can be injected or vaporized in liquid form before it reaches the intake valves. The emissions of criteria pollutants have gotten considerably better. When CNG is burned instead of gasoline, carbon monoxide emissions usually drop by 60 to 70%. This is because the simpler methane molecule is oxidized more completely, and there is no need for rich mixture operation during cold starts or acceleration enrichment with liquid fuels. Unburned hydrocarbon emissions also drop by 40–50%, but the environmental impact assessment must take into account that methane has a far larger potential for global warming (around 28 times CO_2 over 100 years) (Omnitek, 2024). When gaseous fuels are burned, the amount of particulate matter that comes out is almost zero. This

stops the creation of soot that happens when liquid hydrocarbons are sprayed. Advanced pressure regulators with electronic feedback control take the place of older diaphragm-actuated devices. This lets gas pressure be actively controlled, which keeps the best injection characteristics even when conditions change. Self-diagnostic capabilities keep an eye on system parameters all the time and look for any problems including injector failure, pressure changes, temperature changes, and sensor failures. Integrated on-board diagnostics use common OBD-II protocols to talk to the car's systems. This makes it easier to troubleshoot and check that the vehicle meets emissions standards. Forced induction makes up for the lower volumetric efficiency that comes with using gaseous fuel to displace the intake charge. Studies on turbocharged applications showed that employing both CNG and gasoline injection in turbocharged engines improved the synergistic benefits between the two fuels. This was possible because CNG has a high knock resistance, which allowed for higher boost pressures, while gasoline was used to keep power density (Tabar et al., 2017). The dual-fuel method makes it feasible to optimize the compression ratio and boost pressure, which is not achievable with only one fuel.

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THE IMPACT OF PREDICTIVE ACTIVE SUSPENSION ON VEHICLE SAFETY AND OPERATIONAL RELIABILITY

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Introduction

The modern automotive industry sets increasingly high demands for vehicle safety, comfort, and operational reliability. The suspension system plays a critical role in ensuring stability, handling, and ride comfort. While traditional passive suspensions offer limited adaptability to changing road conditions, the evolution of technology has led to the development of sophisticated Active and Adaptive Suspension Systems. These systems can dynamically alter their characteristics in milliseconds to maintain optimal wheel-to-road contact and vehicle stability. This paper focuses on investigating the impact of the Predictive Active Suspension (PAS), exemplified by the system implemented in the Audi A8, on key operational qualities, specifically driving safety and operational reliability. PAS represents the state-of-the-art by not only reacting to road inputs but also anticipating them using sensor data, such as a front camera. This predictive capability significantly enhances both performance and safety, making its detailed analysis highly relevant for the future of automotive engineering.

The Predictive Active Suspension System (PAS)

The Predictive Active Suspension (PAS), as introduced by Audi, is a fully active electromechanical system capable of adjusting the vertical position of each wheel independently. It can raise or lower the body by up to 85 mm within 0.5 seconds from its central position. This precise control is executed via four powerful electromechanical actuators powered by a 48-volt primary electrical system, which contributes to its high energy efficiency compared to traditional hydraulic active systems. The core innovation of the PAS lies in its predictive function: a front-facing video camera, which acts as a key sensor, continuously generates information about road surface properties 18 times per second. This allows the system to detect and prepare for irregularities, such as potholes or speed bumps, before the wheel reaches them. The electronic control units process this road data in near real-time to command the actuators and pre-set the optimal suspension characteristics for the upcoming road segment. This anticipatory function fundamentally distinguishes PAS from traditional active systems, moving control from purely reactive to truly predictive. The overall configuration of the Predictive Active Suspension system, highlighting its core components, is presented in Figure 1.

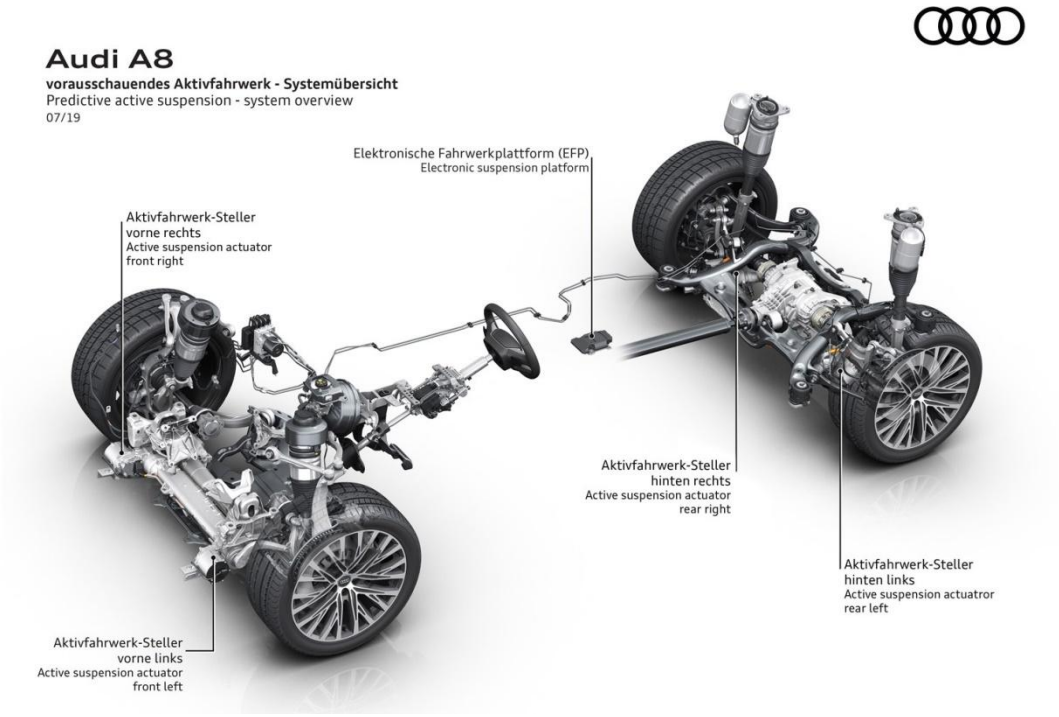

Figure 1 View of Predictive Active Suspension

Enhancing Driving Safety and Handling

The primary contribution of the active suspension to driving safety is its ability to maintain superior vehicle dynamics and handling across all conditions. The control strategy for PAS typically employs sophisticated algorithms, often using a cascaded controller structure with Model Predictive Control (MPC) for slow-frequency body dynamics (roll, pitch) and potentially a Linear Quadratic Gaussian (LQG) filter for high-frequency dynamics (unsprung mass movements). This allows the system to generate precise counter-forces that significantly counteract inertial moments causing body roll and pitch. For instance, in *Dynamic Mode*, PAS drastically reduces maximum body roll during fast cornering (down to roughly 2 degrees from over 5 degrees with a standard suspension) and minimizes pitching and squatting, ensuring the vehicle trajectory closely follows the desired path and eliminating any inherent understeer tendencies. The superior performance of the active system was confirmed through simulation studies using the standard Double Lane Change (DLC) maneuver at 90 km/h. The results highlight the system's effectiveness in controlling lateral dynamics are shown in Figures 2,3,4:

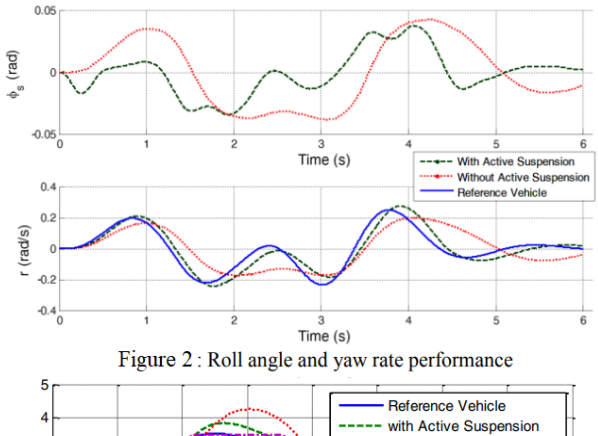

Figure 2 : Roll angle and yaw rate performance

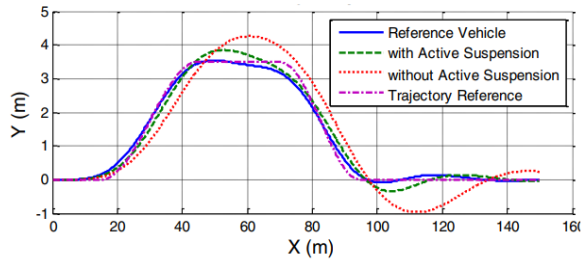

Figure 3 : Trajectory response comparison

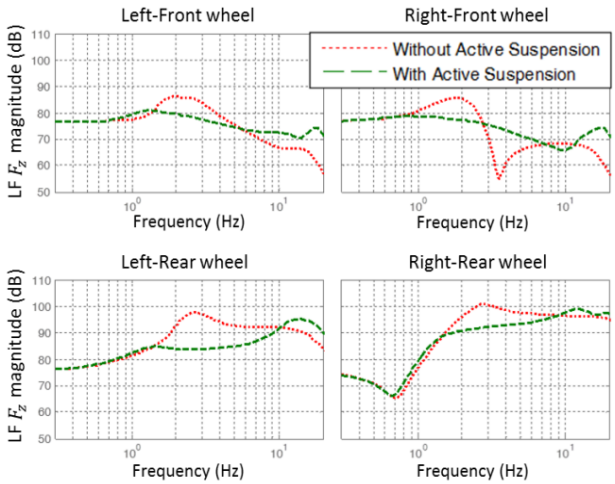

Figure 4 : Frequency response of left-front tire vertical load to road surface input on all four wheels.

Body Roll Control: The active system significantly reduced the maximum angle of body roll (φ) compared to the passive suspension, enhancing stability and comfort.

Yaw Rate: The active suspension provided a faster and more accurate yaw rate (r) response, which is crucial for predictable and controlled cornering.

Trajectory Tracking: The vehicle equipped with active suspension showed a trajectory that closely followed the ideal path, effectively eliminating the understeer tendency evident in the passive model.

Crucially, the active control also minimizes the variation in vertical tire load (Fz), particularly in the unsprung mass resonance range (10-17 Hz). This leads to a more stable and uniform tire contact with the road, which, in turn, improves overall grip, reduces necessary braking distance, and enhances cornering stability. A significant safety feature is the system's integration with the pre sense 360° system: in an impending side impact (above 25 km/h), the suspension instantly raises the body on the impact side by 80 mm. This action shifts the collision force to the more rigid sill structure, reducing cabin deformation and potentially reducing occupant loads by up to 50%, thus actively contributing to passive safety.

Influence on Operational Reliability

Operational reliability encompasses the ability of the vehicle to function without failure and the lifespan of its components. One major benefit of the PAS in this regard is the substantial reduction of vibrational loads and dynamic deformations imposed on the vehicle structure. Compared to passive systems, the active control generates a controlled counter-force that effectively smooths out impact forces from road irregularities, minimizing sharp cyclic stress amplitudes on critical structural elements. By reducing it, the system exponentially increases the number of cycles to failure, thereby significantly extending the service life of suspension components, bushings, and the chassis structure itself.

However, the system's sophisticated, high-tech nature introduces its own reliability challenges. Being an electromechanical system, PAS is susceptible to

failures in electric motors, various sensor faults (e.g., height/speed), and electronic control unit (ECU) issues. To ensure long-term reliability and component longevity, a shift to proactive maintenance is required, involving regular electronic diagnostics (ideally every 15,000 km) and software calibration. Professional, specialized checks are necessary because the system's adaptive nature can potentially mask the early symptoms of minor component wear, making preventative maintenance the key to sustained operational reliability.

Conclusion

The Predictive Active Suspension represents a pivotal advancement in vehicle chassis technology, transitioning from purely reactive damping to anticipatory control. Its demonstrated capability is two-fold: first, it significantly improves driving safety by drastically reducing body roll, stabilizing the yaw rate, and maintaining superior tire-road contact in dynamic maneuvers; and second, it enhances operational reliability by actively reducing dynamic stress and high-frequency vibrational loads on the suspension and body structure. Although the sophisticated electromechanical design of PAS necessitates specialized and potentially costly maintenance, its profound contribution to achieving an unprecedented balance between premium ride comfort and firm sports-car handling solidifies its role as a key element in the future of high-end automotive safety and engineering.

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ANALYSIS OF TRAFFIC SAFETY INDICATORS

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Introduction

The current stage of development of transport systems is characterized by an increase in traffic intensity, complication of traffic flows, and an enhanced role of the human factor in the formation of accident-prone situations. Under such conditions, traditional methods for assessing road traffic safety, based exclusively on retrospective analysis of road accident statistics, do not provide an adequate level of prevention.

In this context, road traffic safety audit is considered as a tool of systemic analysis aimed at identifying potential risks at the stages of planning and design of road facilities. A key element of the audit is a system of quantitative safety indicators that makes it possible to formalize the level of accident rates and ensure comparability of different sections of the road network.

1. Theoretical principles of forming road traffic safety indicators

Road traffic safety should be considered as an integral characteristic of the functioning of the system “driver – vehicle – road – environment”, which reflects the probability of road accidents and the severity of their consequences. Within the quantitative approach, this characteristic is described by a set of accident indicators.

Absolute accident indicators are determined by the total number of road traffic accidents or the number of injured people over a certain period of time. However, their analytical value is limited due to the lack of consideration of traffic intensity and section length.

For this reason, in the practice of road traffic safety audits, preference is given to relative indicators that allow normalization of accident rates by transport work.

2. Formalized accident indicators

One of the basic relative indicators is the accident rate coefficient per unit of vehicle mileage, which is determined by the dependence:

$$ka = \frac{n\text{ДТП}}{\sum L}$$

where:

nДТП – the number of road traffic accidents during the calculation period;

∑L – the total vehicle mileage, km.

For arterial roads, the accident rate indicator per 1 million km of mileage has found practical application:

$$ka, \text{млн} = \frac{n\text{ДТП} * 10^6}{365 * N * l}$$

where:

nДТП – the number of accidents during the calculation period;

N – average daily traffic intensity, vehicles/day;

L – length of the road section, km;

365 – the number of days in a year.

To assess the consequences of road traffic accidents, the accident severity coefficient is used:

$$k\text{т} = \frac{n\text{заг}}{n\text{пост}}$$

where:

nзаг – the number of fatalities;

nпост – the total number of injured people.

3. Integral approaches to safety assessment

Within the framework of road traffic safety audits, integral assessment methods are widely used, based on the application of a summary accident rate coefficient:

$$k\text{під} = \prod_{i=1}^{n} Ki$$

where:

Ki – partial accident rate coefficients that take into account the influence of individual factors (road conditions, geometric parameters of the road, traffic organization, behavioral factors, etc.);

n – the number of considered factors

4. The role of audit in the safety management system

Road traffic safety audit should be considered as an element of the road infrastructure quality management system. Its advantage lies in its focus on preventive identification of unsafe decisions and analysis of the road from the standpoint of perception by different categories of road users.

Road Traffic Safety Assessment of a Project	**Road Safety Audit of a Project**
Conducted by the designer or commissioned by the designer	Conducted independently of the designer
Assessment of compliance with standards and regulations	Assessment of safety impact, taking into account behavioral characteristics and the psychophysiological perception of the traffic situation by road users
Conducted mainly by road engineers	Conducted by specially trained road safety specialists
Project road safety is not subject to review at extended expert meetings	Project road safety is subject to a dedicated review at extended meetings involving the city traffic management center, the audit team, the client, and the designer
Uses assessment methods that provide an indirect understanding of the safety of design solutions	Uses specially developed methodologies for a systematic project audit, including analysis of a set of traffic parameters and factors

Unlike traditional methods, the audit makes it possible to integrate quantitative accident indicators with expert assessment of road conditions, which significantly increases the validity of recommendations for improving traffic safety.

Conclusions

An in-depth analysis of traffic safety indicators as a formalized basis for auditing road transport infrastructure is provided. Theoretical approaches to the quantitative assessment of accident rates are considered, a system of absolute and relative safety indicators is presented, and the feasibility of using integral coefficients in managerial decision-making in the field of improving road traffic safety is substantiated.

The conducted study confirms that the system of formalized road traffic safety indicators is the methodological basis of road infrastructure audit. The use of relative and integral accident indicators makes it possible to ensure an objective assessment of the safety level, increase the effectiveness of managerial decisions, and contribute to reducing accident rates on highways.

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Vovk S. R.

THE NEAREST FUTURE OF AUTOMOBILES: SUSTAINABLE, AUTONOMOUS, AND CONNECTED MOBILITY

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The automobile has historically symbolised freedom, innovation, and

technological progress. Since its inception in the late nineteenth century, the car has undergone continuous mechanical, social, and cultural transformation. However, the next few decades are expected to bring unprecedented changes in vehicle design, production, and functionality. By 2050, automobiles are anticipated to become intelligent, sustainable, and connected systems, integrating environmental responsibility, automation, and digitalisation (Sierzchula et al., 2014). Beyond mobility, vehicles will act as adaptive environments, capable of interacting with users and urban infrastructure while supporting circular energy and production systems.

Environmental sustainability represents the primary driver of future car design. The global automotive industry faces growing pressure to reduce carbon emissions, adopt renewable energy, and eliminate waste throughout the product lifecycle. By mid-century, most vehicles are projected to operate using electricity or alternative carbon-neutral fuels, such as hydrogen or synthetic biofuels. The traditional internal combustion engine will likely become a historical artifact, displayed in museums rather than serving functional purposes. This transition will enable designers to reimagine vehicle forms: without large engines or fuel tanks, cars can adopt more aerodynamic, flexible, and lightweight structures, utilising materials such as carbon composites, recycled metals, and bioengineered fibers to optimise energy efficiency (Breetz et al., 2018).

Production methods will be equally transformed through automation and artificial intelligence (AI). Factories will function as flexible ecosystems in which robotic systems collaborate with human engineers in modular, adaptive production cells. Vehicles will be customisable to individual user preferences, with modular components enabling upgrades and replacements over decades rather than requiring full vehicle replacement. Additive manufacturing, including 3D printing, will facilitate on-demand production of complex parts with minimal material waste, while AI systems will optimise supply chains, energy usage, and assembly processes (Schoemaker & Tetlock, 2016).

Autonomy and connectivity will redefine the concept of a vehicle. By 2050, most cars are expected to operate fully autonomously, removing the need for traditional driver interfaces and transforming interiors into multifunctional spaces for work, leisure, or social interaction. Panoramic smart-glass surfaces will integrate navigation, entertainment, and augmented reality features. Externally, vehicles will communicate with each other and with urban infrastructure through vehicle-to-everything (V2X) systems, optimising traffic flow, preventing accidents, and reducing congestion (Fagnant & Kockelman, 2015). Embedded sensors and AI diagnostics may enable predictive maintenance or even on-board production of replacement components, further enhancing operational reliability and sustainability.

Aesthetic and functional design will reflect the integration of technology and environmental consciousness. Organic, flowing shapes inspired by natural forms will replace the aggressive, mechanical styling of early automobiles. Materials may include self-healing or colour-changing coatings and surfaces capable of energy capture or air purification. Mobility as a service (MaaS) will influence ownership models, with shared autonomous vehicles prioritising durability, cleanliness, and modularity to accommodate multiple users while reducing overall vehicle numbers. Factories will operate on renewable energy, applying circular manufacturing principles to eliminate waste and maximise resource efficiency.

The socio-economic implications of these developments are substantial. Automation will alter employment in manufacturing and related industries, creating demand for skills in AI, software engineering, sustainable materials, and modular design. Localised, digitalised microfactories may decentralise production, increasing access to mobility solutions in developing regions and supporting tailored vehicle designs for specific urban contexts. At the societal level, autonomous, connected, and shared vehicles may enhance accessibility for elderly or disabled populations, while personalisation through AI will allow vehicles to adapt to user habits, emotional states, and preferences.

In conclusion, by 2050, automobiles are projected to evolve into intelligent, sustainable, and socially integrated systems. Electric propulsion, autonomous operation, digital connectivity, circular manufacturing, and flexible ownership models will redefine the role of the car in society. Despite the technological transformation, the car will continue to embody humanity's pursuit of freedom, connection, and adaptive mobility within an increasingly complex urban and environmental context.

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STARTING CHARACTERISTICS OF A DIESEL GENERATOR AT LOW AIR TEMPERATURES

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Relevance. At ambient temperatures during the winter period reaching as low

as –30 °C, a significant challenge arises in ensuring reliable and guaranteed starting and proper operation of a small-sized air-cooled diesel engine. Considering the typical application of products equipped with compact air-cooled diesel engines often associated with harsh operating conditions in remote areas far removed from infrastructure an important and necessary feature of such a diesel engine is its capability for autonomous starting without the use of stationary or technically complex systems that require an external power supply.

The purpose of this work is to improve the starting characteristics of small air-cooled diesel engines at negative ambient temperatures down to –30 °C.

The objective was achieved through the following tasks:

– to analyze the problems of starting a diesel engine in negative ambient temperatures;

– to perform mathematical modelling of pre-start preparation and the starting process of a small air-cooled diesel engine across the entire range of negative ambient temperatures;

– to determine, based on computational and experimental studies, the regularities of the influence of intake-air temperature and average starting crankshaft frequency on the average and maximum temperature in the diesel combustion chamber;

– to select a design and a method for pre-start preparation and starting of a small air-cooled diesel engine suitable for temperature conditions down to –30 °C.

The object of research is a multipurpose high-speed air-cooled diesel engine of type 1Ch 9.0/7.5.

The subject of research is the process of pre-start preparation and starting of a diesel engine under negative ambient temperatures.

An analysis of existing systems for heating the intake air of diesel engines under negative ambient temperatures has shown that several means of air heating exist. These include glow plugs for heating the combustion chamber, both with an open heating element and with a closed heating element, along with their

corresponding components; electric-torch heaters; and aerosol-type devices with an electromagnetic actuator (2025). Widely used systems designed to facilitate diesel engine starting include autonomous air heaters and coolant heaters such as Webasto and Eberspächer (2025), intended mainly for automotive diesel engines.

These devices are installed into a break in the engine's cooling-system circuit. The coolant circulates through the heater's heat exchanger by means of a built-in pump, where it is heated by the heater's combustion chamber located inside the heat exchanger, thereby warming the engine.

Using the mathematical model applied in this work, a series of computational experiments was conducted to investigate the influence of structural and operational parameters on the average and maximum temperature in the diesel combustion chamber.

The obtained results can be used to analyze the correspondence between the temperature in the cylinder and the auto-ignition temperature of the fuel-air mixture, while accounting for changes in diesel compression ratio depending on intake-air temperature.

For the study, a compact single-cylinder four-stroke diesel engine 1Ch 9.0/7.5 with wide industrial and agricultural application was selected.

Based on the results of experimental studies of the pre-start preparation and starting processes of the diesel engine, as well as considering the review of scientific works devoted to facilitating diesel starting under low-temperature conditions, a prototype inductive intake-air heater (IAH) was used, operating at a supply voltage of 24 V and with an electric power of 250 W.

The IAH device consists of a cylindrical body made of magnetic material and is installed in the intake pipeline in a configuration similar to that described in (Utility model patent, 2021).

Conclusions

A distinctive feature of the inductive intake-air heater (IAH) is the simplicity of its design and its low cost, which is especially important when operating in remote

areas far from infrastructure, where the ability to eliminate a malfunction on-site without special tools or assistance from specialized service centers is critically important. The IAH has relatively small dimensions and can be easily integrated into the design of almost any diesel engine, ensuring reliable starting at low temperatures and thereby significantly improving the starting and operational characteristics of diesel engines under adverse climate conditions.

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ARCHITECTURE AND CONSTRUCTION

Bessarabova I. O.

USE OF THE ONIKS-2.5 DEVICE IN THE INSPECTION OF ENGINEERING STRUCTURES

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The ONIKS-2.5 is a modern electronic sclerometer used for non-destructive testing of the strength of concrete and reinforced-concrete structures based on the impact-pulse method. The device consists of a compact electronic unit and an impact sensor that records the impulse after contact with the concrete surface. The use of a two-parameter methodology, adaptive signal filtering, and temperature compensation makes it possible to significantly improve the accuracy of strength determination compared to traditional mechanical sclerometers. The ONIKS-2.5 (Fig. 1) supports operation with a wide range of concrete types – from lightweight to high-strength – due to the availability of specialized sensor modifications. The advantages of the device include portability, autonomy, the ability to operate under harsh environmental conditions, as well as a USB interface for transferring results to specialized software. The device not only allows determining the strength of concrete but also assessing material homogeneity and detecting local areas with reduced strength indicators, which is important for an objective engineering evaluation of the condition of structures.

