EUROPEAN SCIENTIFIC e-JOURNAL

ACTUAL ISSUES OF MODERN SCIENCE

EUROPEAN SCIENTIFIC E-JOURNAL

ISSUE 32

ACTUAL ISSUES OF MODERN SCIENCE

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Table of Contents

Economics and Management

Humanities

Innovations and Technologies

Jurisprudence and Law

Arutiun V. Amalian [1]

Calculation of GNP as a source of income [1]

Abstract: The relevance of the topic is manifested by ongoing negotiations between Ukraine and foreign creditors on the issue of debt restructuring, accompanied by the law, adopted on July 18, 2024, by Ukraine's parliament, allowing the government to suspend foreign debt payments, like by numerous continuous lawsuits against the government of Argentina: in both cases, GDP-linked warrants in general, and GDP calculation, in particular, are the subject matter. With objective limitations of GDP as a measure of economic development being discussed in numerous scientific papers, starting from the author of the concept of GDP Simon Kuznets, this study focuses on the intentional manipulation of data to prevent (or diminish) losses or gain profit. The study aims to research political (as distinct from methodological) approaches to the design of state-contingent debt instruments and risks associated with GDP miscalculation on the example of two case studies (circulation of Argentinian and Ukrainian GDP-linked warrants). The purpose is realized through the application of general scientific and specialized methods. Historical research and comparative analysis were applied to identify similarities and differences in the background, terms, and conditions of GDP-linked warrants issued by the governments of Argentina and Ukraine. Case studies were undertaken to examine the problems connected with their emission and circulation. Qualitative analysis techniques were used to identify problems facing both issuers and holders of warrants. Prima facie, until now, there are no publications on the topic. As primary sources in most cases are unavailable (due to the confidential character of negotiations), the research was based on the experts' opinions on some occasions. The paper seems to interest investors who have already bought or are planning to buy GDP-linked warrants, like the Global Sovereign Debt Roundtable participants. It should also appeal to international financial institutions, substantiating the pressing need to develop a standardized term sheet for the emission of value recovery instruments.

Keywords: GNP-linked warrants, state-contingent debt instruments, value recovery instruments, sovereign debt restructuring, term sheet.

Introduction

GDP is a key macroeconomic indicator that measures a country's economic output.

The OECD defines Gross domestic product (GDP) as an aggregate measure of production equal to the sum of the gross values added of all resident institutional units engaged in production. In 1944, as a result of the decisions of the Bretton Woods Conference, GDP became the main index for measuring a country's economy, and at present, the growth rate of real GDP is traditionally used as a basic indicator of the general state of the economy.

Irrespective of the approach used for GDP calculation (Production, Income or Expenditure) a significant number of eminent economists criticize this indicator, starting from Simon Kuznets, who was the first to introduce the concept of GDP in 1934. Thereafter, this concept was criticized by ecologists, who claimed that it ignores the impact of production growth on the environment; sociologists, who pointed to its inability to measure the quality of life; politicians, focusing on its disregard of freedom of political choice and the level of public safety, and economists, dissatisfied with the methods of GDP calculation. The latest

publications on the topic were authorized by Galvão and Mitchell (*2019*) and Grishin et al. (*2019*). This paper draws attention to the attempts of intentional miscalculations of GDP to gain profit or avoid losses in operations on the global financial market. The volume of the assumed potential gains/losses exceeds dozens of billions of US dollars. Ongoing lawsuits in Argentina and hard ongoing negotiations between Ukraine and its creditors on the issue of linked to GDP securities preordain the topic's relevance.

The study object is the terms and conditions of the emission of GDP-linked warrants by the two biggest IMF borrowers, Argentina and Ukraine. The aim of the article is to analyze known facts of intentional manipulation (or attempt of it) of the macroeconomic statistics and identify risks connected with such manipulations for holders and issuers of GDP-linked warrants and the global capital market.

To do this, the paper is divided into three parts, each performing one of the following tasks:

- outline the economic essence, types, advantages, and disadvantages of the emission of the Value Recovery instruments in general and GDP-linked warrants – in particular;
- explore controversy between the government of Argentina and holders of Argentinian GDP-linked warrants;
- analyze terms and conditions of the Ukrainian GDP-linked warrants and attempt to manipulate data while calculating payoffs.

To the best of the author's knowledge, until now, there have been no publications on this topic.

The research aim was realized by applying general scientific and specialized methods. Historical research and comparative analysis were applied to identify similarities and differences in the background, terms, and conditions of GDP-linked warrants issued by the governments of Argentina and Ukraine. Case studies were undertaken to examine the problems connected with their circulation. Qualitative analysis techniques were used to identify problems facing both issuers and holders of warrants.

The issues discussed in the paper seem to be of practical usefulness for both the emitters and holders of GDP-linked warrants. The Global Sovereign Debt Roundtable and international financial institutions discussed conceptual and, in particular, practical issues of the emission and circulation of the Value recovery instruments may provide an incentive to develop a standardized Term sheet for the emission of such instruments.

The results of the study
Economic sense of manipulation of GDP calculation

To understand the mechanics of profit-making of GDP calculation's manipulation, it is necessary to explore the economic essence of GDP-linked warrants as a particular case of the entire category of Sovereign state-contingent debt instruments (SCDI) and, as a particular case, Value recovery instruments (VRIs). The slight difference between the two categories – mechanics of payment (fluctuating according to the agreed metrics for SCDI and made only when specific thresholds are met for VRI) – for this research is not taken into consideration.

In 2017, the IMF presented its definition of Sovereign state-contingent debt instruments: "SCDI are instruments that (i) bear contractual debt service obligations tied to a pre-defined

state variable and (ii) are designed to alleviate pressure on sovereign indebtedness and/or financing needs in a bad state of the world" (*State-contingent …, 2017*).

The idea behind SCDIs is that by linking debt service to a measure of the sovereign's capacity to pay, such financial instruments can increase fiscal space, allowing sovereign debtors certain policy flexibility in times of distress. SCDIs are designed to provide creditors with a chance to recoup some portion of the financial sacrifice they are enduring in the debt restructuring to make that future prosperity possible. In theory, they are designed to expand the sovereign's investor base, open opportunities for risk diversification for holders, and build up the resilience of the international financial system.

Among the best-known advocates of the use of SCDIs in general and GDP-linked securities – in particular, the most famous are Robert J. Shiller (*2018*), who saw them as a way to help countries manage their debt burden more effectively, Eduardo Borensztein and Paolo Mauro (*2002*), who proved that GDP-indexed bonds could provide centurial benefits in reducing the likelihood of default crises and allowing countries to avoid pro-cyclical fiscal policies, John Williamson (*2017*), Joseph Stiglitz and many others who pointed to the potential benefits of GDP-linked instruments in sovereign debt restructuring.

The group of experts from the Bank for International Settlements (Deniz Igan), IMF (Taehoon Kim), and Massachusetts Institute of Technology (Antoine Levy) proposed their understanding of the difference between SCDIs and plain vanilla bonds in terms of their pricing and volatility (*Igan, 2022*) while Charles Cohen et al. discussed the Role of State-Contingent Debt Instruments in Sovereign Debt Restructurings, pointing that in the period of great macroeconomic uncertainty, VRIs could play an important role in facilitating speedier and less-costly sovereign debt restructurings by tying the payments of restructured debt contracts to future outcomes (*Cohen et al., 2020*). The author of the latest publication Maziar Peihani answers the question "Can SCDI be the answer to sovereign debt crises?" (*Peihani, 2024*).

Sovereign state-contingent debt instruments, which received their definition and theoretical substantiation less than half a century ago, have actually been used for centuries. The State of Virginia, for example, issued bonds linked to the price of land and slaves in 1782; in 1922, the Soviet Union started to issue "Bread Bonds" to be redeemed in grain, and in 1923, "Sugar Bonds" were emitted.

Nowadays, SCDIs are presented in a wide variety of forms, but broadly they can be divided into two main categories:

- Instruments featuring continuous adjustment of debt service payments that provide only upside payouts to creditors under positive scenarios. These value recovery instruments (VRIs) are strongly correlated with the borrower's ability to pay. Upside payouts are usually delayed into the future, and these instruments can typically be traded separately from the renegotiated debt securities.
- Instruments involving discrete adjustment, that provide downside protection to sovereign borrowers under negative scenarios. Typically, such sovereign debt instruments (also called Sovereign contingent convertible debt – S-CoCo) with a built-in trigger to allow a standstill of payments function like insurance contracts by providing relief to borrowers (either in the forms of interest forbearance, maturity extensions, or principal forgiveness) following large negative shocks, such as natural disasters (*Cohen, 2020*). One of the examples is the

2015 Grenada bond "hurricane clause," where a one-off debt service deferral is triggered by a pre-defined event, in this case, a hurricane of the given intensity, verified by the Caribbean Catastrophe Risk Insurance Facility. This type of SCDIs is not the subject of the study.

Value recovery instruments related to the first category can be issued both by sovereign and business entities.

State-contingent debt instruments can be linked to different benchmarks. At first, they were linked predominately to commodity prices. The use of commodity-indexed bonds dates back to 1863, when the Confederate States of America issued "cotton" bonds, either payable in pounds or francs or convertible into cotton at a predetermined price.

The most frequently used commodity for SCDIs issuing was and still is gold. The French government, for example, issued 1973 Gold bonds ("Giscard") that carried a 7% nominal coupon rate and a redemption value indexed to the price of one kilogram bar of gold. As a result of the annulment of the linkage of currencies to gold in 1978, the bonds increased in value by about 700% over 10 years (*Atta-Mensah, 2021*). India issued gold bonds in 2015, with the principal linked to the price of gold.

The oil settles for the second place among commodities to be linked with debt securities: oil-linked securities were issued by Algeria, Nigeria, Venezuela, and Mexico – the latter believed to have been the first to issue such bonds. Mexican "Petrobonds", in particular, were issued on behalf of the government by the National Financiere S.A. – a development bank owned by the Mexican government. Each 1,000-peso bond was linked to 1.95354 barrels of oil. On the maturity date (in three years), the Petrobonds were redeemed at a value equal to the maximum of the face value or the market value of the referenced units of oil plus all coupons accrued during circulation of the bonds.

The most unusual commodity-indexed warrants were issued in 1981 by Cominco Ltd. of Canada: holders of this security had the right to exchange each warrant on or before August 1992 for several common shares of the corporation based on the average market price of zinc or copper and the market value of common stocks on the exercise date (*Atta-Mensah, 2021*).

Alongside commodities, in some cases, SCDIs were linked to particular macroeconomic indices. It could be nominal wages (Uruguay issuing 2014 bonds with principal and coupon payments indexed), inflation (linked by the USA, United Kingdom, France, Germany, Japan, Sweden, India, Israel and many other countries), or revenue. The most frequently used reference variable is GDP, as it meets some significant qualifying requirements, is regularly published, is widely understood, and is comparable across countries.

Currently, SCDIs based on macroeconomic indices embrace two types of financial instruments: bonds and warrants. GDP-linked bonds can be further divided into three types, conditional on payout deferral type: GDP-linked bonds can be designed either linking principal to GDP, coupon, or both principal and interest.

While GDP-linked bonds can be issued at any time by any sovereign in need of funding, GDP-linked warrants are usually issued in the process of debt restructuring as a means of a "haircut": holders of old debt securities agree to recover some part of debt only if the debtor country's economy improves beyond certain benchmarks.

The process of the emission and the Terms and conditions of GDP-linked bonds is the focal point of both academicians and moneymen. Experts from the IMF, World Bank, Universities, and research institutions, such as the London School of Economics (LSE), Brookings Institution, and Centre for Economic Policy Research (CEPR) are conducting studies and publishing papers on the topic. At the same time, top officials discuss GDP-linked bonds at the meetings of G20, G7 Groups and UNCTAD.

In 2015, the meeting of economists, lawyers, and businessmen resulted in the compilation of "The London Term Sheet" – Indicative Term sheet for the fictitious sovereign republic of Arcadia. It included the design of a payment structure, a consistent set of terms and conditions, simplifying the issuance process, and making the bonds more attractive to investors by reducing complexity and uncertainty, triggers, and formulas, like legal and regulatory considerations, while issuing GDP-linked bonds. As of now, the London Term Sheet is a recommended framework. Despite being endorsed by various financial experts, policymakers, and international organizations as a valuable tool for improving debt sustainability and financial stability, its actual adoption varies by country and issuance.

Compared with the regulation of the emission of GDP-linked bonds, the situation with GDP-linked warrants is even worse: there is no standardized framework designed to facilitate the issuance of warrants linked to the GDP of the issuing country. The IMF, while addressing the concept and guidelines for GDP-linked warrants in its publications and working papers, focuses on "Economic and market perspectives", "Benefits and Challenges", and "The Role of State-Contingent Debt Instruments in Sovereign Debt Restructurings" without developing a definitive guideline for the terms and conditions of GDP-linked warrants design.

Summarizing theoretical issues of the GDP-linked warrants emission, it is possible to identify their main mandatory components:

Structure and Design:

- *Payment Formula* – linking payments to the issuing country's GDP growth or level. The formula specifies how payments will increase with higher GDP growth and decrease with lower growth;
- *Maturity and Duration* – ensuring alignment of warrants with the country's economic recovery timeline and debt management strategy;
- *Caps and Floors* – enabling issuers' risk management.

Data and Verification:

- *GDP metrics* to be used, including the source of GDP data (e.g., national statistical offices, international organizations) and the frequency of measurement (e.g., annual, quarterly).
- *Verification Mechanisms:* Procedures for verifying GDP data, including potential third-party audits or validation mechanisms to ensure accuracy and transparency.

Legal and Regulatory Framework:

- *Jurisdiction* governing the warrants and the applicable laws;
- *Dispute Resolution:* Provisions for resolving disputes related to GDP measurements, payments, or other terms of the warrants, often through arbitration or international courts.

Transparency and Disclosure:

- *Regular Reporting* of GDP performance, payment calculations, and payments to investors;

- *Disclosure of Risks* associated with GDP-linked warrants, including economic, political, and data reliability risks.

In the next chapters, the actual compliance of some already circulating GDP-linked warrants to the listed requirements is briefly analyzed.

Case study: Argentinian GDP-linked warrants

In the 21st century, Argentina has defaulted three times – in 2001 (during a very serious financial crisis), in 2014 (in the middle of a legal battle against holdout creditors), and in 2020 (at the height of the COVID-19 pandemic). Following the first default in 2005 while restructuring its external debt (93 billion dollars US), Argentina issued longer-term par, quasi-par, and discount bonds with a much lower nominal value (25-35% of the original). The debt restructuring included GDP-linked units (or warrants), being attached to every restructured Argentinian bond. They were designed to be detached from the underlying bonds 180 days after the issue date so that they would have their trading price after that. Thus, the Argentine warrant could be classified as a detachable option and had to be traded separately.

A second issuance occurred in 2010 during the second phase of debt restructuring. This issuance was similar to the 2005 warrants, offering bondholders the potential for additional payments tied to Argentina's GDP performance. Both GDP-linked warrant emissions were intended to align the interests of the bondholders with the economic performance of Argentina, providing an incentive for investors to support the country's economic recovery.

The notional value of the GDP-linked securities, with a maturity of 30 years, was 62 billion dollars US (76% of the 82 billion dollars US of eligible debt). As the new bonds, they were issued in three different currencies – Argentinian Pesos, Euros, and US dollars – and were governed by the same law as the new bonds to which they were initially attached (*Warren-Rodriguez & Conceição, 2015*). These warrants had no principal and instead acted as a series of standalone, state-contingent coupons.

Argentinian GDP-linked warrants' payments were conditioned by the three criteria stipulating repayment:
- *a level condition:* actual real GDP must exceed baseline real GDP (the base case GDP, measured in 1993 pesos);
- *a growth condition*: growth of actual real GDP must exceed growth of baseline real GDP;
- *a cap:* the cumulative payment amount should not exceed 0.48 per security unit (in its corresponding currency). The total cap on payments has been set at 29.8 billion dollars US. The warrants were not callable, meaning that even if the Argentine Government bought back the debt, it still had to serve the warrant.

The payment was designed to equal a fraction of excess nominal GDP to be distributed among the units of notional GDP-linked securities. With all conditions met, the Government had to pay investors based on the following components of the Payment formula:
(1) Notional Amount: the face value of the underlying restructured bonds to which the GDP warrant is attached, specified in the issuance documents;

(2) Payment Rate: fixed percentage specified in the warrant terms. The rate would have been 5% if participation in the debt exchange had been 100%; since in 2005 participation was 76%, the fraction is 76% of 5%, i.e., 3.8%;

(3) Excess GDP Growth: the amount by which Argentina's GDP growth exceeds a pre-defined threshold. For the 2005 warrants, the threshold GDP growth rate was set at 3% real GDP growth annually;

(4) Trigger Payment Condition: Payments were to be made only if Argentina's real GDP growth exceeded the 3% threshold in any given year; usually, they were made in the same currency as the underlying bond;

(5) Base GDP level: typically, the GDP level at the end of 2004 is used as a benchmark. Payment formula:

$$\text{Payment} = \text{Notional Amount} \times \text{Payment Rate} \times$$
$$\text{x } [(\text{Actual Real GDP} - \text{Base GDP}) / \text{Base GDP})]$$

In 2006, researchers from the United Nations Department of Economic and Social Affairs Stephany Griffith-Jones and Krishnan Sharma concluded that "to the extent that the instrument of GDP-linked bonds is a desirable financial innovation, of benefit to debtors and creditors, Argentina would have done the international community a favour by issuing these warrants and servicing them" (*Griffith-Jones & Sharma, 2006*).

At the time of the emission, investors were confused about how to value the warrants, partly owing to complex and ambiguous rules about exactly when they would pay out. At the time of their emission, the price of the securities was about two dollars US per 100 dollars US of notional value. In the following years, the market price of the Argentine GDP-linked securities sometimes skyrocketed to 19 dollars US (*Aurelis, 2021*) before falling to 0.38 dollars US in 2020; the average price was calculated to be 7.37 dollars US referencing the notional of 100 (*Cohen, 2020*).

During the first two years after the restructuring, investors netted record yields due to renewed economic growth (8-9% per year). However, since then, the rates of growth in Argentina have varied greatly – from negative 5.9% in 2009 to positive 10.25% in 2010.

The first payment was made in December 2006, based on the economic performance of 2005. Subsequent payments were made annually when the conditions were met. Significant payments occurred in the early 2010s after Argentina experienced robust economic growth. For instance, in December 2012, Argentina made a substantial payment of about 3.5 billion dollars US (more than 30 per cent of the total servicing of interest on public sector debt in that year), reflecting strong GDP growth in 2011. Since 2005 and up to 2012, investors have received six payments totaling 18 cents per warrant (on the dollar) as the Argentine economy boomed (*Voris, 2019*).

In total, during nine years after the emission of warrants, Argentina has paid them roughly 10.5 billion dollars US. The warrants can pay a maximum of 48 cents until they mature in 2035.

Since 2012, the GDP warrants haven't delivered a penny to investors and, in the opinion of experts, are not expected to anytime soon (*Aurelius, 2021*), as a long chain of lawsuits started.

The key issue of the legal battles between investors (predominately foreign hedge funds) and Argentina is the contractual interpretation of bond documentation. The main matter of dispute turned out to be "base year": in March 2014, then-president Cristina Fernandez de

Kirchner ordered the National Statistics and Censuses Institute to replace its calculation of real GDP in constant 1993 prices and base it in constant 2004 prices, thus making the relevant data no longer available.

The change of the base year for the data from 1993 (metric agreed by the parties on the contractual documents) to 2004 in the view of the plaintiff's reduced growth in 2013 to three per cent – almost half the previously forecast pace.

The first major lawsuit against Argentina regarding GDP-linked warrants was initiated by the American hedge fund Aurelius Capital Management, which specializes in distressed debt. This is the same fund that intensively acquired Ukrainian debt securities on the eve of their restructuring in 2015 and later refused participation in Ukrainian sovereign debt restructuring.

This hedge fund, that has previously settled a massive litigation over defaulted 2001 bonds with Argentina in 2016, sued the country again in 2019, attempting to force the government of Argentina to pay 1.3 billion dollars US, having claimed that Argentina should have incorporated 1993 data into its base calculation of real GDP expansion (Aurelius Capital Master Ltd. v. the Republic of Argentina, No. 1:2019cv00351, U.S. District Court, Southern District of New York, Manhattan). The claimant argued that Argentina switched to 2004 prices for the reference year and decided not to publish GDP data in 1993 prices was improper, irrational, arbitrary, and capricious (*Klein, 2019*).

The hedge fund stated that Argentina's government had altered the methodology for calculating GDP without proper disclosure or justification; the manipulation of data, as was stated by the fund, included changing the base year and adjusting growth figures, which resulted in reported GDP growth rates that were below the threshold required for payments to warrant holders. The hedge fund's lawyers declared that Argentina's adjustments in GDP calculation methods were intentionally done to prevent these thresholds from being met, thereby avoiding the payments. In the court, they sought to compel Argentina to make the payments that would have been due under the original terms of the warrants. The funds lawyers argued that the changes deprived its funds of about 172 million dollars US in payments and, with interest, Argentina owed more than 253 million dollars US (*Aurelius, 2021*).

Argentina argued that its interpretation enables Base Case GDP to be updated so that the securities are linked to the real economic performance of the Republic as measured by the most reliable estimate of GDP available rather than being compared to an obsolete measure – 1993 prices. Argentina branded the fund a "vulture" for its stance.

In the abovementioned case, the US federal court ruled in favour of Aurelius Capital Master Ltd., acknowledging that the Republic of Argentina had breached certain bond agreements. The court compelled Argentina to reveal its methodology to measure economic activity in 2013 and awarded Aurelius Capital monetary damages as compensation for the breach.

The lawsuit by Aurelius set the stage for other subsequent legal actions by investors in Argentine GDP-linked warrants.

The same Aurelius Capital, together with some other holders of Argentina's contingent 2005 and 2010 GDP-linked warrants and trustee Bank of New York Mellon on December 13, 2023, filed a new action to recover up to 6 billion dollars US in unpaid amounts due under the GDP warrants for reference years after 2013. According to the complaint in the Southern District of New York, Argentina acted "willfully and in bad faith, with full knowledge that it

was not following the plain terms of the Global Securities and that its conduct would have the effect of destroying Holders' right to payment" (*Litigation, 2023*).

In total, in 2023, there were six litigations of beneficial holders of GDP warrants versus Argentina pending before the Southern District of New York court. In all of them, every individual Holder was seeking a portion of any Payment Amounts due for Reference Years after 2013 (including but not limited to 2015, 2017, 2018, 2021, and 2022) representing that Individual Holder's beneficial interest.

In a decision made public in April 2024, U.S. District Judge Loretta Preska in Manhattan dismissed all their claims stating that the hedge funds had no right to sue because they failed to meet five preconditions required under "no-action" clauses in its bond agreements (*Argentina beats …, 2024*).

Another process in regard to the same problem was initiated by Palladian Partners LP, HBK Master Fund LP, Hirsh Group LLC, and Virtual Emerald International Limited in England and Wales High Court. That court, on April 5, 2023, ordered payment of 643 million euros in respect of the claimants' holdings and 1.33 billion euros in respect of all the bonds for the year 2013 and specific performance for subsequent years of the Republic's obligations according to the correct approach to adjusting the Base Case. The judge required the Republic to apply the Annual Adjustment Construction in all subsequent years in determining whether it is obliged to pay under the bonds. Given that the Republic has not measured GDP in 1993 prices since 2013, this will require the Republic to restart the production of data in 1993 prices and to continue producing it until the maturity of the bonds in 2035 (*England & Wales, 2023*).

To summarise, it must be pointed out that in some cases, the disputes between holders of GDP-linked warrants and Argentina led to settlements between Argentina and the plaintiffs. Details of settlements are often confidential, but they typically involve Argentina agreeing to make certain payments or adjustments in future GDP calculations. However, not a single penny was officially paid to the holders of Argentinian warrants for the last decade.

The problem of appropriate calculation of GDP and GDP growth rate, like the possibility of data manipulation by sovereign debtors, is still topical and far from being solved, as demonstrated by contrarian decisions of different courts. The lawsuits against Argentina over GDP-linked warrants, with significant financial stakes for the investors involved, highlighted the complexities and risks associated with calculating and verifying GDP.

Case study: Ukrainian GDP-linked warrants

Understanding GDP data manipulation in the case of Ukrainian VRI necessitates familiarising oneself with the characters engaged in the design process.

The negotiations on the restructuration of the Ukrainian Eurobond started in 2015, following Russia's annexation of Crimea, the Russian-backed separatist movement in the east of the country, and the shrinkage of foreign reserves on waging the war that has destroyed its industrial export and coal mining capacity in the Donbas. Facing the real threat of default, the Ukrainian government was under compulsion to start negotiations with Eurobond holders.

While Ukraine's finance minister Natalia Yaresko was seeking restructuring of Ukraine's foreign debt by way of cutting the interest it pays, extending the debt's maturities, and writing down the principal in a "haircut" (up to 40% of the debt's value), the creditors were toughly

opposed to debt relief, being ready only to postpone payouts in return for extra compensation. Creditors had an upper hand in talks due to the concentration of Ukrainian bonds (up to 7 billion dollars US) in the portfolio of an American investment fund, Franklin Templeton, acting as a leader of the specially formed ad hoc committee of holders of Ukrainian bonds. The committee comprised representatives of American funds TCW and T. Rowe Price and a Brazilian fund BTG Pactual Europe (Aurelius Capital Management excluding). The businesses grouped in the "committee of creditors" held Ukrainian bonds worth approximately 8.9 billion dollars US, of the 18 billion dollars US being restructured. Private creditors (including other American funds – such as PIMCO (owned by Germany's Allianz), Blackrock, Fidelity, and Stone Harbor (*Sadowski, 2015*), claimed that Ukraine's problem is solvency, not the volume of its debt. All declared that they would not accept a haircut.

The ad hoc creditors' committee has hired, among others, Weil Gotshal & Manges (with senior partner and co-head of restructuring Andrew Wilkinson, leading a team of lawyers across London and New York offices) as advisor.

As a result of the very hard negotiation, extremely unfavourable provisions were imposed on Ukraine: in exchange for the deferral of debt service and extension of payment maturities, the interest rate was raised to 7.75%, and instead of a "haircut," 20% of old bonds was reissued in the form of GDP-linked warrants. The de facto issue of the latter was approximately 3,607 billion dollars US.

Terms and conditions of GDP-linked warrants, in comparison with similar Argentinian securities, were highly profitable for their holders:

- They were scheduled to receive a payment equal to 15% of the real GDP growth exceeding 3%, and if real GDP growth exceeds 4% – payment had to be equal to 40% of the growth beyond 4 per cent. An additional precondition ensuring their profits was the extremely low threshold, which gives the kick for GDP-indexed payments – 125 billion dollars US. During the seven years preceding the restructuring, the GDP of Ukraine was below this threshold only once – in 2009 (117,08 billion dollars US), while in 2008, it exceeded 181 billion dollars US.

- While Argentine warrants have a total payment cap equal to 48 per cent of the warrant's face value, Ukrainian payments have had no cap at all for the last 15 years (starting from 2026).

Co-authors of IMF Staff Discussion Notes "The Role of State-Contingent Debt Instruments in Sovereign Debt Restructurings" (*2020*) Charles Cohen, S. Ali Abbas, Myrvin Anthony, Tom Best, Peter Breuer, Hui Miao, Alla Myrvoda, and Eriko Togo pointed that Ukraine's 2015 warrants could end up paying out significantly more than the initial creditor haircut… The essentially uncapped nature of Ukraine GNP-linked warrants could potentially result in large fiscal costs far exceeding initial debt relief" (*Cohen, 2020*). Just before that conclusion experts of Investment Capital Ukraine LLC presented their estimation of the deal, according to which the possible total amount of payments on warrants (with maximum notional value – 3,6 billion dollars US) in a scenario of stable growth of 4% will be 5,34 billion dollars US; in case of 5% growth – 23,27 billion dollars US, 6% – 46,42 billion dollars US and 7% – 76,78 billion dollars US (*Kotovych, 2015*). Calculations performed in 2022 (during the war, resulting in a sharp decline of the Ukrainian economy) envisage the possibility of annual

payment for GDP warrants over 6 billion dollars US in case of a GDP growth rate exceeding 10%, which is very realistic because of the low base (*Bublyk, 2022*).