Figure 1 *The ONIKS-2.5 device*

The ONIKS-2.5 has become widely used in the practice of technical diagnostics and monitoring of various engineering structures that operate under difficult conditions and are subjected to significant loads during service life. First of all, this concerns transportation engineering structures: highway and railway bridges, overpasses, viaducts, culvert crossings, bridge piers, anchoring structures, and retaining walls. For such structures, controlling the strength of concrete is a key component in assessing their actual load-bearing capacity and remaining service life. The device also plays an important role in the inspection of hydraulic engineering structures, where concrete is exposed to freeze-thaw cycles, water saturation, and erosion processes. These include dams, locks, spillway systems, pumping stations, and other water-management engineering structures. The ONIKS-2.5 is also actively used in the diagnostics of industrial facilities – foundations of technological equipment, silos, bunkers, reservoirs, chimneys, etc., where concrete operates under vibrational, temperature, and chemical loads. During the inspection of civil buildings, the device allows for rapid assessment of columns, beams, floor slabs, monolithic walls, and other critical elements, which is especially important in cases of reconstruction, major repairs, and examination of damaged or emergency-condition structures.

The methodologies for using the ONIKS-2.5 involve a set of actions aimed at obtaining reliable indicators of actual concrete strength in accordance with regulatory requirements. Before taking measurements, surface preparation is performed – cleaning from dust, paint, and corrosion layers that may affect accuracy. Representative measurement points are then selected; they are placed taking into account the structural features of the element, zones of maximum load, and potential defects. In each point, a series of several impacts is performed, based on which the average strength value is determined. This approach minimizes the effect of local concrete heterogeneity and provides an averaged, reliable result. Environmental

conditions are also taken into account during the inspection: temperature, humidity, and the degree of concrete moisture saturation may affect the reflected impulse characteristics. The device automatically performs temperature compensation, which ensures measurement accuracy even under difficult conditions. In the inspection of elements with damage – cracks, reinforcement corrosion, delamination – the ONIKS-2.5 results are compared with the indicators of similar areas without defects, allowing the determination of the extent of concrete degradation. The obtained data are exported to software for further analysis, generating strength distribution graphs, localizing problematic zones, and preparing reporting documentation. Combining ONIKS-2.5 results with other testing methods – ultrasonic diagnostics, visual inspection, geodetic measurements, crack analysis – allows obtaining a comprehensive picture of the technical condition of the structure and ensures high reliability of engineering decisions regarding its serviceability.

The use of the ONIKS-2.5 device (Fig. 2) in the inspection of engineering structures is an important element of the modern system for technical diagnostics and monitoring of concrete conditions. The device provides fast, non-destructive, and reliable determination of actual concrete strength, enabling timely identification of potentially hazardous areas, assessment of material homogeneity, and determination of the degree of structural degradation under service and environmental factors. The wide application of the ONIKS-2.5 – from transportation and hydraulic structures to industrial facilities and civil buildings – highlights its versatility and importance for ensuring the reliability of engineering infrastructure. Combining its data with other non-destructive testing methods forms a comprehensive approach to assessing technical condition, supports informed decisions regarding repair or strengthening measures, and overall enhances the safety and durability of engineering structures.

Figure 2 *Working with the device*

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RESTORING UKRAINE'S CULTURAL HERITAGE WITH 3D MODELING

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This year's grant program of the Ukrainian Cultural Foundation “Cultural Heritage” focuses on one of the most important challenges of our time: preserving cultural heritage in wartime. Particular emphasis is placed on digitizing objects located in frontline and de-occupied territories of Ukraine.

The digital form allows accurate copies of these treasures to be preserved for future generations, even if they are damaged or destroyed by war. This approach has

already proven its effectiveness around the world. For example, 3D modeling technology was key in the restoration of Notre Dame Cathedral after the fire. Thanks to the digital copy, architects were able to restore the cathedral's authenticity by recreating every detail. The 3D models created can serve as a basis for the future restoration of monuments in the event of their loss in Ukraine. With the help of the latest technologies, restorers and architects will be able to recreate the smallest details of the original objects, preserving their historical value.

The process of digitizing cultural monuments in Ukraine is still in its early stages. In total, as part of a large-scale project to create 3D objects of cultural and historical heritage, more than 300 monuments of national and local significance have been digitized in Ukraine. One of the project participants is the SKEIRON team, which has digitized about 50% of all currently existing 3D monuments. They have been digitizing Ukrainian heritage for over eight years, and during this time they have managed to digitize St. Sophia Cathedral, St. Nicholas Church, Chernivtsi University, the Golden Gate, the Energetik Palace of Culture in Pripyat, and most UNESCO monuments, including wooden churches. More than 100 of these objects have been digitized in high detail. SKEIRON is currently tracking the status of digitization of monuments across Ukraine. This data is visible on an online map.

Numerous projects have already been implemented in Ukraine, confirming the important role of 3D modeling and geodetic technologies in preserving cultural heritage. An important example is Chersonesos Taurica in Crimea. Here, laser scanning (LiDAR) and geodetic referencing of terrain points were used. This made it possible to create an extremely accurate digital model of the ancient city with coordinates in the state geodetic system. Such a model allows for remote archaeological research, virtual “excavations”, and analysis of the spatial structure of the city without damaging the actual cultural layers.

Equally important is the experience of reconstructing St. Sophia Cathedral in Kyiv. Here, photogrammetric methods were used in combination with tacheometric measurements of key architectural elements. Surveyors performed intermediate

accuracy checks to reduce errors and ensure maximum model reliability. This made it possible to digitize not only the external forms, but also the interior spaces with frescoes, mosaics, and dome structures. This is particularly important because restoration work requires precise geometric parameters, which are very difficult to obtain using traditional methods.

The castle in Starokostiantyniv deserves special attention. To digitize it, surveyors used the GNSS measurement method, which ensured accurate binding of the territory to the coordinates of the state geodetic network. Then, using photogrammetry, a 3D model was created, which serves as the basis for reconstruction. Thanks to the use of drones, it was possible to obtain images in hard-to-reach areas, which made it possible to produce a complete digital copy of the castle with spatial analysis. Such data is further used as a geodetic basis for project documentation.

In Lviv, where many UNESCO heritage sites are concentrated, AR and VR technologies are being actively implemented. They are used to create virtual tourist routes, and the geodetic component consists of the precise positioning of historical buildings in the urban space. For this purpose, urban geodetic networks are used, and 3D models are integrated into GIS systems (geographic information systems), which allows tracking the condition of objects and planning restoration work on a city-wide scale.

A separate category consists of objects destroyed during the war. In Kharkiv and Chernihiv, digital archiving projects were implemented, where surveyors conducted tacheometric surveys of the remains of buildings and recorded the terrain using laser scanning with the installation of benchmarks. This made it possible to create a model not only of what was destroyed, but also a spatial scenario of what could be restored. In the future, such models could become the basis for project documentation for actual restoration, as they contain precise coordinates, scales, and geometry.

All these examples prove that 3D modeling combined with geodetic technologies not only preserves cultural memory – it forms a digital architectural heritage that can be used for future reconstruction, architectural analysis, historical research, and even

forensic investigations in cases of war crimes. Geodesy plays a key role in this process, as it ensures spatial accuracy, measurement reliability, and the ability to link data to state coordinate systems. Thus, 3D modeling and geodesy together are ushering in a new era in the preservation of Ukraine's cultural heritage.

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Klyueva S. V.

OPTIMIZATION OF URBAN PUBLIC SPACE USING ELEMENTS OF ARTS SYNTHESIS IN THE URBAN ENVIRONMENT

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Public space is a social space that is open and accessible to all. Sidewalks, public squares, parks and beaches, courtyards of multi-story buildings, etc. are all types of public spaces (Коцюба, 2014). The main functions of public space are:

recreational, communicative, political, cultural, economic, ecological, political, historical-cultural, and entertainment.

According to the Council of Europe project "Promoting Citizen Participation in Democratic Decision-Making in Ukraine", public space planning is a systematic procedure (sequence of actions, steps) that includes the processes of developing technical specifications for design and architectural design documentation, which ultimately leads to the creation of a public space, including its functional purpose (Проєкт Ради Європи).

A quality public space should be accessible, multifunctional, cultural, safe, free and barrier-free. Unfortunately, not every public space meets these requirements and many urban spaces need improvement. However, using the tools of the synthesis of arts with architecture and urban space, public spaces can be improved without large-scale reconstruction, and even with minimal resource expenditure. Thanks to this, the space can be revitalized, made more attractive and comfortable for visiting, which will encourage economic development, social interaction and cohesion. In addition, such elements of the synthesis of arts can have cultural value and reflect local identity.

The advantage of using artistic elements lies in the general positive impact of art on a person. By placing art objects in public space, you can improve the mental and physical health of citizens, promote self-expression, reduce stress and increase the quality of life in general. Also, such projects are adapted to the existing public space of the city, which does not require additional and unnecessary constructions.

For instance, the "Urbanimals" project by the creative architectural association LAX is a series of interactive projections designed to be placed in the pedestrian areas of the city. Each projection is a stylized representation of one of the taurines (dolphin, rabbit, kangaroo, scarab beetle). Each of them is programmed to perform certain movements on its own and react to the corresponding movements of passers-by. This project not only makes everyday travel through the city exciting, but also activates passers-by around it, creating a safer environment in the usually deserted

streets. “Urbanimals are there to surprise you in the location you would not expect any adventure to happen, and to lift up your spirit by encouraging to explore and to play. Urbanimals bring live to your daily routine wherever you need” (LAX Architecture Laboratory).

In February 2014, Emma Jones, together with the associations Artica and Per Esempio, conducted a street art experiment called “FREQUENZA 200” in the Adelfia Cerdiana district of Palermo. The experiment consisted of optimizing public space through murals designed in collaboration with local schoolchildren. The children developed sketches of how they would like to decorate their neighborhood, and professional muralists helped them realize their ideas, successfully arranging the sketches on the neighborhood's walls. During the project, the neglected neighborhood acquired cultural value and ethnic identity, and the quality of life in it increased. In addition, it contributed to community cohesion: during the work, residents became friends, children and adults began to protect the murals from vandals, children from wealthier neighborhoods expressed a desire to join the project (Borgo Vecchio Factory).

“Pool” is a project by artist Jevi Lane that has been designed to enliven public spaces and bring communities together. Lewin’s playful sculptures exist where art, technology, and communities meet, leaving viewers enchanted while encouraging delight through engagement with the work. It creates connected human experiences where participants not only interact with and enjoy the sculpture's playfulness, but also, more importantly, connect with each other (Jen Lewin Studio, 2014). “Pool” is an installation consisting of about a hundred round sensor panels placed on the ground that change the color of the light when a person steps on it. It is also a portable sculpture, so it has already visited more than 40 cities in the United States and other countries. The interactive sculpture encourages people to be physically active and communicate, which has a positive effect on both physical and mental health.

The project Marcus Leis Allion an interactive installation for King’s Cross commuters was presented in the summer of 2012, located at one of the exits of

the London station. The installation itself "Song Board" is a plastic board on which 2940 plastic balls are installed, each of which rotates around its axis vertically, on one side it is black, on the other – yellow. Accordingly, each of the balls can be placed by the viewer in one of four positions, which allows you to create a wide range of images and inscriptions (Eye Magazine Blog, 2012). This project is an excellent example of optimizing public space, because due to it the space becomes multifunctional and interesting. While passengers are waiting for the train they can have fun interacting with the installation and with each other.

In general, there are many illustrative examples in the world of improving public spaces using the tools of art synthesis, which has had a positive impact on both the community and its mental state, as well as on the economy and the development of security. The optimization project should be individual for each community, calling on urban planners, artists, urbanists and citizens themselves to improve their living space and support its development for years to come.

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THE HISTORICAL DEVELOPMENT OF URBAN GREENING IN KHARKIV

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The history of the development of green spaces in the city of Kharkiv reflects the general trends in the evolution of urban space and embodies the societal needs of each historical period. The formation of Kharkiv's green infrastructure occurred gradually, in close connection with the city's historical, social, and urban planning transformations.

Modern researchers distinguish several key stages in the development of green spaces in Kharkiv: the first – from the mid-17th century to the early 20th century; the second – 1917–1950; the third – 1950–1980; the fourth – 1980–1991; and the fifth – from 1991 to the present (Гришин, Осиченко, 2020). Each stage has its own development features, determined by changes in the city's planning structure, approaches to urban improvement, and the role of vegetation in shaping a comfortable urban environment.

The modern history of Kharkiv begins in the 17th century with the establishment of a fortified Cossack settlement at the confluence of the Lopan and Kharkiv Rivers, which determined its military-administrative role in Sloboda Ukraine. Subsequently, the city developed into the center of Kharkiv Governorate, featuring a well-developed transport network that facilitated economic growth and further urban development of the region (Бірьова, 2014).

In the late 18th and early 19th centuries, the first gardens and parks began to form in Kharkiv, including the botanical gardens established at the city's first university for educational and scientific purposes, as well as the University Garden (now Central Park), which became a prototype for future public green areas (Антонов, Парамонов, 2008). At the same time, in the late 19th and early 20th centuries, street plantings expanded intensively, shaping the appearance of the city's central streets (Колесніков, 1936).

Approximately 80% of Kharkiv's plantings were concentrated in the central elevated districts, where the affluent population resided. During this period, such sites as the Kvitka-Osnovianenko Park, Central Park, and the square on Bursatsky Descent were established (Гришин, Осиченко, 2020). The public green spaces formed at this time became the foundation for the development of a coherent urban green framework.

Based on the analysis of historical photographs and city maps of Kharkiv from the late 18th to the early 19th century, it can be concluded that the urban green spaces at that time had the character of isolated green patches, which did not form a unified spatial structure. The majority of green areas were concentrated in the peripheral parts of the city as well as along the rivers.

From 1917 to 1950, the development of Kharkiv's green infrastructure was influenced by significant historical events. Following the 1917 revolution, urban greenery declined; however, gradual restoration began in 1923. During this period, when Kharkiv served as the capital of the Ukrainian SSR, the modern planning structure of the city was established, and comprehensive greening projects were initiated. In the plans of 1925–1930, the concept of sanitary-protective landscaping was introduced for the first time, including the creation of a 550-meter-wide green belt around the Kharkiv Tractor Plant, which became an important component of the ecological safety of industrial areas (Гришин, Осиченко, 2020).

In 1934, the "Hiprogorad" Institute developed the master plan of Kharkiv, which introduced a wedge-shaped system of green zones, stimulating a significant expansion of urban greenery: the total area of parks increased 2.3 times, reaching 416 ha, and the greenery standard amounted to 6.2 m² per resident. During this period, Central Park was expanded to 130 ha, the Park of Machine Builders was established with an area of 100 ha (Колесніков, 1936), and new green areas were created, including the garden on the site of the present-day Fantasy Park. At the same time, the Taras Shevchenko Garden was reconstructed, with updated alleys, fountains, and restored plantings (Гришин, Осиченко, 2020).

Despite significant achievements, greening during this period had certain shortcomings. In particular, most parks featured standardized elements and planning solutions that did not take into account the characteristics of the landscape and the local context of some sites, resulting in a loss of individuality for specific green spaces.

Based on the analysis of historical photographs and cartographic materials of pre-war Kharkiv, a significant expansion of the city's green areas was observed, directly associated with the overall growth of its territory. During this period, the northern part of the city became the most densely greened. Active formation of new vegetation along roadways was noted, as well as structured park planning with a well-developed network of paths and trails.

The period of the Second World War caused significant losses – as a result of military actions and the occupation of Kharkiv, approximately 70–80% of green spaces were destroyed (Гришин, Осиченко, 2020).

In the 1950s–1960s, the development of Kharkiv's green infrastructure began with the restoration of areas damaged during the war (Гришин, Осиченко, 2020).

The 1966 master plan, which introduced the concept of "green wedges" and envisaged a 2.7-fold increase in green spaces compared to the pre-war period, as well as the creation of a forest-park belt, became a key stage in the city's green infrastructure development. Despite a slowdown in works at the end of the 1980s, 74% of the planned measures were implemented, providing the foundation for Kharkiv's spatial green structure, with particularly high concentrations of green areas in the northern part of the city (Гришин, Осиченко, 2020).

Analysis of Kharkiv's green space layout using cartographic materials demonstrates the formation of a spatially connected green structure extending from the northern part of the city through the southwest to the southeast. This planning allows the city's green infrastructure to be classified as a combined system, integrating elements of green patches with the formation of green wedges.

In the 1980–2000 period, an ecologically oriented approach to spatial planning in Kharkiv was developed, which was formalized in the 1986 General Plan, where greenery was considered for the first time as a key element of the city's ecological stability. Despite the partial reduction of some green zones and the transformation of the wedge-shaped structure, the city maintained spatial integrity and natural connections, while actively planning the greening of new residential neighborhoods, boulevards, and streets. These measures collectively contributed to improving the quality of the urban environment and residents' comfort (Крижановська, Вотінов, 2010).

Based on the analysis of historical photographs and the schematic plan of Kharkiv's green infrastructure from that period, it has been established that the city expanded primarily through the construction of new residential districts. Greening in these areas was predominantly linear in character and was implemented along access roads, motorways, and tram tracks, where the formation of grass cover was also observed.

By the end of 2000, Kharkiv had reached the planned greening targets set in the 1966 General Plan, with the actual green space per capita amounting to 19.2 m², indicating the successful implementation of a comprehensive approach to the development of green infrastructure (Гришин, Осиченко, 2020). However, a gradual reduction in green areas was observed later, most intensively during 2003–2009, primarily due to residential construction and anthropogenic impact, with a total loss of 2.96%, slightly above the regional average but significantly below the national level. Nevertheless, in the long term, urban green zones have maintained a certain stability and functional integrity (Morar et al., 2022).

Thus, the history of Kharkiv's urban greening demonstrates a gradual transition from the chaotic distribution of green spaces to the systematic formation of green infrastructure. The modern stage is characterized by a reduction in green areas due to urbanization, which requires a reconsideration of approaches to preserving and developing green infrastructure under current conditions.

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Loza M. P.

RECONSTRUCTION OF A ONE-STORY ATRIUM RESIDENTIAL BUILDING FOR A COMPUTER CLUB IN THE CITY OF KYIV

Language Advisor – Senior Lecturer Vorobyova S. V.

In modern conditions of rapid development of information technologies and the swift digitalization of society, the need for creating specialized spaces for leisure, communication, and esports is growing. Computer clubs are once again gaining popularity as places not only for gaming but also for hosting tournaments, educational events, and teamwork on IT projects. In this context, the issue of

rethinking and adapting existing architectural heritage sites and residential buildings to new functional needs becomes highly relevant.

The topic of this diploma project is the reconstruction of a one-story atrium residential building into a computer club in the city of Kyiv. The selected building, thanks to its architectural features – such as the presence of an internal atrium, natural lighting, and spatial flexibility – has significant potential for functional transformation. The reconstruction of such an object makes it possible not only to preserve existing development but also to adapt it to modern requirements without the necessity of constructing new buildings.

The goal of the project is to develop architectural, planning, and engineering solutions that will ensure efficient use of the building's space, comfortable conditions for computer club users, and compliance with safety, energy efficiency, and aesthetic standards. Special attention is given to zoning, acoustics, ventilation, lighting, and the organization of communal space for esports events.

Kyiv is the capital and the largest city of Ukraine. It is located in the middle course of the Dnipro River, in the northern part of the Dnieper region. It is the political, socio-economic, transportation, educational and scientific, historical, cultural, and spiritual center of Ukraine. In the system of administrative and territorial structure of Ukraine, Kyiv has a special status defined by the Constitution and does not belong to any region, although it serves as the administrative center of Kyiv Oblast. It is the location of the central authorities of Ukraine, foreign missions, and the headquarters of most enterprises and public organizations operating in the country.

The average annual air temperature is about +8.5 °C. In winter, the average temperature ranges from –1 °C to –4 °C, and in summer it ranges from +18 °C to +23 °C, with peaks reaching up to +35 °C.
The average annual precipitation is 550–600 mm, distributed unevenly throughout the year. Most precipitation falls in summer in the form of short rains or thunderstorms.

The average annual wind speed is about 3.5–4.5 m/s, though gusts of up to 15–20 m/s are possible in open areas or elevated terrain. The prevailing wind directions are northwest and southeast. In winter, wind often intensifies the feeling of cold (wind chill effect), which makes it important to provide protection from drafts, windbreak screens, or landscape barriers when planning entrances and windows.

The diploma project includes the development of a reconstruction plan, optimization of interior space, finishing solutions, and the design of interior and exterior elements of a one-story atrium residential building converted into a computer club. The purpose of the reconstruction is to optimize the internal space of the building according to the needs of a computer club.

After reconstruction, the building will have a rectangular shape with dimensions of 20.18 × 16.65 m along the axes and a floor height of 3.0 m. The load-bearing system is frameless, with longitudinal load-bearing walls.

The zoning of the reconstructed building is organized to ensure efficient use of space and to provide proper hygiene and sanitary conditions. During reconstruction, the following works are proposed: installation of a ramp at the entrance to ensure convenient access; construction of new walls to form separate rooms; dismantling of windows and doors to expand certain areas; demolition of existing partitions and installation of new ones to create a changing room for the staff.

During the reconstruction of the one-story atrium residential building into a computer club in the city of Kyiv, the project provides for the dismantling of load-bearing walls to expand the building’s area. These works begin only after the work execution project has been approved.

Safety regulations during dismantling work include measures aimed at preventing injuries and accidents. It is necessary to follow the sequence of work, use protective equipment, fence off hazardous areas, and conduct safety briefings for workers. Special attention must be paid to work performed at height, with the use of

safety harnesses, lifelines, and scaffolding. It is also important to consider potential hazards related to structural collapse, dust, noise, and vibrations.

Basic safety rules during dismantling work:

– before starting work, all employees must undergo a safety briefing, including instructions on the use of tools, dismantling procedures, and actions in emergency situations;

– workers must be provided with the necessary personal protective equipment, such as helmets, goggles, protective gloves, respirators, safety harnesses, and appropriate workwear and footwear;

– dismantling must be carried out sequentially from top to bottom, with reinforcement or removal of structures that are at risk of collapse;

– a hazardous zone must be identified, with fencing and warning signs installed (such as “Danger Zone”) at a distance that depends on the type of work and potential risks;

– when working at heights, scaffolding, safety ropes, safety belts, and protective screens must be used;

– measures for dust suppression (moistening, dust collectors) and noise protection (earmuffs, earplugs) must be applied;

– tools must be in good working condition, and workers must know how to use them correctly;

– the use of electric tools in wet conditions or with damaged insulation is prohibited;

– workers must know how to act in emergency situations (collapse of structures, smoke, electric shock);

– after completing the work, the workplace must be cleaned, tools and materials removed, and fences installed in hazardous areas;

– unauthorized persons must not be allowed near the dismantling site;

– personal and collective protective equipment must be regularly inspected.

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Makarenkov M. E.

BIO-INSPIRED COMPOSITES FOR SUSTAINABLE INFRASTRUCTURE: ADVANCES IN ENGINEERED BAMBOO STRUCTURES

Language Advisor – Lectuter Lukianenko N. M.

The global demand for sustainable construction materials has led to renewed interest in bio-inspired engineering solutions. This article explores the structural potential of engineered bamboo composites as a renewable alternative to conventional materials in infrastructure. Drawing on recent developments in material science, structural engineering, and digital fabrication, the study examines how bamboo's hierarchical microstructure can be optimized for strength, durability, and environmental performance. Case studies from Asia, Africa, and Latin America demonstrate the viability of engineered bamboo in bridges, housing, and modular systems. The article concludes with a discussion of challenges in standardization, scalability, and integration into global construction codes.