The first actual payments for Ukrainian GDP-linked warrants (UKRAINE 15/41 IO GDP-LKD) took place in 2021. The price for these securities skyrocketed from 49.6 dollars US (the Initial price after offering) to 111.01 dollars US in June 2021, referencing the notional of 100 (*DL-FLR …, 2024*).

In 2022, Russia's full-scale invasion of Ukraine spurred a new wave of negotiations on the restructuration of issued 2015 Eurobond-like GDP-linked warrants.

On August 10, 2022, the negotiations were completed with the successful amendment of Ukraine's sovereign Eurobonds and GDP warrants, like state-guaranteed Eurobonds. Holders of around 75% of the aggregate principal sum of Ukraine's 13 Eurobond series outstanding, like holders of approximately 90% of the notional amount of GDP warrants, voted in favour of amending the conditions of the securities (Investors Supported, 2022). As the result of the negotiations, completed on August 10, 2022, all the payments (including consent payment of 50 dollars US for each 1,000 dollars US in the Notional number of securities, on which interest will also accrue) were deferred until August 16 2024, with interest accruing at a rate of 7.75 per cent per annum. The successful consent, as the Ministry of Finance of Ukraine declared, was a testament to investors' willingness to support Ukraine and mitigate a potential high burden of the instrument for Ukraine's economy during the post-war growth period.

As agreed in 2022, after the end of the grace period, the Ukrainian government would have to pay (or capitalise) about 4.0 billion dollars US of delayed coupons.

In 2024, with the devastating war going on, a new round of talk on a new restructuring has started. As of summer 2024, Ukraine has 19.7 billion dollars US outstanding on its international bonds and owes 2.6 billion dollars US on GDP warrants. On June 17, 2024, it was announced that Ukraine had not been able to reach an agreement with a group of bondholders over restructuring during formal talks. On July 18, Ukraine's parliament passed a law allowing the government to suspend foreign debt payments.

With the news from negotiations and preparations for them being strictly confidential, it seems sensible to quote Andrew Wilkinsonəs statement – the legal advisor of the ad hoc creditors' committees from Weil Gotshal & Manges in 2015, 2022, and 2024.

In a webinar (*Reorg, 2022*), which was broadcast just weeks before Russia invaded Ukraine, on February 4, 2022, Andrew Wilkinson, Senior Partner and Co-Head of Restructuring at an American international law firm Weil Gotshal, discussed the implications of the geopolitical crisis in Ukraine was having on the country's credit market and how investors could mitigate those new risks. His opinion is all the more significant given that he was and still is leading the team advising the Creditors' Committees in the negotiations with Ukrainian on the Eurobonds and GDP-linked warrants.

In the course of the webinar (just 20 days before Russia's full-scale invasion), Mr. Wilkinson mentioned "a very successful" debt restructuring in which he actively participated in 2015 and discussed three possible scenarios of the future development of events:

- escalation of what happened in Donbas and Crimea in 2014 and shrinking of the territory under the control of Ukraine;

- Russia's invasion of Ukraine (full-scale war with Russia's victory and establishment of successor state);
- Status quo – slow destabilization of Ukraine. After this, the leading legal advisor of the committee of Ukrainian GDP-linked warrants explained what was going to happen in case of Donbas annexation and Ukraine losing a further 10% of its territory the following year: "Ukraine will be required to produce its GDP numbers on its reduced by 10% territory and then to show whether the required GDP growth had occurred, take out the territory over which it has lost control and produce numbers for the territory over which it has control and do the previous year's GDP on the same territorial assumption and then showing when comparing like to like there is growth or not".

In politics, the quoted statement, directed at creating conditions enabling the holders of GDP-linked warrants to profit, equals recognition of the results and certainty of unprovoked aggression against a sovereign state.

Thus, during the first stage of Russian aggression, the precarious situation in the Ukrainian economy ensured the success of the aggressive policy of several hedge funds that have hoarded a tremendous number of Eurobonds worth almost 9 billion dollars. Terms and conditions issued as the result of negotiation GDP-linked warrants are extremely unfavourable for Ukraine – even the IMF experts acknowledged that might "generate excessive payouts if an upside scenario materializes" (*Cohen, 2020*). Subsequent attempts of the legal advisors for those hedge funds to manipulate GDP data in times of ongoing war to pump money out of the country, surviving largely due to the international economic support, seem, to say the least, unethical.

Discussion

Lessons learned from GDP-linked warrants emission as a sweetener while restructuring sovereign debts (likening new securities to debt-to-equity conversions that are common in private sector restructurings) have demonstrated advantages like disadvantages of their issuance and circulation. Advantages for issuers include avoidance of default followed by temporary exclusion from capital markets and the counter-cyclical nature of the security, enabling stabilization of government spending and improving the country's prospects for internal and external viability. Investor benefit by way of their portfolio diversification, prospects of potentially higher returns due to an opportunity to take a position on countries' future growth prospects (offering an equity-like exposure to a country).

The main disadvantages include complexity in security structuring, uncertainty of payments, limited market development and illiquidity of the warrants, and legal and regulatory issues, like idiosyncratic risk profiles. Generally acknowledged factors of risk of linking securities to GDP traditionally were:
- incomplete picture with GDP failing to capture such significant aspects of the economy as income distribution, quality of life, and environmental sustainability;
- insufficient data due to the lack of statistics for the informal sector, disregard of price changes, and impact of changes in technology and innovation on the economy.

As it turned out, the accuracy of GDP calculations depends not only on the quality of the data sources but also on the contradictory interpretations of the terms "base year" and "rebasing" by the contract parties.

The problems discussed in the paper seem to be of practical usefulness for the issuers and holders of GDP-linked warrants on the one hand and experts in international finance – on the other hand. As proof of the latter, it is worth noting that the authors of the IMF Staff discussion note "State-Contingent Debt Instruments for Sovereigns", published in 2020, have already pointed, out that "GDP warrants have faced concerns that they can encourage data manipulation and disincentivize reforms" (*Cohen, 2020*).

Contrary to the scantily explored issue of intentional manipulation of GDP calculation, almost all professionals unequivocally recognize the need to cap future payments on VRI. It seems timely to transform this opinion into a mandatory requirement.

Conclusion

When analyzing the theory and practice of the emission and circulation of GDP-linked warrants, the issue of appropriate calculation of GDP and GDP growth rate, like the possibility of data manipulation by both debtors and creditors, was highlighted. Exploration of two case studies has revealed that while the government of Argentina was accused of intentional miscalculation of GDP to avoid payments, Andrew Wilkinson, leading the team of Weil Gotshal & Manges advisors to the committee of creditors of Ukraine, suggested his methodical approach to GDP calculation, ensuring payments to warrant holders even in case of a sharp decline of the economy of the debtor country. In the first case, the following lawsuits have prevented holders of Argentinian warrants from receiving any payment since 2012, and in the second, if Wilkinson's view is transformed into an official agreement, a "haircut" of 3.2 billion dollars US in 2015 will be doomed with the repayment of up to 6 billion dollars US per year during next 15 years – seemingly not an optimal debt restructuring for any country. Especially for the country, which, according to the IMF baseline case scenario, is facing a 38.5 billion dollars US financing gap in 2024 and 23.6 billion dollars US in 2025.

In the case of war-torn Ukraine, such huge profits from foreign hedge funds – primary holders of Ukrainian GDP holders – can be provided only by the taxpayers of European and North American countries, already rendering immense support to Ukraine in its fight against the aggressor. The moral hazard of intentional data manipulation by one or even both parties, as in the abovementioned case studies, substantiates the imperative need to develop a commonly agreed contractual framework and draft conventional guidelines on the design of GDP-linked warrants. Such guidelines can benefit both issuers and investors by enhancing transparency and managing risks.

Participants of the Global Sovereign Debt Roundtable and experts of international financial institutions discussed conceptual and, primarily, practical issues of the emission and circulation of the value recovery instruments that may provide an incentive to develop a standardised Term sheet for the emission of GDP-linked warrants.

Conflict of interest

The author declares that there is no conflict of interest.

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Competitiveness of agricultural enterprises: factors of increasing based on innovative determinants [2]

Abstract: The article examines the critical factors of improving the agricultural enterprise's competitiveness based on innovative determinants. The study object is agricultural enterprises, their activities and management processes. The study subject is the analysis of innovative factors and determinants that influence the increase in agricultural enterprises' competitiveness. The study aims to research the factors of increasing competitiveness, innovative development, and agricultural enterprises' innovation activity conditions. To implement the study, the works of O.S. Litvinov, P.V. Kumanova, L.M. Pronko, K.S. Tokar, V.H. Hranovska, O.P. Khaietska, I.V. Honcharuk, I.V. Tomashuk, O.H. Shpykuliak, L.I. Kurylo, I. Farida, D. Setiawan were used. The main attention is paid to the need to develop and implement an innovative strategy to improve the efficiency of the agricultural enterprises' functioning. The existing concepts of "competitiveness" and "innovation" are analysed, particularly in the context of functioning enterprises in the agricultural sector of the economy. The theoretical and practical aspects of competitiveness, including factors influencing the ability of enterprises to withstand competitive pressure, are considered. Particular attention is paid to the relationship between innovation activity and the level of competitiveness, like strategic approaches to introducing new technologies and management methods to ensure sustainable development of the agricultural sector. The authors present a list of factors that help to increase agricultural enterprises' competitiveness and analyse their impact on forming competitive advantages and intensifying innovation processes in the industry. It is proved that innovations play a crucial role in strengthening the competitive position of agricultural enterprises, contributing to their stable development and adaptation to changes in the market. In particular, it is determined that introducing new technologies and methods of economic activity contributes to increasing production efficiency, reducing costs, and improving product quality. This allows agricultural enterprises to be more competitive in the domestic and foreign markets and quickly adapt to changes in consumer preferences and market conditions. The study results can be used to formulate recommendations for implementing an innovation strategy at agricultural enterprises to increase their competitiveness and ensure sustainable development.

Keywords: enterprise competitiveness, product competitiveness, innovation, innovative transformations, agriculture enterprises, factors.

Abbreviations:

AIC – agro-industrial complex

Introduction

An urgent problem of economic growth, considering the vector of innovative transformations of the world economic system, is the innovative way of agriculture enterprises' development. The enterprise is the main link of the economy, like the driving force of creating products and services necessary for society. The rapid dynamics of changes in the technology of production, management, and organisation of the enterprise leads to an intensification of the competitive struggle, in which enterprises that direct significant resources to the creation of

various innovations and devote enough time to innovative activities become more effective and successful.

The modern struggle for a place on the market is becoming more intense and tougher due to the development of innovative activities as a result of production's innovative improvement and the appearance of new goods and services. At the same time, the available theoretical approaches and tools regarding the implementation of innovations and the ability to activate them do not always meet the expected results.

The study object is agricultural enterprises, their activities and management processes.

The study subject is the analysis of innovative factors and determinants that influence the increase in the competitiveness of agricultural enterprises.

The study aims to research the factors affecting increasing competitiveness, innovative development, and the conditions of agricultural enterprises' innovation activity.

Based on the purpose of the study, the following tasks were solved:
– literary sources in the subject area were analysed, which made it possible to determine the main trends and problems in the field of innovative development of agricultural enterprises;
– the main concepts and characteristics of competitiveness in the context of the agro-industrial sector are defined;
– key factors affecting the ability of enterprises to compete in the market are determined;
– the role of innovations in the development of agribusiness enterprises was investigated;
– the influence of introducing the latest technologies and solutions on the productivity and efficiency of economic activity is analysed.

To implement the study, the works of O.S. Litvinov, P.V. Kumanova, L.M. Pronko, K.S. Tokar, V.H. Hranovska, O.P. Khaietska, I.V. Honcharuk, I.V. Tomashuk, O.H. Shpykuliak, L.I. Kurylo, I. Farida, D. Setiawan were used.

Research methods

The following general scientific and special research methods were used in the study: monographic (allowed to perform an in-depth study of a specific object of study – enterprises of the AIC. In particular, the existing theoretical and practical aspects of the agricultural enterprises' competitiveness were analysed in detail, which made it possible to form a thorough idea of the current state and challenges in this area), logical-theoretical (allowed to create the logical structure of the study. Thanks to this method, it was possible to identify the relationships between different theoretical approaches and concepts related to competitiveness. This made it possible to build a clear theoretical framework, based on which further research questions were developed), and system analysis (It was used for a comprehensive study of the objects and processes under study. The application of this method made it possible to consider agricultural enterprises as complex systems with many interrelated elements, contributing to the understanding of their interaction and the identification of critical factors that affect their competitiveness), abstract-logical (helped to summarise and systematise the data obtained, to identify the main trends and patterns related to innovative determinants of increasing the agricultural enterprises' competitiveness. Using this method made it possible to formulate new theoretical approaches and proposals for improving competitiveness) and generalisation (made

it possible to summarise the study results, systematise the data obtained, and identify the main conclusions. Thanks to this method, it was possible to conclude the effectiveness of using innovative determinants to increase agricultural enterprises' competitiveness, like developing recommendations for their implementation.

The results of the study
Analysis of literary sources from the subject area

The main theoretical and methodological provisions related to the disclosure of the problems of increasing the agriculture enterprises' competitiveness in the prism of the innovation's introduction were reflected in the scientific works of some leading scientists.

O.S. Litvinov and P.V. Kumanova, in their research, having analysed the impact and significance of innovative activity in increasing business entity products' competitiveness, substantiated the need to change the vector of activities of domestic enterprises to an innovative path of their development (*Litvinov & Kumanova, 2021*).

V.V. Boiko and M.Ya. Zarichnyi focus their attention on such priority tools for increasing the level of enterprises' competitiveness under martial law as institutional-legal, fiscal-tax, financial-investment, marketing-market, technical-technological, intellectual-personnel and information-analytical (*Boiko & Zarichnyi, 2023*).

Examining the main factors affecting the business entities' competitiveness in a rapidly changing global economy, R.R. Bilyk and A.H. Sarafinchan emphasise the dynamic interaction between various factors that shape the competitive environment and the significance of continuous innovative development and strategic flexibility to ensure long-term competitiveness (*Bilyk & Sarafinchan, 2023*).

L.M. Pronko and K.S. Tokar studied the enterprises' competitiveness problems through the prism of relationship marketing. In particular, it was proposed to add the following to the basic principles of relationship marketing: consumer orientation, openness and trust, and partnership. Quite appropriate is the number of measures highlighted by the authors, ensuring that enterprises achieve competitive advantages, including

- reduction of the cost of production; increasing its priority;
- change in the quality and technical parameters of products;
- quality service;
- identifying the shortcomings of the competitor's goods;
- implementation of innovations;
- advertising;
- search for new areas of product use (*Pronko & Tokar, 2023*).

In their research, M.O. Akuliushyna, L.H. Zotova, and others conduct a theoretical disclosure of the definition of "competitiveness" in the modern sense. At the same time, the main groups of factors that have the most significant influence on the change in competitiveness are determined, indicating the degree of this influence; identify opportunities for management and control over the probable consequences of the factors' influence and timely response to changes in market conditions (*Akuliushyna et al., 2024*).

V.H. Hranovska suggests considering the competitiveness of agricultural enterprises as a

complex concept that characterises the full range of competitive advantages and potential of the enterprise. Strategic potential and the effectiveness of its use, the speed of reaction to changes and adaptability to the operating environment variability, the speed of response to consumer needs, and the ability to respond adequately to competitors' innovations (*Hranovska, 2016*).

According to the research of Z.V. Kriuchkova, the agricultural enterprise's competitiveness is determined by the following parameters:

(1) the ability of the enterprise to function effectively in the domestic and foreign markets;

(2) the ability of the manufactured products of a separate enterprise to compete on the market with identical products;

(3) obtaining sustainable competitive advantages by the enterprise based on agricultural products of some quality;

(4) effective use of technologies, resources, management methods, skills and knowledge of personnel, components of marketing activity, reflected in the quality and competitiveness of products, and profitability of the enterprise (*Kriuchkova, 2016*).

Special attention is worth paying to the scientific work of P.A. Fisunenko, who thoroughly explored all possible approaches to determining the enterprise's competitiveness, starting from the evolution of fundamental economic theories regarding the study of competitiveness (the theory of absolute advantages, the theory of comparative costs, the theory of comparative advantages, the theory of competitive advantages) and ending with modern scientific interpretations. He established that all existing studies on the understanding of competitiveness are based on general competition theories. He also stated that there is a connection between competitiveness and innovation (*Fisunenko, 2020*).

Scientists I. Farida and D. Setiawan proved that productivity and innovation are the factors that can increase the competitive advantages of small and medium-sized enterprises. Scientists recommend that enterprises improve their efficiency and innovation potential to strengthen their competitive advantages (*Farida & Setiawan, 2022*).

Scientists Feng He, Longxuan Chen, and others reasonably prove that innovation is the driving force of sustainable and healthy economic and social development for the economy as a whole and is the basis of enterprise growth. They believe that balancing access to factors/resources and market competition can encourage enterprises to follow a market-oriented development path in their corporate innovation (*Feng He et al., 2024*).

Based on the analysis of the latest scientific research, most scientists do not see a solution to the problem of increasing the enterprises' competitiveness without innovation. With the recent changes in economic and political conditions, the issue of introducing innovations to increase the competitiveness of enterprises remains relevant and requires further study.

Theoretical aspects of the agribusiness enterprises' competitiveness

To determine the factors that influence the increase in competitiveness, we will first consider the "competitiveness" concept essence as an economic and managerial category, like the "innovation" concept.

Increasingly, scientists draw parallels between the product competitiveness and enterprise competitiveness concepts. Various authors consider the "enterprise's competitiveness" concept in conjunction with the "product competitiveness" concept or without such dependence.

According to O.H. Nefedova, the concepts of enterprise and product competitiveness are worth combining. Competitiveness is worth understanding as the ability of an enterprise to influence the market situation in its interests and produce products that meet the consumer's requirements at a relatively low-cost level (*Nefedova, 2006*). Bohomolova, K.S. also notes that the most significant factor in the agricultural enterprise's competitiveness is its products' competitiveness. At the same time, the author calls the key characteristic of the product its price advantage (*Bohomolova, 2019*).

As mentioned above, some authors consider the "enterprise's competitiveness" concept without interconnecting it with the "product's competitiveness" concept.

According to domestic scientists A.S. Afonin, S.V. Bilousova, and others, the firm's competitiveness is the ability and behaviour of the company, providing it with a long time to achieve its goals and successfully perform in the market together with other entities present there (*Afonin et al., 2008*).

O.P. Khaietska notes that competitiveness is an indicator showing the possibility of adapting an entity to the new conditions of the competitive environment. The efficiency of agricultural enterprises' functioning is due to the strengthening of competitive positions in the national and international markets of homogeneous standardised products (*Khaietska, 2022*).

V.V. Adamyk and H.L. Verbytska argue that the enterprise's competitiveness is a relative concept that reflects the difference between the process of development of this enterprise and a competitor both in terms of the degree of satisfaction of social needs by its products and in the efficiency of commercial activity (*Adamyk & Verbytska, 2008*).

Based on N. Struk's statement, the firm's competitiveness is understood as a company's real and potential ability to design, manufacture, and sell goods. The detailed significance and analysis subject should be the range of products manufactured by the enterprise (*Struk, 2008*). Such an interpretation of competitiveness means that the products' competitiveness is the enterprise's competitiveness component.

J.V. Kryuchkova understands competitiveness as the ability of an enterprise to function in a market economy in the long term, creating and selling products that meet people's needs and are different from similar ones, while taking a stable position in a certain industry and receiving regular profit sufficient to improve production (*Kryuchkova, 2016*).

P.A. Fisunenko established that competitiveness is a set of formative and resultant features that characterise the qualitative side of the enterprise's functioning and whose change reflects its characteristics – opportunity, ability, capability, and condition (*Fisunenko, 2020*).

The enterprise's competitiveness is determined by the competitiveness of goods and services offered in the consumer market, respectively, the set of consumer properties of goods that ensure its ability to compete with analogues in a particular market in some time (*Adler, 2012*).

Based on the above, we believe that competitiveness as a complex category is worth interpreting as the ability of an enterprise and its products to successfully perform their functions in the market for a long time and dominate in some or all areas of its activities over competitors.

System of influencing factors on agribusiness enterprises' competitiveness

Various factors determine the enterprise's competitiveness. Today, scientists single out several factors that affect enterprises' competitiveness. In particular, they classify factors into external and internal, controlled and uncontrolled, micro-, meso-, macro-level factors, factors of product's competitiveness and enterprise potential, etc. (*Table 1*).

As can be seen, the influence of many factor levels forms the agricultural enterprises' competitiveness. Along with adaptation to changes at the macro level and response to global trends at the meta-level, effective management of internal (micro- and meso-level) resources and processes is critically significant for maintaining competitive advantages and ensuring the sustainable development of agricultural enterprises. A comprehensive approach to assessing and managing these factors helps businesses adapt more effectively to a changing environment and maximise their competitive opportunities.

The "Multi-level" influencing factors system can be generally divided into two groups: internal and external (*Table 2*).

Now, it is necessary to take a closer look at the internal factors that are integral to the enterprise. They occur at all stages.

1. Flexibility, system, and management methods. This aspect is considered as the ability to adapt to changes in the internal and external environment, the speed of response, the effectiveness of decision-making and communication strategies, the ability to build successful and effective management mechanisms, and constant monitoring of the activities performed.
2. Strategies used. Implementation and use of action plans, and strategic decisions to achieve goals related to all activity stages aimed at expanding the business or range, etc.
3. The level of enterprise's innovation and technological support. Continuous improvement, updating, and inspection of technical equipment help improve products, optimise production processes, and increase competitiveness.
4. The state of financial resources management. The enterprise's financial stability is the key to further developing and maintaining competitive positions.
5. Product quality. Implementation of laboratories at enterprises, compliance with quality and compliance standards, such as ISO 22000, DSTU 4161-2003, and the degree of compliance with the requirements to meet the needs and expectations of consumers.
6. Personnel management. Appropriate working conditions, high wages, career growth, and staff motivation significantly ensure increased competitiveness.
7. Marketing strategies. Focus on consumer awareness of the company's products and services, effective pricing strategy, direct marketing, promotion and discount use, loyalty programs, and promotion through social networks. All this ensures maintaining market positions and high sales, which increases competitiveness.
8. Level of customer satisfaction. Customer satisfaction must be constantly monitored, feedback on quality, price, and service collected, and suggestions for improvement made.
9. Staffing. Availability of qualified personnel to perform various functions and tasks of the company, low staff turnover, and staff's constant monitoring.
10. Social responsibility. Identification of social responsibility, compliance with ethical standards and environmental norms, and volunteering in the conduct of activities improve the image and attract the attention of consumers.

11. Supply chain management efficiency. The supply chain refers to everything that happens from the stage of purchasing raw materials to the distribution of finished products. It is important to establish cooperation with successful suppliers and distributors and constantly analyse and monitor their condition in the market; in addition, logistics activities are the basis for the delivery of any product from the manufacturer to the consumer, speed, convenience, and good storage conditions are competitive advantages. Thus, effective management allows you to benefit from optimising processes, reducing costs, and improving the quality of goods or services (*Akuliushyna et al., 2024*).

We will also analyse external factors and their impact on increasing the enterprise's competitiveness.

1. Russia's war against Ukraine affected all aspects of life. Thus, many enterprises have suffered heavy losses, some have ceased their activities, and some enterprises have been destroyed, i.e., we must understand that the war poses a threat not only to the enterprise's competitive position but also to its existence as a whole. However, it is worth noting that many enterprises have been able to adapt to changes and requirements of the time, successfully carry out their activities, and increase their competitiveness in the market.

2. Political stability positively affects the enterprises' competitiveness by reducing environmental uncertainty.

3. Tax policy has a significant impact on enterprises' competitiveness. An increase in taxes leads to additional costs for the enterprise, while a reduction in taxes can help the company increase its competitiveness through the investment of released funds in development.

4. Government policy on exports and imports. An effective export and import policy will help create good conditions for developing and entering enterprises into international markets.

5. The number of competitors in an industry significantly impacts enterprises. Many competitors and the absence of barriers to the entry of new enterprises into the market leads to a situation where enterprises may find themselves in difficult conditions of reduced demand for products and the need to retain their customers in various ways, among which one of the most effective will be price reduction. This will lead to lower company profits and fewer development opportunities. At the same time, an enterprise operating in an industry with a moderate number of competitors has a better chance of increasing the level of competitiveness.

6. Effective antimonopoly policy significantly affects enterprises' competitiveness as it prevents market monopolisation and promotes fair competition.

7. Credit availability. If the company does not have free funds, it can use credit funds, e.g., to conduct research work, introduce technological developments and innovations, upgrade equipment, etc. Such actions will increase the enterprise's efficiency and competitiveness level.

8. Purchasing power of the population. An increase in population purchasing power leads to an increase in demand for products and the number of buyers. By organising production and marketing activities, the company can increase production volumes, attract new customers, and increase sales, which will certainly strengthen its competitive position in the market.

9. Demographic situation. Improving the demographic situation can help increase product demand, creating opportunities to improve the competitiveness level.

10. The legislative framework has a decisive impact on enterprises' activities and, therefore, affects their competitiveness. A practical, clear, and understandable legal framework creates the basis for enterprises' activities, with clearly defined frameworks and requirements.

11. Opportunities to obtain grants to develop the enterprise are among the most relevant factors contributing to increasing the enterprise's competitiveness. Currently, there are many grant programs for foreign investors aimed at supporting businesses during the war. Therefore, by taking advantage of the program and receiving a grant, entrepreneurs can increase the enterprise's competitiveness.

12. State support of entrepreneurship. The war in Ukraine has significantly worsened the economic situation, so the state is currently directing significant efforts to support and develop businesses. Thus, assistance is provided in the form of grants, preferential lending, creating an attractive environment for investors, etc. A company can use these opportunities to increase its competitiveness.

13. The high level of technological development of the country and the world creates opportunities to increase the enterprise's competitiveness by introducing new technologies and innovations (*Akuliushyna et al., 2024*).

Separately, it is worth focusing on some factors to increase agricultural enterprises' competitiveness, which are distinguished from other industries by their management specifics. These factors include:

- products (crops and animals that are reared). If the level of yield of a particular crop or return on animal husbandry does not justify the expected results, the enterprise, in a relatively short time (one year, except for horticulture), can change the products it grows;
- weather conditions;
- the land area on which agricultural products are grown and the quality of these areas (e.g., soil fertility);
- availability of equipment and the use of technologies to increase yields (in particular, the use of fertilisers);
- financial (access to financial resources and ability to manage them);
- the legal and economic environment in which the company operates;
- the ability of the management to organise the main agricultural work and the sale of the crop promptly (*Kryvesko & Sidun*).

From this, we can conclude that some factors are objective and related to natural and climatic conditions. In other words, the competitiveness of an agricultural enterprise is largely determined by external conditions, not by the abilities of managers and employees or by available technologies.

Market changes in the Ukrainian economy's agrarian sector necessitate the formation of a complex, multifaceted economic system capable of adapting to conditions, constantly changing, and becoming more complex both within the agricultural sector and in other national economic sectors. Therefore, Ukraine needs to set and consistently solve the tasks of agricultural enterprises' innovative development.

The innovative aspect of the factors of increasing the agricultural enterprises' competitiveness

According to J. Schumpeter, innovation is a change to introduce and use new types of consumer goods, new production and transport facilities, markets, and forms of organization in the industry (*Schumpeter & Backhaus, 2003*).

Innovation is not only innovation, it is also the ability to think in a new way and rethink existing stable, traditional truths, which is a prerequisite for participation in developing Ukraine (*Suprun, 2017*).

Innovation is a proven new concept that has gone through all the stages of its development, supported by qualitative and quantitative indicators (*Oliinyk, 2022*).

Thus, we believe that innovation is a complete, unique solution that, with the help of scientific and technological achievements, has found its implementation in the form of a new or updated social need. This implementation increases the efficiency of the enterprise's functioning in the context of creating competitive advantages to obtain the maximum possible economic, social, environmental, or other effect.

It is worth noting that innovation, in its essence, aims to introduce something new or improve an existing one. However, this process also has certain risks – the higher the project innovation level, e.g., a new method of production or a product with previously unknown properties, the higher the level of uncertainty and risk that corresponds to it (*Figure 1*).

Innovation activity is a prerequisite for the need satisfaction process. Its result is the creation of an innovative economy built on knowledge and the commercialization of science (*Shpykuliak & Kurylo, 2010*). Thus, the essence of innovation lies in implementing changes constituting the functional content of an enterprise's innovation activity.

It is known that the main goal of any enterprise is not only to be competitive with other enterprises but also to constantly modernise each stage of its production. This goal can be achieved only under the condition of high innovation intensity because, thanks to the constant renewal of production facilities, it is possible to respond promptly and at minimal cost to changes in consumer needs, scientific and technical aspects, and the market as a whole. A competitive advantage is gained by those market participants taking an active role in using innovations.

The appendix (*Figure 2*) shows the impact of innovations on the formation of the system's competitiveness.

The essence of innovative development in various national economy sectors does not contain fundamental differences, but unlike others, the development of innovations is much slower in agriculture enterprises, which requires special attention.

Innovative processes in agriculture have some features and are related to their specifics, particularly the presence of living organisms, seasonality, increased risks, etc.

In our opinion, the main features of the formation and development of the innovation process in agriculture should include:

(1) significant regional differences in natural and climatic conditions, specialisation, and volumes of agricultural production;

(2) a variety of types of cultivated crop products, like products of its processing; the presence

of a significant difference in the technology of growing, keeping, and feeding animals;

(3) seasonal nature of agricultural production, characterized by differences in the periods of production of some types of agricultural products;

(4) availability of various production types in different organisational and legal forms, forms of ownership, sizes, and specialisation;

(5) dependence of production technologies in agriculture on natural and climatic conditions;

(6) the logistics system is damaged during the war, making it impossible to cooperate with remote suppliers and product markets;

(7) lack of labour resources and different socio-educational levels of agricultural workers, whose qualifications need to be systematically improved to introduce effective innovation activity at the enterprise;

(8) remoteness from information and consulting services and organisations that produce and implement scientific and technical products, like the lack of a clear and scientifically grounded organizational and economic mechanism for transferring scientific achievements to commodity producers, results in a significant lag in the industry in developing innovations.

According to the subject and scope of application in agriculture, as a rule, there are eight types of innovations (*Table 3*).

Thus, innovation as a factor in increasing competitiveness is scientific, technical, technological, economic, and organizational changes in production, which differ from the existing practice and are aimed at improving the production process to ensure competitiveness. Characterizing the significance of innovations for the achievement of competitive advantages by an enterprise, it is worth noting that innovation processes ensure the optimisation of organisational forms of relationships, contribute to developing infrastructure and become the basis for forming effective motivational mechanisms for their further functioning in the market (*Berezina, 2013*).

Various factors make activating agricultural enterprises' innovation processes possible. Scientists recognise the most significant factor as the enterprises' orientation to the market and attitude to innovations. Significant factors also include an effective system for evaluating and selecting innovative projects, the management effectiveness of such projects, and proper control, like the combined reduction of management links and the timing of developing innovations (*Sitkovska, 2016*).

As world experience shows, the effect of the impact of innovations on increasing competitiveness has three components (*Kolesov, 2010*):

(1) increasing the products' competitiveness, creating competitive advantages in the short and medium term;

(2) the emergence of new consumer needs, creating competitive advantages in the long term;

(3) increasing the efficiency of production, which by its influence transforms the competitiveness of products into the enterprise's competitiveness.

According to this, applying innovations in their activities will not only help domestic enterprises establish internal processes for producing products due to advanced technologies but also help increase their competitiveness level and maintain competitive advantages over time. An enterprise using innovative processes in its activities has a competitive advantage as

long as the innovations' confidentiality is maintained because almost any achievement can be repeated.

Discussion

The question of how innovative determinants can affect agricultural enterprises' competitiveness in the long term remains debatable. On the one hand, innovation can significantly increase productivity, improve product quality, and reduce production costs, which undoubtedly increases the enterprises' competitive position in the market. On the other hand, implementing innovative technologies often requires significant financial investments and time to adapt, which can create particular risks for enterprises, especially those with limited resources. This raises questions about the balance between investing in innovation and the potential benefits it can bring.

Another debatable topic is the role of state support in stimulating innovative processes in the agro-industrial complex. Some experts argue that active government support, such as subsidies, tax incentives, and grants, is a prerequisite for ensuring the sustainable development of innovation in the agro-industrial sector. At the same time, others believe that excessive dependence on government support can lead to a decrease in the enterprises' motivation to implement innovations and develop their research initiatives independently. In this context, there is a discussion about the optimal level of state intervention and support, which would stimulate innovation without reducing the enterprises' independence and competitiveness.

In addition, the issue of the impact of globalization on agricultural enterprises' competitiveness remains unresolved. Integration into the world economy opens up new opportunities for exporting products, accessing new markets, and exchanging innovative technologies. However, globalisation also carries the risk of increased competition from foreign producers, which can lead to a decrease in the profitability of local enterprises. In addition, global markets dictate specific standards of product quality and safety, which can be difficult to meet. This creates additional challenges for agricultural enterprises in the context of increasing their competitiveness at the international level.

Conclusions

The problem of enterprises' competitiveness in the modern world has a universal character. How successfully it is solved depends on the level of economic and social life in any country, including Ukraine.

One promising direction for developing agricultural enterprises in Ukraine is the introduction of innovations to implement successful economic activity. Enterprises that successfully implement innovations in their activities have a competitive advantage as long as they are innovatively active. This is argued by the fact that enterprises that do not pay enough attention to innovative development become obsolete and gradually lose the market, consumers, and the ability to compete with other enterprises.

A favourable combination of certain factors and conditions ensures the success of innovative transformations, the development of which is possible only during the implementation of a purposeful innovation policy.

Thus, the enterprise's innovation activity, accompanied by the continuous introduction of

innovations, increases its competitiveness.

Conflict of interest

The authors declare that there is no conflict of interest.

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Appendix

Table 1. Factors influencing the agricultural enterprises' competitiveness

Impact Level			
Micro Level	**Meso-level**	**Macro level**	**Meta Level ***
Marketing activity at the enterprise	State of innovative activity	The level of solvent consumer demand	Conditions of foreign economic activity, European integration processes *
Logistics activities at the enterprise *	Scientific and technical potential of the industry	Level of support for domestic producers	Global demand amid a shortage of crop and livestock products *
Natural, climatic, and soil conditions *	Awareness of market conditions	Institutional policy of the state	Scientific and technological progress *
Qualification of personnel and the level of their motivation	Competing Enterprises *	Inflation rate *	Logistics processes *
Material, technical, and financial support for the enterprise	Material, technical, and financial support of enterprises in the industry	Information Technology (Smart Technology) *	Regulatory and legal support *

Innovative capacity of the enterprise *	Efficiency of the organization of the industry	Financial, tax, and credit policy of the state	Migration processes *
Production volumes, costs, specialization, and size of the enterprise	Conditions of material and technical supply	Institutional support for innovation *	Military-political conditions *
Quality of raw materials, materials, and semi-finished products *	Level of fertilizer supply	Standardization of production and labelling of products *	Compliance of products with international standards *
Level of technology investment	Level of provision of plant protection products *	Social and Environmental Responsibility *	International Trade Tax Liabilities *

Source: author's development (*Okhota et al., 2024*)

Table 2. Factors influencing the agricultural enterprises' competitiveness

Internal factors	**External factors**
Financial Resources	Economic situation in the country
Material and technical base	Market Conditions
Technology & Innovation	Technological advancement
Human Resources	Socio-demographic factors
Organizational factors	Political and legal stability
Marketing Strategy	Environmental factors
Quality of management processes	Competition in the market
Supply Chain	Regulatory Requirements
Level of corporate culture	Changes in international politics
Internal communications	Changes in consumer preferences
Cost and availability of resources	Global Economic Trends
Availability and quality of intellectual property	Investment climate
Innovative Culture	Trends in Agronomy and Agriculture

Source: author's development (*Chikov et al., 2022; Chikov & Kovalchuk, 2024; Dotsiuk et al., 2024*)

Table 3. Classification of innovations by subject and scope in agriculture

Classification feature	Type of innovation
Biological	− new varieties and hybrids of agricultural plants; − new breeds, types of animals, and birds.
Technical	− use of new types of machinery and equipment.
Technological	− new technologies for processing crops; − new technologies in animal husbandry; − scientifically grounded and ecologically sound systems of agriculture and animal husbandry; − new resource-saving technologies for the production and storage of agricultural products.
Chemical	− new fertilizers and their systems; − new plant protection products.
Economic	− new forms of enterprise organization, and planning; − new forms and mechanisms of innovative development of the enterprise.
Social	− provide favourable conditions for life, work, and recreation of the rural population.
Management	− new forms of organization and motivation of work; − new methods of effective personnel management.

Marketing	– entering new market segments; – improving the quality of products and expanding the range; – new distribution channels.

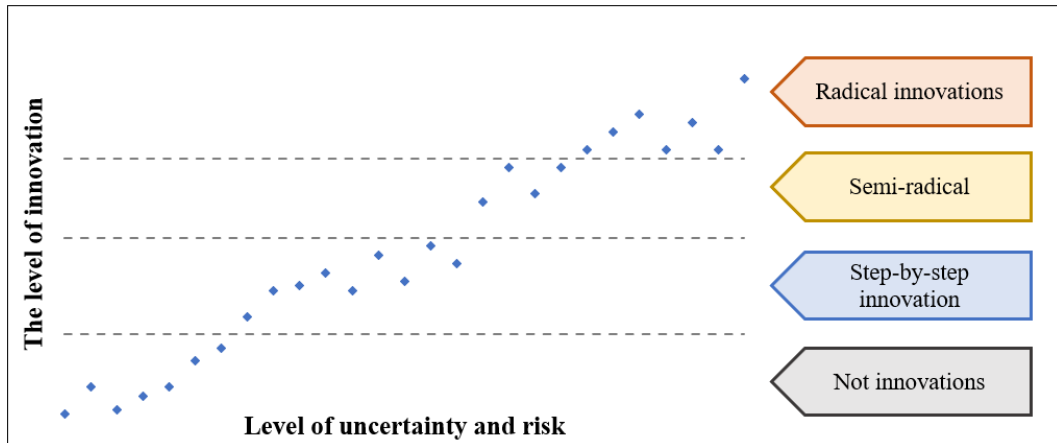Source: compiled from source (*Donets, 2013*)

Figure 1. The interconnection between the level of innovativeness and the level of risk.
Source: graphically presented on the basis of processed literary sources

Figure 2. The Impact of Innovations on the Formation of Competitiveness of Agricultural Enterprises
Source: formed on the basis of (*Chikov & Yaroshchuk, 2024; Chikov et al., 2022; Honcharuk & Tomashuk, 2023*)

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Economic analysis of legal support of the One Health policy [3]

Abstract: The One Health concept aims to balance and integrate the health of humans, animals and ecosystems through six main activities: surveillance, risk assessment and management, policy implementation, governance and coordination of One Health sectors. Legal support for this concept should consider the country's socio-economic, organizational and political characteristics. The study object is the legal support of the single health concept. The study subject is the methodological principles of economic analysis of the legal support of the single health policy. The study aims to identify relevant economic analysis methods of the OH's legal support, with regard to international experience. To achieve the purpose of the study and solve the tasks set, the methods of interdisciplinary research, economic and legal analysis, welfare economics, risk analysis, cost and benefit analysis, etc. were used. The use of interdisciplinary research methods, financial and law analytics, risk and cost-benefit analysis is key to the development of effective legal provisions. The discussion focuses on hazard identification and methods of prevention, like on human life value. The conclusions emphasize the importance of developing optimization models of legal regulation in One Health.

Keywords: economic analysis of law, One Health, cost-benefit analysis, veterinary policy, sustainable development.

Економічний аналіз правового забезпечення політики Єдиного здоров'я

Анотація: Концепція Єдиного здоров'я (ЄЗ) спрямована на збалансування та оптимізацію здоров'я людей, тварин та екосистем через шість основних напрямків діяльності: відстеження загроз, оцінку і управління ризиками, реалізацію політики, врядування та координацію галузей ЄЗ. Правове забезпечення цієї концепції повинно враховувати соціально-економічну та організаційно-політичну специфіку країни. Об'єктом дослідження є правове забезпечення концепції єдиного здоров'я. Предметом дослідження є методологічні принципи економічного аналізу правового забезпечення політики єдиного здоров'я. Метою роботи є визначення релевантних методів економічного аналізу правового забезпечення концепції єдиного здоров'я. Для досягнення мети дослідження і вирішення поставлених завдань були використані методи міждисциплінарних досліджень, економіко-правової аналітики, економіки добробуту аналізу ризиків, аналізу витрат і вигід тощо. Використання методів міждисциплінарних досліджень, економіко-правової аналітики, аналізу ризиків та витрат і вигід є ключовим для розробки ефективних правових норм. Дискусія зосереджена на визначенні факторів шкідливого впливу та методів їх запобігання, а також на визначенні цінності людського життя. Висновки підкреслюють важливість формування оптимізаційних моделей правового регулювання ЄЗ.

Ключові слова: економічний аналіз права, Єдине здоров'я, аналіз витрат і вигід, ветеринарна політика, сталий розвиток.

Abbreviation:

AHHME is the Agriculture Human health Micro-Economic model;

AMR is antimicrobial resistance;

DCFTA is deep and comprehensive free trade area;

OH is One Health (concept);

SEGRA is a scientific expert group on risk assessment.

Introduction

As a system of views, the OH concept aims to sustainably balance and optimise human, animal, and ecosystem health. It covers a wide range of goals, methods, and tools, which include six main areas of activity for its implementation: OH threat tracking, OH risk assessment and management, the ability to implement OH policies, and the management and coordination of OH and OH industries.

Legal support for implementing the national OH policy is based not only on generally recognised conceptual norms but also should consider the socio-economic, organisational and political specifics of the country's economic activities. Considering this, the definition of relevant tools for analysing the legal support of the OH concept is of primary significance in developing and implementing rules and regulations for regulating activities in public health, animal health and environmental protection.

The study's object is the legal support of the OH concept.

The study's subject is the methodological principles of economic analysis of the legal support of the OH policy.

The study aims to identify relevant methods of economic analysis of the legal support of the OH concept.

Based on the purpose of the study, the following tasks were set:

– define the conceptual framework of the OH;

– summarise international experience in implementing the OH policy;

– identify promising methods for analysing the legal support of the OH policy.

To achieve the research goal and solve the tasks set, interdisciplinary research methods, economic and legal analytics, welfare economics, risk analysis, cost-benefit analysis, etc., were used.

OH concept

The OH concept is not new; it has only recently acquired a new definition. The understanding that human health, wild and domestic animals, and natural living systems are linked and closely interlinked has existed for centuries (*Evans & Leighton, 2014*). The modern term was preceded by the definition of "Unified Medicine", which was introduced by William Osler (*Dukes, 2000*) and completely reinterpreted by Calvin Schwabe, a veterinarian and parasitologist in public health, who recognised the close systemic interaction of humans and animals in matters of nutrition, life and health (*Cardiff et al, 2008*; *Schwabe, 1984*). In the early 2000s, the term was replaced by OH. Individual initiatives outlined the principles of the OH concept. At the One World, One Health Symposium in 2004, 12 Manhattan principles were adopted that call for recognising the relationship between human, animal, and wildlife health, considering the environmental implications of decisions, integrating wildlife health science into

global disease control strategies, limiting wildlife trade, increasing investment in health infrastructure and education, and promoting collaboration between different sectors to preserve biodiversity and improve the health of the planet (*Wildlife Conservation Society, 2004*). These principles were updated at the 2019 Berlin Conference "One Planet, One Health, One Future". The "Berlin Principles of One Health" were approved, which contributed to the revival and systematisation of a concept based on the concepts of ecosystem health and integrity, like solving new problems such as the spread of pathogens, climate change and antimicrobial resistance (*Gruetzmacher et al., 2021*; *WHO…, 2019*).

The term took on a new interpretation after the COVID-19 pandemic, which outlined the need for increased attention to the risks associated with zoonoses for the population, which is complicated by the growing resistance of microorganisms to antimicrobial agents, climate change, migration of wild animals, and reduced biodiversity. The risk of increasing the number of new and recurrent infectious diseases exists not only for humans (and the food supply and economy), but also for the fauna and flora that support the viability of the ecosystem (*Streichert et al., 2022*). A group of independent experts created through the so-called Quadrilateral Partnership on OH with the participation of four international organisations: FAO, WHO (formerly OIE), and the United Nations Environment Programme proposed a new definition of the term (*Mettenleiter et al., 2023*): "One Health is a comprehensive, unifying approach aimed at achieving an optimal level of human, animal and ecosystem health and ensuring a sustainable balance between these three components. This approach recognises the close relationship and interdependence between human health and the health of domestic and wild animals, plants and the environment (including ecosystems). This approach is based on mobilising different sectors, disciplines and communities at different levels of society to work together to strengthen well-being and combat threats to health and ecosystems while simultaneously meeting collective needs for clean water, clean energy sources and clean air, safe and nutritious food, and taking action to combat climate change and promote sustainable development."

A new and essential element in the proposed definition is a clear reference to the methodology and approach that can effectively implement the concept's main objectives.

International regulation

A strategic document that identifies ways to solve global problems at the intersection of the human-animal-ecosystem system is the "Joint Action Plan for One Health", published at the end of 2022 (*FAO…, 2022*). Its goal is to support the implementation of the OH concept at the international level and ensure cooperation between sectors and regions, identify synergies and avoid duplication to improve coordination and mobilise investment to optimise resource use (*Barton Behravesh, 2019*). The proposed approach also meets key needs for achieving the UN Sustainable Development Goals and provides guidelines for policymakers, academics and practitioners. The plan identifies six interdependent areas of action to strengthen health systems, reduce the risk of zoonotic epidemics and pandemics, control and eliminate endemic zoonotic, forgotten tropical and vector-borne diseases, strengthen assessment, management and awareness of risks to food safety, curb the "silent" antimicrobial resistance pandemic, and integrate the environment into an OH. To support the implementation of the joint approach to the implementation of the OH concept at the national level, in December 2023, the

Quadrilateral Initiative presented practical recommendations on governance, sector integration and awareness-raising with OH "Guide to Implementing the Joint Action Plan for the Maintenance of One Health at the National Level" (*FAO…, 2023*).

In the policy of the European Union, the OH approach has evolved from its perception exclusively as a link between human and animal health without considering the health of the environment to a direct reference to the OH concept in the European Green Course adopted in 2019 (*European Commission, 2017*). During the transition period, the EU's OH Action Plan against AMR was launched in 2017, which changed approaches to this problem and laid new foundations for its comprehensive solution (*European Commission, 2017*). For the first time, this document introduces a legal definition of the OH concept. It emphasises the need to consider a broad concept that includes environmental factors and defines sustainability as one of the problems to which the OH concept is worth applying.

Following the formal approval of the principles of the OH concept, several policy strategies were introduced within the framework of the European Green course, including the Biodiversity Strategy until 2030 (*European Commission, 2020b*), the Zero Pollution Action Plan (*European Commission, 2021*), the Field-to-Table Strategy (*European Commission, 2020a*), the Chemical Sustainability Strategy (*European Commission, 2020c*) and the Pharmaceutical Strategy for Europe (*European Commission, 2020d*). The latter is directly related to the plan to combat antimicrobial resistance. In addition, the approved policy documents point to other important aspects of "unified health", including pandemic prevention, loss of biodiversity, chemical pollution, and sustainability of food systems. The principles governing EU policy are implemented through legislation. Integrating knowledge from public health, veterinary medicine, ecology, and social sciences is applied to a comprehensive analysis of the legal provision of OH, and collaboration with experts from various fields is used to develop holistic legal strategies. With the development of the concept itself, the normative approach has also changed, reflecting the state of the current public discussion and the way issues are resolved.

Economic analysis of law in forming the National OH Programme

Due to the introduction of administrative and legal norms, forecasting costs and benefits are within the competence of a relatively new area of Interdisciplinary Research-Economic Analysis of law. The economic analysis of law defines a significant difference between politics as a set of goals, methods and tools of purposeful influence on specific aspects of public interaction and the law that monitors compliance with politics. Legal requirements impose certain obligations on individual structures of society that behavioural rationality does not impose. The law forces various structures of society to monitor their activities more closely. They will refrain from taking action when the cost of complying with the law is lower than the benefits of illegal actions, considering the risk of evading responsibility. Formal institutions change behaviour even when the requirements of the law coincide with typical behaviour. Considering the costs of enforcement of legislative norms and the consequences of their implementation, the formation of legal support for policies should be based on obtaining the expected positive effects. Using economic tools for modelling human behaviour and analysing the impact of formal institutions allows us to predict, to a certain extent, the possible costs individuals will be forced to spend due to regulatory norms and the social benefits of such

regulation. Such considerations generally justify introducing a mandatory assessment of the regulatory impact (so-called ODS) of adopting regulatory legal acts in a number of developed countries of the world.

The legal support of human and animal health is based on the provisions of the Ukrainian Constitution, the law of Ukraine "Fundamentals of Legislation of Ukraine on Health Protection" dated November 19, 1992, the law of Ukraine on the public health system dated September 06, 2022, No. 2573-IX, and the law of Ukraine "On Veterinary Medicine" dated February 04, 2021.

The fundamentals of Ukraine's healthcare legislation establish the legal, organisational, economic, and social principles of healthcare in Ukraine. The law aims to eliminate factors that negatively affect health, prevent and reduce morbidity, disability, and mortality, and improve heredity.

The law on the public health system establishes the legal, organisational, economic and social foundations for the functioning of the public health system in Ukraine. Its goal is to promote public health, prevent diseases, improve quality and increase life expectancy. The law regulates public relations in public health and sanitary and epidemic well-being, defines the rights and obligations of state bodies, local self-government, legal entities and individuals in this area, and also establishes the legal and organisational basis for state supervision (control) in areas of economic activity that may threaten the sanitary and epidemic well-being of the population.

The Law on Veterinary Medicine defines the legal and organisational basis for activities in animal health protection and welfare, veterinary practice, production, circulation, and use of veterinary drugs (including antimicrobial agents), including the circulation of animal by-products.

Despite the stated goals, legal support tools and methods do not always have an optimal structure due to the likelihood of incorrect estimates of costs and benefits from the introduction of administrative regulations. Restrictions and barriers in the form of mandatory licensing, certification, sanitary standards, hygiene requirements, and the establishment of maximum permissible standards for pollutants usually restrain business activity and shift significant costs to society, limiting competition and incentives for economic growth.

The RIA applies as a criterion the introduction of administrative regulations regulating the ratio of direct regulatory costs and the public benefits from preventive tools to prevent possible harm.

From the point of view of the economic analysis of law, it is necessary to single out cases when, under any conditions, there will be a threat to people's lives. This concerns preventing and treating diseases, particularly infectious diseases common to humans and animals. An example is the recent events related to the COVID-19 pandemic, when at the beginning of the virus circulation, the risk to the life and health of the general population was high, and the available vaccines did not pass large-scale and comprehensive testing.

More complex cases for analysis will be those associated with excessive overestimation of individual parameters of the OH system. This can apply to both the parameters of the OH's final goals and intermediate (instrumental) goals. The goals of stimulating the development of certain branches of agricultural production may contradict the goals of ensuring environmental protection and Environmental Protection. Another example is excessive attention to the value

of human life, such as treating rare genetic diseases, which requires excessive expenditure of limited resources. These resources are usually reallocated from other OH programmes, which in poor countries can significantly reduce the social level of society and, for example, become a factor in the spread of other diseases (tuberculosis, helminthiasis, etc.).

The third significant problem of direct regulation is the incorrect selection of tools that do not ensure the implementation of goals or contradict them. This situation will almost always arise in the context of the spread of rent-oriented behaviour, lobbying, political entrepreneurship and corruption. It should be noted that the lack of clearly defined and theoretically justified methodological tools for forming administrative and legal support can encourage the development of irrelevant legal norms or the import of formal institutions.

The world experience of Applied Analysis of legal support for human and animal health protection has formed several descriptive, predictive and normative models. An example is the AHHME model, which allows you to calculate the cost-benefit ratio (in terms of human health) and cost-benefit ratio (in terms of the agricultural sector, labour productivity, and health care costs) of any interventions during the maintenance of productive animals (*Emes et al., 2023*). This toolkit also contains epidemiological models for humans and productive animals based on polygamous models using differential equations to model the transition between health conditions. A significant element is the adaptation of models to specific conditions, using regional demographic, production, economic and epidemiological data and considering the political context and local priorities. A holistic understanding of the problem contributes to an informed choice of administrative and legal regulation tools.

Legal support of environmental protection and environmental protection is based on the provisions of the Constitution of Ukraine, laws of Ukraine on Environmental Protection of 25.06.1991 № 1264-xii, on flora dated April 09, 1999, No. 591-XIV, on fauna dated December 13, 2001, No. 2894-III defines relations in protection, use and reproduction of the animal world, on the protection of animals from ill-treatment dated February 21, 2006, No. 3447-IV, which are aimed at regulating relations in the field of protection, use and reproduction of natural resources, ensuring environmental safety, preventing and eliminating the negative impact of economic and other activities on the environment, preserving natural resources, the genetic fund of wildlife, landscapes and other natural complexes, unique territories and natural objects related to historical and cultural heritage.

This area of analysis requires an assessment of legal norms and the legal decision-making process from the point of view of economic efficiency. This case is characterised by a broad interpretation of the efficiency criterion from the strict definition of V. Pareto to the Kaldor-Hicks criteria and Tibor de Scitovsky's double criterion. The latter determines changes in the welfare of society as a result of the implementation of state environmental policy measures effective if the benefits from the increase in the welfare of those who won exceed the losses in the welfare of those who lost, as well as additional analysis in the opposite direction in the case of applying the double Skitovsky criterion.

Such a broad interpretation of the effectiveness criterion forms the appropriate field of research. The analysis of available publications allows us to identify many methodological problems that either continue Coaseэs research to a certain extent or are within the framework of the subject problem of the theory of Public Choice. These include ways of market

transactions for the effective distribution of property rights, opportunities for internalisation of environmental externalities, conditions and methods of unitisation for the limited use of public resources, methods of environmental sanctions by society and promotion of environmental values, as well as analysis of political feasibility in the context of the established organisational and political structure of society (*Heyes, 2001*).

Modern research pays special attention to the applied aspects of environmental protection and the ability of economists and lawyers to influence regulatory policies, tools, and methods. Among such methods, the right of environmental responsibility is distinguished as a particular system of rules that determine the conditions and amounts of compensation for losses caused by externalities. Thus, from the viewpoint of welfare economics, the law of environmental responsibility aims to internalise external effects (*Labenko, 2023*).

The economic analysis of law defines three regimes of Environmental Responsibility: economic, administrative and criminal. According to the principles of ODS, the criterion for choosing tools (Coase negotiations, taxes and fees for Pigou, fines and lawsuits, criminal proceedings) is to minimise public costs associated with applying legal norms. Developing optimisation models of social punishments should include quantitative and qualitative parameters, environmental uncertainty and risk, and monetary and non-monetary sanctions. Environmental uncertainty and risk are divided according to the principles of ex-ante and ex-post. In the first case, the risk of origin (generation risk), due to the uncertainty of pollution parameters due to an environmental incident, and the risk of Impact (impact risk), are introduced separately due to the uncertainty of environmental consequences. The second case is characterised by the complexity of determining strict causal relationships between an environmental incident and environmental damage (*Bartsch, 1998*; *Endres & Rübbelke, 2022*; *Siebert, 1998*).

Unitising and internalising environmental externalities requires significant transaction costs, and their organisation is a commodity of public consumption. That is why the choice of legal regulation tools must meet the criteria of economic efficiency (feasibility, awareness, stability of the balance, long-term nature of the formed incentives, etc.). The application of environmental liability law allows managing two types of environmental externalities and using the tools of court decisions to shift environmental costs to the culprit. However, in the case of established (regular) environmental externalities, the transaction costs of legal regulation may be high (*Siebert, 1998*).