The construction industry is one of the largest contributors to global carbon emissions, with concrete and steel accounting for a significant share of environmental degradation. In response, engineers and architects are increasingly

turning to *bio-based materials* that offer both structural performance and ecological benefits. Among these, *bamboo* stands out for its rapid growth rate, high tensile strength, and low embodied energy.

Traditionally used in vernacular architecture across Asia, Africa, and South America, bamboo has often been dismissed as a "poor man's timber." However, advances in *laminated bamboo composites, resin infusion techniques,* and *parametric design* have transformed it into a high-performance material suitable for modern infrastructure. Engineered bamboo products now rival steel and concrete in specific strength-to-weight ratios, while offering superior sustainability metrics.

This article investigates the engineering principles behind bamboo's structural performance, recent innovations in composite fabrication, and real-world applications in sustainable infrastructure. It also addresses the regulatory and logistical challenges that must be overcome to mainstream bamboo in global construction practices.

Bamboo's mechanical properties derive from its *hierarchical structure,* which includes vascular bundles embedded in a lignin-rich matrix. This configuration provides high axial strength and flexibility, making bamboo particularly suitable for *tensile and bending applications.* Key engineering advantages include:

- *High strength-to-weight ratio:* Comparable to mild steel in tension, with densities as low as 600–800 kg/m³.

- *Rapid renewability:* Bamboo matures in 3–5 years, unlike timber which may take decades.

- *Carbon sequestration:* Bamboo absorbs more CO_2 per hectare than most tree species.

- *Thermal and acoustic insulation:* Natural cellular structure provides passive environmental control.

Recent innovations in *engineered bamboo* – such as laminated bamboo lumber (LBL), bamboo scrimber, and hybrid composites – enhance dimensional stability, fire resistance, and load-bearing capacity. These materials are produced by *splitting,*

treating, and reconstituting bamboo culms with adhesives and heat pressing, resulting in uniform, predictable structural elements.

Engineered bamboo is increasingly being used in *bridges, housing, and modular construction,* particularly in regions with abundant bamboo resources. Notable examples include:

- *ZCB Bamboo Pavilion (Hong Kong):* A digitally fabricated, free-form structure using bent laminated bamboo ribs, demonstrating the material's potential for complex geometries.

- *Bambú Social Housing (Colombia):* Modular housing units built with bamboo panels and frames, offering seismic resilience and low-cost scalability.

- *Bamboo Footbridges (India and Indonesia):* Lightweight pedestrian bridges using pre-stressed bamboo trusses, designed for rapid deployment in flood-prone areas.

These projects highlight bamboo's versatility in both *load-bearing and aesthetic roles,* as well as its adaptability to *digital design and prefabrication workflows.* Moreover, bamboo's biodegradability and low thermal conductivity make it ideal for *climate-responsive architecture.*

However, challenges remain. Bamboo's *biological variability,* susceptibility to pests, and lack of standardized grading systems hinder its widespread adoption. Engineering codes in many countries do not yet recognize bamboo as a structural material, limiting its use in formal construction.

Engineered bamboo composites represent a promising frontier in sustainable engineering. Their combination of mechanical performance, ecological benefits, and cultural relevance positions them as viable alternatives to conventional materials in infrastructure development. As climate change accelerates and urban populations grow, the need for *renewable, low-carbon construction solutions* becomes increasingly urgent.

To realize bamboo's full potential, further research is needed in *material standardization, durability testing,* and *integration into international building codes.*

Investment in *local processing industries, training programs,* and *cross-disciplinary collaboration* will also be essential. Ultimately, the future of sustainable infrastructure may depend not only on technological innovation, but on our willingness to *relearn from nature and revalue traditional materials* through the lens of modern engineering.

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Nykyforchuk N. E.

DEVELOPMENT OF ROAD CONSTRUCTION IN UKRAINE DURING WARTINE

Language Advisor – Senior Lecturer Vorobyova S. V.

Automobile roads have always had significant importance in the economic

development of any country. The total length of automobile roads in Ukraine is about 170 thousand kilometers, which includes 169.5 thousand km of public roads, of which 52 thousand km are of national importance, and 117.6 thousand km are local. Before the military actions on the territory of Ukraine, during the period from 2020 to 2022, a large-scale road construction program called “Big Construction” was in operation. It was developed by former Prime Minister Volodymyr Groysman and implemented by the current President Volodymyr Zelensky.

The project was initiated in March 2020 with the aim of creating jobs and modernizing the country, especially in the context of the COVID-19 pandemic. The program covered the development of transport, educational, social, and sports infrastructure, including the construction and repair of roads, schools, kindergartens, stadiums, as well as the modernization of hospital emergency departments and railways. Due to the national program “Big Construction”, over the course of two years Ukraine managed to renovate and build more than 14,000 km of automobile roads. The head of the government also stated that within the framework of “Big Construction”, Ukravtodor restored more than 350 artificial structures. In total, together with local authorities, more than 600 bridges have been rebuilt. The war has destroyed almost twice as many roads as were repaired over two years.

According to the Ministry of Restoration and Infrastructure Development, as a result of the hostilities in Ukraine, 25,400 km of roads and 344 bridges and overpasses have been destroyed. Experts estimate that their reconstruction will take between 5 and 20 years, depending on the facility. Currently, the construction of road infrastructure projects under the “Big Construction” program has been suspended, and funds have been redirected to meet the needs of the army. However, road companies continue to operate, playing a critical role in maintaining the functioning of both the regions affected by hostilities and the country as a whole. The construction market has undergone significant transformation. Before the war, companies were primarily engaged in road construction, major repairs, and bridge

building. Today, the focus has shifted to infrastructure projects, the restoration of energy infrastructure, and, of course, maintaining roads in proper condition.

Maintaining transport routes is extremely important for evacuation, the delivery of humanitarian aid, and goods that sustain the economy. Roads also play a key role in military logistics related to hospitals and strategic facilities. Roads are one of the three most important components of the economy. Even in peacetime, their development directly affects economic activity in the regions and attracts investment. In wartime realities, since we have lost air connections and rail transport has largely been redirected to evacuation needs, roads remain almost the only means of transporting essential goods both for the army and for exports, which are critical for the country's survival. Therefore, without roads, the economy simply cannot function.

Mykola Berezovskyi, President of the National Association of Road Builders of Ukraine says, that today, 95% of the functions of road construction contractors are carried out by private road construction companies, which, like the entire industrial sector of the country, face the challenges of martial law. Often working on credit or using their own funds, they perform road maintenance and the reconstruction of engineering structures on them. Construction of water pipelines, fortifications, and protection of energy facilities has become a new area of activity for these companies, which they manage to handle. But how long will private companies have the financial, human, and material resources to operate under such conditions? The shameful practice of contractors working on credit has led to nothing good in the past and will not do so in the future. It is clear that our needs, especially during the war, do not match our capabilities, and this must be acknowledged so that adequate decisions can be made. Let us recall historical facts from the experience of the World War II, regarding the role of automobile roads in our territories, and, most importantly, the mechanism of their maintenance at that time. For many reasons, this is not an example to follow, but it is a reason to search for optimal solutions.

Thus, despite the difficult times in the country, road construction companies continue to operate. They build, restore, and protect logistics routes, work on energy infrastructure defense, restore water supply, and construct bridges and transport facilities.

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Okuneva V. K.

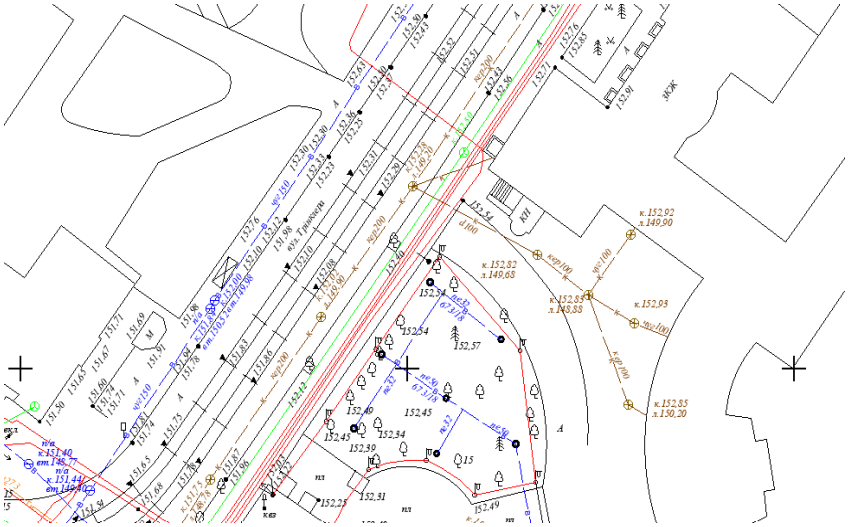
PROJECTING AUTOMOBILE ROADS: FULL WORK CYCLE (FROM GEODETIC SURVEY TO ROAD TRAFFIC ORGANIZATION DESIGN) AND INTERRELATION BETWEEN STAGES USING THE EXAMPLE OF THE RECONSTRUCTION OF TRINKLERA STREET (FROM NEZALEZHNOSTI AVENUE TO KULTURY STREET) IN KHARKIV

Language Advisor – Senior Lecturer Vorobyova S. V.

When designing highways, specialists in this field rely on current standards - DSTU 8752:2017, DSTU 4100, DBN V.2.3-5:2018, DSTU 4092, DSTU 2587 and other regulations that define requirements for geometry, marking, traffic light regulation and technical means. The design process begins with the collection of initial information: field surveys, video recording, calculation of traffic intensity, analysis of the structure of traffic flows, speed regimes and delays. In parallel, the

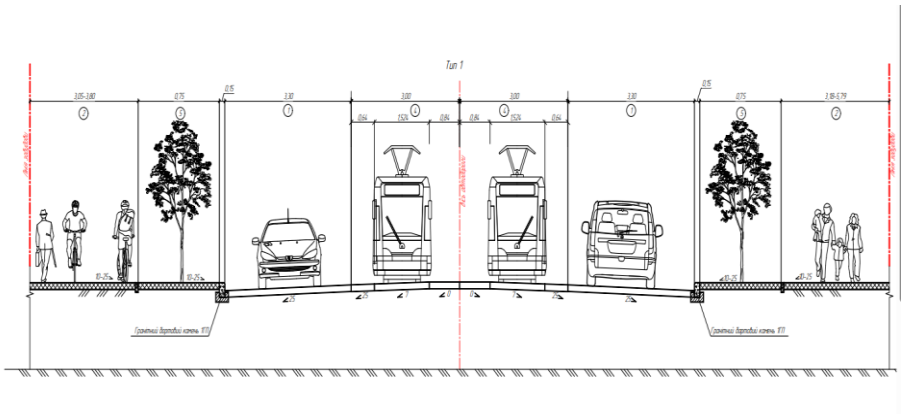
condition of the road infrastructure, the presence of conflict points, restrictions, engineering networks, as well as urban planning conditions and development plans for the territory are studied.

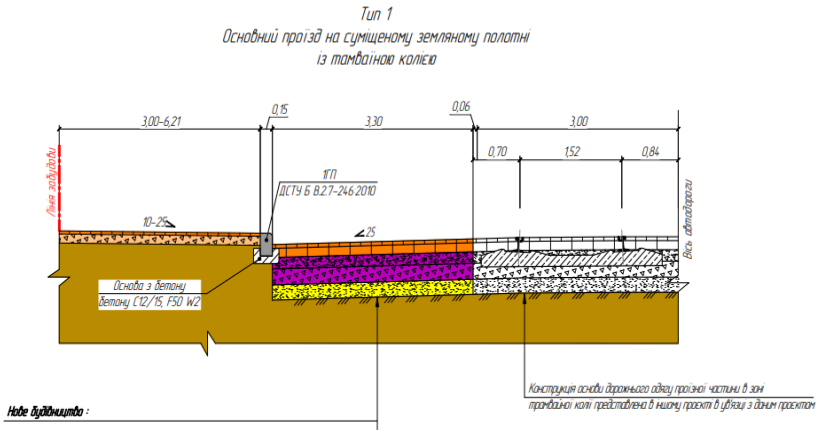
An important element of preparation is geodetic surveying. It allows you to get an accurate spatial picture of the street: the boundaries of the carriageway and sidewalks, existing elements of the ODR, the location of buildings, networks, curbs, slopes and all key objects. Based on this data, a geometric basis for drawings is formed and real possibilities for implementing solutions are determined. Without high-quality surveying, it is impossible to correctly place markings, islands, sewerage schemes, lane adjustments or traffic light objects.



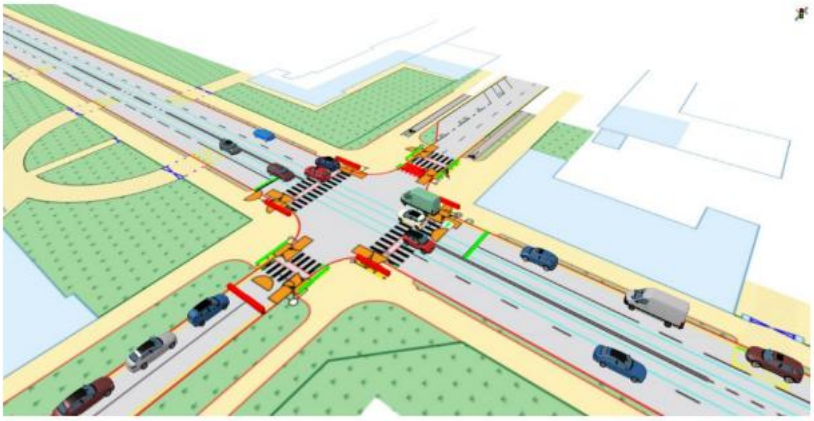
Red lines play the role of a planning framework. They set the regulatory boundaries of the street and determine the maximum space that can be used for

transport infrastructure. The designer compares the actual state according to the geodetic survey with the red lines to find out whether the real development meets the regulatory boundaries and whether the space allows adding lanes, bicycle infrastructure, safety islands or changing the geometry of intersections. In the event that existing objects exceed the established boundaries, alternative solutions have to be sought or such objects have to be removed.



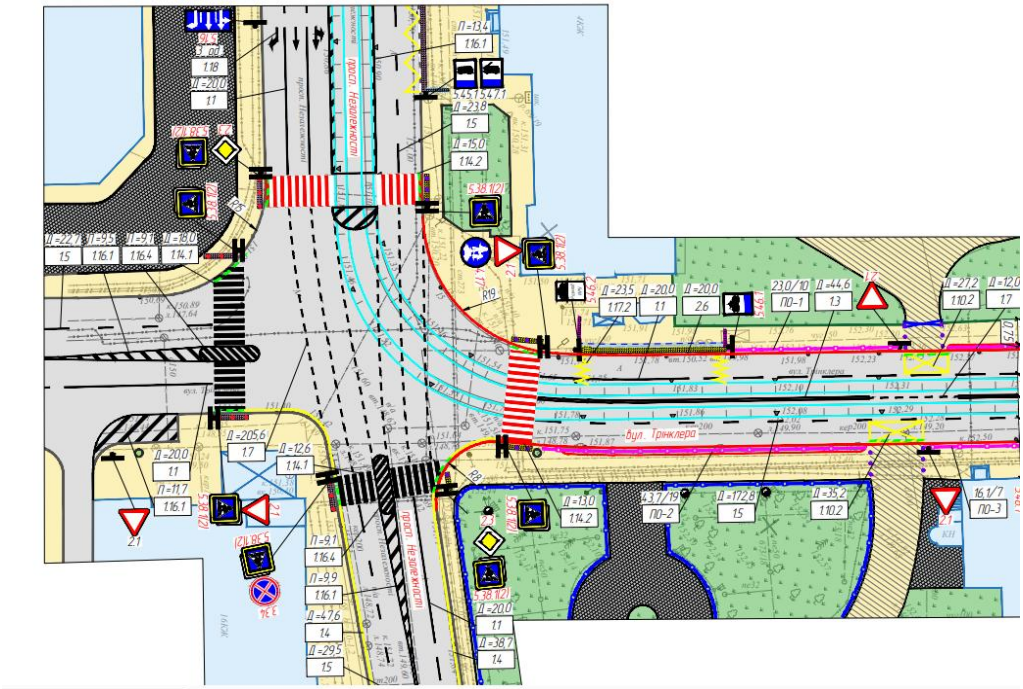


At the analysis stage, the designer examines the capacity and identifies problem areas – delays, bottlenecks, dangerous conflict zones. In many cases, transport modeling is used: macroscopic – to assess the distribution of flows across the network, and microscopic – to reproduce the behavior of individual cars. Modeling allows you to check the effectiveness of various traffic organization options, calculate queues on approaches, assess delays and the impact of planned solutions on public transport and pedestrian flows. It helps to justify the feasibility of changing traffic directions, redistributing lanes, implementing reverse, optimizing intersections, or installing traffic light regulation.



In the example of Trinkler Street, I demonstrated the logic and sequence of this work – how the path from data collection goes to analysis, modeling, evaluating options, and forming a final scheme. I also personally developed traffic organization schemes and a transport modeling model for a given section of the road.

After analysis and modeling, the designer proceeds to the development of technical solutions. They may include changing the geometry, channeling flows, installing traffic calming devices, creating new traffic patterns, optimizing pedestrian crossings, adjusting public transport lanes, introducing signs and markings. Each solution is based on calculations of visibility, stopping distances, capacity, ensuring convenience for pedestrians and people with disabilities, as well as compliance with regulatory requirements.



A special part of the work is the design of traffic light regulation. The designer determines the need for regulation by analyzing the intensity of flows, accidents, conflict points and the requirements of DSTU 4092. After that, a series of calculations are performed: determining critical flows, their combinations, phase distribution, calculating the yellow interval, interphase pauses, optimal cycle duration using Webster methods or modern adaptive algorithms. Finally, a cyclogram is created – a graphic representation of the interaction of traffic phases, which ensures conflict-free and minimizes delays.

ГОДИННА ПРОГРАМА №1

Номер світлофора	Тип технічних засобів		Тц=60с Фаза 1 Фаза 2
Т1, Т2	Т 1.3	НТ1, НТ2	
Т3, Т4	Т 1.3	НТ3, НТ4	
Т5, Т6	Т 1.3	НТ5, НТ6	
Т7, Т8	Т 1.3	НТ7	
П1, П2	П 1.2	НП1	
П3, П4	П 1.2	НП2	
П5, П6	П 1.2	НП3	

The final stage is the preparation of project documentation. It includes drawings of traffic organization schemes, an explanatory note, calculations, information on technical means, requirements for work performance and accompanying materials for approval. The documentation undergoes technical control and, if necessary, is approved by the police or balance holders.

As a result, design is a complex engineering work, in most cases by several specialists, which combines analysis, modeling, work with standards, spatial planning, geodetic accuracy and technical creativity. The goal of all these stages is to increase safety, reduce delays and create more comfortable conditions for moving around the city.

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SMART CITIES: INNOVATIVE APPROACHES TO URBAN DESIGN

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Cities worldwide are experiencing unprecedented growth, and this rapid urbanization is creating numerous challenges that traditional governance and infrastructure systems are struggling to handle. As urban populations grow, existing infrastructure increasingly fails to meet the rising demands for housing, transportation, water supply, waste management, and energy distribution. Energy systems face immense pressure, often operating near capacity, while natural resources are being used at unsustainable rates. By 2050, projections show that most

of the global population will live in urban areas, meaning cities will encounter intensified traffic congestion, higher air pollution levels, shortages of vital resources, and worsening social inequality (Bramly, 2025). This demographic change highlights the urgent need for innovative solutions to ensure cities stay livable, resilient, and sustainable amid growing complexity and environmental challenges.

Traditional urban planning methods, which depend heavily on inflexible zoning laws, static infrastructure projects, and slow bureaucratic procedures, are no longer adequate for tackling these challenges. These approaches tend to be rigid, unable to quickly address emerging issues, and incapable of foreseeing the ripple effects of rapid urban expansion. As a result, modern cities often struggle to efficiently manage energy and water, handle natural disasters like floods or heatwaves, and respond effectively to man-made crises. Residents are forced to spend significant time commuting, navigate crowded public spaces, and live in environments that do not sufficiently support their health, well-being, or productivity. The overall result is a decline in urban living quality, increased stress, and lower economic efficiency.

To address these challenges, cities need a fundamentally new approach – one that combines modern technology, adaptability, and a human-centered design philosophy. This shift in thinking is reflected in the concept of a Smart City, which has garnered considerable attention in recent years. A Smart City is not just a technological experiment; it provides a comprehensive framework for enhancing urban life, making it more comfortable, safe, and environmentally friendly. One of the most powerful tools in this framework is the Digital Twin, which is an accurate virtual model of an entire urban environment. Digital Twins enable city planners and policymakers to view real-time activity, simulate the effects of proposed infrastructure changes, and assess the environmental, social, and economic impacts of new developments before they are physically constructed (Bramly, 2025). This ability supports data-driven decision-making and proactive management of urban resources, ultimately improving the efficiency and sustainability of city operations.

Complementary to technological solutions is the urban planning strategy known as the “15-Minute City”. This concept emphasizes the proximity of essential services, including shops, schools, workplaces, healthcare facilities, and parks, so that all daily necessities are accessible within a 15-minute walk or bike ride from any residential location. By reducing dependence on private automobiles, the 15-Minute City model lowers traffic congestion, diminishes greenhouse gas emissions, saves time, and fosters stronger social cohesion within neighborhoods (Moreno, 2024). Moreover, this approach encourages active mobility, such as walking and cycling, which has additional benefits for public health and environmental sustainability.

Artificial intelligence (AI) and the Internet of Things (IoT) are increasingly integrated into urban management systems to optimize resource allocation and enhance operational efficiency. Sensors deployed throughout cities continuously monitor environmental indicators, including air quality, noise levels, water consumption, and waste accumulation. AI algorithms analyze these data streams to dynamically control traffic flows, predict demand for public services, and manage smart grids for electricity distribution. This integrated technological infrastructure reduces operational inefficiencies, minimizes environmental impact, and enhances residents’ quality of life by providing responsive and adaptive urban services (Пожарська, 2024). For instance, intelligent traffic systems can automatically adjust signal timings to prevent congestion, while predictive analytics can optimize waste collection routes to reduce emissions from municipal vehicles.

Sustainability is a cornerstone of contemporary urban design, and modern cities are increasingly embedding ecological considerations into their infrastructure and public spaces. Urban planners are prioritizing green spaces, energy-efficient lighting, and the use of locally sourced or recycled materials in construction projects. Climate change adaptation strategies, including flood-resistant infrastructure, green roofs, and urban cooling initiatives, are becoming integral to city planning. Such measures not only enhance environmental resilience but also contribute to social

well-being by providing residents with accessible, safe, and pleasant communal areas.

Furthermore, Smart Cities emphasize inclusivity and citizen engagement. Digital platforms enable residents to interact with municipal authorities, report issues, and participate in decision-making processes. This participatory approach ensures that urban development reflects the needs and preferences of the community, promoting transparency, trust, and social cohesion. By integrating citizen feedback with real-time data analytics, cities can create more equitable and responsive urban environments, fostering a sense of ownership and shared responsibility among residents.

The convergence of technology, ecological awareness, and human-centered design defines the essence of the Smart City. Its overarching goal is to create urban environments that are not only efficient and sustainable but also comfortable, safe, and enriching for all inhabitants. The adoption of Digital Twins, AI, and IoT systems, as well as concepts such as the 15-Minute City, collectively enables cities to anticipate challenges, optimize resource use, and improve the daily experiences of their residents. As urban populations continue to grow and the pressures on infrastructure intensify, these innovative approaches offer practical and scalable solutions for addressing the complex realities of contemporary urban life.

In conclusion, Smart City represents a transformative approach to urban planning that combines advanced technology, sustainability, and a focus on human well-being. By leveraging AI, IoT, Digital Twins, and compact neighborhood planning, modern cities can operate more efficiently, reduce environmental impact, and create inclusive and vibrant communities. As cities evolve, these strategies will become increasingly vital to ensuring that urban environments remain livable, resilient, and capable of supporting the social, economic, and environmental needs of future generations. The integration of technological, ecological, and social strategies within urban planning represents a comprehensive vision for tomorrow's

cities, emphasizing the importance of adaptability, innovation, and citizen-centered development.