Environmental responsibility law regimes are defined using the following characteristics:

- liability rules, which include negligence-based liability and strict liability;
- the scope of liability, which includes the definition of potentially dangerous activities that fall under the liability regime, like the legal definition of the losses caused by them that must be compensated;
- legal identification of the responsible person (operator), which can be the company's owner, the "parent" corporation, or credit institutions (borrowers).

Legal support for food safety

In 2014, with the signing of the DCFTA agreement with the EU, Ukraine began modernising the food safety system, committing to bring its legislation closer to EU requirements. Legal support of food safety is implemented through the introduction of the laws

of Ukraine "On Fundamental Principles and Requirements for Food Safety and Quality", "On State Control over Compliance with Legislation on Food Products, Feed, Animal By-Products, Animal Health and Welfare", "On Information for Consumers Regarding Food Products", "On Basic Principles and Requirements for Organic Production, Handling and Labelling of Organic Products", and other regulatory legal acts.

The law of Ukraine "On Basic Principles and Requirements for Food Safety and Quality" has the ultimate goal of protecting the life, health and interests of consumers and defines ways to achieve this goal based on the principle "from field to table" and declares the application of necessary measures based on risk assessment, based on existing scientific justifications, international standards, instructions or recommendations. Suppose international standards, instructions or recommendations are absent or insufficient. In that case, measures are developed based on risk assessment, according to the methods established by international organisations, and should be based on the principles of independence and objectivity.

Coordinating work on conducting an independent, objective, transparent, scientific risk assessment is provided by an independent structural division of the competent Food Safety Authority (Derzhprodspozhivsluzhby) – the risk assessment sector. The sector initiates the formation of SEGRA of hazards in the food chain to provide scientific and technical support in the form of a report indicating conclusions and recommendations for managing identified risks for decision-making by risk managers of the competent authority. The risk assessment results can be qualitative or quantitative, depending on the available resources (time, data, etc.), and must necessarily include an explanation of the sources of uncertainty. Conducting a risk assessment allows you to get information for making informed decisions on risk management at the level of state authorities on the formation of administrative and legal tools.

Since the responsibility for food safety is assigned to market operators, including through the obligation to implement management systems based on the hazard analysis principles, according to the ex-ante regulatory principle, entrepreneurs are responsible for compliance with the provisions of current regulations and minimising risks on their initiative. The final result depends on the manufacturer's competence, desire and ability to comply with current requirements. Risk management decisions are based on enterprise-specific conditions based on hazard analysis. However, quantifying risks requires the manufacturer to collect and analyse significant amounts of data, which is almost impossible, so companies can rely on government agencies, international bodies, or trade organisations that can provide data such as dose-response dependence, baseline levels of pathogen prevalence, toxicity and other adverse effects of food contaminants, consumption patterns, and consumer demographics. These general data can be combined with data about a specific product or enterprise, such as ingredient sources, processing parameters, distribution systems, and product expiration date, to obtain a risk assessment that supports the development of hazard analysis systems (*Buchanan & Whiting, 1998*). The hazard analysis determines control measures necessary to prevent contamination, unacceptable increase in pollutants or their reduction to acceptable levels.

Methodological problems of optimising the legal support of the unified health policy

The excess of information costs over the benefits of applying regulatory norms while at the same time, a low level of compliance with legislation is one of the key problems in the formation

of optimisation models in the economic analysis of administrative law in general and the economic analysis of the legal support of OH policy in particular.

The main focus of such models should be on the incentives of participants in legal regulation, namely, the violator chooses the commission of an offence, victims – regarding the filing of complaints, and administrative authorities – regarding the consideration of cases. The low cost of filing complaints and the obligation of administrative authorities to respond to each complaint increases the number of open cases and reduces the likelihood of punishment in the event of significant damage to OH.

Discussion

Further areas of interdisciplinary research on the legal support of the unified health policy will be the determination of circumstances and factors of harmful impact on the OH system, criteria for their detection, and the search for optimal methods and tools for their prevention. Identifying obstacles to implementing the OH policy and ways to overcome them can be the subject of Applied Analysis to ensure the OH policy. Also debatable are the ways of adapting formal institutions of developed countries in countries that are reforming the system of social, organisational, political and socio-economic interaction.

Defining the value of human life and forming the unified health policy's normative target function requires a wider range of specialists in general philosophical, social, political, economic, biological, environmental, and veterinary areas. This will allow for a more relevant determination of all the value parameters and establish relationships between them.

Conclusion

The methodological principles of economic analysis of the legal support of EU policy formulated by us can form optimisation models of administrative and Legal Regulation methods that will ensure the minimisation of public costs in implementing target priorities. Using methods and tools for cost-benefit analysis allows us to attract qualitative influence parameters and consider the National specifics of public interaction.

In this context, it is worth noting that state failures can be overcome in countries that are reforming the system of public interaction through the active formation of public control structures (consumer protection societies, trade unions of doctors, veterinarians, environmentalists, public organisations for Environmental Protection, etc.). This will allow for continuous public monitoring of compliance with EU principles.

Conflict of interest

The authors declare that there is no conflict of interest.

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Electrical engineering as a modern fundamental discipline and the logic of its teaching in military higher education institutions [4]

Abstract: Understanding the processes that relate to the formation and transformation of the modern army and as a consequence of the modernisation of the education system of the Military University, the article pays special attention to the formation of a modern officer as a specialist not only in military affairs but also in military engineering. Military leaders must have electrical knowledge and the ability to choose and use appropriate modern military management technologies and information and technical means, the element base of which is electrical engineering, and the scientific and technical basis of Electrical Engineering is the synthesis of such fundamental sciences as mathematics, physics and chemistry. The study aims to provide scientific and methodological conclusions on updating electrical education's teaching methodology and mathematical tools. In Ukrainian literature, a discourse on this issue has already been formed. Examples include the monograph "Methodological System for Forming Integrated Knowledge in Physics in the Process of Training Technology Teachers", the article "Integration of Physics and Electrical Engineering in the System of Training Technology Teachers" and others. A. Didyk, L. Pavlyuk, and I. Petritsina describe intersubject relations and the role of physics as the basis of technical disciplines in more detail. These works deal with electrotechnical education's scientific and methodological problems in modern universities. The authors point to the growing demand for professional training of Higher Education graduates, which entails the need to move from traditional teaching styles to innovative ones. The article emphasises that engineering education is of great significance in modern society, and as for military affairs, it has become a necessary component. Military personnel who have received a high-quality modern electrical engineering education usually have developed technical skills, understand the technological features of modern weapons, and have a joint scientific base for innovations.

Keywords: military university, education, modernisation of education, information technologies, simulation models, computer modelling languages.

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Олексій Сергійович Білозьоров, Олександр Володимирович Цемма

Електротехніка як сучасна фундаментальна дисципліна та логіка її викладання у військових вищах

Анотація: Розуміючи процеси, які відносяться до становлення та трансформації сучасного війська і як слідство модернізації системи освіти військового університету, в статті особливу увагу звернуто на формування сучасного офіцера як фахівця не тільки у військовій справі, але і у військово-інженерній. Військові лідери повинні володіти електротехнічним знанням і вмінням вибирати та використовувати відповідні сучасні військові управлінські технології та інформаційно-технічні засоби, елементною базою яких є електротехніка, а науково-технічним базисом електротехніки є синтез таких фундаментальних наук як математика, фізика і хімія. Метою дослідження є науково-методичні висновки щодо оновлення методлогії викладання і математичного інструментарію електротехнічної освіти. У вітчизняній літературі вже оформився дискурс, присвячених даній проблематиці. Прикладами можуть стати монографія «Методична

система формування інтегрованих знань з фізики в процесі підготовки вчителів технологій», стаття «Інтеграція фізики та електротехніки в системі підготовки вчителів технологій» та інші. Більш детально описують міжпредметні зв'язки та роль фізики як основи технічних дисциплін А. Дідик, Л. Павлюк, І. Петрицина. В цих роботах розглядаються науково-методологічні проблеми електротехнічної освіти в сучасних університетах. Автори вказують на зростаючий попит на професійну підготовку випускників вищих навчальних закладів, що тягне за собою питання необхідності переходу від традиційних стилів викладання до інноваційних. В статті підкреслено, що у сучасному суспільстві інженерна освіта має величезне значення, а щодо військової справи, то вона стала її необхідною складовою. Військові, які отримали якісну сучасну електротехнічну інженерну освіту, зазвичай мають розвинуті навички технічного характеру, розуміються на технологічних особливостях сучасної зброї, мають загальну наукову базу для новацій.

Ключові слова: військовий університет, освіта, модернізація освіти, інформаційні технології, імітаційні моделі, мови комп'ютерного моделювання.

Introduction

Understanding the processes that relate to the formation and transformation of the modern army and as a consequence of the modernisation of the education system of the Military University, the article pays special attention to the formation of a modern officer as a specialist not only in military affairs but also in military engineering. Military leaders must have electrical knowledge and the ability to choose and use appropriate modern military management technologies and information and technical means, the element base of which is electrical engineering, and the scientific and technical basis of Electrical Engineering is the synthesis of such fundamental sciences as mathematics, physics and chemistry.

The issue of professional training of future officer-engineers in the electrical engineering direction is one of the key issues in modern pedagogical theory and practice, which has a long pedagogical tradition. "Researchers have developed a fairly large fund of scientific knowledge that reveals various areas of University Electrical Engineering Education" (*Finin, 2020*). This is due, on the one hand, to the growing demand for modern electrical officers due to the complication of information and computer technologies of modern military equipment and, on the other, the rapid development of information technologies for comprehensive training. "The professionalism of a modern electrical engineering officer is not only his competence in various fields of information technology, computer languages of mathematical modelling but also his high qualification, which is the key to the successful performance of combat missions" (*Finin, 2020*).

We emphasise that "today, in covering the transformations of educational reality, it is necessary to rely not only on the methodology of pedagogy but also to consider the conceptual provisions of the philosophy of education and the philosophy of the development of modern society. Because it is they who strengthen the theoretical base of scientific studios" (*Korostylev &*

Dolskaya, 2022, p. 12). The authors rely on the works of M. Castels (*2013*), V. M. Kremen (*2021*) and others, who draw attention to the need for "constant modification of educational practice in the context of the development of the information society" (*Kremen, 2021, pp. 11-20*). When developing the theoretical and methodological foundations of education to use new technologies that consider the virtual space, it is necessary to rely on the works of researchers who directly and indirectly worked on this problem: E. Giddens, E. Durkheim, P. Bourdieu, K. Meinheim, E. Masuda, R. Merton, T. Parsons, E. Toffler, etc.

You should also pay attention to the comments of the classics on the methodology of teaching mathematics. As M. Kline notes, there are several possible approaches to teaching it. Among them is "plural theoretic, axiomatic, also based on logic, intuition" (*Kline, 1980*; *Kline, 1984*). The choice of one of the teaching logic is largely determined by historical and cultural factors and the personal orientation of the teacher. Features of the mathematical method allow it to focus on specific concepts, which already makes it possible to discuss a new impetus in teaching mathematics. George Polya also emphasised the importance of methodology as "a way of studying mathematics, suggesting that students not only focus on solving problems but also think about the methods and means that they apply" (*Polya, 1991, p. 448*).

The analysis of publications of Ukrainian scientists in the field of electrical Education shows that the practical and theoretical nature of reflection on the problems posed are interrelated. Therefore, "the general direction of all works, namely, theoretical and methodological," is natural (*Korostylev & Dolskaya, 2022, p. 12*). It is significant to emphasise the role of the works of specialists in the electrical industry in the context of the historical development of electrical engineering, which focuses on changes in the methodology of its teaching V. Savchenko, Yu. Lavrenenko (*2016*), N. Shvager (*2014, pp. 15-18*). This issue is becoming increasingly relevant, as modern information technologies directly and indirectly affect the organisation and methodology of teaching. "For the modern military education system to meet existing needs, certain transformations of the training system using modern information technologies are necessary. The main ideas are based on creating and maintaining information and educational environments of open, distance learning, developing new technologies for creating bases of educational materials and developing traditional technologies for developing electronic textbooks and educational portals. We can say that a new promising subject area is beginning to form – "Information Technologies in Education". This area includes the problems of intelligent learning systems, open education, distance learning, and information educational environments. Teaching methods and tools used in information technologies in education contribute to the fulfilment of increased requirements for the level of training of graduates of the higher military school" (*Korostylev & Dolskaya, 2022, p. 13*).

In Ukrainian literature, a discourse on this issue has already been formed. Examples include the monograph "Methodological System for the Formation of Integrated Knowledge in Physics in the Process of Training Technology Teachers" (*Shishkin, 2012*), the article "Integration of Physics and Electrical Engineering in the System of Training Technology Teachers" (*Shishkin, 2014*) A. Didyk (*2018*), L. Pavlyuk (*2020*), and I. Petritsina (*2013*) describe intersubject relations and the role of physics as the basis of technical disciplines in more detail. These works deal with electrotechnical education's scientific and methodological problems in modern universities.

The authors point to the growing demand for professional training of higher education graduates, which entails the need to move from traditional teaching styles to innovative ones.

Study materials

In general, electrical engineering is not only a science but also a branch of technology that converts various types of energy into electrical energy, which is then used to change the composition of a substance, produce and process materials, transmit information, and so on. Modern, efficient technologies are somehow based on the use of electric energy. By combining the course of Electrical Engineering with other subjects of training, the topics of modern electrical engineering can take their proper place in the professional training of future military managers and provide the necessary basis for the successful training of cadets in military universities.

Electrical engineering is one of the first modern technologies. Like nothing else, electricity has primarily influenced the development of modern man-made civilisation and changed human life. When we talk about electricity in general, we should understand that electricity is everything that surrounds us. Changes in the scientific, technical, technological and information-technological nature of warfare, which lead to qualitative technical and technological changes in production technologies and technical characteristics of modern types of weapons: drones, UAVs, high-precision artillery systems, GPS navigation, target detection location systems, Starling space communication systems, etc. It is worth noting that all these military technologies appeared due to the development of applied science, such as electrical engineering, and its transformation into a modern element base. These qualitative changes in the composition and technological structure of equipment put forward new modern requirements for training military electrical engineers as the leading specialists in the operation and repair of this equipment.

The subject of electrical engineering in the modern educational teaching structure plays a significant role in forming a particular physical reality, which combines knowledge of physics, mathematics, and chemistry. Thanks to this combination, didactics and methodology of teaching electrical engineering are aimed at intersubject relations: "Electrical knowledge is widely used in many technological processes of modern military equipment and technical means of controlling troops. Given that physics and mathematics are the fundamental basis of electrical engineering, the relationship between teaching these disciplines is particularly important in military universities. Implementing intersubject relationships in teaching physics, mathematics, and electrical engineering creates favourable conditions for creative application of the general principles of didactics in teaching" (*Korostylev, 2020*).

Since the study of electrical engineering affects the perception and understanding of the modern technological world, we will specify some key aspects that confirm the fundamental nature of this subject:

- studying electrical engineering helps cadets understand the role of technology in the modern world;
- studying electrical technologies helps cadets develop critical thinking about technical solutions, the effectiveness of techno-technological systems, possible actions with them and their consequences.

Based on electrical engineering and its main task – creating a particular reality that occupies an intermediate position between nature and man – the modern educational structure has a problem of narrow methodological foundations and practical tools. Using the example of electrical education in modern military universities, the authors tried to show the nature of changes in the educational space analyse and systematise them.

Justification of changes in the methodology of teaching electrical engineering

Since one of the central tasks of military education is primarily to acquire technical and engineering education, it is necessary to outline the components of technical science. "Technical science is formed based on complex processes associated with the formation of engineering activities and is the result of a combination of natural science and technological knowledge. The first component of developing and forming technical sciences is the stage of obtaining natural science knowledge, which leads to the ontologization of technology" (*Korostylev & Dolskaya, 2022, p. 12*). For D. Willis, we have the process of creating mechanisms that he built himself, from simple to complex. According to the principle of "from simple to complex", objects and knowledge of classical technical sciences are formed (*Korostylev & Dolskaya, 2022, p. 13*). In addition, research engineers sought to explore the entire field of engineering capabilities, i.e., they tried to understand what other characteristics and calculations of an engineering object could be obtained. During the analysis, "the research engineer sought to gain knowledge about objects, describing their construction, functioning, individual processes, dependent and independent parameters, relationships between them, etc." (*Korostylev & Dolskaya, 2022, p. 13*).

An equally important stage in the development of the technical sciences is their mathematical process. "From a certain stage in developing technical science, researchers move from using individual mathematical knowledge or fragments of mathematical theories to using entire mathematical apparatuses (languages) in technical science. This was prompted by the need to carry out in the course of design not only analysis but also the synthesis of individual processes and their structural elements" (*Korostylev & Dolskaya, 2022, p. 13*).

Using a mathematical apparatus affects the process of designing any technical object model. As a rule, ideal objects of technical science (such as drawings, structured diagrams, mathematical models, etc.) "start" a long process of development and construction to get the status of engineering objects in the future. In other words, the process of ontologising technical objects is unfolding. "From this point on, the engineer gets the opportunity to (a) successfully solve the problems of synthesis and analysis; (b) investigate the entire area of engineering objects for theoretically possible cases; (c) go to the theory of ideal engineering devices. Each mechanism begins to be considered as a mathematical circuit consisting of one or more closed circuits and several closed circuits that connect the contour link to the main links of the mechanism. In the theory of mechanisms, it becomes possible to obtain new design schemes of mechanisms by deductive method" (*Korostylev & Dolskaya, 2022, p. 13*).

Teaching electrical engineering in modern military universities could not help but feel specific changes. "From the mid-20th to the beginning of the 21st century, electrical engineering teachers focused on engineering and applied mathematical support for electrical processes. For the modern military education system to meet existing needs, certain changes in the training system using modern information technologies are necessary" (*Finin, 2020*; *Nikitenko et al., 2023*). Today, many concepts related to virtual reality are used, and computer mathematics is

becoming a necessary component in teaching electrical engineering. The best authors in the world present computer programming languages: "The new military education continues to change along with the change in the overall engineering picture of the world. The main emphasis is placed on using virtual products, on creating so-called simulation models of existing military weapons" (*Korostylev, 2022*).

Computer mathematics plays a unique role in this process. The best authors in the world represent computer programming languages: S. McConnell (*2006*), E. Thomas and D. Hunt (*1999*), M. Fowler (*2018*), R. Martin (*2019*), D. Knut (*2020*). Computer mathematics should be defined as a set of theoretical, algorithmic, hardware and software tools designed to effectively solve all mathematical problems on computers with a high degree of visualisation of calculation stages (*Tyutyunnik & Mikhalevich, 2013*). The latter plays a crucial role in CMS implementation in education. Modern CMSs are influential electronic reference books and databases on all sections of modern mathematics, practical tools for solving most mathematical problems, and tools for creating high-quality electronic lessons, articles and books. When we talk about computer mathematics, we mean computer programming languages.

How can you not remember the most famous names of those who devoted their thoughts to the inventions of virtual reality and opened the way for innovative changes in the technical world? "Given the questions raised, we will need work that deals with reviews of technical means of virtual reality systems. These are the works of Linus Torvalds (developed the Linux operating system), Tim Bernes (developed the program for Hypertext documents and hyperlinks), James Gosling (author of the Java programming language), Anders Heilsberg (developed the software Borland Delphi, C#, TypeScript, Turbo Pascal), Mark Zuckerberg (founder of Facebook), Bram Cohen (author of the Bit Torrent protocol), Brendan Ike (founder of the JavaScript programming language, was the chief engineer of Mozila Firefox), Bjarne Stroustrup (founder of the C++ programming language)" (*Korostylev & Dolskaya, 2022, p. 12*).

What programmes are used to create new divisions in educational processes? The primary virtual environments include PhET, Multisim, Electronics Workbench, LabVIEW, etc. Particular attention should be paid to PhET, a free site for creating interactive simulations in natural sciences and mathematics; the Electronics Workbench program is compatible with the P– SPICE programme, i.e., provides the ability to export and import measurement diagrams and results to various versions of it; Grapher and Postprocessor are Multisim programs that allow you to display simulation results in graphical form, etc. all programmes allow you to work in virtual laboratories, and this is the realisation of the ability to conduct experiments without direct contact with the actual installation or in its absence (*Korostylev & Dolskaya, 2022, p. 13*).

Modern teachers and scientists emphasise the need to use interactive technologies in teaching (we find this in the works of A. Didyk (*2018*), G. Shishkin (*2012*), I. Petritsin (*2013*). "According to military analysts, the need to use virtual models for educational purposes and scientific activities is an urgent need" (*Korostylev & Dolskaya, 2022, p. 13*).

Based on their experience of teaching electrical engineering subjects, it is necessary to emphasise the following: for improving the theoretical knowledge of cadets, practical training is of great importance – conducting laboratory classes. The methodological basis for conducting laboratory classes is the development of methodological manuals for conducting laboratory classes and the development of visualised programmes for computer interactive training. With

the help of a user-friendly interface, cadets have the opportunity to compose, simulate, and study electrical circuits in their free time.

Programmes for schematic modelling of analogue, digital, and analogue-digital circuits allow the laboratory workshop to draw up an equivalent circuit of the device using library components, simulate almost any electrical or electronic circuit, change the nominal values of its elements with a healthy check, and show actual waveforms of signals at any point of the circuit on the monitor. It becomes possible to demonstrate simulated circuit errors and their impact on specific electrical circuit parameters.

There are also disadvantages to working in the virtual world, e.g., one of them is the inability to conduct objective research on electrical circuits and radio components, affecting the ability of cadets to comply with safety regulations when working with live electrical equipment. At the same time, an ordinary computer, in combination with auxiliary devices, can be used as a powerful research laboratory. Using computer programs such as oscilloscope, pulse generator, millivoltmeter, spectrum analyser, and microphone input of a sound card, you can perform much real laboratory work without spending significant material resources.

Thus, in modern education, particularly in the teaching of electrical engineering, we observe the use of computer mathematics, which determines changes in the teaching of natural sciences. "Today, these changes are tied to the active use of virtual reality with the language of computer mathematics" (*Korostylev & Dolskaya, 2022, p. 16*).

Conclusion

The article emphasises that engineering education is of great significance in modern society and has become a necessary component of military affairs. Military personnel who have received a high-quality modern electrical engineering education usually have developed technical skills, understand the technological features of modern weapons, have a joint scientific base for innovations, and so on. It is impossible not to emphasise that modern, innovative electrical engineering education contributes to a systematic vision of problematic issues of a purely military nature.

The education of the future officer is complicated due to the integrated nature of teaching natural, technical, and technological sciences. These sciences' methodologies are related to innovative processes and require the use of increasingly complex computer mathematics tools.

It is worth emphasising that today it is increasingly necessary to turn to computer mathematics because the functioning of technical objects is directly and indirectly related to the appeal to the possibilities of virtual reality. Computer programming languages have become an active tool in the organisation of theoretical and practical tasks of electrical engineering, so introducing computer mathematics into educational programmes is becoming an objective necessity.

Using software products PhET, Electronics Workbench, Multisim, and many other alternative simulators of electrical and electronic circuits with similar functionality allows future military specialists to significantly expand their capabilities and improve their understanding of educational topics while performing laboratory workshops and control tasks. Also, it encourages a deeper study of the virtual object to create, calculate and test electrical circuits at all stages of their operation.

Conflict of interest

The authors declare that there is no conflict of interest.

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Igor Andrushchak [10], *Viktor A. Kosheliuk* [11]

Integration of machine learning algorithms for intrusion detection in IoT networks [5]

Abstract: The Internet of Things (IoT) is a powerful technology transforming many aspects of our lives, from how we connect and work to how we receive healthcare and manage the economy. IoT holds promise for enhancing life across diverse settings, from urban environments to educational institutions, through task automation, productivity enhancement, and stress reduction. As new threats and vulnerabilities emerge, the old ways of securing IoT devices are no longer sufficient. The future of secure IoT systems relies on machine learning and deep learning optimised for efficiency. To ensure robust security in constantly evolving next-generation IoT systems, we need to harness the power of artificial intelligence, particularly machine learning and deep learning solutions. To achieve this vision of constantly adapting security for next-generation IoT, the authors must create new methods that guarantee the highest levels of security within the entire IoT infrastructure. The study subject is detection systems for intrusions into IoT infrastructure and compromised IoT devices based on machine learning algorithms. The study object is a machine learning model that will detect anomalies in an IoT network's behaviour and identify patterns that indicate normal behaviour and deviations that may signal an intrusion. The study aims to enhance the security of IoT networks by developing effective and efficient intrusion detection systems using machine learning techniques. The study used scientific methods such as data collection and preprocessing, algorithm selection and development, model training and evaluation, experimentation and analysis, scalability and efficiency testing. The authors used the works of such scientists and researchers as A. Géron, N. Sengupta, R. Vinayakumar, S. Sarwar, and Wang Meng. The study investigates security mechanisms for understanding attacker behaviour in the realm of the IoT. This could be a significant step forward in fortifying IoT security. This approach to securing IoT devices relies on machine learning to analyse the data traffic these devices produce during communication. Additionally, this paper proposes incorporating machine learning methods to enhance honeypot operation by integrating them into the lambda function's design. Machine learning is becoming increasingly popular across many fields because it often performs better than traditional rule-based approaches. While fully automated cyber security detection and analysis using machine learning is appealing, it is essential to carefully assess how well machine learning works in this area. The authors offer an analysis tailored for security professionals, focusing on utilising machine learning techniques to develop a honeypot for detecting intrusions.

Keywords: Internet of Things, honeypot, lambda function, MQTT, machine learning.

Abbreviations:

AI – artificial intelligence

AISB – AWS IoT security baseline

ANN – artificial neural networks

API – application programming interfaces

CNN – convolutional neural networks

CPS – cyber-physical systems

CVE – common vulnerabilities and exposures

DL – deep learning

DNN – deep neural networks
DoS – denial of service
DT – decision trees
HIH – high interaction honeypot
HVM – hardware virtual machine
IaaS – infrastructure as a service
ID – device identifier
IoT – internet of things
KNN – K-nearest neighbour
LIH – low interaction honeypot
LSTM – long short-term memory
MIH – medium interactive honeypot
ML – machine learning
OTA – over the air
PaaS – platform as a service
RF – random forest
RL – reinforcement learning
RNN – recurrent neural networks
SVM – support vector machine
XGBoost – extreme gradient boosting.

Introduction

The world is becoming increasingly "smart" as the IoT turns ordinary objects into portals to the digital world. The network of IoT physical objects equipped with sensors, software and other technologies can collect, process and exchange data over the Internet. IoT is currently proliferating. As these networks expand and become more complex, so does the range of their capabilities. IoT is already used in various areas, from household appliances that automatically order products to sophisticated industrial equipment that optimises production (*Abdallah Wasan, 2023*).

The evolution of IoT technologies has made them a force that spans many industries and is no longer new. Sensors, automation, networks, data collection, and analytics, like miniature information processing devices, are all components of this evolution. A combination of technologies, such as sensors, automation, networks, data collection, and analytics, like miniature information processing devices, is the basis of this evolution. Incorporating these components into various objects results in the creation of intelligent vehicles, drones, instruments, and other machines. Security and privacy concerns can arise due to the variety of IoT devices and CPS. This problem is becoming more acute due to the growing dependence on IoT in areas such as online shopping, banking, education, and business (*Liang & Kim, 2021*; *Sengupta, 2019*; *Salau et al., 2022*).

Using communication protocols, the Internet of Things is a network that allows objects to be connected. Connecting IoT nodes to the Internet has been made possible through multiple

protocols, such as TCP/IP using the MQTT queue message transport protocol, Modbus TCP, and LoRaWAN technologies (*Kasongo, 2021*). Communication protocols incorporate safeguards to protect against various types of threats, such as data theft, brute-force attacks, port scanning, DoS and DDoS attacks, MITM, R2L, and probing attacks. There are two types of IoT attacks: user root (U2R) attacks and operating system attacks (*Sarwar et al., 2022*).

Detecting cyber threats can be achieved using honeypots and honeynets, providing valuable information about attackers' actions. A honeypot is a device that can attack and potentially steal information (*Fan et. al., 2018*). The network becomes a Honeynet when two or more Honeypots are deployed. IPS formation can be accomplished by integrating honeypots with firewalls and IDS, obtaining complete information about attackers, studying their actions, developing strategies to enhance system security, and preventing similar attacks in the future.

The study subject is detection systems for intrusions into IoT infrastructure and compromised IoT devices based on machine learning algorithms.

The study object is a machine learning model that can detect anomalies in the behaviour of an IoT network and identify patterns that indicate normal behaviour and deviations that may signal an intrusion.

The study aims to enhance the security of IoT networks by developing effective and efficient intrusion detection systems using machine learning techniques. By achieving these aims, the research seeks to significantly advance the security mechanisms available for IoT networks, leveraging the power of machine learning to protect against the increasing number of cyber threats targeting these environments.

Based on the set purpose, the following tasks are set:
− gathering diverse IoT network traffic data, including standard and attack scenarios;
− training and evaluating machine learning models;
− comparing different machine learning algorithms and their combinations;
− evaluating the system in real-world IoT environments.

The presented work proposes using ML and DL methods to build the lambda function through the honeypot intrusion detection method. ML, which can analyse large amounts of data and detect patterns, is a promising method for improving intrusion detection systems in IoT environments. Adaptive solutions based on data are offered that can identify anomalous patterns and behaviour in real-time. ML algorithms have demonstrated particularly effective results in identifying potential threats owing to the significant amount of data generated by IoT devices (*Spitzner, 2020*). The quality and significance of the datasets used to train these algorithms determine their effectiveness.

By combining these scientific methods, our study proposes integrating machine learning algorithms to detect intrusions in IoT networks and contribute to developing robust security solutions.

The authors used the works of such scientists and researchers as A. Géron, N. Sengupta, R. Vinayakumar, S. Sarwar, and Wang Meng.

Study problem

The communication protocol defines a standard way for two or more entities to establish meaningful interactions, enabling valid, legitimate, and expected behaviour by all involved. In the case of IoT, application layer protocols can define how IoT devices exchange information and how the devices are managed as part of the IoT platform. Since protocols define the fundamentals of expected behaviour, we can identify anomalies (that may be part of malicious activity) through dynamic protocol analysis, including payload (content) processing, context, and common patterns. data), analyse it, and perform specific processes. analysis can be done. For this purpose, various approaches can be implemented, such as traffic analysis, honeypot techniques, and protocol analysis of all systems involved in communication.

Honeypot technology

Honeypot technology is a mechanism that intercepts an attacker's activities by simulating a natural system but placing it in a protected environment. Once recognised as a natural system or device, an attacker can reach a honeypot. Honeypots are implemented in a protected and monitored manner so that while the attacker's information is being recorded, the attacker's activities do not harm the system. The central concept of honeypot technology is that a communication protocol running on service (software) acts as a decoy system or trap for intruders. The level of interaction can be defined as the range of possibilities a honeypot offers an attacker. Generally, there are three types of honeypots in terms of interaction level (*Wang, 2017*).

HIH is essentially a natural system that uses standard protocol implementations. Its main feature is that, as a natural system, it allows entire interaction with the attacker. However, security concerns must be considered as exploits may occur in the real world. Therefore, HIH involves monitoring and network control systems that protect the environment during the attacker's activities. IoT platforms can be implemented using XMPP/MQTT/REST HIH honeypots.

LIH detects attackers by employing software emulation to mimic the characteristics of specific operating systems, applications, network services, or protocols on the host operating system. This approach offers several advantages. Firstly, attackers operate within a simulated environment, reducing the risk associated with real exploitation scenarios. Secondly, the emulation provides greater control over the attacker's actions, allowing for more detailed monitoring and analysis of their activities. However, there are also drawbacks to this approach. While LIH emulates services or steps within a protocol, it may not fully replicate the design or functionality of the targeted applications or protocols. This limitation can affect the effectiveness of data collection and interaction with the attacker. Examples of LIH implementations include Dionaea, Honeyd, NetBait, and Kippo. LIH can also emulate IoT devices and interact with natural and emulated XMPP and MQTT services.

MIH. Honeypots provide attackers with more interaction opportunities than low-interaction honeypots but have fewer features than high-interaction solutions, known as medium-interaction honeypots. They may expect certain activities designed to provide predetermined responses beyond what a low-interaction honeypot would offer. MIH combines features of LIH and HIH, but it can be more complex in design and implementation. The proposed IoT honeypot prototype is related to MIH.

Communication protocols establish a consistent method for two or more entities to engage in meaningful interaction, ensuring proper and expected behaviour from all parties involved. Because there are no universally defined standards for all IoT components, the technologies employed by IoT platforms vary in their features. Essentially, any technology that meets the connectivity criteria can be utilised. Presently, various companies have developed their unique IoT architectures.

No matter the type of wireless technology employed, the data from end devices can be made accessible on the internet through two methods (*Wang, 2017*): transmitting information to a specialised web service or API that can be accessed via the internet, utilising cloud-based platforms.

These web services, APIs, or cloud platforms serve as the database for storing and processing data, act as an intermediary node between devices and end-users, and provide APIs that enable end-users to monitor and control the devices remotely.

Numerous application protocols have been identified as suitable for IoT communication. These include MQTT, XMPP, AMQP, CoAP, UPnP, JMS, HTTP REST, and DDS. Each protocol possesses distinct characteristics and can be applied in various scenarios. Furthermore, they can collaborate by being implemented in different segments of an IoT system. Several surveys have compared these protocols, assessing their suitability for IoT based on reliability, security, and energy consumption.

Security issues can be considered from three perspectives: protocol flaws, implementation issues, and integration vulnerabilities. It is crucial for ensuring robust security in IoT systems. When implementing protocols with IoT platforms, leveraging their inherent security mechanisms is essential. Table 1 (*Wang, 2017*) provides a summary of the security mechanisms employed by the communication protocols mentioned earlier.

Security issues can arise during protocol implementation, such as building and installing a server, due to development-related factors like bugs, weaknesses, or inadequate validations. These issues can introduce vulnerabilities into the overall implementation, potentially leading to security breaches. These vulnerabilities may eventually be documented in the CVE database. The CVE database maintains a comprehensive list of known vulnerabilities for various software products, including operating systems, libraries, frameworks, and open-source and closed-source implementations.

Indeed, various databases maintain a shared list of CVE identifiers, such as CVE Details (*Vulnerability List…, 2023*) and the NVD NIST databases (*Merenda et al., 2020*). These repositories provide comprehensive information about vulnerabilities, including details about the affected vendor, product, time of discovery, vulnerable versions, vulnerability type, description, and more. By searching for CVEs associated with IoT-related protocols, developers can identify potential exploitation vectors for IoT applications or platforms that utilise these protocols. It is crucial for developers to regularly update their systems and implement solutions to mitigate the risk of exploitation from known vulnerabilities. This proactive approach helps enhance the security posture of IoT deployments and reduces the likelihood of successful cyber-attacks.

IoT platforms' integration of various technologies and protocols makes them susceptible to security attacks. These vulnerabilities often emerge when integrating different IoT application protocols, signalling potential challenges in IoT security. To address these issues, stakeholders can implement various approaches to collect, analyse, and identify threat patterns targeting IoT platforms. This proactive stance helps mitigate potential security risks and fosters a more secure environment for IoT deployments.

Machine Learning techniques

Recent academic studies have demonstrated the effectiveness of AI technologies, specifically ML, in monitoring cybersecurity (*Géron A., 2019*). ML's ability to create a model capable of learning the statistical patterns within different datasets enables it to make predictions without explicitly coding a set of rules.

ML is a subset of AI that enables computers to learn without explicit programming. It entails crafting a predictive algorithm specific to each problem at hand. These algorithms learn from data to recognise patterns and trends, constructing a prediction or classification model. DL, a subset of ML, employs multiple layers to extract increasingly complex features from raw input. "Deep" in "deep learning" refers to the depth of layers used in data transformation. Many DL algorithms rely on ANN (*Zhang et al., 2021*).

Constructing ML methods can be computationally demanding when dealing with intricate datasets, necessitating significant memory and time resources. Consequently, ML techniques must be optimised to function effectively in resource-constrained environments resembling the IoT. The premise is that feature reduction can lower the training cost of ML algorithms using a given dataset. Subsequently, it introduces an optimisation approach capable of generating a lightweight ML technique that consumes minimal memory and execution time while accurately distinguishing between attacks and regular traffic on IoT networks (*Moustafa et al., 2019*).

Intrusion detection is a binary classification task with one main goal: detecting or classifying whether a traffic sample is part of an attack. However, in today's world of specialisation, with more data to analyse and more complex devices in the infrastructure, attacks need to be classified in more detail for proper countermeasures and future fixes and workarounds. Binary classification alone is insufficient to deal with detected threats properly; a more granular classification is required. Therefore, classifying groups of attacks or specific attacks is the task of a multi-category problem.

Machine learning systems can be grouped based on the level and manner of supervision they receive during training, with three main classifications: supervised learning, unsupervised learning, and reinforcement learning. The supervised classifiers that underwent training and evaluation belonged to five categories (*Banaamah & Ahmad, 2022*; *Shone et al., 2018*; *Tuna et al., 2022*): DT, RF, CNN, RNN and LSTM.

Enhancing the resource efficiency of the LGBM technique encourages further exploration of additional AI technologies, particularly those based on DNN. Recent studies have highlighted the effectiveness of DNN in intrusion detection, surpassing many traditional ML models in cybersecurity monitoring. However, a drawback of DNN-based approaches is their demand for substantial resources to construct a model capable of achieving superior detection accuracy with a multidimensional feature set.

This challenges training scenarios like edge machine learning, where smart devices can process data locally using machine and deep learning algorithms (e.g., federated learning). Furthermore, unlike mainstream IT devices, IoT devices have constrained computing resources (processing and storage) to ensure maximum data output with minimal energy consumption while being cost-effective. Consequently, DNN-based security solutions tailored for mainstream IT devices cannot be directly applied for security monitoring in environments with limited computing resources.

This necessity arises from the constraints of IoT resources, such as memory and processing power, coupled with the resource-intensive nature of existing AI-driven cybersecurity approaches for handling complex multidimensional data. Therefore, the outcomes of this research can offer valuable insights to security professionals and industries on implementing secure, resilient, and efficient AI solutions in resource-constrained settings. Moreover, other cybersecurity researchers can leverage the techniques introduced in this thesis to enhance current AI security solutions within IoT network environments.

Literature

The evolution of technology has brought forth new cyber/physical attack vectors that pose significant challenges in identification and assessment. Integrating IoT-enabling technologies with air-gapped legacy cyber/physical systems, particularly in expansive and intricate environments like critical infrastructures, has rendered assessing risk within these domains exceptionally challenging. Even with the utilisation of well-established risk assessment methodologies, evaluating the risk in any one of these domains is inherently daunting.

Vinayakumar et al. (*2019*) delve into the exploration of DNNs for constructing an adaptable and efficient intrusion detection model. This model aims to detect and categorise unplanned and unpredictable cyber-attacks within a network, leveraging various freely available cyber community malware datasets. Given the dynamic nature of malware attacks, the study aims to identify the most effective algorithms for detecting cyber threats. Vinayakumar et al. propose the Scaled-hybrid_IDS model, which employs hybrid DNNs to detect network malware. This model monitors cyber-attacks at both the host level and network traffic in real-time environments.

To identify an effective machine learning algorithm for intrusion detection or cyberattacks within IoT-based intelligent city applications, a machine learning selection framework was introduced utilising a bijective soft-set approach and its associated algorithm (*Shafiq et al., 2022*). The Bot-IoT dataset was employed to evaluate this framework. Among the algorithms assessed, including NB, BayesNet, C4.5, RF, and RT, the NB machine learning algorithm emerged as the preferred choice for anomaly and intrusion detection of IoT device attacks in intelligent cities. This algorithm demonstrated superior accuracy and the time required to build the model compared to the other algorithms evaluated.

Sequeiros et al. (*2020*) provide an overview of related research concerning attack and threat modelling for IoT systems and cloud mobile applications. On the other hand, the authors introduce IotCom, an approach to uncover concealed threats. Specifically, the researchers investigated multi-app coordination threats capable of initiating infinity activation loops or chain coordination events that may result in race conditions and physical wear of a device. They

conducted static analysis of multiple IoT applications through their platform and identified numerous safety violations.

In their study, Chen et al. (*2020*) reviewed IoT application cyber-attacks within intelligent city environments, specifically addressing detection and classification using deep learning algorithms. The authors explored deep learning models, including deep belief networks, Boltzmann machines, restricted ones, CNNs, recurrent ANNs, and generative adversarial networks for attack detection and classification within intelligent cities. Furthermore, they presented several ML-based cyber-attack detection models tailored for IoT applications within intelligent city contexts.

One of the myriad challenges confronting the IoT, which integrates diverse objects into networks to facilitate sophisticated and intelligent applications, is safeguarding user privacy and thwarting various attacks, including spoofing, DoS, jamming, and eavesdropping. The author (*Sangra, 2023*) examines the vulnerabilities present in IoT systems and explores potential strategies to bolster the security of IoT networks, utilising ML techniques such as supervised learning, unsupervised learning, and RL. The analysis of data privacy delves into ML-based approaches for tasks such as authenticating IoT devices, regulating access to these devices, securely offloading data, and identifying viruses.

Materials and methods

This study focuses on deploying honeypots in AWS EC2 and utilising machine learning techniques to create a lambda function. The aim is to entice potential cybercriminals to engage with these deployed honeypots, thereby gathering substantial data for analysis. Because low-interaction honeypots are easily replicated, modifying default service banners and settings will help to make them more realistic. The main objectives are to monitor harmful intruders' behaviours, assess their origins, accumulate different attack strategies, and collect malware samples and payloads.

When crafting an IoT solution, it is crucial to grasp the potential threats it may face and implement defence in depth by incorporating multiple security measures. These measures should cover identification, protection, detection, and response to threats. Designing the solution with security in mind from the outset is crucial because comprehending how an unauthorised individual could potentially compromise the system enables the implementation of appropriate mitigations.

The AISB outlines a collection of security controls that establish a minimum foundation for customers to construct secure IoT solutions on the AWS platform. In the AISB solution architecture, an IoT device transmits data to AWS IoT Core. This data from the edge device is then forwarded to AWS for tasks such as processing, storage, analytics, and visualisation. In addition to telemetry data, AWS IoT Device Defender allows IoT and IoT devices to report security events directly to AWS. This event information is merged with cloud-based events to pinpoint security misconfigurations, identify anomalies in device behaviour, and alert personnel to respond promptly to security events. The principle of operation solution architecture AISB is presented in the appendix (*Figure 1*).

While deploying honeypots (decoy devices mimicking natural IoT systems seems straightforward – just setting up boxes with simulated IoT software – this approach has

limitations. It might only capture a narrow range of attack data. The longer an attacker interacts with a honeypot (a decoy device mimicking an IoT system), the more valuable information we gain about their goals and methods. As attackers become more invested in a seemingly actual device, the honeypot needs more complexity to maintain the illusion and gather richer intel.

Given an IoT device's intricate interaction with its environment, an IoT honeypot needs to be structured to enable intelligent adaptation to diverse types of traffic. The success of this ongoing battle is gauged by the quantity of valuable insights gained relative to the engineering effort invested. The authors aim to construct a meticulously designed system comprising a range of honeypot devices operating in coordination with a vetting and analysis infrastructure.

IoT Core Frame. The AWS IoT core services comprise five services responsible for maintaining the needs of all IoT devices, connecting to the AWS cloud, managing devices, updating OTA, and safeguarding the IoT devices. Within this framework, the TLS communication protocol encrypts all communication. Rules facilitate interaction between IoT devices and AWS services.

AWS IoT Core provides security through policies and X.509 certificates, like support for MQTT over TLS/SSL. An AWS IoT Core policy is a JSON document encompassing one or more statements. These statements consist of three types: effect, which determines whether the action is permitted or denied; action, specifying the action permitted or denied by the policy; and resource, identifying the resource or resources on which the action is permitted. This policy lets devices connect to AWS IoT Core if their client ID is the same as their thing name (a unique name assigned in AWS). Additionally, devices can publish data to any topic that starts with their thing name. Instead of relying on usernames and passwords, AWS IoT Core uses a more secure method for devices to publish data. Devices need to identify themselves with special certificates called X.509 certificates. These certificates are unique to each device and are created by AWS IoT Core after the device is registered (becomes a "thing").

MQTT protocol. At its core, AWS IoT Core relies on a messaging protocol called MQTT to communicate with devices. This protocol acts like a middleman, separating the devices that send data (publishers) from the ones that receive it (consumers). Devices publish their data, and the MQTT broker efficiently routes and delivers the messages to the interested parties. This approach keeps things flexible and scalable.

Rules are analysed, and actions are executed based on the MQTT topic stream. Topics serve to identify AWS IoT messages. A message broker assigns topic names and filters, routing messages sent via MQTT and HTTP to the Hypertext Transfer Protocol Secure message URL.

Devices publish data using organised topic names that act like addresses. To receive specific data, services subscribe to matching "topic filters". These filters act like sieves, sorting messages based on their topic names and delivering them only to the relevant subscribed services. Large-scale IoT deployments, like those managing farms with thousands of devices, can get complex. To simplify this, AWS offers a "shadow service". This service creates a virtual representation (shadow) of each device in the cloud. In the context of your intelligent livestock system, each animal's sensor would have a corresponding shadow in the AWS cloud. This approach enables each utilised device to be accessed and managed distinctly by various services. These modifications are enacted through the MQTT protocol or HTTP using the device shadow REST API.

Lambda Frame. AWS lambda functions are short pieces of code that run on demand. Unlike traditional applications, they do not require constant server maintenance. They take input, process it, and produce an output. These functions can be triggered by various events within or outside AWS, making them highly versatile. One key benefit is automatic scaling. Lambda functions can handle a surge in traffic without you needing to adjust server capacity manually. In contrast to an EC2 instance, a Lambda is designed to run for a single purpose and is only meant to run for a short while. Lambda functions require no platform maintenance and scale immediately to hundreds of instances.

Machine Learning Frame. Infrequently accessed data is stored in S3 Glacier (Serverless), designed for long-term data archiving. Unlike S3 Buckets, it is not readily accessible and intended solely for archived content. If needed, this data can be unarchived and restored to S3. Subsequently, it can be effectively utilised within the machine learning framework, where the data trains machine learning algorithms for regression or classification predictions. Amazon SageMaker handled the interface models' development, training, and deployment.

In our study, we implemented the most common machine learning algorithms (*Wang, 2017*) to create a lambda function in the AWS IoT security framework to detect multi-vector cyberattacks in the IoT:

- DT;
- KNN;
- RF;
- SVM;
- XGBoost.

Architecture for ML inference is presented in the appendix (*Figure 2*).

Results

Cloud computing provides on-demand access to computing power and storage using virtual machines that can be scaled up or down based on your needs. Cloud computing removes limitations on processing power and storage. Applications can access the immense computing resources of cloud data centres, eliminating the need for expensive on-site hardware. The architecture of honeypots is entirely constructed within the AWS cloud environment.

This research proposes an architecture built entirely on serverless services offered by AWS, such as AWS lambda, Amazon S3, Amazon SNS, Amazon API Gateway, Amazon DynamoDB, etc. This allows us to create data pipelines that efficiently handle the large amount of data from IoT devices.

We set up a virtual server on Amazon's cloud following T-Pot's recommendations to run the experiment. This server had the processing power and memory of a t3.xlarge instance type. The virtual machines used for the experiment ran the Debian 12 operating system on a unique virtualisation technology called HVM. The instance had a decent amount of processing power with two virtual CPUs (vCPUs), 8 Gigabytes of memory (RAM), and a high-speed network connection capable of handling up to 5 Gigabits of data per second.

The evaluation metrics listed and defined in Table 2 are used to assess the performance of feature extraction algorithms and machine learning models. TP, FP, TN, and FN denote the counts of True Positives, False Positives, True Negatives, and False Negatives, respectively.

Experimental results are presented in the appendix (*Tables 3*; *Table 4*; *Table 5*; *Table 6*). The total comparisons of the different MLA efficiencies of detecting attacks on the main IoT Core communication protocols such as MQTT, HTTPS, MQTT over WSS, and Hybrid are presented in the appendix (*Tables 3*; *Table 4*; *Table 5*; *Table 6*). The Hybrid connection method means that devices connect to AWS IoT Core for management but receive data through other means, such as Amazon Kinesis Data Streams, Amazon MSK, Amazon SQS, or Amazon API Gateway.

Discussion

Cyber-attacks will likely become more common and complex as technology advances and creates more data. The importance of cybersecurity is proliferating on the list of priorities for governments worldwide. To keep our information safe online, it is essential to be able to spot cyber-attacks. These detection systems can find unusual activity and warn people about threats so they can take action to protect themselves.

This research explores how machine learning can be used to build honeypots, being tools for detecting cyberattacks. Machine learning and deep learning are becoming popular in many areas, including cybersecurity. However, figuring out which techniques work best for cybersecurity problems is essential. This thesis explores powerful machine-learning methods for building cutting-edge systems that can detect cyberattacks.

IoT security must rely on machine learning or deep learning models that leverage data attributes to be genuinely adequate. To make intelligent choices, the system needs a robust learning algorithm that considers both its knowledge of IoT security and the specific task it is designed for.

The more sophisticated IoT and cloud computing become, the more crucial cloud platforms become for managing them effectively. Amazon's AWS cloud platform provides many IaaS components, like PaaS offerings. You can combine Amazon's IoT Core service with their Rules engine and DynamoDB storage for robust and efficient storage of data collected from IoT devices.

Conclusion

This research has investigated how effectively honeypots detect cyberattacks in an IoT setting. We achieved this by simulating real-world IoT devices and deploying honeypots within that simulated environment. Honeypots are decoy computer systems designed with vulnerabilities to attract attackers. This clever strategy diverts their attention away from natural, critical systems. Honeypots are secret weapons that mimic natural systems and record attacker activity. They allow us to gather valuable information about what attackers are after, how they operate, and their tactics.

This article describes an improvement to honeypots designed for IoT devices using AWS's IoT Core platform. This improvement leverages machine learning to better defend against attackers who use similar techniques. We tested our honeypot with a modified Lambda function on AWS. The honeypot successfully fooled attacker tools designed to sniff out honeypots and

even tricked attackers into uploading malicious software. How well machine learning can spot multi-pronged attacks on IoT systems depends heavily on the data quality used to train and test these algorithms. We examined the feasibility of detecting attacks on IoT infrastructure by focusing on IoT's most commonly used connection methods, including MQTT, HTTPS, MQTT over WSS, and hybrid connection methods.

It is recognised that each attacker adheres to their unique "strategy" to execute an attack successfully. Even though attackers have their own styles, their everyday actions can reveal their overall objective. Critical infrastructure systems are often targeted with well-known attack techniques. These include brute-force attempts to crack passwords, exploiting software flaws to take control of devices remotely, and launching malware attacks within the network once a foothold is gained.

To improve how honeypots lure attackers, we will focus on creating more intricate reward systems and crafting believable and consistent responses. In the next phase, we will expand the honeypot to mimic an even more comprehensive range of IoT devices. We will also deploy these improved honeypots across different public cloud platforms. Our primary objective is to assess the efficacy of machine learning methods in constructing a lambda function within a honeypot architecture to detect cyber-attacks preemptively before widespread deployment across various cloud providers.

We are confident that our research on security solutions based on machine learning and deep learning represents a positive stride forward. It is poised to assist fellow academics and practitioners in discovering and deploying IoT security solutions in the future.

Conflict of interest

The authors declare that there is no conflict of interest.

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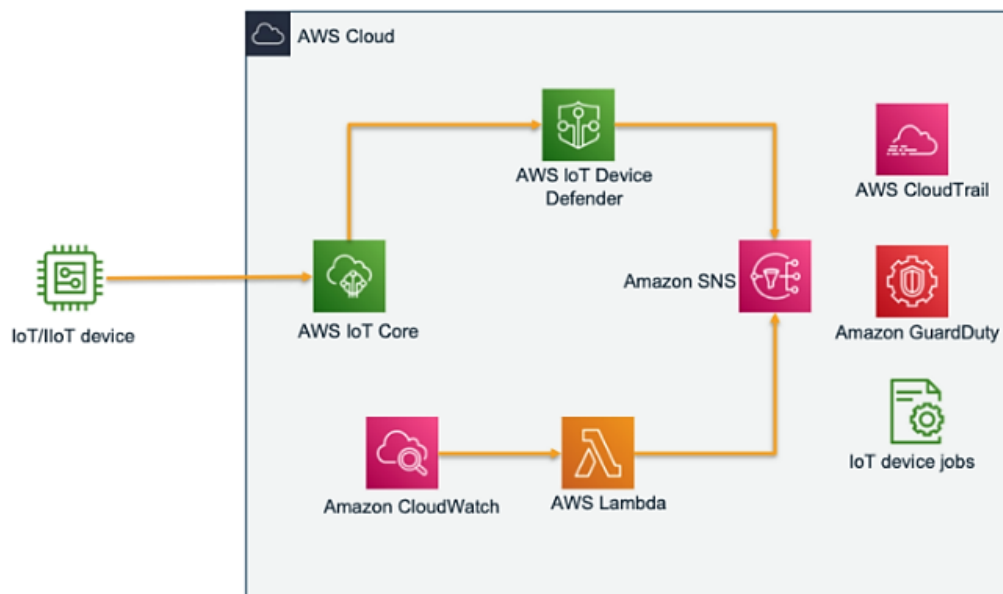
Appendix

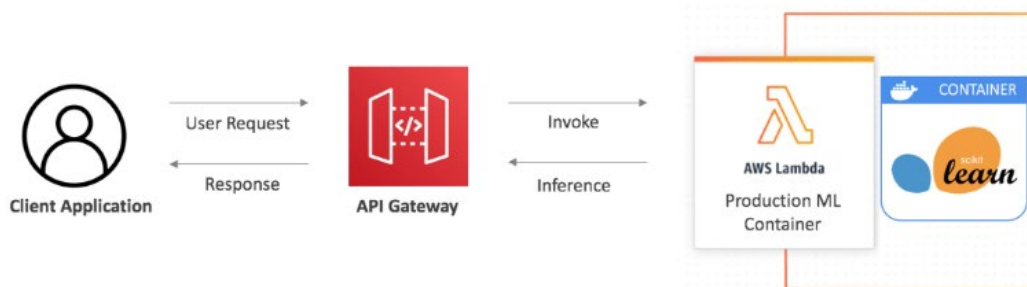Figure 1. Solution architecture AISB

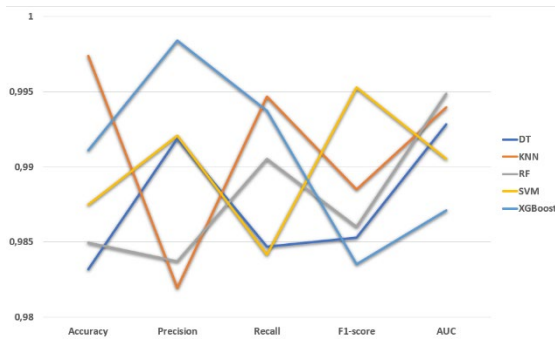Figure 2. Architecture for ML inference

Figure 3. Comparison of different MLA efficiencies for detecting attacks on the MQTT
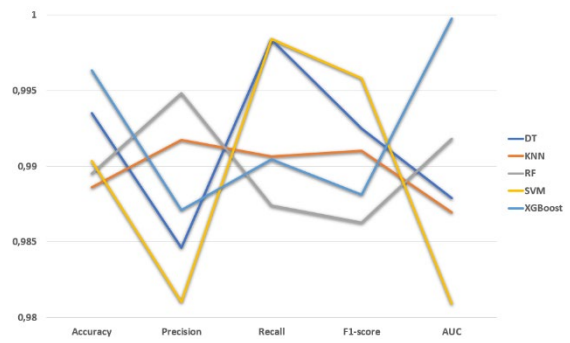

Figure 4. Comparison of different MLA efficiencies for detecting attacks on the HTTP
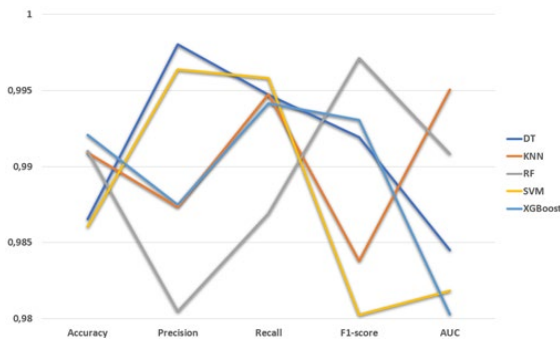