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CHALLENGES AND PROSPECTS OF CIVIL ENGINEERING DEVELOPMENT IN UKRAINE

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Civil engineering plays a fundamental role in the socio-economic development of any country, as it directly influences infrastructure quality, transportation efficiency, industrial productivity, and living standards. In Ukraine, civil engineering has historically been a strategic sector due to the country's geographic position, extensive transport network, and industrial potential. In recent decades, however, the Ukrainian construction industry has faced significant challenges related to aging infrastructure, economic instability, environmental concerns, and, more recently, large-scale destruction caused by military actions (Адамська, 2029).

One of the key problems in Ukrainian civil engineering is the deterioration of infrastructure assets. According to international assessments, a significant proportion of bridges, roads, and public buildings were constructed during the Soviet period and have exceeded their designed service life. Insufficient maintenance and limited

investment have accelerated structural degradation, resulting in reduced safety and functionality. This situation necessitates urgent modernization using contemporary engineering solutions and materials.

Road and transport infrastructure is a particularly critical area. Ukraine possesses one of the largest road networks in Europe, yet a considerable share of roads does not meet modern technical standards. Pavement failures, insufficient load-bearing capacity, and inadequate drainage systems are common problems. Modern civil engineering approaches emphasize the use of durable pavement materials, improved structural design, and life-cycle cost analysis to enhance long-term performance and reduce maintenance expenses.

Sustainability has become an essential principle in modern civil engineering worldwide, and Ukraine is no exception. The construction sector significantly contributes to carbon dioxide emissions and natural resource consumption. The adoption of sustainable construction practices, such as energy-efficient buildings, recycled materials, and low-carbon concrete, is increasingly viewed as a strategic priority. For Ukraine, this transition is also aligned with European integration goals and harmonization with EU environmental standards.

Concrete technology remains central to Ukrainian civil engineering due to the widespread use of reinforced concrete structures in residential, industrial, and transport facilities. Traditional Portland cement production, however, is associated with high energy consumption and greenhouse gas emissions. Research indicates that partial replacement of cement with supplementary cementitious materials, such as fly ash and blast furnace slag, can significantly improve environmental performance while maintaining mechanical properties and durability (Scrivener, 2018). Ukraine's industrial background provides potential access to such by-products, creating opportunities for more sustainable material use.

Another important issue is seismic and structural safety. Although Ukraine is not classified as a high-seismicity region overall, certain areas, particularly in the southwestern part of the country, are exposed to seismic risks. In addition, increased

loads due to traffic growth and changes in building usage demand updated structural assessment methods. Modern civil engineering relies on advanced numerical modeling, structural health monitoring, and performance-based design to ensure safety and resilience (Neville, 2011).

Post-conflict reconstruction represents a unique and urgent challenge for Ukrainian civil engineering. Large-scale damage to residential buildings, bridges, roads, and industrial facilities has created the need for rapid yet sustainable reconstruction strategies. International experience demonstrates that post-conflict rebuilding should not merely restore damaged structures but improve their quality, energy efficiency, and resilience to future risks. For Ukraine, this approach offers an opportunity to modernize infrastructure in accordance with contemporary engineering standards.

Human capital is another critical factor influencing the development of civil engineering in Ukraine. Engineering education, particularly in technical universities, plays a decisive role in preparing qualified specialists capable of implementing innovative solutions. Strengthening cooperation between universities, research institutions, and the construction industry can enhance applied research and accelerate the introduction of new technologies into practice. Institutions such as Kharkiv National Automobile and Highway University contribute significantly to training engineers in transport and construction engineering fields.

In conclusion, civil engineering in Ukraine faces a complex set of challenges, including infrastructure degradation, environmental concerns, and post-conflict reconstruction needs. At the same time, these challenges create opportunities for modernization, innovation, and sustainable development. The integration of advanced materials, modern design approaches, and international best practices can significantly improve the quality and resilience of Ukrainian infrastructure. Continued investment in engineering education, research, and sustainable technologies will be essential for the long-term development of the civil engineering sector in Ukraine.

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THE IMPACT OF INNOVATIVE MATERIALS ON THE CONSTRUCTION PROCESS

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Introduction

Modern construction is characterized by a high rate of development due to the introduction of innovative materials and technologies that enhance the efficiency, durability, and environmental safety of structures. The use of advanced materials makes it possible to optimize construction processes, reduce the duration of work, and improve the operational properties of structural elements. Examples of such innovations include laser technologies for pavement control, “flexible concrete”, self-healing cement composites, and polymer-matrix composite materials.

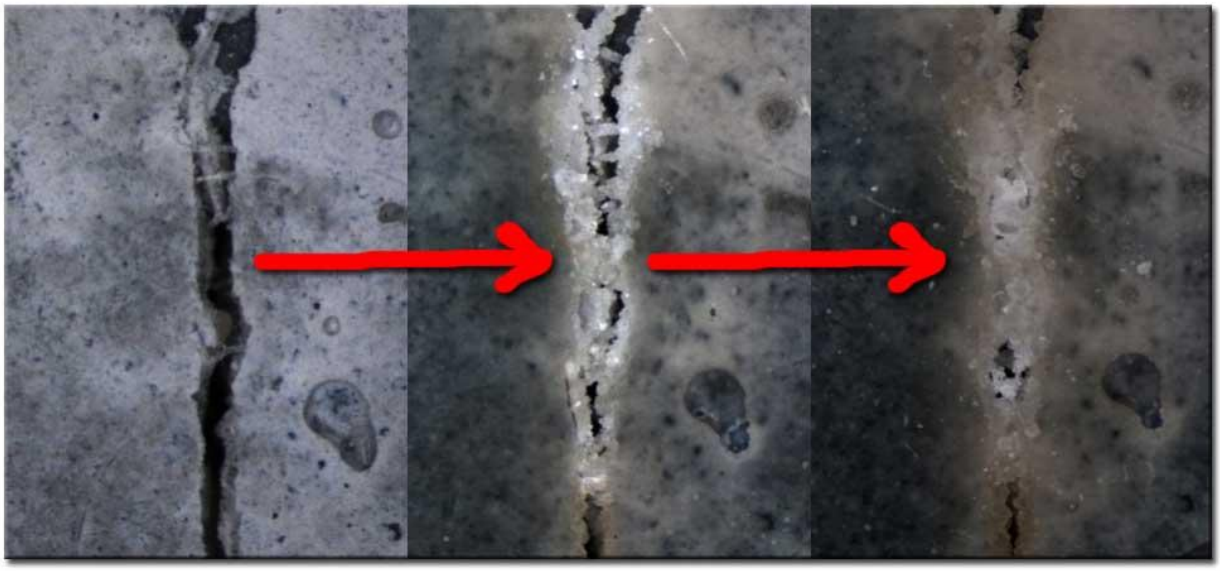

Figure 1.1 *Demonstration of 'self-healing' concrete using bacteria*

The problem that requires scientific investigation lies in determining the precise ways in which innovative materials influence:

– the technological process of construction;

– the durability and reliability of structures;

– the environmental performance and energy efficiency of buildings;

– the cost and timeline of project implementation.

The technological process of construction

Nanomaterials represent one of the key groups of innovations applied in construction. Their effectiveness is determined by their large specific surface area as well as their unique mechanical and physicochemical properties. The main areas of application include strengthening concrete and cement-based materials, reducing material porosity, increasing corrosion resistance and water impermeability, and improving crack resistance (Кондир, 2016; Goel, 2022). A prominent example consists of carbon nanotubes (CNTs) and nanofilms. Carbon nanotubes are particularly promising due to their high strength and elasticity. Their incorporation into cement composites increases compressive strength by approximately 20-40%, reduces the formation of cracks, and enhances the material’s resistance to deformation.

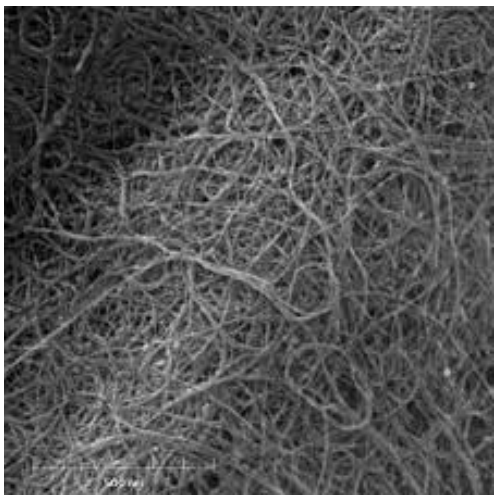

Figure 1.2 *Carbon nanotubes*

Nanofilms with a thickness of 1-100 nm are used as protective coatings for metal, concrete, and glass structures. They provide reliable protection against corrosion, increase resistance to ultraviolet radiation, and reduce the impact of chemically aggressive environments.

Polymer Composites in Bridge Construction

The introduction of FRP composites has become a breakthrough in modern bridge engineering. These materials combine high strength, low weight, corrosion resistance, and ease of installation.

The main types of FRP materials include:

– GFRP – glass fiber-reinforced polymers;

– CFRP – carbon fiber-reinforced polymers;

– BFRP – basalt fiber-reinforced polymers.

Since FRP materials are significantly lighter than steel, they reduce the load on bridge supports and provide a longer service life.

Table 1. Comparison of polymer materials with traditional ones

Parameter	**Steel**	**Concrete**	**GFRP**	**CFRP**
Strength (Mpa)	250-400	20-40	500-1200	1500-3000
Density (kg/m³)	7850	2400	1600-2000	1500

Corrosion resistance	Low	Medium	High	High
Service life	25-50 yrs	50-100 yrs	100+ yrs	100+ yrs

A notable example of the use of innovative materials in bridge construction is the application of various types of FRP bridge decks. In particular, pultruded profiles such as EZ-Span, SuperDeck, and DuraSpan are characterized by low weight, high strength, and suitability for mass production. Their structural simplicity ensures rapid installation and enables their application in aggressive operating conditions.

Another example is sandwich panels composed of two composite skins and a lightweight core. Owing to the combination of high stiffness and minimal mass, they are suitable for short- and medium-span bridges. Hybrid beams that combine polymer composites with concrete are also becoming increasingly common. Such elements merge the strength of FRP with the stiffness of concrete, reducing the cost of the structure and improving its durability.

The Impact of Innovative Materials on the Environmental Sustainability of Construction

Sustainable development requires the implementation of materials with a low carbon footprint, and innovative materials play a crucial role in minimizing the environmental impact of construction activities. Their use supports the efficient utilization of natural resources, reduces CO_2 emissions – especially in the case of biocement and increases the energy efficiency of structures through solutions such as aerogels and vacuum insulation panels. An important advantage is the possibility of employing recycled materials and biocomposites, which additionally reduces the volume of construction waste.

Graphene-based materials and intelligent sensor-enabled concrete systems play a particularly important role by enabling real-time structural health monitoring. This allows timely detection of damage, extends the service life of structures, and

reduces the need for frequent maintenance interventions, thereby further improving the environmental performance of construction processes.

The Impact of Innovative Materials on Construction Time and Cost

The use of innovative materials can significantly influence the economic aspects of construction by altering both the duration and the overall cost of building processes. One of the main advantages of such materials is the substantial reduction in construction time. This is achieved through the use of modular structures, rapid-hardening mixtures, lightweight composite elements, and FRP panels that enable installation within hours, thereby drastically accelerating the technological cycle.

The economic effect is also reflected in the structure of expenditures. Although innovative materials typically have a higher initial cost compared to traditional ones, they compensate for this through significant operational advantages. Advanced solutions reduce curing or installation times from 28 days to several hours or days, offer higher energy efficiency, require minimal maintenance, and shorten the overall construction period from 6-12 months to 1-3 months.

Thus, while the initial investments in advanced materials are higher, their application ensures long-term savings. This is due to reduced repair and maintenance costs, optimization of operational expenses, and increased durability of structures, which ultimately makes construction more efficient and economically advantageous.

Conclusions

Innovative materials significantly influence the development of modern construction by increasing the strength and durability of structures, improving the environmental and energy performance of buildings, reducing construction time, and optimizing operational and maintenance costs. The application of nanomaterials, polymer composites, and recycled materials marks a new stage in the evolution of the industry, although their widespread adoption is still constrained by high production costs and a limited amount of long-term practical research.

Prospects for Further Research. Future scientific developments may focus on improving production technologies for more affordable nanocomposites, creating

new hybrid systems based on FRP and concrete, developing biomaterials for sustainable construction, and implementing intelligent structural health monitoring systems. Special attention should be given to expanding regulatory frameworks governing the use of composite materials in bridge construction, which will support their more active integration into engineering practice.

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ARCHITECTURE AND CONSTRUCTION: CURRENT TRENDS AND DEVELOPMENT PROSPECTS

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Architecture and construction are fundamental components of the development of any society. They shape not only the physical space in which people live and work, but also determine cultural identity, economic stability, and the level of technological progress of a country. Furthermore, in the modern world, architectural activity is increasingly connected with innovative technologies, environmental responsibility, and the need to adapt to climate change. Therefore, this article examines the main trends in the field of architecture and construction, their impact on society, and the prospects for the industry's development.

Architecture emerged as a human response to the need for protection from the surrounding environment. Over time, it evolved into a complex system of knowledge that combines art, engineering, sociology, and ecology. Historically, architectural structures were primarily symbols of status or religious affiliation; however, today they reflect the pursuit of functionality, safety, and sustainable progress.

Beginning in the 19th century, when industrialization encouraged the use of steel and concrete, architecture gained new possibilities. High-rise buildings, large-scale infrastructure projects, and extensive transportation systems became indicators of urban development. In contrast, in the 21st century, the focus has shifted toward energy efficiency, innovative materials, and the harmonious integration of structures into the natural environment.

One of the key trends in modern architecture is the pursuit of sustainability. This means using natural resources in a way that does not harm the environment while ensuring the durability of structures. Among the many solutions, the most common are green roofs, solar panels, water purification and reuse systems, and high-quality thermal insulation materials.

Bionic architecture is based on the imitation of natural forms and structures. Such buildings not only appear futuristic but are also more adaptable and efficient. For instance, façade systems change configuration depending on lighting levels, or buildings mimic bone structure to increase strength while reducing weight.

Modern architects actively use software tools to model complex shapes, optimize structural solutions, and predict building performance under various conditions. As a result, parametric design makes it possible to create constructions that were previously impossible from an engineering standpoint.

Population growth in cities stimulates the development of concepts for compact and comfortable urban environments. Consequently, prioritizing pedestrians, developing public transport, creating multifunctional complexes, and revitalizing abandoned industrial zones all shape the urbanism of the 21st century.

Contemporary research has enabled the creation of materials with unique properties: self-healing concrete, high-strength composites, and lightweight insulating panels. Overall, the use of such materials increases the strength, durability, and energy efficiency of buildings.

3D printing is becoming a revolutionary technology in construction. It makes it possible to build houses in just a few days, reducing the cost of materials and labor. Moreover, 3D printing opens opportunities for creating buildings of complex shapes that are impossible to construct using traditional methods.

Modular buildings are assembled from separate blocks manufactured in factory conditions. This approach ensures rapid construction, high structural quality, and reduced human error. Because of this, modular construction is widely used for housing, hotels, hospitals, and office buildings.

Robots and autonomous systems are increasingly used to perform dangerous or monotonous tasks – such as laying bricks, welding, or dismantling old structures. As a consequence, this increases worker safety and accelerates construction processes.

The construction industry is one of the largest sources of CO_2 emissions. Therefore, today architects and engineers focus on reducing the carbon footprint of construction by using recycled materials, optimizing logistics, and implementing low-energy-consumption technologies.

Rapid urbanization poses new challenges for architects: providing affordable housing, creating efficient transportation systems, and using land rationally. At the same time, many cities face overloaded infrastructure and a lack of green spaces.

With the spread of digital technologies, the need for data protection is increasing. Smart buildings that use monitoring and automated control systems may be vulnerable to cyberattacks, making security a top priority.

The future of architecture and construction is closely linked to innovation, environmental awareness, and global digitalization. The development of autonomous buildings capable of producing their own energy and managing their internal climate is expected. Additionally, the use of artificial intelligence will allow for more precise building design and optimization of construction processes.

Among promising directions are the development of underground and underwater construction, the use of new spatial forms, and the integration of natural systems into building structures.

Architecture and construction are in constant development, responding to technological, social, and environmental changes. Overall, modern trends indicate a gradual shift toward sustainable, energy-efficient, and technologically advanced solutions aimed at improving people's quality of life. The industry continues to play a key role in shaping the future of civilization, creating spaces where people can live, work, and grow in harmony and safety.

One of the most striking innovations of modern times is the concept of vertical forests – buildings whose facades are fully or partially covered with vegetation. Such structures not only improve the aesthetic appearance of the city but also perform important ecological functions: they reduce air pollution, create an additional microclimate, and serve as natural sound insulation. A well-known example is the

Bosco Verticale complex in Milan, which has become a symbol of sustainable architecture.

The “smart city” concept involves the use of digital technologies to optimize all aspects of life in megacities: energy consumption, transportation, communications, and public safety. In such cities, buildings, transport systems, and utility networks interact through a unified information system. Thus, smart sensors monitor resource usage, optimize traffic flow, and improve the overall quality of the urban environment.

In response to global sea-level rise and extreme weather events, interest is growing in floating buildings and structures capable of withstanding climate-related stresses. Notably, in the Netherlands, projects involving floating schools, residential houses, and even office buildings are already being implemented. This indicates the emergence of a new direction – climate-adaptive architecture.

Modern housing is increasingly designed with a focus on psychological comfort. The use of natural lighting, biophilic design, ergonomic layouts, and transformable spaces helps create maximally comfortable living conditions. Furthermore, the COVID-19 pandemic has accelerated the adoption of such solutions, as homes have become not only places for living but also functional workspaces.

Despite the development of high technologies, traditional materials such as clay, wood, straw, and natural stone are becoming increasingly popular. Thanks to modern processing methods, these materials demonstrate high durability and environmental friendliness. A particularly fast-growing area is CLT (cross-laminated timber) – multilayer engineered wood that makes it possible to construct multi-story buildings with a minimal carbon footprint.

Architectural studios around the world are implementing bold experimental projects, including underground museums, suspended bridges between skyscrapers, gravity-defying structures, and futuristic desert cities. One of the most ambitious

projects is The Line in Saudi Arabia, which envisions the construction of a 170-kilometer linear city without cars or harmful emissions.

Research on how architectural space influences mental health is gaining popularity. Scientists study how room shapes, colors, ceiling heights, lighting, and even corridor layouts affect human behavior and emotional well-being. Consequently, this knowledge is already being applied in the design of hospitals, schools, business centers, and residential complexes.

Modern architecture is increasingly integrating new fields of knowledge – from biology to digital analytics, from psychology to ecology. In essence, innovative solutions aim to create spaces that are not only functional but also healthy, environmentally friendly, and harmonious for living. The industry continues to evolve toward sustainability, integration with nature, and the use of advanced technologies to their fullest potential.

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GEODESY AND LAND MANAGEMENT

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MODERN GNSS AND TOTAL STATION SURVEYING FOR ROAD DESIGN: ACCURACY, WORKFLOW, AND PRACTICAL APPLICATIONS

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Introduction

Road design is data-driven: alignment selection, longitudinal and cross profiles, drainage solutions, earthwork volumes, and safety elements all depend on the quality of the initial geodetic information. In modern practice, a combined approach is widely used: GNSS (Global Navigation Satellite Systems) for rapid positioning and control, and total stations for detailed topographic measurements, especially where satellite signals are unreliable. GNSS fundamentals, error mechanisms, and practical observing constraints are well described in the surveying literature (Hofmann-Wellenhof et al., 2008).

For linear infrastructure such as roads, the key engineering task is to convert field measurements into consistent planimetric and height data suitable for digital terrain modelling, cross-sections, and design calculations. Applied GNSS workflows for engineering surveying, including static and RTK methods, are summarized in standard references (Leick, 2015).

This paper presents an applied GNSS + total station workflow for road design, highlights typical accuracy expectations and major error sources, and proposes quality-control steps appropriate for student projects and practical engineering work (Wolf & Ghilani, 2018).

Materials and methods

A typical survey-to-design chain for a road corridor can be organized into five stages: 1) planning and reconnaissance, 2) establishing a geodetic control network,

3) topographic surveying and cross-sections, 4) data processing and adjustment, and 5) CAD/GIS integration and digital terrain modelling.

Planning starts with defining deliverables (control points, topographic plan, DTM/contours, profiles and cross-sections, and identification of utilities). Site reconnaissance helps identify GNSS limitations such as multipath from buildings and metal structures, canopy effects from trees, and signal masking in deep cuts.

Control networks are often established by static or rapid-static GNSS sessions for primary points along the corridor, connected to the required coordinate system. In GNSS-challenging areas, a total station traverse tied to GNSS-controlled points ensures continuity and local geometric stability.

Topographic detail collection typically combines GNSS RTK for open-sky areas and long linear features (e.g., road edges, ditches, fences) with total station measurements for dense detail, sharp breaks in slope, curbs, and structures. Cross-sections are measured at regular station intervals and at geometry-change points (crests, sags, ditch bottoms, slope toes and crests).

Processing includes coordinate verification, height handling (ellipsoidal vs orthometric heights), and adjustment of traverses and redundant observations. Least-squares adjustment and residual analysis are recommended to control accumulated errors and document the reliability of the final dataset (Ghilani, 2017).

For road design, the survey dataset is integrated into CAD/GIS and used to create a DTM. Breaklines (pavement edges, ditch lines, and slope toes/crests) must be correctly coded, because breaklines often govern terrain discontinuities more strongly than point density.

Expected accuracy and practical notes

Accuracy requirements vary by project stage and road class, but it is useful to set realistic expectations. GNSS RTK in open-sky conditions commonly provides centimeter-level horizontal accuracy; vertical results are typically less stable due to satellite geometry, multipath, and height-model uncertainty. Static GNSS improves reliability for primary control points over longer baselines. Total station observations

deliver high precision for angles and distances, while final coordinate accuracy depends on control quality and field procedures (centering, prism constant, and instrument calibration).

From a design standpoint, consistent geometry and reliable heights are critical for longitudinal profiles, cross-fall design, drainage, and earthwork computations. General design guidance for geometric elements and roadway cross-sections is available in widely used standards (AASHTO, 2018).

Major error sources

Common GNSS error sources include multipath reflections, poor satellite geometry (high PDOP), incorrect coordinate system parameters, and height transformation mistakes. Total station errors often arise from centering issues, incorrect prism constants, weak traverse geometry, and unaccounted atmospheric effects. Workflow errors include inconsistent point/breakline coding, lack of redundancy, and insufficient documentation of processing settings.

Recommended quality control procedures

A practical quality-control package for road surveys includes: 1) re-observation of a subset of control points and comparison of coordinates, 2) traverse closure checks and adjustment with residual reporting, 3) independent check points measured by both GNSS and total station in open areas, 4) height checks using benchmarks where available, and 5) visual verification of contours and cross-sections against expected terrain logic.

Instrument testing and periodic verification are also important to maintain measurement reliability. Field procedures for testing geodetic instruments are standardized and can be used as a reference framework for checks and documentation (ISO, 2012).

Conclusions

GNSS and total station surveying are complementary in modern road design. GNSS provides rapid corridor control and efficient data capture in open environments, while total stations support reliable detail surveying and stable

geometry in GNSS-restricted zones. A consistent workflow with correct coordinate settings, careful height handling, traverse adjustment, and systematic quality control reduces geometric and elevation inconsistencies and improves the reliability of design inputs.

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THE ROLE OF ENGINEERING GEODESY IN MODERN ROAD CONSTRUCTION AND DIGITAL TERRAIN MODELING

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Modern road construction is characterized by increasing technological complexity and the continuous growth of safety, durability and environmental requirements. Engineering geodesy plays a central role in the successful realization

of road infrastructure projects, as it ensures the accurate acquisition, processing and interpretation of spatial data that form the basis for design and construction decisions. The introduction of digital technologies, including high-precision GNSS systems, terrestrial laser scanning, unmanned aerial photogrammetry, Geographic Information Systems (GIS) and Digital Terrain Modeling (DTM), has significantly enhanced the quality and efficiency of geodetic support at every stage of road construction. These technologies enable engineers to analyze natural landscapes more thoroughly, anticipate geotechnical risks, optimize earthworks and create accurate models of the present and future condition of road infrastructure. As a result, geodesy has evolved from purely measurement-oriented tasks into an integrated analytical discipline essential for the full lifecycle of transport infrastructure.