Figure 5. Comparison of different MLA efficiencies for detecting attacks on the MQTT over WSS
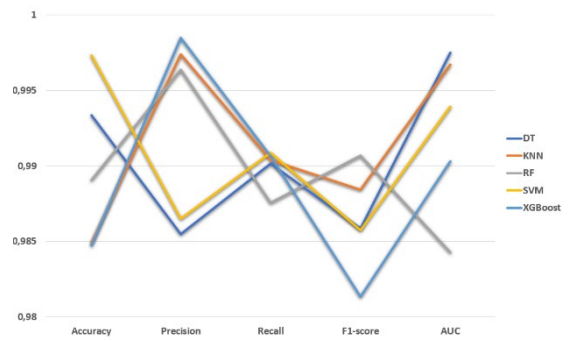

Figure 6. Comparison of different MLA efficiencies for detecting attacks on the hybrid connection method

Table 1. Security mechanisms of IoT communication protocols

Honepots	Open ports
MQTT	Simple User-name/password Authentication, TLS/SSL for data encryption
XMPP	SASL authentication, TLS/SSL for data encryption
AMQP	SASL authentication, TLS/SSL for data encryption
CoAP	DTLS/IPSEC
JMS	Vendor specific but typically based on TLS/SSL. Commonly used with JAAS API
SOAP	Address by WS-Security

Table 2. Evaluation metrics

Metric	Equation	Definition
Accuracy	$$\frac{TP + TN}{TP + FP + TN + FN}$$	Number of correctly classified samples divided by the total number of samples
Precision	$$\frac{TP}{TP + FP}$$	The fraction of detected attacks to total alarms
Recall	$$\frac{TP}{TP + FN}$$	Number of correctly classified attack samples divided by the total number of attack samples
F1-score	$$2 \times \frac{Recall \times Precision}{Recall + Precision}$$	The harmonic mean (weighted average) of the precision and recall
AUC	Area under the Receiver Operating Characteristics (ROC) curve	

Table 3. Modelling results of ML algorithms for detecting attacks on the MQTT

Model	DT	KNN	RF	SVM	XGBoost
Accuracy	0.98320	0.99739	0.98496	0.98750	0.99109
Precision	0.99187	0.98195	0.98371	0.99208	0.99840
Recall	0.98471	0.99468	0.99052	0.98417	0.99372
F1-score	0.98528	0.98851	0.98603	0.99529	0.98351
AUC	0.99284	0.99396	0.99485	0.99053	0.98709

Table 4. Modelling results of ML algorithms for detecting attacks on the HTTPS

Model	DT	KNN	RF	SVM	XGBoost
Accuracy	0.99351	0.98863	0.98953	0.99035	0.99634
Precision	0.98462	0.99174	0.99482	0.98106	0.98712
Recall	0.99837	0.99063	0.98740	0.99842	0.99045
F1-score	0.99249	0.99102	0.98627	0.99581	0.98813
AUC	0.98791	0.98694	0.99183	0.98093	0.99975

Table 5. Modelling results of ML algorithms for detecting attacks on the MQTT over WSS

Model	DT	KNN	RF	SVM	XGBoost
Accuracy	0.98654	0.99089	0.99104	0.98605	0.99209
Precision	0.99803	0.98732	0.98046	0.99638	0.98747
Recall	0.99470	0.99474	0.98693	0.99581	0.99414
F1-score	0.99193	0.98381	0.99711	0.98027	0.99306
AUC	0.98452	0.99504	0.99084	0.98184	0.98029

Table 6. Modelling results of ML algorithms for detecting attacks on the hybrid connection method

Model	DT	KNN	RF	SVM	XGBoost
Accuracy	0.99336	0.98493	0.98905	0.99732	0.98472
Precision	0.98549	0.99737	0.99638	0.98651	0.99849
Recall	0.99014	0.99039	0.98756	0.99088	0.99066
F1-score	0.98586	0.98843	0.99070	0.98574	0.98135
AUC	0.99750	0.99672	0.98428	0.99393	0.99030

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Study of the deformation characteristics of the pneumatic spring of the high-speed rolling stock of railways within the cross-section of the turnout [6]

Abstract: Investigation of the deformation features of the pneumatic spring of high-speed rolling stock of railways within the frog of the railroad switch. The study object is a pneumatic spring of high-speed rolling stock of the railway. The method of experimental testing of a pneumatic spring using the developed installation for running dynamic spring tests is presented. Experimental tests of the deformability of the pneumatic spring, when the test unit moves along the frog of the railroad switch, are carried out. It is established that the transition of the wheel from the wing rails to the frog and from the core to the frog's moustache, like the frog's rear joint, has a significant impact on the vertical and horizontal deformations of the pneumatic spring. It is determined that the maximum deformations in the vertical plane when the wheel moves from the wing rails to the frog are 2,75 mm; when the wheel moves from the frog to the wing rails, they are 3.7 mm; when the installation passes through the rear joint of the frog, the value of vertical deformations of the pneumatic spring is 6,2 mm. At the same time, the horizontal deformations of the pneumatic spring are 1,0 mm, 1,2 mm and 0,58 mm, respectively. Establishing the deformation features of the pneumatic spring of high-speed railway rolling stock when driving on a railroad switch is an urgent task of scientific research. Since this will make it possible to determine dynamic and safety indicators of high-speed rolling stock in operational conditions.

Keywords: pneumatic spring; high-speed rolling stock; vertical spring deformations; horizontal spring deformations; railroad switch frog.

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Дослідження особливостей деформування пневматичної ресори швидкісного рухомого складу залізниць у межах хрестовини стрілочного переводу

Анотація: Об'єктом досліджень є пневматична ресора швидкісного рухомого складу залізниці. Наведено методику експериментальних випробувань пневматичної ресори із використанням розробленої установки для ходових динамічних випробувань ресори. Проведено експериментальні випробування деформативності пневматичної ресори при русі випробувальної установки по хрестовині стрілочного переводу. Встановлено, що значний вплив на вертикальні та горизонтальні деформації пневматичної ресори має перехід колеса із вусовика на сердечник та із сердечника на вусовик хрестовини, а також задній стик хрестовини. Визначено, що максимальні деформації у вертикальній площині при русі колеса із вусовика на сердечник становлять 2,75 мм, при русі колеса із сердечника на вусовик – 3,7 мм, а при проїзді установки по задньому стику хрестовини, величина вертикальних деформацій пневматичної ресори склала 6,2 мм. При цьому горизонтальні деформації пневматичної ресори відповідно склали: 1,0 мм, 1,2 мм та 0,58 мм. Встановлення особливостей деформування пневматичної ресори швидкісного рухомого складу залізниці при проїзді по стрілочному переводу є актуальною задачею наукових досліджень. Оскільки це дасть змогу визначати динамічні показники та показники безпеки руху швидкісного рухомого складу в експлуатаційних умовах.

Ключові слова: пневматична ресора; швидкісний рухомий склад; вертикальні деформації ресори; горизонтальні деформації ресори; хрестовина стрілочного переводу.

Introduction

In high-speed trains DPKR-2, DPKR-3, ekr-1 "Tarpan" and HRCS2 "Hyundai Rotem", a pneumatic spring is used to dampen the vibration effect on rolling stock, which is given in the appendix (*Figure 1*) (*Kuzyshyn et al., 2023*). In addition, it allows you to dissipate energy during the movement of rolling stock over irregularities on the railway track (*Mendia-Garcia et al., 2022*; *Kovalchuk et al., 2018b*; *Kuzyshyn et al., 2024*; *Mendia-Garcia et al., 2024*).

When rolling stock moves along a rail track, the pneumatic spring accepts vertical and horizontal (longitudinal and transverse) loads, which are caused by the technical condition and design features of the rail track and the mechanical part of the rolling stock. As a result of vibrations, the pneumatic spring undergoes vertical and horizontal deformations. It is worth noting that it is significant to choose the optimal spring performance at the design stage of a pneumatic spring. One of them is the stiffness of the pneumatic spring, which depends on the load that falls on the spring and the amount of deformation of the spring. Therefore, studying the features of spring deformation under operating conditions and determining its maximum vertical and horizontal deformations is an urgent task of scientific research.

To date, there are many studies of the dynamic behaviour of the pneumatic spring of high-speed rolling stock, which is reflected in the works (*Reidemeister et al., 2016*; *Liufeng et al., 2020*; *Li & Li, 2013*; *Zhu et al., 2017*). However, most works use theoretical methods for studying the pneumatic spring. The paper (*Reidemeister et al., 2016*) considers a model of a pneumatic spring as a dynamic system with three-phase coordinates. Based on the laws of thermodynamics and hydrodynamics, a mathematical model has been developed to study the dynamic characteristics of springs in the vertical direction (*Liufeng et al., 2020*; *Li & Li, 2013*). Labour (*Zhu et al., 2017*) is devoted to the study of considering thermodynamic processes in the calculation of pneumatic Springs. In the paper (*Kuzyshyn et al., 2023*), authors perform theoretical studies of a pneumatic spring's dynamic parameters, considering the geometrical parameters of the connecting pipeline. A study of the effect of the state of the pneumatic spring suspension system on the dynamic behaviour of rolling stock is given in the paper (*Facchinetti et al., 2010*). Based on this, it is concluded that lateral deformation and deformation of the spring roll do not lead to significant fluctuations in the air pressure inside the pneumatic spring.

From the analysis of scientific works, it is established that most works are devoted to theoretical studies of the pneumatic spring of railway rolling stock. There are no experimental sea trials of the pneumatic spring. Therefore, conducting experimental dynamic tests of the pneumatic spring is an urgent task of scientific research, which will allow determining the maximum vertical and horizontal deformations of the pneumatic spring in actual conditions of railway track operation.

Materials and methods

The study's object is a pneumatic spring of high-speed rolling stock that undergoes deformations when moving along the crosspiece of the switch. The proposed installation design for running dynamic tests, given in the appendix (*Figure 2*), determines the pneumatic spring's vertical and horizontal deformations.

When the installation moves along the crosspiece, the pneumatic spring vibrations occur, which cause vertical and horizontal deformations of the spring. The values of vertical and horizontal spring deformations are measured using a potentiometric displacement sensor. To measure vertical spring deformations, the displacement sensor is installed vertically at right angles to the upper metal plate of the spring. A movement sensor installed perpendicular to the side of the rubber cord shell of the pneumatic spring is used to measure the horizontal deformations of the pneumatic spring. The layout of linear displacement potentiometric sensors is shown in the appendix (*Figure 3*).

The measured values of the pneumatic spring's vertical and horizontal deformations are read by a high-frequency analogue-to-digital converter and stored in the laptop's memory.

Results

The results of recording vertical deformations of the pneumatic spring of high-speed rolling stock when moving from the core to the crosspiece tendril and in the opposite direction are shown in the appendix (*Figure 4*). The results of recording vertical deformations of the pneumatic spring showed that the maximum deformations when moving the test unit in the direction from the core to the crosspiece moustache are 3.7 mm, and when moving from the moustache to the core – 2.75 MM.

The results of recording horizontal deformations of the pneumatic spring of high-speed rolling stock when moving from the core to the crosspiece moustache and in the opposite direction are shown in the appendix (*Figure 5*). The maximum value of horizontal deformations of the pneumatic spring, when moving in the direction from the core to the moustache, is 1.2 mm, and when moving from the moustache to the core – 1.0 mm. In addition, when the wheel rolls along the core within a cross-section of 35 mm, peak deformations are observed on the lines of recording spring deformations. This is due to the peculiarities of rolling the wheel in this area of the switch crosspiece (*Kovalchuk et al., 2018c*; *Kovalchuk et al., 2017*; *Kovalchuk et al., 2018a*).

The results of recording vertical and horizontal deformations of the pneumatic spring of high-speed rolling stock during the movement of the test unit along the rear joint of the crosspiece are shown in the appendix (*Figure 6*). From the records of spring deformations when moving along the rear joint of the crosspiece, it can be seen that the maximum vertical deformation of the spring was 6.2 mm, and the maximum horizontal deformation was 0.58 mm. The difference between vertical and horizontal deformations of the pneumatic spring is explained by the significantly higher vertical load on the spring due to the short butt unevenness. As a result of the wheel passing through the joint zone, a dynamic vertical force addition occurs, which causes vertical deformations of the pneumatic spring. At the same time, harmonic vibrations of the spring and their gradual extinction in a short time are observed from the recording line of vertical deformations of the spring. Furthermore, from the lines of recording

horizontal deformations of the spring, it can be seen that the spring shifts in the horizontal plane when hitting the crosspiece joint and returns to its original position when leaving.

Discussion

Evaluation of the dynamic characteristics of a high-speed rolling stock pneumatic spring is a significant scientific research task. This will allow monitoring changes in the characteristics of the spring's rubber-cord shell over time during its operation on rolling stock, according to the established indicators of the new spring. The developed test unit, given in the appendix (*Figure 2*), allows testing the spring in any operating conditions of the railway track, considering the operational and design features.

As part of our work, the pneumatic spring of high-speed rolling stock was tested within the crosspiece of the Switch. The results of experimental studies of the pneumatic spring have shown that the value of vertical deformations (*Figure 4*) is higher than the horizontal deformations of the spring (*Figure 5*). When moving the test unit in the direction from the core to the crosspiece moustache, the maximum value of vertical spring deformations was 3.7 mm, horizontal – 1.2 mm, and when moving from the moustache to the core – 2.75 MM and 1.0 mm, respectively.

It is established that the direction of movement of the test unit has a majestic deformation of the pneumatic spring. Higher values of vertical and horizontal spring deformations occur when the test unit moves in the direction from the core to the moustache. In this direction of movement, the value of vertical deformations was 3.7 mm, and horizontal deformations were 1.2 mm. In the case of movement from the moustache to the core, the value of vertical deformations was 2.75, and horizontal deformations – were 1.0 mm.

The difference in deformations of the pneumatic spring when moving in different directions of the test unit along the crosspiece of the switch is explained by the peculiarity of rolling the rolling stock wheel from the core to the moustache and vice versa, which is reflected in work (*Kovalchuk et al., 2018c*). The wheel passes an unevenness in the vertical plane (*Kovalchuk et al., 2018a*), which causes a dynamic load on the rolling stock and, accordingly, causes deformation of the spring. At the same time, the unevenness, depending on the direction of movement, has different angles of inclination when the wheel moves down and out of the roughness (*Orlovsky et al., 2011*), which, as a result, affects the difference in the values of spring deformations.

If the wheel rolls over the rear joint of the crosspiece, a significant vertical deformation of the spring occurs, measuring 6.2 mm (*Figure 6*). At the same time, the horizontal deformation value was only 0.58 mm. Recording the lines of vertical deformations of the spring in the vertical plane (*Figure 6*) shows that the wheel moves down (causing a blow to the joint), which causes a sharp increase in vertical deformations of the pneumatic spring. On such a short roughness, the wheel hits the joint, causing vertical deformations in the spring. At the same time, the number of horizontal deformations remains insignificant since there is no lateral load from the joint on the moving wheel of the test unit.

In contrast to the deformation features of the pneumatic spring when passing the rail joint, the passage from the core to the moustache or from the moustache to the core causes a more

lateral swing of the test unit. This leads to higher values of horizontal deformations of the spring compared to the movement along the rear joint of the crosspiece.

Conclusion

The developed methodology of experimental dynamic testing of a pneumatic spring of high-speed rolling stock allows testing the spring in the operating conditions of a rail track. This will allow you to set the dynamic parameters of the pneumatic spring, considering the technical and structural parameters of the rail track and rolling stock's undercarriage.

The maximum vertical deformations of the pneumatic spring when moving the unit in the direction from the core to the moustache are 3.7 mm, and when moving from the moustache to the core – 2.75 MM. At the same time, the maximum horizontal deformations of the spring were 1.2 mm and 1.0 mm, respectively.

The most significant vertical deformations occur when the test unit moves along the rear joint of the Switch crosspiece. At the same time, the vertical deformation of the pneumatic spring was 6.2 mm against 3.7 mm when moving in the direction from the core to the crosspiece moustache. However, horizontal deformations when moving along the joint of the crosspiece are less than deformations when moving in the direction from the core to the moustache or from the moustache to the core. Horizontal deformations are 0.58 mm, 1.2 mm and 1.0 mm, respectively.

Conflict of interest

The authors declare that there is no conflict of interest.

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Appendix

Figure 1. Pneumatic spring of high-speed rolling stock

Figure 2. Installation for running dynamic tests of a pneumatic spring: 1 – Direction of movement from the core to the crosspiece moustache; 2 – Direction of movement from the crosspiece moustache to the crosspiece core

Figure 3. Layout of displacement sensors for measuring vertical and horizontal spring deformations
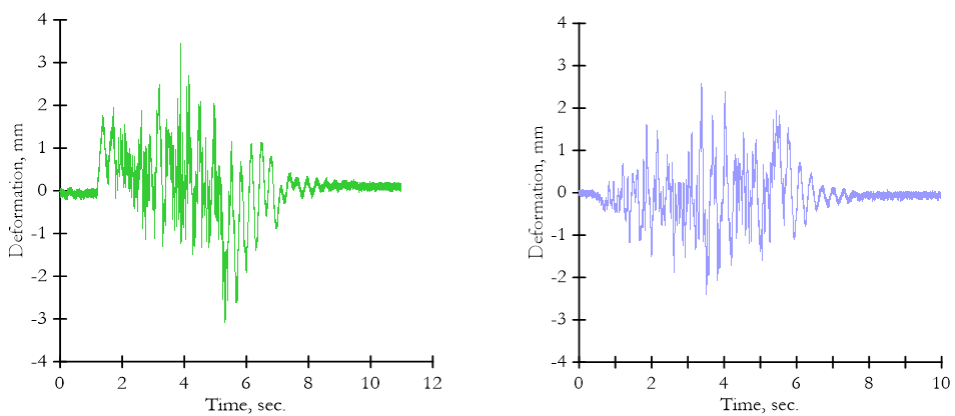

Figure 4. Records of vertical deformations of the pneumatic spring of high-speed rolling stock (a) movement in the direction from the core to the crosspiece mustache; (b) movement in the direction from the crosspiece mustache to the crosspiece core
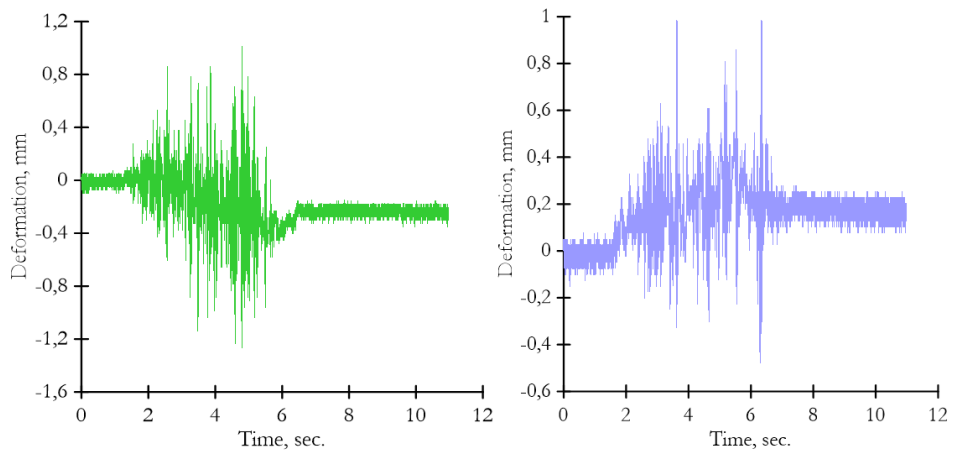
Figure 5. Records of horizontal deformations of the pneumatic spring of high-speed rolling stock (a) movement in the direction from the core to the crosspiece mustache; (b) movement in the direction from the crosspiece mustache to the crosspiece core
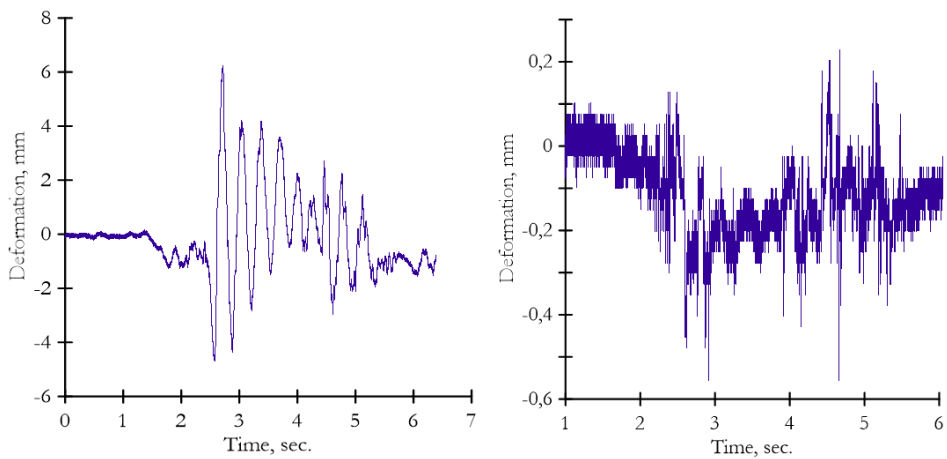

Figure 6. Records of vertical and horizontal deformations of the pneumatic spring of high-speed rolling stock when moving along the rear joint of the crosspiece (a) vertical deformations of the spring; (b) horizontal deformations of the spring

Nataliia V. Zhdaniuk [15]

Study of the phenomenon of magnetism in iron-containing silicate glasses [7]

Abstract: Studying the structure and properties of iron-containing glass-crystalline materials is an urgent task, as it makes it possible to develop glass compositions with high magnetic properties. The study subject is the structure and magnetic properties of iron-containing silicate glasses of the SiO_2-FeO-CaO system in the presence of MgO and Al_2O_3. The study object is the structure and magnetic properties of iron-containing silicate glasses. The study aims to obtain silicate glasses with a high content of iron oxides and study their properties. DTA and X-ray phase analysis methods were used to study the materials. The glass's relative quality factor and magnetic permeability were determined using a Q-meter. The phase diagrams of systems containing oxides SiO_2, FeO, Fe_2O_3, CaO, MgO, Al_2O_3, B_2O_3, and K_2O and selected compositions corresponding to the minimum eutectic temperatures were analysed. The studies were based on the works of N. Wojcik, A. Paladino, A., S. Zhang, M., Yu. Ebisawa, M. Plemyannikov and other scientists. The glass was synthesised at a temperature of 1300°C for 2 hours. The resulting glass was crystallised by slowly increasing the temperature to 550-800°C for 3 hours. The results of differential thermal analysis confirmed the tendency of specific glass compositions to crystallise. According to the X-ray phase analysis results, the formation of magnetite, a ferromagnet, was confirmed. Studies of the relative quality factor and glasses' magnetic permeability confirmed the magnetic properties of the samples that were obtained. These results are consistent with theoretical studies of system state diagrams and the results of instrumental analysis methods.

Keywords: state diagram, glass, iron oxides, crystallisation, magnetism; magnetite.

Наталія В. Жданюк

Вивчення явища магнетизму у залізовмісних силикатних стеклах

Анотація: Вивчення структури та властивостей залізовмісних склокристалічних матеріалів є актуальним завданням, так як дозволяє розробити склади стекол з високими магнітними властивостями. Предметом дослідження є структура і магнітні властивості залізовмісних силікатних стекол системи системи SiO_2-FeO-CaO в присутності MgO, Al_2O_3. Об'єктом дослідження є структура та магнітні властивості залізовмісних силікатних стекол. Метою роботи є отримання силікатних стекол з підвищеним вмістом оксидів заліза та вивчення їх властивостей. Для дослідження матеріалів використано методи ДТА, РФА та визначено відносну добротність та магнітну проникність стекол за допомогою Q-метра. Були проаналізовані діаграми стану систем, що містять оксиди SiO_2, FeO, Fe_2O_3, CaO, MgO, Al_2O_3, B_2O_3, K_2O та обрані склади, що відповідають мінімальнім евтектичним температурам. Дослідження опиралися на праці N. Wojcik, A. Paladino, A., S. Zhang, M., Yu. Ebisawa, М. Племянникова та інших вчених. Синтез скла проводили при температурі 1300°C протягом 2 годин. Отримане скло кристалізазували шляхом повільного підвищення температур в інтервалі 550-800ºC протягом 2 годин. Результати диференціального термічного аналізу підтвердили схильність визначених складів стекол до кристалізації. За результатами рентгенофазового аналізу підтверджено утворення магнетиту, що є феримагнетиком. Дослідження відносної добротності та магнітної проникності стекол підтвердили наявність магнітних властивостей отриманих зразків. Ці результати узгоджуються з теоретичними дослідженнями діаграм стану систем та результатами інструментальних методів аналізу.

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Abbreviations:

DTA is differential thermal analysis;

EPR is electron paramagnetic resonance;

SEM is scanning electron microscopy;

XRD is X-ray fluorescence analysis;

XRPA is X-ray phase analysis.

Introduction

Studying the structure and properties of iron-containing glass-crystalline materials is an urgent task, as it makes it possible to develop glass compositions with high magnetic properties. Also, this study will allow us to expand knowledge about the effect of FeO on the properties of silicate systems SiO_2-FeO-CaO, SiO_2-FeO-CaO-MgO, SiO_2-FeO-CaO-MgO-Al_2O_3.

The study focuses on the structure and magnetic properties of iron-containing silicate glasses in the SiO2-FeO-CaO system in the presence of MgO and Al_2O_3.

The study object is the structure and magnetic properties of iron-containing silicate glasses of the SiO_2-FeO-CaO system.

The study aims to obtain silicate glasses with a high content of iron oxides and study their properties.

To achieve this goal, you must complete the following tasks:

- select glass compositions that will have the lowest melting points and increased crystallisation capacity, according to the diagrams of the state of the systems;
- investigate the crystallisation capacity of the obtained glasses and use differential thermal analysis;
- study the phase composition of the obtained samples using X-ray phase analysis;
- study the magnetic properties of glass-crystal materials, namely the magnetic permeability of the material.

The materials were studied using the DTA and XRD methods, and the glasses' relative Q-factor and magnetic permeability were determined using a Q-meter.

Overview of information sources

Glasses containing ferum oxides are constantly of interest to researchers. Since the presence of these oxides significantly affects the properties of the resulting glass and glass-crystalline materials. Features of the primary raw material for producing industrial silicate glasses is quartz sand. For this material, the content of ferum oxides is strictly regulated since even a tiny amount (fractions of a per cent) of iron oxides leads to undesirable staining of the glass, and with a high iron content (up to 10 per cent or more), the glass becomes opaque and black. As an exception, such compositions can produce brown or green glass containers or facing tiles or black glazes (*Plemiannikov & Zhdaniuk, 2023*). When the problem of staining transparent glass arises, it is

necessary to consider that ferum can be in two valence states: Fe(II) and Fe(III). Thus, the Fe^{2+} ion has a strong absorption band in the near-infrared range, while Fe^{3+} absorbs mainly in the ultraviolet range. The presence of FeO turns the glass blue and Fe_2O_3 yellow. The combined presence of Fe(II) oxide and Fe (III) oxide causes gradations of glass shades that fall in the green region of the spectrum (*Vercamer, 2016*). The state of thermodynamic equilibrium of FeO↔Fe_2O_3 depends primarily on the redox potential of the cooking process, the cooking temperature, the concentration of oxides, and the chemical composition of the glass itself, which must be taken into account when developing charge compositions (*Plemiannikov & Zhdaniuk, 2023*).

When studying the properties of glasses with a high content of Froome oxides, it is necessary to take into account that these compounds can perform a twofold role – a grid-forming agent (Fe^{+3}) and a modifier (Fe^{+2}) (*Vercamer, 2016*; *Plemiannikov & Zhdanyuk, 2021*). Therefore, the shift in the equilibrium of Fe_2O_3↔FeO in silicate melts with a high ferum compound content significantly affects the glass structure's properties. The study of the equilibrium state between FeO and Fe_2O_3 in the melt, depending on its composition and temperature, showed that as the temperature increases, the equilibrium shifts towards forming Fe(II) oxide. At 1320-1410°C, Fe(II) oxide in the melt contains 50% more than at 1230-1320°C. with an increase in the content of silica and alumina in the melt, the reaction equilibrium shifts towards the formation of Fe(II) oxide, and with an increase in the content of MgO – towards Fe (III) oxide (*Falkovskaya, 1989*).

Depending on the valence state of iron, ferum oxides play a twofold role in glass: a grid-forming agent (Fe^{+3}) and a modifier (Fe^{+3}) (*Vercamer, 2016*; *Calas & Petiau, 1983*; *Plemiannikov & Zhdanyuk, 2021*). The Fe^{3+} ion is located in the glass in tetrahedral oxygen coordination and can replace silicium in the structure of anions and ensures the structural integrity of the vitreous body. In addition, an increase in the concentration of Fe_2O_3 leads to forming Fe–O–Si bonds, indicating the glass mesh's depolymerisation. The Fe^{2+} ion in glass has octahedral oxygen coordination and acts as a typical glass modifier (*Ebisawa et al., 1991*; *Tasheva et al., 2023*; *Alderman et al., 2017*; *Peys et al., 2018*).

The course of glass crystallisation is significantly affected by the concentration of ferum ions and their redox state. In some cases, crystallisation may occur spontaneously. Fe^{2+} causes glass crystallisation faster and more significantly than Fe^{3+} (*Alderman et al., 2017*; *Wisniewski et al., 2011*; *Zhdaniuk & Plemiannikov, 2024*). This is due to the role of the modifier Fe^{2+}, which can stimulate crystallisation, while Fe^{3+} is a grid-forming agent and is less mobile. Trivalent ferum ions can form magnetite, crystallising from the silicate melt at temperatures below 1300°C. Magnetite increases glass heterogeneity and its viscosity (*Chevrel et al., 2013*).

The paper (*Wisniewski et al., 2011*) confirmed that during the crystallisation of iron-containing glasses, magnetite can give glass magnetic properties due to the presence of clusters or crystals with magnetic properties. In addition, the paper (*Wisniewski et al., 2011*) proved that hematite (Fe_2O_3) is the primary crystallised phase, and magnetite (Fe_3O_4) is the result of phase transformation after primary crystal growth. In addition, the presence of MgO in the iron-containing silicate melt contributes to the formation of magnesioferite ($MgFe_2O_4$), which is characterised by high magnetic properties in addition to magnetite. SEM combined with electron backscattering diffraction was the primary method for phase characterisation (EBSD).

Thus, the analysis of literature sources confirms the possibility of shifting the chemical equilibrium of FeO↔Fe₂O₃ and determines the possibility of directional synthesis to obtain glass-crystalline materials containing magnetic nanoparticles. Oxide glasses containing paramagnetic inclusions attract attention as materials from which it is possible to obtain magnetically ordered particles of microscopic size, which is one of the innovative directions of modern physics of magnetic phenomena.

Materials and methods

To determine the optimal compositions of iron-containing glass-crystalline materials, state diagrams of the two-component SiO_2–FeO and SiO_2–Fe_2O_3 systems were analysed. System state diagram analysis indicates the presence of low-melting eutectics at temperatures of 1173ºC and 1455ºC, respectively (*Figure 1*).

SiO_2-FeO is selected for cooking iron-containing glasses. To optimise the properties of glasses, state diagrams of systems were analysed, in which various combinations were added to the essential components: CaO, MgO, Al_2O_3. Then, the composition of the glass was determined at a minimum eutectic temperature. Mass percentages were recalculated for the glass compositions selected in this way. The recipe for various systems' glasses is in the appendix (*Table 1*).

The following chemical reagents were used for cooking glass: amorphous silica (SiO_2), Fe(II) oxide (FeO), calcium carbonate ($CaCO_3$), magnesium oxide (MgO), and aluminium oxide (Al_2O_3). Cooking took place in a silite electric oven at 1300°C for 2 hours in neutral conditions. Chamotte crucibles with a capacity of 250 ml were used for cooking. Before the study, the glass was heat-treated to crystallise it. The glass was slowly heated in the temperature range of 550-800°C for 2 hours.

The cooking capacity of glass and the aggressiveness of glass mass concerning chamotte were performed visually according to the method described in the article (*Plemiannikov & Zhdanyuk, 2021*).

Thermal studies of samples of glass-crystalline materials were performed on the derivatograph Q-1500 device (Hungary) of the Paulik-Paulik-Erdey system. The samples were heated to 1000ºC in the air atmosphere at a heating rate of 10ºC/min. The samples' weight was 1500 mg. Al2O3 was taken as the reference substance. The experiments used a platinum crucible. The device's sensitivity on the DTA scale is 250 MV.

The phase composition of vitreous materials was studied using the XRPA method on a DRON 3M diffractometer. The X-ray tube is Cukaα. U = 30 kW. The phases were identified using the ICDD file.

The paper also investigated the magnetic properties, namely the relative Q-factor and magnetic permeability of glasses using Q-meter E 9-4. The equation calculated the relative magnetic permeability of the material:

$$\Delta Q = \frac{Q_0 - Q}{Q_0} \cdot 100\%,$$

where

Q_0 – Q-factor of a circuit with a coil filled with air (μ≈1),

Q – Q-factor of a circuit with a coil filled with a substance (μ≠1).

The relative magnetic permeability of the core material was calculated by the formula:

$$\mu = \frac{C_0 - C}{C_0} \cdot 100\%,$$

where

C_0 – capacity of a circuit with a coil filled with air ($\mu \approx 1$),

C – capacity of a circuit with a coil filled with a substance ($\mu \neq 1$).

Results

All three compounds formed an opaque black glass during cooking. All windows were air-conditioned. It is worth noting that the lowest-melting glass was formed for Composition No. 1 after recrystallisation, and the colour of glass-crystalline materials was also black.

DTA was used to examine samples of glass-crystalline materials. Exothermic effects on the DTA curves of all samples indicate a high crystallisation capacity of the glasses and the probability of formation of glass-crystalline materials. Moreover, several peaks are present for some compositions, indicating a complex crystallisation polymineral nature (*Figure 2*).

Analysis of the XRD results of sample No. 1 confirmed the presence of a crystal phase – magnetite (Fe3O4). The resulting magnetite has spheres of magnetic properties. Also, a wide halo is visible on the diffraction pattern, indicating a large proportion of the glass phase (*Figure 3*).

For composition No. 2, in addition to small amounts of magnetite, the formation of magnesioferite ($MgFe_2O_4$) is also possible. The presence of MgO in the iron-containing silicate melt contributes to this (*Wisniewski et al., 2011*). For sample 3, only a small number of crystals with magnetic properties can form. We studied this system in our paper (*Plemiannikov & Zhdanyuk, 2021*). It is confirmed that Crystal phases are formed in this system $2(Mg,Fe)O \cdot SiO_2$, $FeO \cdot SiO_2$, FeO, Al_2O_3, $MgO \cdot FeO \cdot Al_2O_3$, for which magnetic properties are uncharacteristic. It is also possible to form small amounts of magnesioferite, which is justified in the work (*D'Ippolito et al., 2015*). To test the effect of Fe^{2+} and Fe^{3+} cations on the vibrational spectra, solid solutions of $MgAl_2O_4$–$MgFe_2O_4$ were examined using Raman spectroscopy. It was found that the Raman scattering modes are affected by the substitution of Mg^{2+} for Fe^{2+} in tetrahedral locations of the $MgAl_2O_4$–$FeAl_2O_4$ system and the substitution of Fe^{3+} for Al^{3+} in octahedral locations of $MgAl_2O_4$–$MgFe_2O_4$, which confirms the possibility of magnesioferite formation.

An important part of the research was studying the magnetic properties of the samples. The results of experimental tests showed the relative magnetic permeability and changes in the Q-factor of the contour of the obtained glass-crystal materials (*Figure 4*).

According to research results, Composite glasses have ferrimagnetic properties. The most pronounced magnetic properties are characteristic of sample No. 1, explained by the formation of magnetite crystal phases ($FeO \cdot Fe_2O_3$). Magnetite is a typical representative of magnetic materials. Due to the ordering of the spin moments of ferum cations due to the exchange interaction between the electrons of the 3D shell of neighbouring cations, it has ferrimagnetic properties. According to the structure, the magnetic spin moments of Fe(III) ions located in the octa – and tetrahedral positions are mutually compensated, and the parallel ordering of the magnetic spin moments of Fe(II) ions located in the octahedral positions forms the magnetic moment of the mineral (*Dudchenko, 2011*). In samples 2 and 3, magnetite and magnesioferite are

formed in small amounts. Magnesioferite, like magnetite, has strong properties. It is the extreme member of the isomorphic series: magnetite ($FeO \cdot Fe_2O_3$) – magnesioferite ($MgO \cdot Fe_2O_3$). Substitution of Fe^{2+} by a magnesium cation in the octahedral position interrupts the exchange of the Fe^{2+} 3D electron with neighbouring Fe3 + cations and has a lower magnetic susceptibility than magnetite. In this paper, we have obtained an iron-containing glass-crystal material with pronounced magnetic properties. Compositions with a high content of magnetite are promising. Research on the properties of iron-containing glasses will continue, as this is one of the innovative areas of modern physics of magnetic phenomena.

Discussion

Studying glass-crystalline materials based on iron-containing glasses is an urgent task. Since the content of ferum oxides in industrial silicate glasses is strictly regulated (fractions of a per cent), most studies were carried out on such materials. Introducing more ferum oxides into the silicate system significantly changes its properties. It makes it possible to obtain materials with unique properties, such as glass ceramics containing a magnetic phase in a biocompatible vitreous Matrix. Such materials can be used as thermal mattresses for treating cancer with magnetic induction hyperthermia. Magnetic properties are usually explained by the presence of a magnetic phase (magnetite (Fe_3O_4) or hematite (Fe_2O_3) in the glass mass. In such glass-crystal materials, the $Fe^{3+}(3d^5, 6S^{5/2})$ ion EPR absorption at room temperature. For modern medical magnetic glass ceramics, silicate systems are used $CaO–SiO_2$; $CaO–SiO_2–P_2O_5$; $Na_2O–CaO–SiO_2–P_2O_5$; $MgO–CaO–SiO_2–P_2O_5–CaF_2$. The study of $CaO–Na_2O–B_2O_3$, $CaO–SiO_2–P_2O_5–Na_2O$ systems is promising.

The magnetic properties of glasses allow them to be used in electronics. The unique magnetic and mechanical properties of some amorphous alloys make the materials attractive for magnetic heads. Electromagnetic transducers and sensors made from conventional magnetic alloys have been used to measure compression or tension for several years, and the development seemed almost complete. The use of metal glasses in surface acoustic wave delay lines is particularly interesting, as they give a relatively large variation in the delay time with a slight change in the shear field.

Anisotropic microstructures accompanying spatial changes in magnetisation can also create effective magnetic anisotropies. In many cases, the magnetisation is significantly reduced due to exchange fluctuations, and materials usually have a low coercive force and no magnetic anisotropy.

The conducted research allowed us to expand our knowledge about the properties of iron-containing glasses that can be used to recycle iron ore processing waste. What wastes have a high raw material value, containing SiO_2, Na_2O, CaO, MgO, Al_2O_3, and up to 15% iron oxides? Studies of the properties of iron-containing silicate systems make it possible to conduct directional glass synthesis and dispose of waste using glass technology. For example, the production of facing material with high decorative properties ($SiO_2–Na_2O–CaO$, $SiO_2–CaO–MgO$, $SiO_2–MgO–Al_2O_3$ systems) or the production of fibrous materials using glass technology from rocks containing a high content of ferum oxides.

Developing thermal insulation materials based on iron-containing glass by foaming iron-containing glass is relevant and promising. The resulting foam glass has a cellular structure. It is

characterised by high thermal insulation properties (0,05-0,07 M/(m·K)) and noise absorption up to 56 dB. Using highly ferruginous foam glass compositions requires optimisation of its production's chemical and physical processes.

Conclusion

Silicate glasses containing an increased amount of iron oxides and glass-crystalline materials based on them are studied in this paper. The DTA results confirmed that the proposed glass compositions have a high crystallisation capacity. Analysis of the XRD results confirmed the presence of a crystalline phase in glass-crystalline materials-magnetite (Fe_3O_4), which determines the magnetic properties of glasses. Studies of relative magnetic permeability have confirmed that the synthesised glasses have ferromagnetic properties. Thus, it is confirmed that high magnetic properties characterise iron-containing glass-crystal materials and can be used in high-tech devices.

Conflict of interest

The author declares that there is no conflict of interest.

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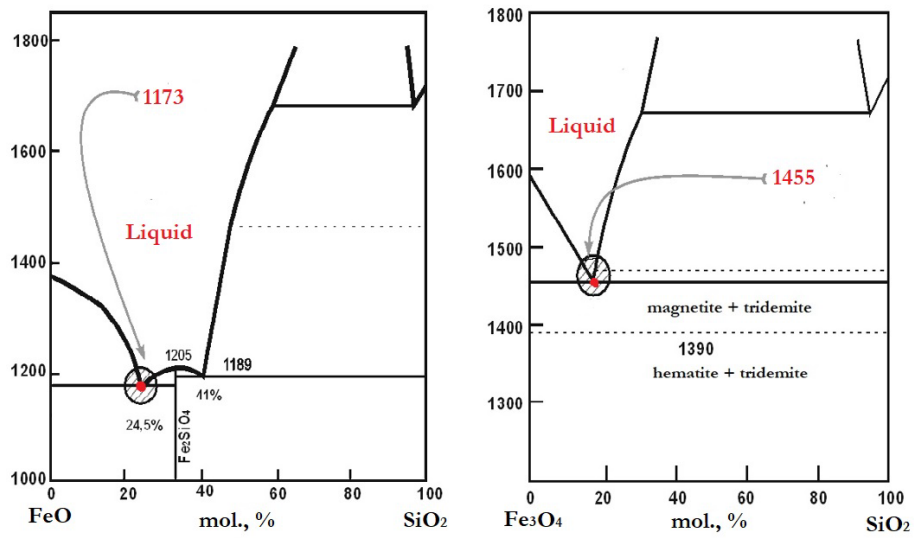
Appendix

Figure 1. binary systems FeO–SiO$_2$ and Fe$_2$O$_3$–SiO$_2$
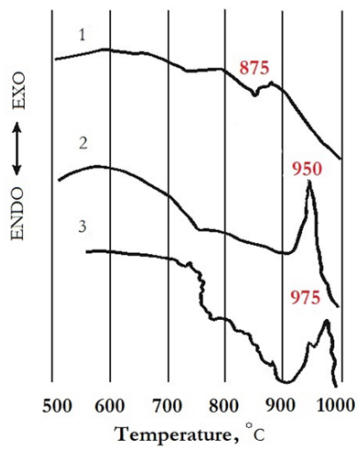
Figure 2. DTA results of glass samples
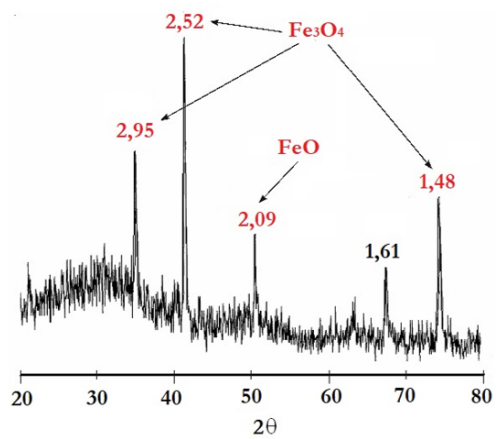
Figure 3. Diffraction pattern of composite glass No. 1
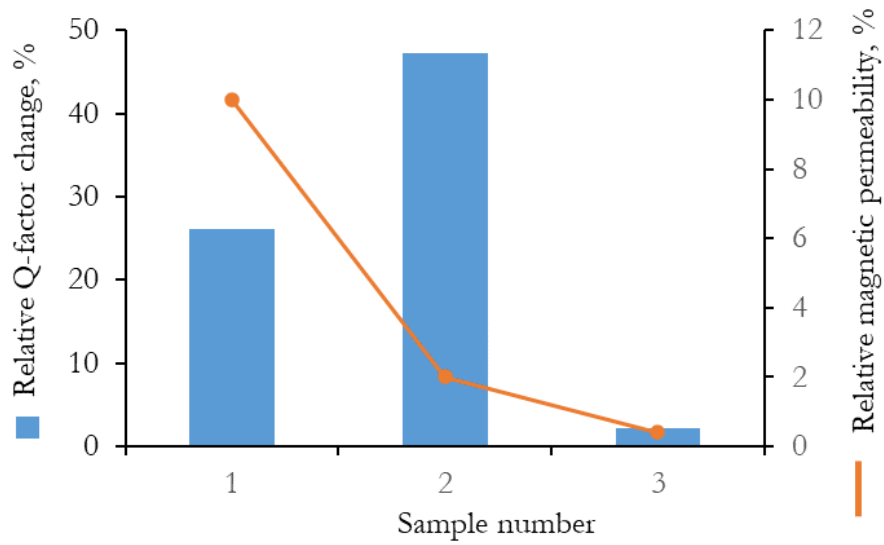
Figure 4. Relative change in contour Q-factor and relative magnetic
permeability of glass

Table 1. Compositions of iron-containing glasses

No.	System	T,°C	Glass composition, weight %				
			FeO	SiO_2	CaO	MgO	Al_2O_3
1	SiO_2–FeO–CaO	1200	40	40	20	-	-
2	SiO_2–FeO–CaO–MgO	1150	40	37.5	13	9.5	-
3	$SiO2$–FeO–CaO–MgO–Al_2O_3	1220	17	53	8	7.5	14.5

Ivan B. Kravets [16], *Vitalii V. Kovalchuk* [17], *Ihor A. Karnakov* [18]

Experimental estimation of the degree of compaction of the roadbed by the propagation time of elastic shock waves [8]

Abstract: The study is a model of a roadbed with a heterogeneous structure. The method of laboratory experimental studies for determining the accelerations of elastic waves in the model of an inhomogeneous roadbed at different degrees of density is presented. Experimental studies were conducted using the developed laboratory setup, and it was found that with increasing density, The Wave travel time decreases since, in a dense medium, the wave propagation speed is higher. It is determined that the shortest Wave travel time is obtained to the A3 sensor, and it is 0.0016 ms in the case of non–compacted state, in the case of intermediate compaction – 0.0015 ms and at the maximum compaction – 0.0012 ms. The travel time of the wave to the sensors A2 and A4, which are located at the same distance from the drummer, is almost the same and is 0.0022 Ms. and 0.002 ms in case of non–compacted state, in case of intermediate compaction-0.0018 Ms. and 0.0019 ms and at the maximum compaction – 0.001 ms and 0.0009 ms. Experimental studies will help determine the degree of compaction of the soil of the roadbed based on the time and speed of propagation of elastic waves. It is worth noting that the laboratory installation allowed studying the propagation of elastic waves for a roadbed model, which can be designed from different types of soils. In addition, it makes it possible to consider various inhomogeneities that may occur during the operation of the roadbed of a railway track.

Keywords: roadbed, acceleration sensor, elastic wave, degree of compaction, inhomogeneous medium.

Іван Богданович Кравець, Віталій Володимирович Ковальчук, Ігор Анатолійович Карнаков

Експериментальна оцінка ступеня ущільнення земляного полотна за часом поширенням пружних хвиль удару

Анотація: Об'єктом досліджень є модель земляного полотна з неоднорідною структурою. Наведено методику лабораторних експериментальних досліджень для визначення прискорень пружних хвиль у моделі неоднорідного земляного полотна при різних ступенях щільності. Проведено експериментальні дослідження за допомогою розробленої лабораторної установки та встановлено, що при збільшенні щільності час проходження хвилі зменшується, оскільки у щільному середовищі швидкість поширення хвилі є вищою. Визначено, що найменший час проходження хвилі отримано до датчика А3 і він становить 0,0016 мс. при неущільненому стані, при проміжному ущільненні – 0,0015 мс. та при максимальному ущільненні – 0,0012 мс.. Час проходження хвилі до датчиків А2 та А4, які розташовані на однаковій відстані від ударника, практично однаковий і становить 0,0022 мс. та 0,002 мс. при неущільненому стані, при проміжному ущільненні – 0,0018 мс. та 0,0019 мс. та при максимальному ущільненні – 0,001 мс. та 0,0009 мс. Експериментальні дослідження допоможуть визначити ступінь ущільнення ґрунтів земляного полотна на основі часу та швидкості поширення пружних хвиль. Варто зазначити, що створена лабораторна установка дозволяє проводити дослідження поширення пружних хвиль для моделі земляного полотна, яке може бути спроектоване з різних типів ґрунтів. Крім того, вона дає можливість враховувати різні неоднорідності, які можуть виникати під час експлуатації земляного полотна залізничної колії.

Introduction

Ukraine's railway transport is significant in ensuring the state's defence capability. The functioning of many branches of the national economy depends on its state. Increasing the capacity and speed of trains is an important task.

The roadbed is one of the main elements of the railway track structure (*Danilenko, 2010*). Under operating conditions, the roadbed, under the influence of increasing loads and natural factors, undergoes deformations and inhomogeneities, leading to loss of load-bearing capacity and stability. Especially dangerous are deformations of clay soils, which lead to the formation of weakened zones, hidden cracks, loss of soil density and, as a result, the development of splashes (*Kravets, 2021*), as shown in the appendix (*Figure 1*) and other defects (*Dyachenko et al., 2001*). This requires developing design solutions to increase its load-bearing capacity and durability (*Dubinchik et al., 2023; Kravets, 2021*).

One of the most significant indicators of reliable roadbed operation is ensuring the soil density's design degree (*Danilenko, 2010*). Therefore, the assessment and control of the soil density of the roadbed, both in the conditions of construction and operation, is relevant. Increasing soil density reduces deformations and increases the stability of the roadbed. One of the methods that can be used to estimate the soil density of the roadbed is the method of measuring the speed of propagation of sound waves of impact (*Karnakov et al., 2023*; *Kovalchuk et al., 2023a*; *Kovalchuk et al., 2023b*). To date, there are many studies on the use of inertial methods to assess the degree of density of the ballast layer and soils of the railway roadbed, which are given in the works (*Kovalchuk et al., 2021*; *Przybylowicz et al., 2020*; *Sysyn et al., 2020*; *Sysyn et al., 2019*). In addition, inertial technologies are used to assess the degree of compaction of ground backfill of transport structures made of metal corrugated structures (*Onishchenko et al., 2024*).

In the paper (*Przybylowicz et al., 2020*), a homogeneous crushed stone layer was studied by inertial measurements to assess the quality of lining the ballast layer of a railway track. The study of the degree of compaction of the crushed stone layer by ballast compaction machines by complex dynamic and kinematic interpretation of the pulse response is given in the paper (*Sysyn et al., 2019*). The paper (*Sysyn et al., 2020*) presents the results of laboratory experiments on the propagation of elastic waves in a crushed stone layer depending on the degree of its compaction. In the paper (*Kovalchuk et al., 2021*), it is noted that the propagation of elastic waves through a granular medium depends on the mineralogical and granulometric composition of grains, as well as on the density of the soil layer, i.e., the number of contacts between grains. By measuring the speed of waves after each soil compaction, you can determine the degree of compaction. As the density increases, many contacts and friction between the grains increases, and the porosity decreases. However, the wave velocity does not directly depend on the shear strength. It serves as a qualitative indicator of changes in strength, especially in heterogeneous soils. In coarse-grained soils, shear strength and transverse wave velocity depend on grain density (*Dashwood et*

al., 2020). The propagation of waves is also affected by the humidity of the medium; such studies were conducted in the paper (*Seoungmin et al., 2023*).

The analysis of scientific papers (*Kovalchuk et al., 2021*; *Przybylowicz et al., 2020*; *Sysyn et al., 2020; Sysyn et al., 2019*) found that the primary studies of the degree of compaction of the roadbed were conducted on models with a uniform structure. However, there are no experimental studies on the propagation of waves and their accelerations in an inhomogeneous soil environment. Therefore, conducting laboratory experimental studies on wave propagation in heterogeneous soils is an urgent task of scientific research. This will allow us to establish the dependence of the acceleration value on the degree of compaction of soil with inhomogeneities.

Materials and methods

The study object is a roadbed model made of heterogeneous soil in a glass box with dimensions of 1.0x0.5x0.7 m. The accelerations of elastic waves are determined on the roadbed model given in the appendix (*Figure 2*). The study was performed at different degrees of compaction of the roadbed's heterogeneous soil.

Experimental laboratory studies consisted of a sequence of soil compaction cycles of the roadbed model and recording the accelerations of the passage of elastic shock waves. The drummer set the impact on a round die located in the centre of the model, as shown in the appendix (*Figure 3*). The experiment was performed for three states of the model: non-compacted state, intermediate compaction, and maximum compaction.

After each compaction cycle, wave propagation was recorded in the medium of a model of an inhomogeneous roadbed using an inertial instrument (*Kovalchuk et al., 2021*; *Kravets, 2021*). To determine the optimal value of the wave propagation time for each state (non-compacted, intermediate compaction, maximum compaction) of the inhomogeneous roadbed model, impacts (pulses) were set five times.

Results

The results of recording the wave propagation time in the roadbed model with non-compacted, intermediate compaction, and maximum soil compaction are shown in the appendix (*Figure 4*). According to the results of the recordings (*Figure 4a*), in the non-compacted state, the wave travel time from the beginning of the pulse setting to analogue acceleration sensors is up to sensor A1 – 0.0004 ms, sensor A2 – 0.0022 ms, sensor A3 – 0.0015 ms, sensor A4 – 0.002 ms and sensor A5 – 0.0026 ms.

During intermediate compaction of the roadbed model's ground (*Figure 4b*), the wave travel time from the start of pulse setting to analogue acceleration sensors is up to sensor A1 – 0.0002 ms, sensor A2 – 0.0018 ms, sensor A3 – 0.0016 ms, sensor A4 – 0.0019 ms and sensor A5 – 0.0021 ms.

At the maximum compaction of the roadbed model's ground (*Figure 4c*), the wave travel time from the start of pulse setting to analogue acceleration sensors is up to sensor A1 – 0.0001 ms, sensor A2 – 0.001 ms, sensor A3 – 0.0012 ms, sensor A4 – 0.0009 ms and sensor A5 – 0.0012 ms.

For better clarity of the results, the experimental data obtained are given in the appendix (*Table 1*), which is given in the appendix. As we can see from the results of experimental studies,

the propagation time of the sound wave of impact decreases with an increased degree of soil compaction. This suggests that wave propagation speed in a dense medium is higher.

Discussion

Conducting laboratory experimental wave propagation studies in heterogeneous soils is a significant scientific study task. Such experimental studies will make it possible to determine the degree of compaction of the soil of the roadbed by the time and speed of propagation of elastic shock waves. It is worth noting that the developed laboratory installation, given in the appendix (*Figure 2*; *Figure 3*), allows you to perform studies of the propagation of elastic waves for the roadbed model, which can be designed from various types of soils. In addition, it allows you to set various inhomogeneities that may occur during the operation of the roadbed of a railway track.

The results of experimental studies of the roadbed model at different degrees of soil compaction showed that as the density increases, the wave travel time decreases (*Figure 4*). According to the diagram (*Figure 3*), we can see that the sensor A3 located is located at the smallest distance to the impactor, so the time (*Table 1*) of wave passage is the smallest. Sensors A2 and A4 are located at the same distance from the impactor, respectively, and the wave travel time is almost the same with a slight deviation. This is due to the presence of heterogeneous inclusions in the form of clay. It is also worth noting that the wave's travel time to sensor A1 is the shortest because it is located where there is no inhomogeneity of the roadbed, i.e., the wave speed in such a medium is the highest.

Conclusion

A laboratory installation has been developed for conducting experimental studies of wave propagation in soils with different densities and inhomogeneities. This will allow determining the degree of compaction of the roadbed's soil at the time of elastic shock wave propagation.