The aim of this article is to examine the role of engineering geodesy in modern road construction with particular focus on Digital Terrain Modeling as a vital element in route planning, construction management and long-term monitoring of road systems.

Engineering geodesy ensures the spatial accuracy of every phase of road design and construction, beginning with preliminary topographic analysis and ending with operational monitoring of the finished infrastructure. In the early stages, geodetic surveying provides reliable data on terrain elevation, geological conditions, hydrological features and natural obstacles, which serve as the foundation for evaluating possible road alignments. The reliability of geometric and elevation data is paramount, as it determines the safety of curves, gradients and visibility zones as well as the stability of the road in challenging natural environments. High-quality geodetic support minimizes deviations from the project, reduces costs associated with corrections and allows construction processes to be carried out in accordance with precise geometric parameters.

The growing complexity of modern transport networks requires a transition to advanced geospatial modeling techniques that capture terrain details with much greater precision than classical surveying methods. Laser scanning, aerial

photogrammetry and satellite observations have become indispensable tools for documenting the natural landscape and the geometry of construction objects. These technologies provide detailed three-dimensional representations that help engineers evaluate slope stability, identify areas susceptible to erosion, analyze drainage and plan earthworks effectively. They also support the transition to digital construction management, allowing the integration of spatial data with BIM and GIS platforms.

Digital Terrain Modeling plays a crucial role in modern road construction. A DTM represents the land surface in three dimensions and enables detailed interpretation of relief properties that influence route selection, construction costs, drainage conditions, environmental risks and long-term operational stability. A high-quality DTM allows engineers to assess alternative alignments with respect to slope gradients, cut-and-fill requirements, potential landslide zones and the interaction between natural and artificial features. This analytical capability helps minimize earthwork volumes, avoid geotechnically unstable regions and reduce the environmental impact of road construction.

Digital terrain models also serve as essential tools in earthwork planning. Accurate estimation of excavation and embankment volumes is vital for managing construction materials, fuel consumption and project scheduling. Modern data processing tools create terrain surfaces with high resolution and enable automated calculations that significantly improve planning accuracy. DTMs are also used to analyze the behavior of natural water flows, which influence both construction safety and the long-term durability of the road. Hydrological simulations based on digital terrain information help identify areas at risk of flooding, erosion or groundwater interference.

The integration of DTMs with GIS and BIM systems enhances design precision and improves decision-making. A combined digital environment enables detailed visualization of planned road geometry within the real terrain context. Engineers can detect potential conflicts with existing structures, assess environmental constraints, simulate earthwork processes and create more accurate

as-built documentation. This integration strengthens coordination between designers, constructors and geodetic specialists, contributing to improved efficiency and safety throughout the project lifecycle.

Modern road construction increasingly relies on advanced geodetic technologies that ensure high accuracy of spatial measurements and enable continuous monitoring of construction progress. GNSS technologies make it possible to establish reliable geodetic control networks, monitor the position of road elements during construction and guide machinery with high precision. Real-Time Kinematic (RTK) positioning supports centimeter-level accuracy necessary for shaping road surfaces, slopes and embankments according to design specifications.

Terrestrial Laser Scanning (TLS) has become an essential method for acquiring detailed three-dimensional models of terrain and structural elements. TLS produces dense point clouds that represent the terrain with exceptional accuracy. These data are used to analyze slope stability, verify excavation geometry, monitor roadbed deformation and create digital documentation of construction phases. Modern software solutions allow automatic classification and processing of point clouds, accelerating data interpretation and improving engineering analysis.

Unmanned aerial vehicles equipped with high-resolution cameras have transformed the surveying process in road construction by enabling fast and safe data acquisition over large or difficult-to-access areas. UAV photogrammetry generates orthophotos, digital surface models and high-accuracy DTMs that support route planning, construction monitoring and environmental assessment. Drone-based surveying is especially valuable in mountainous regions, areas with steep slopes or places where traditional surveying methods pose safety risks.

Robotic total stations complement satellite and scanning technologies by providing continuous monitoring of critical control points with millimeter accuracy. This capability is vital in areas prone to landslides, subsidence or significant geotechnical instability. Automated monitoring systems help identify hazardous

deformations at an early stage and ensure construction quality in accordance with design requirements.

The long-term safety and durability of road infrastructure depend on continuous monitoring of changes caused by natural processes and traffic loads. Geodetic monitoring systems that combine GNSS receivers, inclinometers, laser scanning and robotic total stations provide comprehensive information about the deformation behavior of slopes, embankments, retaining structures and pavement layers. Early detection of subsidence, lateral displacements or erosion processes helps prevent accidents, reduce maintenance costs and extend the operational life of the road.

Digital monitoring tools also support predictive analysis of infrastructure behavior. Advanced geospatial data processing techniques allow engineers to forecast slope instability, evaluate the impact of groundwater changes and assess the influence of climatic factors on road performance. This information is essential for designing preventive measures and adopting a proactive maintenance strategy.

Engineering geodesy plays a fundamental role in modern road construction by providing reliable, high-precision spatial data essential for safe, efficient and sustainable infrastructure development. Digital Terrain Modeling greatly enhances the interpretation of natural landscapes and supports accurate planning of road alignment, earthworks and geotechnical safety. The integration of GNSS, terrestrial laser scanning, UAV photogrammetry, robotic measurement systems and digital modeling platforms creates a comprehensive geodetic environment that improves the quality and speed of engineering processes. As road networks continue to expand and environmental challenges become more complex, the importance of engineering geodesy will grow even further. The future of road construction lies in the continuous development of digital geospatial technologies, the advancement of monitoring systems and the integration of intelligent analytical tools that contribute to resilient and durable transport infrastructure.

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TOPOGRAPHICAL, GEODETIC, CARTOGRAPHIC SUPPORT OF TERRITORIAL COMMUNITIES: GIS AS THE BASIS OF A GEOPORTAL

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Decentralization, changes of administrative structure, and reforms in the field of urban planning and land cadastres towards their digitalization require a new approach to the issue of information support for territorial (Ачкасов, 2024). The management of a community's territory, in particular land resources, forecasting of adverse natural phenomena and modeling of their consequences, monitoring of industrial, agricultural, nature reserve, recreational lands according to the requirements of legislative acts should be carried out using accurate topographic and geodetic materials on a geoinformation basis, creating the prerequisites for the development and implementation of geoportals, which will allow, in accordance with the law, to publish all available spatial data on the websites of territorial communities (Бубир, 2025). In turn, the hierarchical network of geoportals underlies the concept of the third generation of the national infrastructure of geospatial data (Fig. 1).

Figure 1 *Structure of the national geoportal* (Штерндок, 2025)

The history of the development and implementation of GIS has a long history, the final stage of which is their active distribution in all industries that operate with spatial data. Currently, it is a familiar tool for ecologists, geographers, surveyors, and land managers. Gradually, GIS is also being mastered by representatives of local

governments. Among the main advantages: efficiency, comprehensiveness, accuracy, and binding to a geodatabase. This is what allows GIS to be actively used to automate field and office work for topographic and geodetic support of community development and their publication.

Such extraordinary capabilities of GIS could not go unnoticed when implementing reforms in the field of urban planning and land cadastre. Thus, in 2021, the mandatory development of a comprehensive spatial development plan for the territory of each community was legally introduced, which includes urban planning documentation, land management documentation, a land use plan, etc. (Achkasov et al., 2025). The implementation of a comprehensive spatial development plan and the need for rapid and transparent monitoring of land and natural resources impose a number of requirements for the accuracy and integration of geospatial data. Of course, this involved the creation and use of an accurate geodetic network, a detailed topographic base, and the possibility of operational spatial planning. Unfortunately, historically, a situation has developed when topographic plans and cadastral information were developed in different coordinate systems, scales, and were often incompatible. The most suitable for performing all these tasks were identified as geographic information systems, which act as a technological "bridge", ensuring the transformation, unification, and integration of these disparate layers into a single, reliable geodatabase. This allows you to avoid legal conflicts and technical errors in design.

During martial law, the functioning of geoportals and the publication of comprehensive spatial development plans for territorial communities are limited, but at the same time this provides more time for their full development and implementation.

Work on geoportals should begin with an analysis of topographic and geodetic support, in particular, with monitoring and inventorying of existing paper, raster and vector topographic maps, orthophotomaps. As a result, we obtain metadata for sets of geospatial data and geoinformation services that are to be published on the

geoportal (taking into account modern realities - upon the end of martial law, taking into account the norms of the legal framework in force at that time). The next stage is the scanning of paper cartographic materials (in the absence of digital ones). If there are already digital, but inconsistent, cartographic materials, it is necessary to bring them to the USK-2000 coordinate system. Simultaneous work on the ground on the reconstruction of geodetic networks is important. Regarding the establishment of a topographic base, attention should be paid to modern technologies, in particular the use of high-resolution remote sensing data and UAV photography in the post-war period, which will allow the creation of an up-to-date orthophotomap at a scale of 1:5 000. Larger-scale cartographic materials for settlements require surveying by ground methods or using aircraft.

An important stage is the analysis of the variability of GIS and their capabilities. The modern GIS market offers both commercial and open source software products.

Popravko O. noted the relevance of using ArcGIS in land management as a tool for land information systems, which provides the ability to quickly process, use and store various information about land resources, back in 2014 (Поправко, 2024). Currently, these are wide capabilities of 3D-modeling, network complex in-depth analysis, working with surfaces, support for the transformation of coordinate systems, etc. It is recommended for a centralized corporate Geodatabase, which is essentially geoportals, but requires a significant budget.

QGIS, which is distributed on the basis of open source code, has fewer capabilities, but supports numerous plugins for geodesy. It has tools for developing digital terrain models, which is very important when managing local land resources and modeling the consequences of natural disasters. Another positive feature is the adaptability of GIS to various formats, which allows you to fully integrate disparate data.

Digitals is a Ukrainian software product that greatly facilitates obtaining technical support and adaptation to specific, in particular cadastral, requests of local

communities. The software product provides specialized tools for land management and data exchange of the state land cadastre. It is advisable to use it at the stage of entering cadastral data and exchanging them.

Thus, today's challenges require the use of GIS for effective management of the community and its land resources, determining ways of post-war restoration of the territory, involving methods of spatial analysis and cartographic modeling, and undoubtedly drawing up a comprehensive plan, which provides many advantages, and representatives of local self-government bodies have wide opportunities for spatial planning and analysis based on the use of ArcGIS, Digitals, Karta, QGIS, etc., which has already been confirmed in many communities and at the level of regional geoportals.

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TOURISM

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MILITARY TOURISM IN UKRAINE

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Introduction. Military tourism, also known as war tourism or heritage conflict tourism, refers to travel motivated by interest in military history, sites of armed conflict, locations of significant battles, memorials, museums, and landscapes shaped by war. Around the world, this form of tourism includes visits to former battlefields, military cemeteries, fortifications, bunkers, museums, and reconstructed historical environments. Since 2022, Ukraine has unexpectedly become one of the central topics in global discussions on military tourism, though the country is still in the phase of active warfare. Despite the tragic conditions, the concept of military tourism has acquired new meanings: preserving memory, documenting destruction, fostering national identity, and raising international awareness about the realities of the Russian-Ukrainian war.

Military tourism in Ukraine existed long before the full-scale invasion. Sites related to World War I, World War II, the Cold War, and the Soviet era attracted researchers, veterans' families, and history enthusiasts. Examples include fortifications in Western Ukraine, museums dedicated to the Ukrainian Insurgent Army (UPA), Soviet-era missile bases, and the Chornobyl Exclusion Zone, which before 2022 was one of the most visited military-technical tourism objects in Eastern Europe. However, after 24 February 2022, interest in Ukrainian military history transformed dramatically: the current war became the central focus of international attention, making Ukraine an emerging destination for future post-war military tourism.

Currently, active warfare limits the physical development of tourism. Yet Ukrainian and international experts already discuss prospects. Military tourism as a phenomenon now includes several components: documentation of war-related sites,

creation of digital and virtual tours, preservation of damaged cultural heritage, and development of memory spaces. Many Ukrainian cities have become symbols of resistance, including Kyiv, Kharkiv, Mykolaiv, Odesa, Chernihiv, Hostomel, Bucha, Mariupol, Bakhmut, and Avdiivka. Their defensive structures, destroyed infrastructure, memorials to civilians, and preserved shelters may become future objects of educational and memorial tourism.

A core element of military tourism is memorialization. In Ukraine, military memorialization has gained strategic significance because it helps preserve collective memory and honor fallen defenders. Temporary memorials, volunteer museums, and open-air exhibits of destroyed Russian military equipment already attract visitors domestically. For example, exhibitions titled “The Destroyed Military Equipment of the Russian Army” in Kyiv or similar displays in Kharkiv and Mykolaiv serve not only as patriotic sites but also as early prototypes of military tourism infrastructure. These exhibitions allow citizens and international guests to witness material evidence of the war and understand the scale of the aggression.

Another important aspect is educational military tourism. Post-war Ukraine is expected to experience a growing demand for guided tours that explain key battles, military strategies, and stories of civilian resistance. Regions such as Chernihiv, Kyiv, Kharkiv, and Kherson may develop educational routes dedicated to the defense of cities, the operation of territorial defense units, and volunteer initiatives. International tourists, journalists, researchers, and students of political science, conflict studies, and modern warfare are potential audiences for such tours. Experience from countries like Poland, Germany, Vietnam, and Israel shows that military tourism can become a powerful educational tool for future generations.

Digital and virtual military tourism already plays a significant role during the ongoing war. Dozens of Ukrainian media platforms, museums, and volunteer organizations have created digital archives, interactive maps of destruction, and online exhibitions documenting war crimes and cultural losses. VR/AR technologies allow users from around the world to explore formerly occupied towns, 3D

reconstructions of damaged landmarks, and immersive tours of the most significant locations of the current conflict. These digital resources help preserve fragile evidence and prepare a foundation for future physical tourism routes.

The development of military tourism in Ukraine, however, raises a number of ethical questions. The first concern is respect for the victims. Military tourism cannot turn human suffering into entertainment or a commercial spectacle. Proper regulation, professional guides, and memorial standards are required to ensure that tours emphasize education, remembrance, and cultural understanding. Another ethical issue is safety. Many areas of Ukraine remain contaminated with unexploded ordnance and mines. Post-war demining will be a major prerequisite for developing any tourism infrastructure. Without safe zones, regulated access points, and government oversight, military tourism could pose significant risks.

Another challenge is the emotional impact on residents. Many Ukrainians experienced occupation, loss, and destruction. Transforming their neighborhoods into tourism sites requires careful dialogue and community participation. International experience shows that communities must be involved in planning, as they are the primary guardians of memory. Military tourism should therefore not exploit trauma but rather support recovery, commemoration, and local economic development (Ткаченко, 2023).

Despite challenges, military tourism has significant economic potential. After Israel, Bosnia and Herzegovina, Vietnam, and Germany ended their wars, military tourism contributed substantially to their post-conflict economies. Visitors came to understand history, study military strategies, explore museums, and witness reconstruction. For Ukraine, military tourism may become a powerful driver for rebuilding local economies, supporting museums, creating jobs for guides, and promoting regional development. Cities that suffered the most destruction could use military tourism as part of their recovery strategy, balancing historical memory with modern reconstruction projects.

In the long term, Ukraine may develop national military tourism routes, including memorial parks, museums dedicated to the Russian-Ukrainian war, restored fortifications, preserved trenches, virtual simulation centers, and educational hubs. Modern architectural approaches may be used to design memorial complexes that combine digital technologies, interactive exhibitions, and educational programs. Partnerships with international institutions such as UNESCO, ICOMOS, and global universities could enhance the authenticity and historical quality of these projects.

Conclusion. Military tourism in Ukraine is a future-oriented field with complex ethical, educational, and economic dimensions. Although active warfare limits current development, the foundations for post-war military tourism are already being formed through documentation, preservation, and digital memorialization. With proper planning, safety measures, and respect for historical memory, Ukraine can transform sites of tragedy into powerful spaces of education, reflection, and international understanding. Military tourism will play an important role in ensuring that the events of this war are remembered accurately and respectfully, contributing to both national healing and global awareness.

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DIGITAL AND VIRTUAL TOURISM IN UKRAINE

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Introduction. Digital and virtual tourism has become one of the fastest-growing segments in Ukraine’s tourism industry, particularly after the full-scale

Russian invasion began in 2022. While traditional tourism was severely affected by security concerns, infrastructure damage, and the decline of international travel flows, digital formats have provided an alternative means of cultural preservation, tourism promotion, and international engagement. Digital tourism refers to the use of online platforms, interactive applications, digital maps, and social media to promote destinations and create immersive user experiences. Virtual tourism encompasses technologies such as 3D reconstruction, 360-degree tours, VR/AR environments, and interactive historical simulations, enabling users to explore cultural sites remotely. In wartime Ukraine, these innovative approaches have not only compensated for the loss of physical tourism but have also served as tools of cultural diplomacy and global awareness.

The rapid rise of virtual tourism in Ukraine began with the digitization of cultural heritage sites. Museums, local communities, and digital volunteers created virtual tours of cities such as Kyiv, Lviv, Odesa, Kharkiv, and Chernihiv, allowing users to experience architectural landmarks despite physical restrictions. A number of Ukrainian museums launched online exhibitions, enabling international visitors to explore collections digitally. For example, virtual reconstructions of UNESCO-listed sites and historic churches became popular educational resources. Digital mapping projects and 3D scanning initiatives also played a crucial role in documenting cultural heritage that was at risk due to military actions. Thus, virtual tourism became both an educational tool and a method of preserving national heritage under threat.

Another important area of development has been the creation of virtual reality experiences that help international audiences understand the impact of war on Ukrainian society. Several digital storytelling projects use VR to demonstrate destroyed cultural sites, simulate pre-war cityscapes, or show comparisons between past and present. Such initiatives help global communities visualize the scale of losses and build empathy. They also act as a bridge between Ukraine and the world, promoting cultural understanding and encouraging support for reconstruction efforts. Online travel platforms, social media campaigns, and virtual walking tours of

Ukrainian cities have attracted millions of views, proving that virtual engagement can maintain global interest in Ukraine even during wartime.

In addition, digital tourism has empowered domestic users. Since physical travel is restricted in many regions, Ukrainians increasingly use virtual tours to explore cultural heritage and educational sites. Digital platforms have become important resources for schools, universities, and cultural institutions, allowing them to continue providing access to educational content. Moreover, small businesses and local tourism operators have shifted to online promotion strategies, using digital marketing, social media storytelling, and user-generated content to maintain visibility. Online events such as virtual festivals, digital heritage tours, and interactive historical lectures have become common substitutes for traditional tourism activities.

Despite these achievements, digital and virtual tourism in Ukraine also faces significant challenges. The first challenge is the uneven level of digitalization across regions. While major cities such as Kyiv and Lviv have developed advanced digital infrastructure, smaller towns and rural areas lack resources for high-quality digital content creation. The second challenge is financial: many institutions operate with limited budgets, making it difficult to invest in VR equipment, software, or professional digitization services. The war has intensified these issues, with cultural institutions redirecting their resources toward preservation and emergency needs.

Another challenge concerns technological accessibility. While virtual tourism is available online, not all users have access to high-speed internet or modern devices capable of supporting VR experiences. This creates a digital divide, particularly among older populations and internally displaced persons. Additionally, content quality varies significantly—some virtual tours are highly professional, while others remain basic, limiting their global competitiveness.

Nevertheless, the wartime context has also presented new opportunities. Digital tourism has become a platform for raising international awareness about Ukraine’s cultural heritage and its destruction by war. Many global audiences

discover Ukrainian cities, cultural sites, and traditions through virtual formats, strengthening cultural diplomacy. Furthermore, virtual tourism can play an essential role in future post-war reconstruction: digital models and 3D scans are already being used to document damaged sites, helping architects and preservationists plan restoration. When physical tourism eventually resumes, digital platforms will support marketing campaigns, route planning, and smart tourism initiatives (Герасименко, 2021).

Looking forward, the development of digital and virtual tourism in Ukraine is expected to continue. Key priorities include improving technological infrastructure, expanding the digitization of museums and heritage sites, training specialists in VR/AR technologies, and creating partnerships between government institutions, educational organizations, and the IT sector. The integration of artificial intelligence may also transform digital tourism, enabling personalized virtual tours, automated translations, and interactive cultural guides. Another important direction is the promotion of Ukraine's digital heritage internationally through global tourism platforms, virtual museums, and multicultural educational programs.

Conclusion. Digital and virtual tourism have become not only innovative forms of cultural experience but also strategic tools for Ukraine during wartime. They preserve cultural identity, support educational needs, raise global awareness, and prepare the foundation for future tourism revival. While challenges remain, the progress achieved since 2022 demonstrates the resilience and creativity of Ukrainian institutions and digital communities. The continued development of digital tourism will help Ukraine maintain its cultural presence globally and ensure that its heritage remains accessible, protected, and valued regardless of physical limitations.

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DEVELOPMENT OF TOURISM DURING WAR: CHALLENGES AND NEW TRENDS

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Introduction. War is a profound shock to a nation, affecting its economy, population, infrastructure, and international image. For the tourism sector — which thrives on stability, safety, and freedom of movement — armed conflict represents one of the most severe and complex crises. The Russian full-scale invasion of Ukraine in 2022 has dramatically reshaped the country's tourism industry. Traditional tourism has largely stalled, but at the same time, the war has stimulated innovation and new kinds of travel that reflect resilience, remembrance, and adaptation. In this context, tourism in Ukraine is not only an economic sector but also a cultural and social tool: it helps sustain local communities, preserve memory, and build a narrative for the future.

Challenges of Tourism During War

1. *Security Risks.* The first and most pressing issue is physical safety. Active combat, missile strikes, minefields, and general instability make large parts of the country inaccessible or dangerous for both domestic and international tourists.

2. *Infrastructure Damage.* Roads, airports, railways, hotels, and cultural sites are often damaged or destroyed. Such destruction disrupts not just tourist access but the basic functioning of the tourism industry.

3. *Economic Constraints.* Tourism depends on people having disposable income. With war, many individuals prioritize essential needs; inflation, currency volatility, and economic instability reduce spending on "non-essential" things like travel.

4. *Psychological Barriers.* The constant threat of violence, uncertainty, and trauma discourages people from traveling. Even in safer regions, the mental burden of war can reduce demand for leisure tourism (Гавриліна, 2024)

New Trends and Opportunities in Wartime Tourism

Despite the many obstacles, war also drives the creation of new tourism models adapted to wartime realities:

1. *Domestic and Local Tourism.* Travel within safer regions of Ukraine has increased. Local communities, especially in the west and in less-affected rural areas, are developing rural, eco, and cultural tourism. This helps sustain local economies, supports displaced people, and reinforces local identity.

2. *War, Memorial, and Historical Tourism.* The conflict has created a strong interest in war-related tourism: visits to memorials, battlefields, destroyed or reconstructed cities, and museums. This "tourism of memory" allows both Ukrainians and visitors to engage with the history and trauma of the war.

3. *Digital and Virtual Tourism.* When physical travel is limited, virtual experiences gain importance. Virtual tours, interactive maps, and augmented/virtual reality (VR) experiences of cultural heritage sites or cities affected by war help maintain global interest and connect people to Ukraine's story.

4. *Socially Responsible and Volunteer Tourism.* Some tourists combine travel with volunteering: helping rebuild heritage, assisting in humanitarian projects, or participating in community initiatives. This kind of "philanthropic tourism" strengthens social cohesion and gives meaning to travel during conflict.

Specific Ukrainian Examples

– In western Ukraine (e.g., Lviv, Ivano-Frankivsk, Zakarpattia), domestic tourism has seen a growth: people visit the Carpathian Mountains, castles, and safe cultural sites.

– Cultural institutions in relatively safe regions have adapted: museums run exhibitions themed on war, memory, and resilience.

– Universities and NGOs have launched virtual-tourism platforms to show Ukrainian landmarks and historical places online.

– There is a growing academic and policy interest in *military tourism*: for example, the Kyiv region is being studied for war-tourism potential, like battlefield tours and museum complexes.

Strategic Directions and Challenges for the Future

1. *State Support and Policy.* Ukraine needs strong government policies to support tourism in wartime: tax incentives, financial support for damaged businesses, and reconstruction funds directed at tourist infrastructure.

2. *Safe Corridors and Tourist Routes.* Developing "safe tourist routes" within the country is vital – mapping destinations that are secure but meaningful, creating regional clusters that can sustain tourism.

3. *Investing in Innovation.* Digital tourism (virtual tours, hybrid experiences) should be further developed and promoted internationally to keep Ukraine on the global tourist map, even if physical travel remains limited.

4. *Education and Workforce Training.* Tourism workers need retraining in new forms of tourism: memorial tourism, volunteer tourism, digital services, and crisis management (Божко, Холодок, 2022).

Conclusion. War deals a heavy blow to tourism, especially in terms of safety, infrastructure, and economic viability. However, in Ukraine, the conflict has also catalysed creative and resilient responses: a shift to domestic and memorial tourism, a surge in digital experiences, and socially responsible travel. For tourism to not only survive but also contribute to recovery, there must be a coordinated effort from the government, the private sector, and local communities. Tourism in wartime can become more than a source of income – it can be part of collective healing, national identity, and long-term reconstruction.

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ECOLOGY

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SUSTAINABLE URBAN DEVELOPMENTAS A PILLAR FOR A GREEN FUTURE

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Rapid urbanisation in the twenty-first century has created unprecedented challenges and opportunities for human settlements. By 2050, over two-thirds of the global population is expected to reside in urban areas, placing immense pressure on infrastructure, energy systems, and natural resources (United Nations, 2019). In this context, sustainable urban development emerges as a critical strategy to ensure environmental protection, social equity, and economic resilience. A green urban future relies on integrating ecological, technological, and social innovations to create cities that are both liveable and climate-resilient.

Environmental sustainability is central to the vision of future cities. Urban areas are responsible for the majority of global greenhouse gas emissions, resource consumption, and waste generation. Implementing sustainable practices such as energy-efficient buildings, renewable energy integration, and green infrastructure can significantly reduce the ecological footprint of cities. Green roofs, urban forests, and permeable surfaces improve air quality, regulate urban temperatures, and mitigate flooding risks, contributing to the overall resilience of urban ecosystems (Newman et al., 2017). Moreover, the transition to clean energy and low-emission transport systems, including electric vehicles and public transit powered by renewable sources, is essential to achieving carbon neutrality and limiting climate change impacts.

Urban planning and design play a pivotal role in promoting sustainability. Compact city models, such as the “15-minute city”, reduce travel distances, encourage walking and cycling, and decrease reliance on private vehicles (Moreno

et al., 2021). Mixed-use developments integrate residential, commercial, and recreational spaces, fostering social interaction and economic activity while optimising land use. Smart infrastructure, equipped with sensors and data analytics, enables real-time monitoring of traffic, energy consumption, and environmental conditions, allowing cities to optimise resource allocation and improve public services. Such data-driven approaches enhance efficiency and support long-term strategic planning.

Social inclusion and equity are also fundamental components of sustainable urban development. Cities must provide accessible public services, affordable housing, and equitable mobility options for all residents, including vulnerable and marginalised groups. Community engagement in planning processes ensures that development projects reflect local needs, values, and cultural heritage, enhancing social cohesion and participatory governance (Bulkeley & Betsill, 2013). Sustainable cities are not only environmentally responsible but also socially just, creating spaces where human well-being is prioritised alongside ecological health.

Economic sustainability underpins the viability of green urban futures. Investment in renewable energy, circular economy practices, sustainable transportation, and green construction generates employment, stimulates innovation, and reduces long-term costs associated with environmental degradation. By fostering a green economy, cities can simultaneously achieve economic growth and environmental stewardship, promoting a model of development that is resilient to shocks and adaptable to emerging challenges (Seto et al., 2014). The integration of sustainability principles into urban policy ensures that economic activities contribute positively to both local and global environmental goals.

Sustainable urban development is a crucial determinant for achieving a green and climate-resilient future for global society. The integration of environmental, social, and economic dimensions into urban planning enables the creation of cities that not only reduce their ecological footprint but also enhance the quality of life for residents. The implementation of renewable energy, electric and public transport

systems, green spaces, smart infrastructure, and resource management technologies contributes to lowering greenhouse gas emissions, improving air quality, and reducing noise pollution, while simultaneously promoting healthier, more livable urban environments.

The social dimension of sustainable development emphasizes equitable access to services, transportation, housing, and public spaces. Community participation in decision-making, preservation of cultural heritage, and consideration of vulnerable groups strengthen social cohesion and improve public acceptance of innovative urban projects. Therefore, sustainable urban development is not only an ecological necessity but also a social and ethical imperative in the context of rapid urbanisation.

From an economic perspective, sustainable cities support the green economy through investments in renewable energy, energy-efficient construction, and circular economy practices. These measures stimulate innovation, generate employment opportunities, and enhance the long-term resilience of urban systems to socio-economic and climate-related challenges. Cities that effectively integrate sustainability principles into their policies and planning processes have the potential to become hubs of innovation, economic growth, and environmental security while simultaneously improving the well-being of their inhabitants.

Ultimately, the future of cities depends on the decisions made today by policymakers, urban planners, and communities. Implementing sustainable development principles across all aspects of urban life – from transportation and construction to energy systems and waste management – provides the foundation for a climate-safe, inclusive, and economically viable future. Cities that successfully adopt these principles will not only serve as centers of economic and social development but will also play a pivotal role in safeguarding the planet for future generations. In this sense, sustainable urban development functions not only as a strategic tool for urban management but as a fundamental condition for global ecological security and long-term stability.

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ECOLOGY AND MODERN CHALLENGES OF DEVELOPMENT

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Ecology is a science that studies the interaction of living organisms with the environment. In modern conditions, it plays an extremely important role, since it is the ecological balance that determines the prospects for the existence of humanity and the preservation of the biosphere. However, in recent decades, human activity has caused significant changes in natural systems, and today humanity faces large-scale challenges that require immediate solutions.

One of the key environmental problems has become climate change. Greenhouse gas emissions from fossil fuel burning, industrialization, and transportation are causing the average temperature on the planet to rise. According

to the Intergovernmental Panel on Climate Change, temperatures have already risen by more than one degree Celsius compared to pre-industrial levels. This is leading to melting glaciers, rising sea levels, and more extreme weather events such as hurricanes, droughts, and floods. The consequences of these changes are felt on all continents and affect not only the environment, but also the economy and human health.

Another serious environmental threat is environmental pollution. Emissions of harmful substances from industrial enterprises and transport negatively affect the health of citizens, provoking respiratory and cardiovascular diseases. Pollution of water bodies - from chemical waste, plastic and household waste – leads to the degradation of ecosystems and a decrease in fresh water supplies. Soils also suffer from pesticides and heavy metals, which significantly reduces their fertility and poses a threat to food security. According to the World Health Organization, more than seven million people die every year from diseases caused by air pollution.

The loss of biodiversity is also of particular concern. Deforestation, poaching, urban expansion and the transformation of natural landscapes are causing the rapid disappearance of various species of flora and fauna. According to UN estimates, about one million species are threatened with extinction due to human activities. This situation leads to a disruption of the ecological balance and a weakening of the adaptive capacity of ecosystems. The loss of even one species can have ripple effects on the entire natural environment, because each organism is an integral part of the ecological chain.

Freshwater scarcity is also one of the most pressing problems of our time. Freshwater accounts for only 2.5% of the planet's total water resources, and much of it is frozen in glaciers. Population growth and the increasing use of water in industry and agriculture are creating a situation where millions of people are already facing a shortage of clean water. According to UN forecasts, by 2050, more than half of the world's population could be living in conditions of chronic water scarcity.

These problems are only individual aspects of a broader development crisis. Their solution requires joint international efforts and the introduction of environmentally friendly technologies.

To solve these problems, a systematic and integrated approach is needed. One of the key strategies is the transition to the use of renewable energy sources, in particular solar, wind, geothermal and hydropower. Such a transformation contributes to reducing dependence on fossil fuel and energy resources and, accordingly, significantly reduces greenhouse gas emissions. An equally important component is the popularization of environmental education and the development of environmental awareness among the population. Citizens should be aware that their daily actions, such as waste sorting, rational use of natural resources, and responsible consumption, play an important role in ensuring the sustainable development of the planet.

Legislative regulation is also a critical tool in environmental protection. Governments should set clear environmental standards, supervise the activities of industrial enterprises and apply effective control mechanisms, including fines for environmental violations. At the same time, it is necessary to create and actively implement the principles of a circular economy, which involves the reuse of materials, recycling of waste and rationalization of resource consumption. Such an approach not only reduces the burden on the natural environment, but also serves as a catalyst for the emergence of new opportunities for economic development.

Environmental problems in Ukraine have their own specifics. For example, in industrial regions such as Donbas and the Dnieper region, air and water pollution are widespread. In the Carpathian region, large-scale deforestation continues, causing soil erosion and a decrease in biodiversity. Steppe zones continue to suffer from soil degradation due to excessive use of agrochemicals. At the same time, Ukraine has significant potential for the development of "green" energy, the expansion of ecotourism and the introduction of modern technologies for environmental

purification. Among the successful examples are the construction of solar power plants, the development of wind energy and forest restoration projects.

The future of environmental security in Ukraine and the world depends on close cooperation between states, scientists, business and citizens. Only joint efforts will allow us to overcome global challenges and ensure sustainable development. Environmental science is the key not only to preserving nature, but also to shaping the prospects for the existence of humanity.

Solving environmental problems is possible only with a comprehensive approach that includes international cooperation, conscious participation of citizens, progressive government policies and active implementation of innovative technologies. The future of the planet depends on how quickly humanity can change its habits and switch to an environmentally responsible lifestyle.

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PROBLEM OF MUNICIPAL WASTE SORTING AND DISPOSAL IN UKRAINE

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Introduction

The problem of household waste is global and particularly acute in Ukraine. More than 10 million tons of municipal solid waste are generated annually in the

country, yet over 90% of it continues to end up in landfills and dumps, many of which do not comply with safety standards (Verkhovna Rada of Ukraine, 2022). This situation creates numerous risks, including soil, surface, and groundwater contamination, the formation of toxic gases and leachates, uncontrolled fires, and chronic threats to human health.

A particularly critical issue is the absence of an effective system for separate waste collection. While the recycling rate in EU countries reaches 50–60%, in Ukraine it averages only 3–8%. This results in the loss of valuable secondary raw materials and economic opportunities.

In recent years, attempts have been made to implement structural reforms and align national legislation with EU Directives as part of the European integration process (Cabinet of Ministers of Ukraine, 2017). However, the practical implementation of these reforms remains fragmented. Russia's military aggression has only exacerbated the waste management crisis: construction waste volumes have increased, infrastructure has been damaged, and local communities face limited financial resources.

1. Regulatory and Legal Framework of Waste Management in Ukraine

In 2023, the Law of Ukraine "On Waste Management" No. 2320-IX entered into force (Verkhovna Rada of Ukraine, 2022). It represents a key milestone of the reform and harmonizes Ukrainian legislation with EU directives. The law provides for:

• a transition from the "collect–transport–dispose" model to the waste management hierarchy;

• the introduction of extended producer responsibility (EPR);

• mandatory separate collection of waste by fractions: paper, glass, plastic, metal, organics;

• the creation of a national electronic waste registry;

• landfill modernization requirements in accordance with EU norms.

The National Waste Management Strategy until 2030 is also in force (Cabinet of Ministers of Ukraine, 2017), defining the following objectives:

• reducing landfilling to 50%;

• constructing more than 200 sorting lines;

• developing a regional network of recycling enterprises;

• introducing local-level organic waste composting.

Despite the existence of a solid regulatory framework, implementation mechanisms are still not fully operational.

2. Current State of Household Waste Sorting and Disposal

2.1. Low Recycling and Reuse Rates

Only 3–8% of household waste in Ukraine is recycled or composted. The vast majority is disposed of in landfills, contrary to EU environmental principles (Chebotarova et al., 2025).

Main reasons:

• insufficient number of sorting facilities;

• lack of regional integrated recycling centers;

• an underdeveloped market for secondary raw materials;

• low quality of sorted materials due to improper separation by residents

2.2. Landfills and Illegal Dumpsites

There are approximately 5,500 official landfills and dumpsites in Ukraine (Verkhovna Rada of Ukraine, 2022), many of which:

• are overfilled;

• lack soil isolation;

• are not equipped with leachate and biogas collection systems;

• pose fire hazards.

In addition to official sites, thousands of illegal dumps emerge due to weak enforcement, low fines, and underdeveloped municipal infrastructure.

2.3. Problems with Sorting Infrastructure

In most cities, sorting is limited to containers for plastic or glass, yet:

• containers are frequently overfilled;

• waste is mixed again during transportation;

• recyclable materials become contaminated with organics, hindering processing.

In rural areas, infrastructure is almost nonexistent – residents must transport waste themselves or burn it, contributing to air pollution.

3. Social and Economic Barriers

3.1. Low Environmental Awareness

According to sociological surveys, only 25–30% of Ukrainians consistently sort at least one type of waste. Many believe sorting is pointless, claiming that "everything gets mixed in the truck anyway" (Chebotarova et al., 2025).

3.2. Lack of Economic Incentives

Mechanisms that have proven effective in EU countries are still not widespread in Ukraine:

• deposit-return schemes for containers;

• PAYT (pay-as-you-throw) models;

• reward programs for sorting.

4. Environmental Consequences of Ineffective Waste Management

• Soil and water pollution caused by toxic leachates from landfills.

• Distribution of heavy metals, microplastics, and pathogens.

• Emission of methane—one of the most potent greenhouse gases.

• Landfill fires, leading to the release of dioxins and carcinogens.

• Reduced recreational value of territories and a decline in quality of life.

5. Possible Solutions to the Problem

5.1. Infrastructure Measures

• construction of modern regional waste processing complexes;

• development of organic waste composting stations;

• modernization of existing landfills;

• establishment of eco-points for residents.

5.2. Governance and Legislative Reforms

• full implementation of EPR systems (packaging, electronics, batteries);

• introduction of deposit-return systems (bottles, aluminum cans);

• fines for mixing separately collected waste;

• state control over illegal dumpsites.

5.3. Educational and Communication Measures

• environmental education in schools and universities;

• municipal sorting awareness campaigns;

• transparency of waste flow data (electronic tracking systems).

5.4. Economic Incentives

• reduced tariffs for households that sort waste;

• preferential loans for recycling enterprises;

• EU grants and investment programs;

• support for innovations (plastic recycling, biofuels, RDF).

Conclusions

Household waste sorting and disposal remain among the most problematic areas of environmental policy in Ukraine. Despite progress in legislation, practical changes occur slowly: infrastructure is outdated, landfills are overloaded, and recycling rates remain critically low. Solving this problem requires a comprehensive approach that combines infrastructure modernization, economic incentives, educational initiatives, and effective public policy. The development of the secondary raw materials market and full implementation of EU environmental standards will enable Ukraine to transition to sustainable resource management and reduce the negative impact of waste on the environment and public health.

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ECOLOGY CLIMATE CHANGE: A GLOBAL CHALLENGE

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Climate change is the most urgent environmental issue facing humanity. It is primarily caused by the increasing concentration of greenhouse gases, especially carbon dioxide and methane, in the atmosphere. These gases trap heat, raising the global temperature and leading to consequences such as:

- melting glaciers and rising sea levels
- stronger hurricanes and heatwaves
- droughts and water shortages
- loss of habitats
- extinction of climate-sensitive species

Climate change affects not only nature but also human health, agriculture, and economic stability. Ecologists play a crucial role in studying the effects of climate change and developing strategies to reduce greenhouse gas emissions. Renewable energy, efficient public transportation, sustainable agriculture, and reforestation are key tools in combating global warming.

Sustainable Development and Ecological Responsibility

Sustainable development is a concept that aims to meet the needs of the present without compromising the ability of future generations to meet their own needs. It focuses on balancing economic growth, environmental protection, and social well-being. To achieve sustainability, society must:

- transition to renewable energy sources
- reduce waste and promote recycling
- improve water and energy efficiency
- protect natural habitats
- develop green technologies
- educate the population about environmental responsibility

Governments, businesses, and individuals all play a role in sustainability. Policies such as environmental regulations, national parks, and recycling programs help preserve natural resources. Corporations can reduce their ecological footprint by using eco-friendly materials and optimizing production processes. Individuals can contribute through everyday habits, such as reusable bags, energy-saving appliances, and responsible consumption.

The Role of Individuals in Protecting the Environment

While global problems require large-scale solutions, individual actions remain important. Small changes in daily behavior can collectively make a significant impact. Each person can:

- reduce plastic use
- recycle household waste
- save electricity and water
- use public transportation or bikes
- buy environmentally friendly products
- support environmental charities and initiatives

Education is also essential. When people understand how their choices influence the environment, they are more likely to adopt sustainable habits. Schools, media, and community programs can help raise ecological awareness.

Conclusion

Ecology teaches us that all life on Earth is deeply connected. The health of the planet depends on the balance of ecosystems, the protection of biodiversity, and the responsible use of natural resources. As environmental challenges grow more serious, humanity must act collectively to protect nature and ensure a sustainable future. By understanding ecological principles and taking informed steps, we can preserve the planet for ourselves and for generations to come.

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HEALTH, MEDICINE AND VETERINARY MEDICINE

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AI-ASSISTED EARLY DIAGNOSIS OF CARDIOVASCULAR DISEASES

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Heart diseases are problems with the heart and blood vessels. Every year, millions of people die from heart attacks, strokes, and heart failure. Early diagnosis is very important because it can save lives. Artificial Intelligence (AI) is a computer system that can learn from data and help doctors find heart problems early. AI can read medical tests, pictures of the heart, and other patient information. It can find small problems that humans may not see.

Heart diseases include heart attack, stroke, heart failure, irregular heartbeat, and valve problems. Many people have no symptoms at first. Sometimes they feel tired, weak, or short of breath. If doctors find the disease too late, it can be very serious. Early diagnosis is very important. Doctors can check risk factors like high blood pressure, high cholesterol, diabetes, obesity, smoking, and family history.

Medical professionals typically employ a variety of diagnostic tools, including electrocardiograms (ECGs), echocardiograms, computed tomography (CT) scans, and blood tests to check patients. It is a lot of work, and humans can make mistakes. AI helps because it works very fast and can check many tests at the same time. AI works in several steps. First, it collects data from patient tests and medical history. Second, it is trained with many examples of healthy and sick patients. Third, AI is tested with new data to see if it works correctly. Finally, it gives a prediction, like «high risk of heart disease» or «normal condition». The doctor checks the AI results and decides the next steps.

For example, in the United States, a 55-year-old man with high blood pressure and mild chest pain went to a hospital. The doctor took ECG and blood

tests. AI analyzed the data and said there was a high risk of heart disease. The doctor did more tests and found a small blockage in the heart. The patient started treatment early. AI helped prevent a heart attack.

In Germany, a 40-year-old woman with diabetes had no symptoms. AI read her ECG and lab results and noticed unusual patterns. The doctor checked carefully and found early signs of heart disease. She started treatment and changed her lifestyle. Without AI, the disease might have gone unnoticed for years.

In India, hospitals use AI to predict heart disease risk for thousands of patients using both lab tests and lifestyle information. AI helped identify many high-risk patients who would not have been noticed otherwise. Early treatment and lifestyle changes reduced the number of heart attacks in these patients.

In Japan, a hospital in Tokyo used AI to monitor elderly patients remotely. The AI analyzed daily heart rate, blood pressure, and oxygen levels. One patient, an 80-year-old man, showed unusual heart patterns. The hospital called him immediately, and doctors found a serious heart condition that needed urgent care. AI saved his life.

In Brazil, researchers used AI to analyze heart images and predict heart failure in patients with no symptoms. They found that AI could detect small changes in the heart before any doctor could notice them. This early detection allowed patients to start treatment earlier, reducing hospital admissions.

Real studies show that AI is effective. One study reached 92% accuracy in detecting heart problems. Another study showed that AI can alert doctors 10-15 minutes before a heart event. AI can read heart pictures and detect valve problems with very high accuracy. Deep learning, a type of AI, uses neural networks to read images. AI can also analyze ECG signals and heart sounds to find disease. AI can combine information from blood tests, images, heart sounds, and lifestyle data. This is called «risk prediction». Doctors can start treatment early, and patients can change habits to avoid serious problems.

AI is fast, accurate, and consistent. It can check hundreds of tests in seconds. It helps doctors make better decisions. AI is useful in hospitals with few specialists.

However, AI also has limitations and problems. First, it needs good data. If patient information is wrong or incomplete, AI may give incorrect results. Second, many AI systems work as a «black box», which means doctors do not always understand how AI makes its decisions. This can make it hard to explain to patients and reduce trust. Third, patient privacy is very important. AI needs access to personal health data, and not all hospitals have strong data protection. Fourth, AI systems are expensive, and not every hospital can afford them. Finally, there are legal and ethical questions: if AI gives a wrong diagnosis, who is responsible?

AI is interesting because it can learn from mistakes. Every time it sees new data, it becomes smarter. AI can also compare patients from many countries and learn patterns that doctors may not know. This is useful for rare diseases. Some rare heart problems are difficult to find, but AI can help detect them.

The future of AI in medicine is very promising. AI may work with smartwatches to check heart health all the time. It may combine data from images, blood tests, genetics, and lifestyle to predict heart disease better. In the UK, some hospitals are testing AI systems that combine genetic data with ECG and blood tests to predict heart attack risk years in advance. AI and doctors working together can prevent many heart attacks and save lives. AI is a tool to help doctors, not replace them.

Interesting facts: heart disease can sometimes be detected from unusual signs in the eyes. AI can analyze retinal images and find changes in blood vessels that show early heart problems. Some AI systems can even predict heart disease from voice recordings. Scientists found that small changes in a person’s voice may indicate heart problems before other symptoms appear.

In the near future, AI might become an essential part of every hospital. It will not only diagnose diseases but also predict them before they appear. For example, AI could analyze daily smartwatch data and warn users about potential

heart issues weeks or even months before symptoms. Many tech companies are already creating portable AI-based ECG scanners that people can use at home. They will connect to doctors online, allowing early medical help even in remote areas.

AI might also personalize treatment. Instead of one plan for all, AI will create unique therapy plans based on a person's DNA, age, diet, stress level, and environment. Such personalized medicine could significantly increase survival rates and reduce hospital costs. Moreover, AI will help in heart surgery. Robotic systems powered by AI will guide surgeons during complex heart operations, improving precision and reducing recovery time. AI will also help design artificial hearts and smart pacemakers that adapt to a patient's condition in real time.

Governments around the world are already investing in «AI cardiology programs». For example, in South Korea, national health insurance supports AI-based health screening, and in Canada, AI predicts which patients may develop hypertension in five years. These initiatives prove that AI will soon be an everyday medical assistant. AI could also change medical education.

Future doctors may train together with AI simulators that recreate thousands of virtual patients. Students will practice diagnosing and treating heart diseases using real medical data from around the world. This will make future healthcare faster, safer, and more intelligent.

In conclusion, AI helps doctors find heart problems early. It can read tests, pictures, and patient data. It works fast and finds small changes humans may not see. AI improves accuracy and supports doctors. Problems exist, but with good data and careful use, AI can save many lives. AI is not only a tool, it is a partner for doctors and patients. AI is already changing medicine and will continue to do so in the future.

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INTEGRATED ZOONOTIC SURVEILLANCE AND ONE HEALTH STRATEGIES: STRENGTHENING HUMAN-ANIMAL HEALTH SYSTEMS IN THE POST-PANDEMIC ERA

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Zoonotic diseases – those transmitted between animals and humans – account for over 60% of emerging infectious threats globally. This article explores the integration of One Health strategies into zoonotic disease surveillance systems, emphasizing the need for cross-sectoral collaboration between human medicine, veterinary science, and environmental health. Drawing on case studies from Uganda, Ukraine, and Southeast Asia, it analyzes how data harmonization, early warning systems, and joint outbreak response can improve resilience and reduce transmission risks. The article concludes with recommendations for policy alignment, workforce training, and digital infrastructure to support sustainable One Health implementation.

The COVID-19 pandemic underscored the urgency of addressing zoonotic disease threats through coordinated, interdisciplinary approaches. Zoonoses such as avian influenza, rabies, brucellosis, and leptospirosis continue to pose significant risks to public health, livestock productivity, and biodiversity. Fragmented surveillance systems and siloed responses have historically hindered timely detection and containment.

The One Health framework – which recognizes the interconnectedness of human, animal, and environmental health – offers a holistic model for managing zoonotic risks. By integrating veterinary epidemiology, clinical medicine, and ecological monitoring, One Health enables early identification of spillover events, coordinated outbreak response, and shared data platforms.

This article investigates how integrated zoonotic surveillance systems can be designed and implemented to strengthen health security. It focuses on practical strategies for harmonizing data, training cross-sectoral teams, and deploying digital tools to support real-time decision-making.

Effective zoonotic surveillance requires a multi-tiered system that captures data from diverse sources and translates it into actionable insights. Key components include:

- Sentinel surveillance networks: Monitoring high-risk populations such as livestock, wildlife, and rural communities for early signs of disease emergence.

- Laboratory integration: Linking veterinary and human diagnostic labs to enable cross-species pathogen detection and genomic analysis.

- Digital reporting platforms: Mobile apps and cloud-based dashboards that allow veterinarians, clinicians, and field workers to report cases in real time.

- Geospatial mapping tools: Visualizing outbreak hotspots and ecological risk zones to guide targeted interventions.

- Interoperable data standards: Ensuring that health records, lab results, and environmental data can be shared across ministries and agencies.

In Ukraine, for example, the integration of veterinary field data with public health reporting during anthrax outbreaks has improved response coordination. In Uganda, community-based animal health workers use mobile platforms to report suspected zoonoses, triggering rapid investigation and containment.

Several regions have pioneered One Health strategies to address endemic and emerging zoonoses:

- Uganda: The Ministry of Health and Ministry of Agriculture jointly operate a One Health platform that coordinates rabies vaccination campaigns, wildlife monitoring, and outbreak response.

- Ukraine: Post-2022, veterinary and human health services have collaborated on brucellosis and leptospirosis surveillance in conflict-affected zones, supported by EU-funded digital infrastructure.

- Thailand and Vietnam: Integrated avian influenza surveillance combines poultry farm inspections, wild bird monitoring, and hospital-based respiratory illness tracking.

These initiatives demonstrate the value of cross-sectoral governance, community engagement, and international support. They also highlight challenges such as data fragmentation, workforce shortages, and limited funding for veterinary public health.

Integrated zoonotic surveillance is essential for preventing future pandemics and safeguarding both human and animal health. The One Health approach provides a robust framework for aligning policies, sharing data, and coordinating responses across sectors.

To scale these efforts, countries must invest in:

- Workforce development: Training veterinarians, clinicians, and environmental scientists in joint outbreak investigation and risk communication.

- Digital infrastructure: Building interoperable platforms that support real-time reporting, analytics, and geospatial visualization.

- Policy harmonization: Aligning legal frameworks and funding mechanisms to support sustained collaboration.

- Community participation: Engaging farmers, pet owners, and wildlife stakeholders in surveillance and prevention efforts.

Ultimately, the resilience of health systems depends on their ability to anticipate, detect, and respond to zoonotic threats in an integrated, inclusive, and evidence-based manner. One Health is not a theoretical ideal – it is a practical necessity in the post-pandemic world.

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CROSS-SPECIES ANTIMICROBIAL STEWARDSHIP: INTEGRATING HUMAN AND VETERINARY STRATEGIES TO COMBAT RESISTANCE

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Antimicrobial resistance (AMR) poses a growing threat to global health, affecting both human and animal populations. This article explores the integration of human and veterinary medicine in antimicrobial stewardship programs, emphasizing the need for coordinated surveillance, prescription practices, and public education. Drawing on case studies from the European Union, Kenya, and Ukraine, it analyzes how cross-sectoral collaboration can reduce resistance rates, preserve drug efficacy, and protect food systems. The article concludes with recommendations for harmonized guidelines, One Health policy frameworks, and digital tools to support sustainable antimicrobial use.

Antimicrobial resistance (AMR) is a complex, transboundary challenge that undermines the effectiveness of life-saving treatments across species. In both human and veterinary medicine, the overuse and misuse of antibiotics have accelerated the emergence of resistant pathogens, threatening clinical outcomes, animal welfare, and food safety.

Historically, human and veterinary sectors have operated in parallel, with limited coordination in surveillance, regulation, and education. However, the One Health approach – which recognizes the interconnectedness of human, animal, and environmental health – offers a framework for integrated antimicrobial stewardship. By aligning prescription practices, monitoring resistance trends, and promoting responsible use, cross-species strategies can mitigate AMR and safeguard public health.

This article investigates how joint stewardship programs can be designed and implemented, focusing on policy alignment, diagnostic innovation, and behavioral change. It highlights the importance of interdisciplinary collaboration and data harmonization in building resilient health systems.

Effective antimicrobial stewardship begins with robust surveillance systems that track resistance patterns across species and sectors. Key components include:

- Integrated AMR databases: Linking veterinary and human laboratory data to identify emerging resistance hotspots.

- Prescription audits: Monitoring antibiotic use in hospitals, clinics, and farms to detect inappropriate prescribing.

- Rapid diagnostics: Deploying point-of-care tools to distinguish bacterial from viral infections, reducing unnecessary antibiotic use.

- Guideline harmonization: Developing unified treatment protocols for common infections in humans and animals.

In the European Union, the European Surveillance of Veterinary Antimicrobial Consumption (ESVAC) complements human AMR monitoring, enabling joint policy responses. In Kenya, community-based animal health workers are trained to follow standardized treatment guidelines, reducing indiscriminate antibiotic use in livestock. Ukraine's post-2022 health reforms include digital prescription tracking and veterinary reporting systems to improve transparency and accountability.

Reducing AMR requires not only technical solutions but also cultural and behavioral shifts. Public awareness campaigns, professional training, and regulatory enforcement play critical roles in shaping antimicrobial use.

- Public education: Informing consumers about the risks of self-medication, over-the-counter antibiotics, and meat from animals treated with growth-promoting antimicrobials.

- Professional training: Equipping physicians, veterinarians, and pharmacists with stewardship competencies and diagnostic skills.

- Policy enforcement: Banning non-therapeutic antibiotic use in agriculture and incentivizing compliance through certification schemes.

- Digital stewardship tools: Mobile apps and dashboards that guide prescribing decisions and track usage trends.

Case studies show that multilingual, culturally adapted campaigns are more effective in changing behavior. In Ukraine, veterinary schools have introduced stewardship modules, while public health agencies collaborate with agricultural stakeholders to promote responsible farming practices.

Antimicrobial resistance is a shared challenge that demands shared solutions. By integrating human and veterinary medicine through coordinated stewardship programs, health systems can reduce resistance rates, preserve drug efficacy, and protect both patients and animals.

To advance this agenda, countries must invest in:

- Surveillance infrastructure: Building interoperable platforms that capture resistance data across species.

- Policy alignment: Harmonizing treatment guidelines, regulatory frameworks, and enforcement mechanisms.

- Education and outreach: Engaging professionals and the public in stewardship efforts.

- Innovation and access: Supporting research into alternative therapies, vaccines, and diagnostics.

Ultimately, the fight against AMR is not only a scientific endeavor but a societal commitment. Cross-species stewardship – grounded in One Health principles – offers a path toward sustainable, equitable, and effective antimicrobial use in the post-pandemic world.

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INTERRELATION OF MEDICINE AND VETERINARY SCIENCE WITHIN THE ONE HEALTH CONCEPT

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Medicine and veterinary science are two closely related branches of knowledge that have developed over centuries to address the health needs of humans and animals. While medicine traditionally focuses on the diagnosis, prevention, and treatment of human diseases, veterinary science is dedicated to ensuring the health of animals, including companion animals, livestock, and wildlife. Despite their different objects of study, both fields are interconnected through the *One Health* concept, which emphasizes that the well-being of humans, animals, and the environment are inseparable.

The following paper explores the scientific foundations of both medicine and veterinary science, highlights major historical and modern achievements, and explains the importance of their cooperation for global health and biological security.

Medicine is built upon a solid basis of fundamental sciences such as anatomy, physiology, biochemistry, microbiology, immunology, and pharmacology. Together,

these disciplines provide the framework for understanding how the human body functions in health and disease.

Over time, medicine has evolved into a highly specialized system of knowledge, encompassing areas such as:

- *Internal medicine* (therapy), focused on chronic and systemic conditions;
- *Surgery*, dedicated to operative treatment of injuries and diseases;
- *Pediatrics*, dealing with child health;
- *Oncology*, which studies cancers and develops targeted therapies;
- *Cardiology and neurology*, addressing diseases of the heart and nervous system.

Moreover, modern medicine is distinguished by rapid advances in technology. For example, molecular diagnostics now allow physicians to detect diseases at the genetic level, while magnetic resonance imaging (MRI) and computed tomography (CT) provide highly detailed images of internal organs. In addition, genetic engineering and gene therapy are opening possibilities for correcting inherited diseases that were once considered untreatable.

Perhaps one of the most revolutionary developments of the 21st century has been the creation of mRNA-based vaccines, most prominently against COVID-19. These vaccines not only contributed to overcoming the pandemic but also paved the way for future protection against a wide range of infectious and even oncological diseases.

Similarly, veterinary science shares much of the same scientific foundation as human medicine. Veterinary professionals must understand anatomy, physiology, pathology, microbiology, parasitology, and pharmacology, but in relation to a broad spectrum of animal species.

The major branches of veterinary science include:

- *Epizootiology* - study of infectious animal diseases and their spread within populations;
- *Parasitology* - research of parasitic organisms and their control;

- *Veterinary surgery and therapy* - clinical care for injured and diseased animals;

- *Veterinary sanitation and expertise* - ensuring that food of animal origin is safe for human consumption.

Furthermore, recent technological advances in veterinary science include the widespread use of ultrasound and X-ray diagnostics for animals, as well as PCR-based tests for detecting infections such as avian influenza, African swine fever, and canine parvovirus. Equally importantly, vaccination programs have been instrumental in controlling deadly diseases, such as rabies, which is a zoonosis (a disease shared between animals and humans).

In the 21st century, the interconnectedness of medicine and veterinary science has become more evident than ever. The *One Health* approach, promoted by organizations such as the World Health Organization (WHO), the Food and Agriculture Organization (FAO), and the World Organisation for Animal Health (WOAH), underlines that human health cannot be considered in isolation.

Indeed, diseases such as avian influenza, COVID-19 (suspected animal origin), rabies, brucellosis, and bovine tuberculosis demonstrate how pathogens can move between humans and animals, often with devastating global consequences. Therefore, controlling these diseases requires the collaboration of physicians, veterinarians, ecologists, and public health specialists.

One Health also highlights the role of environmental health. For example, pollution, climate change, and biodiversity loss directly affect both human and animal well-being. Thus, interdisciplinary collaboration is necessary to ensure sustainable health for all living beings.

Both fields share rich histories of discovery: In medicine, milestones include the invention of vaccination by Edward Jenner (1796), the development of antiseptic methods by Joseph Lister (1867), and the discovery of antibiotics by Alexander Fleming (1928). In veterinary science, significant achievements include the establishment of the first veterinary school in Lyon, France (1761), the control of

rinderpest (a deadly cattle disease) in the 20th century, and modern programs of mass vaccination for pets and livestock.

These breakthroughs not only improved human and animal health but also reshaped societies by increasing life expectancy, agricultural productivity, and global food security.

Ultimately, medicine and veterinary science, though traditionally seen as separate disciplines, are bound together by shared goals and methods. Both rely on fundamental biological sciences, use advanced diagnostic and therapeutic technologies, and aim to prevent and treat diseases. Consequently, the growing importance of the *One Health* concept demonstrates that the health of humans, animals, and the environment is inseparably linked.

In conclusion, the continued development of these sciences — through molecular biology, genetics, immunology, and biotechnology – will determine the future of global health and security. By uniting their efforts, medicine and veterinary science provide humanity with the tools to build a safer, healthier, and more sustainable world.

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THE INFLUENCE OF MICROPLASTICS ON HUMAN HEALTH

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Introduction

Microplastics, defined as plastic particles smaller than 5 millimeters, have become one of the most concerning environmental pollutants of recent decades. They originate from the breakdown of larger plastic items, synthetic clothing fibers, cosmetic products, and industrial waste. Due to their extremely small size and widespread presence, microplastics easily enter water, soil, air, and eventually the human body. Recent studies indicate that microplastics are found in drinking water, seafood, salt, bottled beverages, and even in the air we breathe. As a result, understanding the influence of microplastics on human health has become a global scientific priority.

Sources and Pathways of Microplastic Exposure

Humans are exposed to microplastics primarily through ingestion, inhalation, and skin contact. Contaminated food and water represent the most significant route of exposure. Seafood, particularly filter-feeding organisms such as mussels and oysters, contains increased concentrations of microplastics due to their ability to trap particles from seawater. Another major source is drinking water: both tap and bottled water have been shown to contain microplastic particles. Airborne microplastics, released from synthetic textiles, vehicle tires, and waste incineration, can reach indoor and outdoor environments, where they are inhaled by humans daily.

Microplastics in the Human Body

Recent research has demonstrated that microplastics can be detected in human blood, lungs, placenta, and even in breast milk. Their ability to travel through the bloodstream raises concerns about their potential to accumulate in vital organs. Nanoplastics – particles smaller than 1 micron – pose an even greater threat due to their ability to penetrate cell membranes and interact with biological structures at the molecular level.

Potential Health Impacts

Microplastics may negatively affect human health through chemical toxicity, physical irritation, and microbial contamination.

Firstly, microplastics often contain toxic additives, such as bisphenol A (BPA), phthalates, flame retardants, and heavy metals. These chemicals are known endocrine disruptors, capable of interfering with hormonal regulation, reproductive health, and metabolism. When microplastics enter the digestive system, such chemicals may leach into the body.

Secondly, the physical presence of microplastics in tissues can trigger inflammatory responses. Chronic inflammation increases the risk of cardiovascular diseases, gastrointestinal disorders, and weakened immune function.

Thirdly, microplastics frequently act as carriers of pathogenic microorganisms and environmental pollutants. Their surfaces easily attract bacteria, viruses, and toxic substances like pesticides or hydrocarbons. When microplastics contaminated with harmful agents enter the human body, they may facilitate infections or increase exposure to hazardous chemicals.

Microplastics and Long-Term Health Risks

Although the full long-term effects of microplastic exposure are not yet fully understood, emerging research suggests potential links to several serious health problems. These include oxidative stress, DNA damage, fertility disruptions, developmental abnormalities, and increased cancer risk. Vulnerable populations—such as children, pregnant women, and individuals with chronic illnesses—may face heightened risks.

Prevention and Global Response

Addressing the microplastic crisis requires coordinated international efforts. Key strategies include reducing plastic production, promoting recycling, banning microbeads in cosmetics, developing biodegradable materials, and improving water filtration systems. At the individual level, people can reduce exposure by avoiding plastic packaging, choosing natural textiles, and using high-quality water filters.

Scientific innovations continue to emerge, such as microbial degradation of plastics, nanotechnology-based filtration systems, and the development of environmentally friendly polymers. These biotechnological and engineering solutions provide promising prospects for reducing human exposure to microplastics in the future.

Conclusions

Microplastics represent a growing environmental and public health challenge. Their widespread presence in food, water, and air means that human exposure is unavoidable. Although research is still developing, existing evidence indicates that microplastics may contribute to chemical toxicity, inflammation, and long-term health disorders. Understanding the risks associated with microplastics and implementing effective prevention strategies are crucial steps toward protecting human health and ensuring a sustainable environment.

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POWER ENGINEERING

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THE FUTURE OF ENERGY: GLOBAL TRENDS AND THE UKRAINIAN PERSPECTIVE

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Energy is a cornerstone of the modern economy, powering industry, transport, infrastructure, and everyday life. A nation's energy security and efficiency are determinants of its economic stability, global competitiveness, and its citizens' quality of life. In the 21st century, the world faces pressing challenges: the depletion of traditional resources, rising energy demand, climate change, and the imperative to reduce greenhouse gas emissions. These factors make the diversification of energy sources, enhanced efficiency, and the adoption of renewable technologies critical priorities.

Currently, the global energy mix is still dominated by fossil fuels – oil, natural gas, and coal. While they remain accessible and cost-effective, their use contributes to environmental degradation and the gradual depletion of resources. Consequently, focus is shifting toward renewable energy, next-generation nuclear power, and energy storage solutions.

The share of renewables – solar, wind, hydro, and biomass – is expanding in many countries, driven by falling technology costs and active government support. Digital transformation is also playing a major role; smart grids, intelligent management systems, and automation enable more sustainable resource use. However, the electrification of industry and the proliferation of electric vehicles are increasing overall energy demand, creating new challenges for storage and transmission infrastructure.

Ukraine possesses substantial energy potential and a diversified energy mix that includes nuclear, thermal, hydro, and renewable sources. Nuclear power remains

a cornerstone of national energy independence. However, the country's energy infrastructure often requires modernization due to outdated equipment and the need to comply with contemporary safety and efficiency standards.

The sector faces several systemic issues, including high transmission losses, dependence on imported fuels, and damage to infrastructure from hostilities. Despite these challenges, renewable energy development in Ukraine continues, with new solar and wind farms, small hydropower plants, and bioenergy projects being launched, laying the groundwork for sustainable growth.

Renewables are foundational to the global transition toward sustainability. Solar panels and wind turbines can be deployed rapidly, and their costs have fallen dramatically in recent years. For Ukraine, renewable energy is of strategic importance, it reduces dependence on imported fuels and fosters regional economic development by generating jobs and attracting investment.

Bioenergy, which utilizes agricultural and industrial waste, helps mitigate environmental impact while producing energy. Hydropower remains a stable and dispatchable source, particularly in regions with developed river systems. However, scaling up renewable energy requires resolving challenges related to grid integration, balancing supply and demand, and developing efficient energy storage.

Energy storage systems are becoming a pillar of the future energy landscape. They help balance electricity supply and demand, especially when generation relies on intermittent sources like solar and wind. Modern storage solutions include lithium-ion batteries, pumped hydro systems, and advanced chemical storage technologies.

Hydrogen energy is also gaining global traction. "Green hydrogen", produced using renewable electricity, could become a universal energy carrier for heavy industry, long-haul transport, and seasonal energy storage. For Ukraine, developing a hydrogen economy opens prospects for international cooperation and export, though it demands significant investment in infrastructure and research.

Improving energy efficiency remains the most cost-effective way to reduce consumption and emissions. Modernizing buildings, adopting energy-saving technologies in manufacturing, and implementing optimized lighting, heating, and smart management systems yield substantial economic and environmental benefits.

Digitalization is transforming the energy sector. Smart meters, monitoring systems, and energy management platforms enable utilities to forecast demand, optimize generation, and prevent outages. The integration of distributed energy resources – such as rooftop solar panels or electric vehicles that can function as storage units – further enhances grid flexibility and resilience.

The shift to clean energy significantly reduces greenhouse gas emissions, improves air quality, and alleviates pressure on ecosystems. Yet, it also presents social challenges, including the transformation of traditional industries, the need to retrain workers, and ensuring a just transition for communities reliant on fossil fuels. Effective policy must integrate environmental goals with social support programs to guarantee equitable and inclusive change.

Addressing global energy and climate challenges necessitates international collaboration. For Ukraine, integration into European energy networks, diversifying supply routes, and participating in joint infrastructure projects are vital steps. Strengthening domestic renewable capacity, modernizing transmission networks, and attracting foreign investment will bolster national energy security and resilience.

The future of energy hinges on technological innovation, sound governance, and long-term investment strategies. Key priorities for Ukraine's energy transformation include:

- developing energy storage infrastructure and hydrogen technologies;
- modernizing power grids and reducing transmission losses;
- supporting renewable energy through financial incentives and guarantees;
- promoting energy efficiency in the residential and industrial sectors;
- investing in scientific research and digital innovation.

In conclusion, the global energy sector is undergoing a profound transformation aimed at reconciling economic growth with environmental stewardship. For Ukraine, this process represents both a challenge and an opportunity to strengthen energy independence, modernize infrastructure, and secure a sustainable future. Success will depend on the coordinated efforts of government, business, and civil society to build an energy system that is efficient, resilient, and environmentally sound.

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SOLAR POWER OF THE FUTURE: THE DYSON SPHERE

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As global energy consumption continues to rise, conventional terrestrial and orbital solar technologies may ultimately become insufficient. A visionary astroengineering concept – the Dyson sphere – proposes that instead of relying on the small portion of a star’s light reaching a planet, an advanced civilization could capture a substantial fraction of the star’s total radiative output through a massive megastructure (Dyson, 1960). Although hypothetical, the Dyson sphere remains a

relevant theoretical object in discussions about the long-term future of solar energy and advanced technological civilizations (Wright, 2020).

Although similar ideas appeared earlier in science fiction, most notably in Stapledon's Star Maker (Stapledon, 1937), the formal scientific foundation of the Dyson sphere was introduced by Freeman Dyson. In his 1960 paper, Dyson suggested that long-term technological development would compel civilizations to expand their energy harvesting beyond planetary surfaces and toward direct stellar capture (Dyson, 1960).

Originally, Dyson imagined a rigid spherical shell surrounding the star, but later analyses demonstrated that such a structure would be gravitationally and mechanically unstable (Wright, 2020). Consequently, contemporary models favor more realistic configurations such as the Dyson swarm – a collection of autonomous satellites orbiting the star (Smith, 2021).

A star like the Sun emits approximately 3.8×10^{26} W of power (PagerPower, 2024). Only an infinitesimal portion of this energy reaches Earth, while the rest is lost to space. A Dyson-type structure could potentially capture a dramatically larger amount of radiation, theoretically providing a near-limitless and sustainable energy supply (Wikipedia, 2023).

Capturing even a small percentage of a star's luminosity would exceed the total energy consumption of present-day civilization by several orders of magnitude. Models of Dyson swarms estimate that such systems could collect between 0.7% and 2.7% of the Sun's output depending on scale and density (Smith, 2021).

This aligns with the concept of a Type II civilization on the Kardashev scale – one that utilizes the full energy output of its star (Kardashev, 1964).

The Dyson swarm is the most accepted contemporary model: billions of autonomous photovoltaic or reflective satellites orbiting the star. This configuration avoids the mechanical instabilities inherent in a rigid shell and allows for incremental construction (Smith, 2021).

A recent analysis by Peters (2025) explores a photovoltaic Dyson sphere, in which the structure's surface is composed of solar modules that directly convert stellar radiation into electricity. While the concept is presently beyond engineering capabilities, the study demonstrates that the thermodynamic equations governing such structures are well-understood (Peters, 2025).

Wright (2023) examined Dyson spheres from a thermodynamic perspective, analyzing their potential as work extractors and computational platforms. His findings suggest that optimal Dyson spheres may be “small and hot”, maximizing efficiency per unit mass. Furthermore, multi-layered ("Matrioshka") configurations provide only marginal advantages under realistic constraints (Wright, 2023).

Constructing a Dyson sphere or swarm requires astronomical quantities of raw materials, potentially necessitating the disassembly of asteroids or even entire planets. Although swarm-based architectures significantly reduce structural requirements compared to a shell, the mass demand remains immense (Smith, 2021).

Rigid shells suffer from inherent gravitational instability and would drift uncontrollably without continuous correction (Wright, 2020). Conversely, individual swarm components must maintain precise orbits using onboard propulsion or solar sails.

Converting stellar radiation into useful energy inevitably generates waste heat. Without efficient thermal dissipation, components could overheat and fail (Wright, 2023).

Energy must be transferred from stellar orbit to inhabited regions or industrial stations, potentially through microwave or laser transmission. However, such systems introduce efficiency losses and safety challenges (Peters, 2025).

Most analyses conclude that Dyson spheres require technological maturity far beyond current global capabilities – including large-scale space manufacturing, robotics, and resource extraction infrastructure (Bars, 2024).

The Dyson sphere remains one of the most ambitious and theoretically rich ideas in astroengineering. Although its construction is far beyond current

technological capability, contemporary scientific literature – including photovoltaic, thermodynamic, and orbital modeling studies – sustains interest in the concept.

Whether or not humanity ever constructs a Dyson sphere, the idea provides a powerful perspective on the long-term future of energy acquisition, space industry, and evolutionary trajectories of advanced civilizations.

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DEVELOPMENT OF RENEWABLE ENERGY IN UKRAINE

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Renewable energy plays an essential role in shaping Ukraine's modern energy strategy. As global trends shift toward decarbonization and environmentally friendly technologies, Ukraine faces the urgent need to strengthen its energy independence while reducing greenhouse gas emissions. The country possesses significant natural resources that allow active development of solar, wind, biomass, and small hydropower sectors. Over the past decade, renewable energy has evolved from a marginal direction into a strategically important component of national economic development.

Solar energy remains one of the fastest growing sectors. Ukraine's geographic position provides sufficient solar radiation for effective operation of photovoltaic systems. The introduction of the feed-in tariff in previous years encouraged investments, leading to the construction of numerous solar power plants. Although legislative changes have reshaped financial incentives, solar energy continues expanding through household and commercial installations. Small-scale solar systems increasingly support local communities by reducing electricity costs and contributing to decentralized energy supply.

Wind power also occupies a vital position in Ukraine's renewable energy structure. Coastal regions, including the Odesa, Mykolaiv, and Zaporizhzhia areas,

possess strong and stable wind flows that enable the construction of large wind farms. Modern turbines have become more efficient, allowing higher energy output even at moderate wind speeds. International companies have demonstrated growing interest in Ukrainian wind energy, contributing to technology transfer and local employment. The development of wind energy not only diversifies the energy balance but also promotes regional economic growth by creating new infrastructure and jobs.

Furthermore, bioenergy has gained significant attention. Ukraine is one of Europe's leaders in agricultural production, which provides abundant resources for biomass and biogas generation. Agricultural waste, wood residues, and organic by-products serve as valuable fuel for modern bioenergy facilities. In many rural regions, biogas plants provide stable heating, electricity, and fertilizer production, supporting local communities and encouraging sustainable farming practices.

Small hydropower represents another promising renewable energy direction. Although Ukraine's large rivers are already heavily exploited, small hydropower plants have the potential to supply clean energy to remote or mountain regions. Advances in turbine design and river-flow optimization technologies minimize the environmental impact compared to older hydropower systems. Small hydropower networks also enable energy autonomy for local settlements and small industries.

Despite strong progress, the renewable energy sector still faces numerous challenges. Legislative instability, frequent policy changes, and financial uncertainties present obstacles for long-term investment. The revision of tariff systems created tension between investors and state authorities, emphasizing the need for transparent and predictable regulation. Grid infrastructure also requires modernization. Many renewable energy plants face technical limitations due to insufficient grid capacity, especially in southern and central regions.

Another important issue involves balancing energy production. Renewable energy sources are often dependent on weather conditions, leading to fluctuations in electricity generation. To address this, Ukraine must invest in energy storage systems, smart grid technologies, and advanced forecasting tools. International

experience demonstrates that integrating battery storage, hydrogen energy, and automated grid management significantly enhances system stability. According to Radu (2015), technological modernization is strongly linked to sustainable economic growth and national competitiveness.

In recent years, public awareness of environmental issues has grown substantially. Citizens increasingly support renewable energy initiatives, participate in energy efficiency programs, and install personal energy systems in households. This reflects a broader cultural shift toward environmental responsibility and conscious energy consumption. Educational programs, government campaigns, and international cooperation have all contributed to this trend.

Looking toward the future, renewable energy is expected to play a crucial role in Ukraine's reconstruction and economic modernization. The decentralization of energy systems will help minimize regional vulnerabilities, while green technologies will support the country's integration into European energy markets. Continued investment in infrastructure, research, and innovative technologies will be essential for long-term success.

In conclusion, renewable energy development in Ukraine represents not only an environmental necessity but also a strategic opportunity. Despite challenges, the sector demonstrates steady growth and substantial potential. Strengthening policy stability, modernizing energy infrastructure, and expanding technological innovation will allow Ukraine to build a sustainable, secure, and competitive energy future.

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PROSPECTS FOR THE DEVELOPMENT OF RENEWABLE ENERGY IN UKRAINE

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Renewable energy development has become one of the fundamental priorities for Ukraine as the country continues its integration into the European energy space and works toward strengthening its independence from fossil fuels. The transition to renewable energy sources (RES) is not only an environmental necessity but also a strategic imperative that directly affects national security, economic growth, and long-term sustainability. Over the past decade, Ukraine has witnessed impressive progress in the expansion of renewables, although this progress has been influenced by political, economic, and security challenges.

Solar energy remains the most dynamically growing sector of Ukrainian renewable energy. The geographical position of the country provides favorable conditions for the installation of photovoltaic systems, especially in southern and central regions where annual solar irradiation is relatively high. Prior to 2022, Ukraine experienced a rapid increase in solar power plants due to an attractive feed-in tariff mechanism, which made the market appealing to domestic and international investors. Even though legislative adjustments have made investors more cautious, solar energy continues to expand through decentralized systems such as rooftop installations and industrial solar roofs (Добрянська, 2020).

Wind energy also plays a significant role in Ukraine’s energy transition. Coastal regions along the Black and Azov Seas offer ideal conditions for wind farms due to stable and powerful wind flows. Several large onshore wind farms have

already proven the feasibility of this technology, and offshore wind potential remains largely untapped. Given the European Union's growing interest in offshore wind development, Ukraine may play an important role in future cross-border projects once security conditions stabilize (Добрянська, 2020).

One of the critical requirements for increasing renewable energy penetration is the modernization of Ukraine's electricity grid. Currently, the grid faces significant challenges in balancing the intermittency of solar and wind energy. Outdated infrastructure, limited balancing capacity, and insufficient integration of smart-grid technologies hinder the full utilization of RES potential. For Ukraine to progress, it is vital to invest in automated control systems, digital monitoring tools, and advanced forecasting technologies. Energy storage systems, including lithium-ion batteries, pumped hydro storage, and emerging hydrogen storage technologies, will also contribute to improving grid stability.

Bioenergy constitutes an additional strategic direction for Ukraine. Due to its strong agricultural sector, Ukraine generates a substantial amount of organic waste and agricultural residues that can be transformed into biomass and biogas. This not only provides an environmentally friendly energy source but also helps rural regions become more energy-independent. Furthermore, the development of bioenergy stimulates economic activity, creating jobs and fostering more sustainable agricultural practices. According to Ukrainian researchers, using agricultural residues could significantly reduce the country's dependence on traditional fuels, particularly natural gas.

Hydrogen energy represents a long-term vision for Ukraine's participation in Europe's clean energy transition. Ukraine's gas transmission system, one of the largest in Europe, provides a unique opportunity to transport hydrogen or hydrogen-natural-gas blends. With active support from European partners, Ukraine could become a key exporter of green hydrogen, especially to Central and Western Europe. Pilot projects exploring hydrogen production, storage, and transportation have already attracted attention, suggesting that hydrogen may become one of the most

promising strategic assets for Ukraine's future energy landscape (Добрянська, 2020).

Despite promising prospects, numerous challenges hinder the rapid expansion of *renewable energy.* Political instability, legislative uncertainty, delayed payments to renewable energy producers, and war-related destruction of energy facilities create a complex environment for investors. The full-scale invasion has severely damaged energy infrastructure, including power plants and transmission lines, demonstrating the vulnerability of centralized energy systems. However, this also opens an opportunity for rebuilding the energy sector according to modern principles of decentralization, security, and sustainability. Strengthening microgrids, emergency power systems, and distributed generation could significantly enhance Ukraine's resilience (Маммедов, 2024).

In conclusion, Ukraine possesses substantial potential for the further development of renewable energy. Natural conditions, geographical advantages, agricultural resources, and alignment with European strategies form a solid foundation for long-term growth. Solar, wind, biomass, and hydrogen technologies will play a decisive role in shaping Ukraine's sustainable future. Continued cooperation with international partners, grid modernization, and transparent energy policies are essential for unlocking this potential. As the world moves toward a low-carbon future, Ukraine has every opportunity to become an active contributor to global climate goals and a strong participant in the European energy community.

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THE FEASIBILITY AND ENERGY-EFFICIENCY OF USING WIND ENERGY

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Wind energy has increasingly become a cornerstone of the global transition toward sustainable and low-carbon electricity generation, driven by the need to address climate change, improve energy security, and reduce dependence on fossil fuels. As nations face rising energy demand and mounting environmental pressures, the shift to renewable energy sources has become not only desirable but necessary. Wind power, in particular, stands out due to its renewable nature, wide geographical availability, and the impressive technological advancements that have greatly increased its efficiency over recent decades (Hadnagy & Molnár, 2020). Unlike fossil fuels, wind resources are not subject to market volatility or depletion, making them an attractive long-term solution for stable and environmentally responsible energy production (UEEX Press Center, 2022; Eco-Cluster, 2024).

One of the most significant advantages of wind energy is its ecological sustainability. Electricity generation from wind does not produce greenhouse-gas emissions, air pollution, or toxic by-products during operation (Eco-Cluster, 2024; VDE, 2015). Numerous international studies have confirmed that increasing the share of wind power in the energy mix can substantially reduce national carbon footprints and help meet global climate targets (IPCC, 2018). When evaluated across an entire life cycle – from the manufacture of turbine components to installation,

operation, and eventual decommissioning – wind energy demonstrates markedly lower environmental impacts compared with coal, petroleum, and natural-gas-based generation (Lopushanska et al., 2024). The absence of combustion processes eliminates emissions of CO2, NOx, SO2, and particulate matter, making wind energy a key contributor to the mitigation of global warming and health-related environmental hazards (Eco-Cluster, 2024).

Economic factors further support the feasibility of wind energy. Although the initial capital cost of wind turbines, grid connection, and foundation construction is relatively high, the long-term operational expenses are remarkably low, primarily because wind is a free resource. Once installed, wind turbines require limited maintenance, and major components often have operational lifetimes exceeding twenty years (Hadnagy & Molnár, 2020). Over the past decade, the levelized cost of wind-generated electricity has decreased substantially due to larger rotor diameters, improved blade aerodynamics, advanced generator systems, and more efficient power electronics (IPCC, 2018). In many regions, wind energy has already reached cost parity with or even become cheaper than conventional energy sources (abjdrones.com, 2025). This economic competitiveness makes wind farms attractive investments for both governments and private companies, particularly in countries seeking to strengthen their energy independence (UEEX Press Center, 2022).

Wind energy development also generates significant socio-economic benefits. The construction, installation, and operation of wind farms create jobs across multiple sectors – including engineering, manufacturing, transport, logistics, environmental assessment, and maintenance services (Hadnagy & Molnár, 2020; Eco-Cluster, 2024). Many wind farms are located in rural areas where employment opportunities are limited, thus contributing to regional economic growth and community development. Wind turbines occupy relatively small land footprints, allowing continued agricultural use of land surrounding their bases (VDE, 2015). This makes wind energy compatible with existing local economies and land-use

patterns, enabling communities to benefit from energy production without sacrificing productive land.

From a technical perspective, modern wind turbines have undergone extensive optimization. Turbine efficiency is constrained by the Betz's law, which states that no turbine can capture more than 59.3% of the kinetic energy available in the wind. However, contemporary turbine designs incorporate sophisticated blade profiles, optimized pitch and yaw control systems, and highly efficient power converters, enabling them under favorable conditions to approach a significant portion of this theoretical limit (IPCC, 2018; Grokipedia, 2025). Improvements in computational fluid dynamics, materials science, and sensor technologies have contributed to more durable, reliable, and lighter turbine structures. These advancements not only improve energy capture but also reduce mechanical stress, noise, and the frequency of repairs (IPCC, 2018).

Despite these strengths, wind energy faces several challenges that must be addressed to ensure its long-term feasibility.

The most significant limitation is the inherent variability and intermittency of wind resources. Wind speed can fluctuate hourly, daily, and seasonally, which complicates the stability of electricity supply (Wikipedia, 2025). To manage this variability, modern energy systems rely on advanced forecasting techniques, grid management tools, and the integration of complementary energy sources such as hydropower or solar photovoltaics (Weitemeyer et al., 2014; Roth & Schill, 2022). Battery storage technologies – including lithium-ion and emerging solid-state systems – offer an increasingly effective means of smoothing fluctuations and providing backup power during periods of low wind activity (Zhou et al., 2025). Furthermore, advances in hydrogen production via electrolysis open new possibilities for storing surplus wind energy in the form of green hydrogen (Weber et al., 2017).

Geographical factors play a crucial role in the efficiency of wind energy systems. Not all regions experience sufficiently strong or consistent winds (Hadnagy

& Molnár, 2020). Optimal sites typically include coastal zones, elevated terrains, or open plains where wind flow is stable and unobstructed (Lopushanska et al., 2024). However, these ideal locations are often far from major urban centers, requiring the construction of high-voltage transmission lines to deliver electricity to consumers. This infrastructure can increase project costs and raise environmental or social concerns (UEEX Press Center, 2022).

Although wind energy is far cleaner than fossil fuels, the installation and operation of wind turbines can have localized ecological impacts. Turbine blades may pose risks for birds and bats, particularly in migratory pathways (Dorrell et al., 2020). Modern environmental impact assessments, proper site selection, and technological solutions such as radar-based monitoring and smart curtailment strategies can significantly reduce these risks (Lopushanska et al., 2024). Additionally, concerns have been raised regarding noise generation and the visual impact of turbines on landscapes. Advances in turbine design have reduced noise levels, and ongoing research continues to explore community-friendly solutions for siting and aesthetic integration (UEEX Press Center, 2022).

The future feasibility and efficiency of wind energy are closely tied to hybrid renewable energy systems, which combine wind with solar power, energy storage, or other technologies to create more resilient and balanced energy networks (Weitemeyer et al., 2014; Roth & Schill, 2022). Hybrid systems are particularly advantageous because wind and solar resources often complement each other: wind tends to be stronger at night or during winter, while solar power peaks during daytime or summer (Weber et al., 2017). This natural balancing effect improves the reliability and stability of electricity generation. Additionally, modern smart-grid technologies, improved inverter systems, and digital optimization tools enhance the integration of wind power into existing electrical networks, reducing transmission losses and enabling more effective demand forecasting.

Wind energy presents a feasible, increasingly efficient, and sustainable component of future energy systems. Thanks to technological advancements,

reductions in production cost, and environmental benefits, wind power is competitive with conventional energy sources in many regions. However, to fully realize its potential, challenges related to resource variability, grid integration, environmental impact, and infrastructure must be addressed. Hybrid renewable systems, modern storage solutions, and careful site planning emerge as critical strategies for overcoming these limitations. In this context, wind energy can play a central role in achieving long-term carbon reduction, energy security, and socio-economic development.

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UKRAINE'S ENERGY SECTOR DURING THE WAR

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The development of Ukraine's electricity during the war of 2022-2025 is very unstable, with massive shelling of the energy system, damaged substations, and thousands of power lines cut off. But how did it all begin, and what now? The active development of the Ukrainian people began after the Second World War; even then, the foundation for the Ukrainian energy industry was laid.

According to the Ministry of Energy of Ukraine, in the early 1920s, the GOELRO plan was developed, which aimed to introduce almost a third of new energy capacities in Ukraine. In April 1928, the First All-Ukrainian Energy Congress was convened, at which the electrification plan for Ukraine, based on the GOELRO project, was discussed. In particular, the feasibility of building a powerful

hydroelectric power station on the Dnieper and industrial power stations in Donbas was confirmed.

According to this plan, Ukraine was to put into operation, within a short period, the Shterivska, Zuivska, KRES, ESCHAR, Starobeshivska, Lysychanska and other district and industrial power plants.

By the end of 1940, the capacity of Ukrainian power plants had reached 2,630 MW, and electricity production had increased to 12.41 billion kWh. The basis of the energy sector in Ukraine was state-owned district power plants, which generated over 85% of the country's electricity. Centralization of electricity and heat production became the most significant and characteristic feature of Ukraine's energy sector development.

The development of the electric power industry and the advancement of science have underscored the need to collaborate the efforts of scientists and practitioners. Design and scientific institutes, as well as research laboratories, were created, the number of power engineering specialists in higher educational institutions increased, and the domestic power engineering industry developed. (MEV, n.d.)

In 1994, the concepts of renewable and non-traditional energy sources were first introduced in Ukraine. The memories of this term were published in the Law of Ukraine “On Energy Saving”.

In 2003, the Law of Ukraine “On Alternative Sources of Electricity” was adopted.

Table 1 Renewable energy potential in Ukraine

№	RES	Annual technical and achievable potential	
		billion kWh/year	Million t. and e./year
1	Wind energy	60	15
2	Solar energy, including:	38,2	4,2
2.1	- electric	5,7	1,4
2.2	- thermal	32,5	2,8
3	Large hydropower	20,1	4,9

4	Small hydropower	8,6	2,1
5	Bioenergy, including:	178	21,7
5.1	- electric	27	7,21
5.2	- thermal	151	14,49
6	Geothermal thermal energy	97,6	8,4
7	Environmental energy	146,3	12,6
Total volumes of FER trend shifts		548,8	68,9

(Chernyuk, Kyrysov, Cherevyk, 2021, p. 242)

The most effective indicators of bioenergy are 178 billion square meters, and environmental energy is not far behind, with a generation of 146.3 billion square meters.

The full-scale war since 2022 has radically changed the priorities of Ukraine's energy development, putting the security and sustainability of the energy system at the forefront. The energy transition strategy has been adapted to wartime conditions, with an emphasis on developing distributed generation and energy storage systems. Ukraine's energy system has begun active integration with the European electricity market, providing additional opportunities for the export and import of electricity. The private sector has received greater incentives to invest in its own energy capacity, particularly in renewable energy sources. Ukrenergo has developed new approaches to managing the energy system in the face of constant threats and the need to quickly restore damaged facilities (Ukrayinska energetyka u chas vijny, 2025).

Nuclear power remains a crucial component of Ukraine's energy security, providing affordable, reliable, and environmentally friendly electricity. The number of safely operating power plants in Ukraine is critical to the country's economic strength and energy independence.

As of April 2025, there are four nuclear power plants operating in Ukraine:

1. Zaporizhzhia NPP (6 units, under Russian occupation since 2022, partially shut down);

2. Rivne NPP (4 units, operating stably);

3. Pivdenno-Ukrainian NPP (3 units, operating at full capacity);

4. Khmelnytskyi NPP (2 units, active, 3rd and 4th planned for completion) (Diyuchi AES v Ukrayini stanom na 2025 rik, 2025).

Green energy demonstrates impressive resilience in 2025. The volume of electricity generated from renewable sources increased by 6.4% compared to 2023, reaching 11 million MWh. Ukraine entered the top 10 countries in the world in terms of the pace of renewable energy development and secured a place in the top 5 European countries for solar energy development. The sector attracted more than $12 billion in foreign direct investment, indicating the high confidence of the international community in Ukraine's green energy potential. The annual maximum production was recorded in August 2024 – 1,165 thousand MWh. The three largest green energy producers are Elementum Energy, with a capacity of 635 MW, and DTEK Renewable Energy, with a capacity of 569 MW (Zelena energetyka v Ukrayini 2025, 2025).

As reported by GOLAW: Ukraine is currently continuing to actively reform the energy sector, implementing the requirements of the EU's fourth energy package into legislation and transforming the energy industry in accordance with carbon neutrality standards. Nowadays, the country is focusing on key areas in the energy sector, including the development of nuclear energy, decentralization of electricity generation, and enhancing the physical protection of energy infrastructure facilities (Suchasnij stan ukrayinskoyi energetiki, 2024).

In general, the energy infrastructure is functioning, and most territories experience almost no discomfort from blackouts. People are massively switching to alternative power sources, reducing the load on the power grid.

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SMART GRIDS AND RENEWABLE INTEGRATION: ADVANCING POWER SYSTEM RESILIENCE IN THE DECARBONIZATION ERA

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The global transition toward low-carbon energy systems has intensified the need for intelligent, adaptive power infrastructure. This article examines the role of smart grids in integrating variable renewable energy sources (VRES) such as solar and wind into national power systems. It explores the technical architecture of smart

grids, including advanced metering infrastructure (AMI), distributed energy resource management systems (DERMS), and real-time demand response. Case studies from Germany, China, and Ukraine illustrate how smart grid deployment enhances grid flexibility, reliability, and resilience. The article concludes with a discussion of regulatory, cybersecurity, and interoperability challenges that must be addressed to ensure equitable and secure energy transitions.

The decarbonization of the energy sector is a cornerstone of global climate policy. As countries increase their reliance on renewable energy sources, power systems face new challenges related to intermittency, bidirectional flows, and distributed generation. Traditional grid architectures – designed for centralized, predictable power flows – are ill-suited to accommodate the variability and decentralization inherent in renewable energy.

In response, the concept of the smart grid has emerged as a transformative solution. A smart grid integrates digital communication, automation, and real-time analytics into the electrical infrastructure, enabling dynamic coordination between producers, consumers, and storage systems. It supports demand-side flexibility, self-healing capabilities, and grid-edge intelligence, all of which are essential for managing high shares of renewables.

This article investigates the engineering principles, deployment strategies, and policy frameworks that underpin smart grid development. It focuses on how smart grids facilitate renewable integration while enhancing system reliability, operational efficiency, and consumer participation.

Smart grids are characterized by a layered architecture that combines physical infrastructure with digital intelligence. Key components include:

- Advanced Metering Infrastructure (AMI): Enables two-way communication between utilities and consumers, allowing for real-time monitoring, time-of-use pricing, and automated billing.

- Supervisory Control and Data Acquisition (SCADA) and Energy Management Systems (EMS): Provide centralized control and visualization of grid

operations.

- Distributed Energy Resource Management Systems (DERMS): Coordinate decentralized assets such as rooftop solar, battery storage, and electric vehicles.

- Phasor Measurement Units (PMUs): Offer high-resolution data on voltage and frequency, improving situational awareness and fault detection.

- Demand Response Platforms: Allow consumers to adjust consumption patterns in response to price signals or grid conditions.

These technologies enable real-time decision-making, predictive maintenance, and automated fault isolation, significantly improving grid resilience and efficiency. Integration with machine learning algorithms and blockchain-based energy trading further enhances system adaptability.

Several countries have pioneered smart grid initiatives to support renewable integration:

- Germany: Through its Energiewende policy, Germany has deployed smart meters and virtual power plants to manage over 50% renewable penetration. The use of decentralized control and peer-to-peer energy trading has improved grid stability.

- China: The State Grid Corporation has implemented wide-area monitoring systems and AI-driven load forecasting to manage large-scale wind and solar farms in remote regions.

- Ukraine: In response to wartime disruptions and energy insecurity, Ukraine has accelerated the deployment of microgrids and smart inverters to support critical infrastructure and community resilience.

These examples demonstrate that smart grids are not one-size-fits-all solutions. Their design must reflect local grid topologies, regulatory environments, and socio-economic conditions. However, common benefits include reduced curtailment, enhanced load balancing, and greater consumer empowerment.

Smart grids are essential enablers of the global energy transition. By integrating digital intelligence into power systems, they allow for the seamless

incorporation of variable renewables, enhance operational resilience, and empower consumers as active participants in energy markets.

However, the deployment of smart grids also raises critical challenges. Cybersecurity vulnerabilities, data privacy concerns, and interoperability gaps must be addressed through robust standards, cross-sector collaboration, and transparent governance. Moreover, equitable access to smart grid benefits requires targeted investment in underserved regions and inclusive policy design.

As power systems evolve, the smart grid will serve not only as a technical upgrade but as a socio-technical infrastructure – one that redefines the relationship between energy, society, and the environment. Future research should focus on multi-agent coordination, AI-enhanced grid forecasting, and resilience modeling under extreme climate and geopolitical stressors.

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ДЛЯ НОТАТОК

Наукове видання СТУДЕНТСТВО. НАУКА. ІНОЗЕМНА МОВА

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ІНФОРМАЦІЙНІ ТЕХНОЛОГІЇ
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ТУРИЗМ
ЕКОЛОГІЯ
ЗДОРОВ'Я, МЕДИЦИНА ТА ВЕТЕРИНАРІЯ
ЕНЕРГЕТИКА

Засновник – Харківський національний автомобільно-дорожній університет

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