Based on the obtained values of the travel time of impact waves in the roadbed model, it was found that with increasing density, the wave's travel time decreases since, in a dense medium, the wave propagation speed is higher. Accordingly, the shortest wave travel time is obtained by the sensor A3. It is 0.0016 ms in the non-compacted state, in the case of intermediate compaction – 0.0015 ms and at the maximum compaction – 0.0012 ms. The travel time of the wave to the sensors A2 and A4, which are located at the same distance from the drummer, is almost the same and is 0.0022 ms and 0.002 ms in case of non-compacted state, in the case of intermediate compaction-0.0018 Ms. and 0.0019 Ms. and at the maximum compaction – 0.001 ms and 0.0009 ms.

Conflict of interest

The authors declare that there is no conflict of interest.

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Appendix

Figure 1. Defective places of the roadbed (a) a section of railway track with spills, (b) loss of stability of the slope of the roadbed due to soil compaction
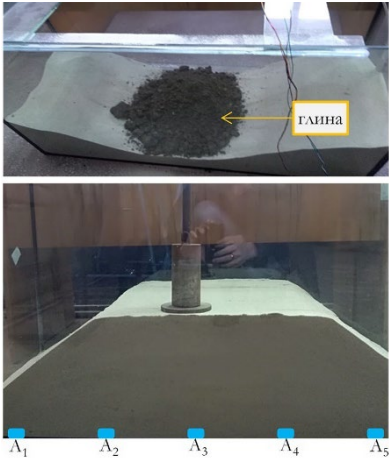
Figure 2. Model of a roadbed with non – uniform inclusion: A1, A2, A3, A4, A5-analogue acceleration sensors
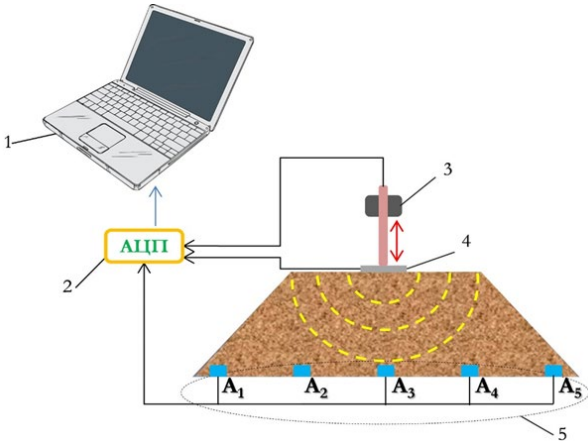
Figure 3. Diagram of a laboratory installation for performing measurements: (1) laptop, (2) analogue-to-digital converter, (3) drummer, (4) stamp, (5) acceleration sensors
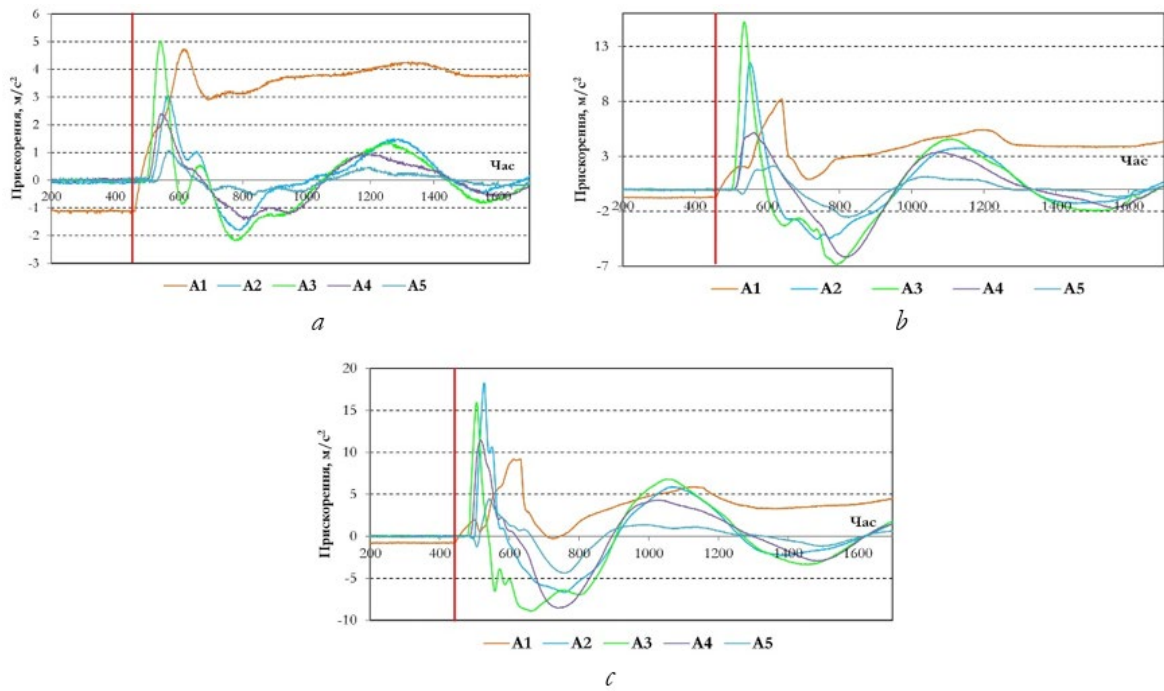
Figure 4. Wave propagation records in the roadbed model (A1, A2, A3, A4, A5 are analogue sensors; vertical line impacts moment (start of pulse setting)): (a) in the non-compacted State; (b) intermediate seal; (c) maximum seal

Table 1. Results of wave travel time in the roadbed model at different degrees of soil compaction

Analog acceleration sensors, ms	A1	A2	A3	A4	A5
Degree of compaction					
not compaction	0.0004	0.0022	0.0016	0.002	0.0026
intermediate compaction	0.0002	0.0018	0.0015	0.0019	0.0021
maximum compaction	0.0001	0.001	0.0012	0.0009	0.0012

99

Oresta B. Kovalchuk [19], *Olena M. Bal* [20], *Ivan B. Kravets* [21]

Development of a methodology for researching the technical condition of elements of the upper structure of railway track [9]

Abstract: To date, several specific methods have been developed for conducting a railway transport expertise to study the circumstances of a railway accident. The study of the technical condition of the elements of the upper structure of a railway track is a significant diagnostic task in forensic railway transport expertise. The need for such expertise arises from pre-trial investigation bodies, courts, legal entities, and individuals when resolving economic and civil disputes, such as criminal and administrative cases. The study aims to describe the order (algorithm) for determining the technical condition of elements of the upper structure of a railway track. This work is based on modern scientific research in forensic railway transport expertise and regulatory and technical documentation. To study the technical condition of the railway track's upper structure elements, it is necessary to develop an appropriate method. This study gives the conditions for appointing forensic experts for railway transport. The main criteria for the track's good condition and the requirements it must meet are described. The result of this study is the development of an algorithm to investigate the technical condition of the elements of the upper structure of the railway track in forensic science.

Keywords: forensic science of railway transport, traffic safety, derailment of rolling stock, technical condition of the railway track.

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Розробка методики дослідження технічного стану елементів верхньої будови залізничної колії

Анотація. На сьогоднішній день розроблено кілька спеціальних методик, які використовуються при проведенні судової залізнично-транспортної експертизи в частині вивчення обставин залізничної пригоди. Метою дослідження є опис порядку (алгоритму) визначення технічного стану елементів верхньої будови залізничної колії. Ця робота базується на сучасних наукових дослідженнях у сфері судової залізнично-транспортної експертизи та нормативно-технічній документації. Для дослідження технічного стану елементів верхньої будови залізничної колії необхідно розробити відповідну методику. В даному дослідженні наведено умови для призначення судової експертизи залізничного транспорту. Описано основні критерії справного стану залізничної колії та вимоги, яким вона повинна відповідати. Результатом даного дослідження є розробка порядку (алгоритму) дослідження технічного стану елементів верхньої будови залізничної колії.

Ключові слова: судова залізнично-транспортна експертиза, безпека руху, схід рухомого складу з рейок, технічний стан залізничної колії.

Abbreviations:

RTD is regulatory and technical documentation.

Introduction

The relevance of this work is determined by the need for scientific and methodological support of forensic expert activities within the framework of the expert speciality 10.13.1 "Research of Engineering Equipment of the Upper Structure of the Track". This involves solving diagnostic tasks to assess the technical condition of the elements of the upper structure of the track and check their compliance with the regulatory requirements for the safety of railway transport infrastructure.

The study aims to describe the order (algorithm) for determining the technical condition of elements of the upper structure of a railway track. This work is based on modern scientific research in forensic railway transport expertise and RTD. RTD on this topic is held for the first time and is registered with UkrINTEI (NDDKR registration card 0123u101166).

As of today, the Ministry of Justice of Ukraine has approved several specially developed methods for forensic railway transport expertise, in particular for analysing the circumstances of railway accidents (*Sokol, 2007*). During 2019-2020, the Lviv Research Institute of Forensic Examinations developed "Methodological Recommendations for the Study of Elastic Rail Fasteners," which became the basis for creating a "Methodology for Studying Elements of the Upper Structure of the Track in Forensic Examination" (*Bal, 2020*).

The study of the technical condition of the elements of the upper structure of a railway track is a significant diagnostic task in forensic railway transport expertise. The need for such expertise arises from pre-trial investigation bodies, courts, legal entities, and individuals when resolving economic and civil disputes, such as criminal and administrative cases. Forensic railway transport expertise is assigned to analyse the circumstances of railway accidents or to assess the technical condition of elements of the upper and lower structure of the track, like rolling stock. The need to study the elements of the upper structure of the track also arises when checking their compliance with technical conditions and standards at the production and input control stage, i.e., even before they are laid in the structure of the railway track.

The results of the study
Investigation of the technical condition of the railway track in the presence of malfunctions of the elements of the upper structure of the track

Railway transport experts' main tasks are solving diagnostic and situational problems. One of these diagnostic tasks is to study the technical condition of the railway track.

The technical condition of the elements of the upper and lower structure of the railway track must meet the requirements of regulatory documents in force on the Railways of Ukraine, constantly guarantee reliability and ensure the safety of passenger and cargo transportation.

Among other things, the following basic requirements apply to a railway track as an engineering structure:

- the strength and stability of the railway track must ensure the safe and smooth movement of trains at the highest speeds set for this section.
- the railway track must ensure uninterrupted transportation at any time of the day and year.

Thus, the main criterion for the track's serviceability is its ability to ensure trains' safe and smooth movement at the highest speeds set for this section. (*Danilenko, 2010*; *Bondarenko, 2018*).

Therefore, to establish the technical condition of the railway track, it is necessary to comply with the requirements of regulatory documents in force on Ukraine's railway transport and the ability of the railway track to perform its functions.

To study the technical condition of a railway track, it is necessary to consider the technical condition of its elements:

- technical condition of the rails,
- technical condition of rail joints,
- technical condition of sleepers,
- technical condition of intermediate and butt joints,
- technical condition of the ballast layer,
- technical condition of the rail track as a geometric structure: technical condition of the rail track in width, technical condition of the rail track in the relative position of the rail threads in height ("level"), technical condition of the rail track in the direction in the plan (straightening).

The main and receiving and sending tracks and switches on them are considered to be in good working order if the following conditions are met:

(a) absence of acute defect rails in the track;
(b) the absence of unsuitable sleepers in the track of bushes that require a speed limit compared to the established one;
(c) there is no indentation or connection in the track through which it is required to limit the speed of trains or completely stop traffic;
(d) the track is secured from theft;
(e) the ballast prism is kept to the specified dimensions and clean;
(f) switches and blind intersections are kept according to the requirements of the PTE, established standards and tolerances, and in the absence of acute defect elements;
(g) rail joints, butt and intermediate joints, and rail connectors are kept in reasonable condition; there are no splashes and sleepers in the joints that do not rest tightly on the ballast;
(h) roadsides, ditches, trays, mountain ditches and other drains are kept clean and ensure normal water outflow;
(i) the bridge bed, spans, supports, cones, riverbeds and fire-fighting equipment on artificial structures, the supervision of which is entrusted to the teams for the current maintenance of the track, are in good working order;
(j) railway crossings, approaches, decking, fences, main and spare barriers, warning signs and lighting are in good working order;
(k) signal and road signs in order;
(l) materials are stored in designated locations and cleaned on time upon completion of work.

If the listed conditions are met, the track is considered to be kept in excellent, good, satisfactory, or unsatisfactory condition, respectively, when evaluated in points according to the readings of the track measuring car. A kilometre is also considered unsatisfactory if it has at least one indentation, which requires reducing the set train speeds or closing it (*Instruction, 2012*; *Technical instructions…, 2012*).

There are 5 degrees of deviations from the norms of rail track maintenance.

The first-degree margins include margins within tolerances that ensure the safety and smoothness of train traffic. The established train speeds do not decrease with such deviations, and no work is required to eliminate them.

The 2nd-degree margins include margins that do not require a reduction in the set speed and do not threaten the safety of train traffic but affect its smoothness. They are the basis for assigning and carrying out scheduled preventive work.

Single 3rd degree indentations include indentations that do not require a decrease in the set speed and do not threaten the safety of train traffic but affect the smoothness of train traffic and the intensity of accumulation of residual track deformations. They are the basis for assigning and carrying out scheduled preventive work.

The 4th degree includes indentations, the presence of which at set speeds worsens the smoothness of movement and leads to an intensive accumulation of residual track deformations. These indentations should be eliminated first.

The 5th degree includes deviations that increase the forces of interaction between the track and rolling stock to such critical values that in the presence of unfavourable combinations with deviations in the content and loading of rolling stock, violations of the train driving mode and other conditions can lead to too rapid a growth of deformations and a threat to traffic safety. These deviations must be eliminated immediately.

Penalty points are awarded for deviations of the 3rd-5th degrees. Detected by track-measuring cars, the 2nd-degree deviations are considered only for scheduled preventive track work.

Other station tracks – sorting, traction, cargo, etc. - are considered in good working order, provided they are safe traffic at the set speeds. These tracks are checked by track-measuring trolleys and manual track measurement within the established time frame.

Field inspections and measurements are systematically performed using special equipment to control the technical condition of the railway track.

Railway track crawlers and crossing attendants inspect their sections constantly. The track Foreman checks the railway track once a week, the roadmaster and the track Foreman check the track once every two weeks, and the Senior Road Master and the site manager check their section once a month. Commission monthly, quarterly, autumn, and spring inspections are also conducted.

The width and level of the rail track are checked using track templates, bogies, and track cars.

Track measuring car data provides complete information about the rail track's technical condition (*Technical instructions…, 2012*). On the belts of track measuring cars, data on the relative position of rail threads in height (level), on local subsidence (bumps, depressions) of each rail thread, on the width of the track, on the position of rail threads in the horizontal plane are continuously recorded in the form of a diagram.

Classification of all track faults divides them into five stages. Deviations within the established tolerances are a fault of the first stage. The most significant and unacceptable deviations belong to the fifth degree. Each deviation from the norms of rail track maintenance is decoded and evaluated in points. A qualitative assessment of the technical condition of the rail track based on the readings of the track measuring car is established depending on the sum

of points per kilometre for all types of deviations and their degree.

Flaw detection trolleys and wagons equipped with electromagnetic and ultrasonic flaw detectors detect defects in track rails.

Investigation of the technical condition of the railway track in the presence of damage to the track

Over the last period, the number of theft cases of elements of the upper track structure has increased. It is worth noting that, in such circumstances, the main problem is the possibility of a threat to traffic safety due to the absence of stolen elements in the track.

As the practice of forensic railway transport expertise has shown, most often, there are steals of elements of intermediate and butt fasteners.

Rail fasteners, for their purpose, are divided into two groups: 1 – intermediate, 2 – butt. The first provides fastening of the rails to the sub–ref supports, and the second connects the rails at the joints. Thus, rail fasteners connect individual elements of the upper structures of the track into a single structure – a rail-sleeper grid and ensure the operation of this integral structure (*Danilenko, 2010*).

The joints of the rails are called joints. The most common design of a rail joint for a link track is a conventional mechanical patch-bolt joint. The composition of the bolt fastening of a mechanical joint includes two linings and four (with a four-hole pad) or six (with a six-hole pad) butt bolts with nuts and washers.

It should also be noted that the joint is the track's weakest and most stressful point. When the rolling stock passes through the joint, additional shock-dynamic actions are created on the track due to a significant (approximately twice) elastic drawdown of the rail thread and a gap. As a result, residual deformations in the ballast accumulate much more intensively in the joint zone, and sleepers and rail ends wear out. Therefore, the requirements for holding joints are pretty high.

According to the requirements of regulatory documentation, namely instructions for the device and maintenance of the track of Railways of Ukraine (*Instruction, 2012*), in the absence of one butt bolt at the end of the rail with four-piece linings or two-with six-piece ones, the speed of trains is limited to 25 km per hour. If all the bolts at the end of the rail are missing, train traffic stops.

In order to establish the technical condition of the railway track after the theft of butt bonding elements and whether this technical condition meets the requirements of traffic safety, the expert needs to know the following information: the established speed of trains on this section, the type and number of stolen elements. It is significant whether the elements are stolen from the same joint or different ones.

According to the requirements of the instruction on the device and maintenance of the track of Railways of Ukraine (*Instruction, 2012*), defective intermediate rail fasteners (considering the missing ones) include: on the track with wooden sleepers – unsuitable linings, essential crutches and screws; on the track with reinforced concrete sleepers – unsuitable linings, embedded and terminal bolts, terminals, screws and anchors or fasteners that have wear, in which they lose their functions.

The defect rate of fasteners is calculated on a link and non-link track per kilometre or picket

or link with a length of 25 m.

In order to establish the technical condition of the railway track after the theft of elements of intermediate rail fastening and whether this technical condition meets the requirements of traffic safety, the expert needs to know the following information: the type of fastening, the plot of sleepers (the number of sleepers per one km), the set speed of trains on this section. The track is located in a straight or curved section (if in a curve, then you need to specify the radius of the curve), the number of stolen elements. It is significant whether the elements are stolen in a row or selectively since it depends on what conditions the permissible movement speed will be set – if there is a defective fastener or a cluster unsuitability.

The main stages of conducting a study of the technical condition of the elements of the upper structure of the track and the railway track in general

The first stage is preparatory.

At the preparatory stage, the expert gets acquainted with the resolution (resolution) on the appointment of an expert examination and other materials and finds out whether the technical parameters of the elements of elastic rail fasteners are provided in the initial data. If they are not present, it is necessary to inspect the research objects to obtain technical parameters that will be subject to detailed research in the future.

The second stage is a detailed study.

During a detailed study, the actual technical parameters of the elements of the upper track structure are compared with the standard ones.

According to the task assigned to the expert, the study of IBC elements can be performed in one of two directions. The need to study the elements of the IBC may arise both at the stage of operation, i.e., when it is necessary to determine the technical condition of the track and at the stage of input control, when it is necessary to establish compliance with the technical parameters of the IBC elements with regulatory documents (technical conditions and state standards).

The third stage is the analysis of the study results and the formation of conclusions.

The study results are summed up at this stage, and conclusions are formed.

The third stage of studying the elements of the upper track structure at the entrance control stage is to determine whether they meet the technical conditions and state standards.

When studying the elements of the upper structure of the track in operation, the third stage is to determine the technical condition of the track by comparing the set speed on this section of the track with the permissible one. Provided that the set speed does not exceed the permissible speed limit, the technical condition of the track will be operational.

Discussion

The technical condition of the elements of the upper track structure is determined by analysing data obtained through full-scale inspection using special measuring devices (templates, track measuring and Flaw Detection cars, etc.), analysing data from the database of regulatory documents in force on the Railways of Ukraine, and performing particular calculations.

When conducting forensic examinations, this study can be performed when it is necessary to establish the technical condition of the element as a separate unit, for example, when

determining whether the element meets the requirements of DSTU or other regulatory documents. Alternatively, if a specific section of railway track needs to be examined after the rolling stock derails. Since the condition of each structural element of a railway track affects its overall technical condition.

The study of the technical condition of the track on the section of rolling stock derailment is performed to establish compliance of the actual condition with the proper (regulatory) one, i.e., to establish malfunctions of the elements of the upper structure of the track before a railway accident.

Characteristic malfunctions in the track that can lead to the derailment of rolling stock can be:

- unsuitability of sleepers, transfer and bridge beams;
- unsuitability of fasteners;
- excess slope of the track width diversion or increase in the outer rail;
- excess deviations of the track in plan, level or width;
- track discharge; rail breakage;
- non-fit of the tip to the frame rail and others (*Guidelines, 2012*).

Conclusion

The methodology for studying the technical condition of the elements of the upper structure of the railway track will provide a systematic approach to assessment and control, which is key to ensuring the safety and reliability of railway transport.

This method will allow specialists to assess the causes of incidents and determine responsibility objectively, check the compliance of the technical condition of the elements of the upper structure of the track with the requirements of technical conditions, state standards, and regulatory documents, analyse the technical condition of the elements of the track in the event of railway accidents or disputes, and determine responsibility.

A clearly defined procedure (algorithm) for studying the technical condition of the elements of the upper structure of the railway track will allow us to systematise processes and ensure a high level of accuracy and objectivity in assessing the technical condition of the railway track.

Also, in the future, the algorithm can be adapted to new technologies and methods, which ensures continuous improvement of research processes.

Conflict of interest

The authors declare that there is no conflict of interest.

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Implementation of foreign experience in fighting corruption and corruption offences in Ukraine [10]

Abstract: Corruption is one of the most severe threats to the stability and development of states, including Ukraine. It undermines trust in state institutions, hinders effective governance, and threatens national security. The study's relevance is determined by integrating fighting corruption's international experience into Ukrainian legislation to increase the effectiveness of anti-corruption measures. The high level of corruption crime in Ukraine and constant changes in the legal environment require revision and adaptation of the existing anti-corruption mechanisms. Global practice analysis allows us to identify successful models and strategies that can be adapted to the Ukrainian context. The study object is the world's experience in the fight against corruption and corruption offences and their implementation in Ukraine. The study aims to research foreign experience in the fight against corruption and corruption offences to highlight best practices and further implement the relevant norms in domestic legislation. The author summarises the available doctrinal and normative sources regarding the purpose and principles of legal responsibility; the synthesis method is used to determine the essence of corruption and corruption offences, the comparative method is for studying the criminal legislation for criminal offences of other countries for existing legal norms on combating corruption, generalisation method – for summarising the results of the study. The works of such scientists as I.Y. Grishova, S.S. Zadvornykh, O.V. Zinchenko, T.V. Ilienko, M.V. Kikalivshvili, O.I. Kozinets, I.V. Korulya, V.O. Prikhodko, I.O. Roshchina, V.M. Trepak, D.Yu. Chernikov, O.M. Khalkovsky, Ya.Yu. Shvydkiy were used in the study. The article examines corruption's legal and criminological aspects, the need for political will, public support and effective implementation of anti-corruption policy. International legal acts, such as the Strasbourg Convention, covering bribery, abuse of influence and other corruption offences are analysed. In particular, in Georgia, Italy, Germany, the Netherlands, and others, the methods of combating corruption are considered in various countries. The significance of integrating international standards into Ukraine's national legislation and developing effective anti-corruption strategies based on successful foreign experience are emphasised.

Keywords: corruption, responsibility, criminal law, criminal offences.

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Імплементація іноземного досвіду щодо боротьби з корупцією та корупційними правопорушеннями в Україні

Анотація: Корупція є однією з найсерйозніших загроз для стабільності та розвитку держав, зокрема й України. Вона підриває довіру до державних інституцій, заважає ефективному управлінню та загрожує національній безпеці. Актуальність статті зумовлена необхідністю інтеграції міжнародного досвіду боротьби з корупцією в українське законодавство для підвищення ефективності антикорупційних заходів. Високий рівень корупційних правопорушень в Україні та постійні зміни у правовому середовищі вимагають перегляду та адаптації існуючих механізмів боротьби з корупцією. Аналіз глобальних практик дозволяє виявити успішні моделі та стратегії, які можуть бути адаптовані до українського контексту. Об'єктом дослідження є світовий досвід у боротьбі з корупцією та корупційними

правопорушеннями та його імплементація в Україні. Метою є вивчення іноземного досвіду боротьби з корупцією та корупційними правопорушеннями для виокремлення кращих практик та подальшої імплементації відповідних норм у вітчизняне законодавство. У статті проводиться узагальнення наявних доктринальних та нормативних джерел щодо мети і принципів юридичної відповідальності; метод синтезу – для визначення сутності корупції та корупційних правопорушень; порівняльний метод – для дослідження кримінального законодавства за кримінальні правопорушення інших країн на предмет наявності правових норм щодо боротьби з корупцією; метод узагальнення – для підсумовування результатів дослідження. Вивченням питання сутності та шляхів боротьби з корупцією займалися такі вчені як І.Ю. Гришова, С.С. Задворних, О.В. Зінченко, Т.В. Іліенко, М.В. Кікалішвілі, О.І. Козинець, І.В. Коруля, В.О. Приходько, І.О. Рощина, В.М. Трепак, Д.Ю. Черніков, О.М. Халковський, Я.Ю. Швидкий. У статті розглядаються юридичні та кримінологічні аспекти корупції, необхідність політичної волі, суспільної підтримки та ефективної реалізації антикорупційної політики. Аналізуються міжнародні нормативно-правові акти, такі як Страсбурзька конвенція, що охоплюють підкуп, зловживання впливом та інші корупційні правопорушення. Розглядаються методи боротьби з корупцією в різних країнах, зокрема в Грузії, Італії, Німеччини, Нідерландів та інших. Наголошується на важливості інтеграції міжнародних стандартів у національне законодавство України та розробці ефективних стратегій протидії корупції, базованих на успішному іноземному досвіді.

Ключові слова: корупція, відповідальність, кримінальне право, кримінальні правопорушення.

Introduction

Corruption is one of the most severe threats to the stability and development of the state, which manifests itself in various forms at different stages of society's development. It undermines the credibility of state institutions and hinders the effective functioning of the management system. To combat this phenomenon, it is significant to understand both the legal and criminological aspects of corruption manifestations to develop effective counteraction strategies.

Corruption manifests itself in different ways at different stages and in different spheres of state and society development, and accordingly, its consequences are also different. It contributes to the moral and ethical degradation of society's members and undermines confidence in the authorities and the main processes of state development. Civil servants are involved in corrupt transactions, which naturally become potential targets for foreign counterintelligence services and thus pose a severe threat to national security.

The study object is the world's experience in fighting corruption and corruption offences and their implementation in Ukraine.

The study aims to research foreign experience in the fight against corruption and corruption offences to highlight best practices and further implement the relevant norms in domestic legislation.

To achieve this goal, you must complete the following tasks:

– investigate the content content of the category "corruption";
– analyse the world experience of rationing anti-corruption measures;
– identify critical factors in the fight against corruption and corruption offences.

The article summarises:

- the existing doctrinal and normative sources regarding the purpose and principles of legal responsibility;
- the synthesis method is to determine the essence of corruption and corruption offences;
- the comparative method is to study the criminal legislation for criminal offences of other countries for the existence of legal norms to combat corruption;
- the generalisation method is to summarise the results of the study.

Such scientists as I.Y. Grishova (*2015*), S.S. Zadvornykh (*2015*), O.V. Zinchenko (*2013*), T.V. Ilienko (*2012*), M.V. Kikalivshvili (*2019*), O.I. Kozinets (*2019*), I.V. Korulya and V.A. Prikhodko (*2014*), I.O. Roshchina (*2020*), V.M. Trepak (*2015*), D.Yu. Chernikov (*2015*), O.M. Khalkovsky (*2011*), Ya.Yu. Shvydkiy (*2020*) studied the issue of the essence and ways to fight corruption. Analysis of sources and publications shows that corruption is studied by specialists in various fields of science who suggest ways to counteract this negative phenomenon. However, the anti-corruption legislation of different countries, the changes in society, and the high level of corruption and criminal offences in Ukraine make it necessary for the further scientific development of this problem.

The results of the study

Corruption is a criminal offence in politics and Public Administration, which consists of abuse of an official position for personal enrichment (Latin "corruption" is damage, bribery). This is not only a problem of the modern world but also one of the oldest criminal offences, which remains relevant in any era and poses a significant problem for any state. The laws of Hammurabi also provided punishment for bribery. The corruption problem has become particularly relevant with the advent of government bodies. Charles Montesquieu noted that "it is already known from centuries of experience that any person endowed with power tends to abuse it, and he follows this path until he reaches the limit assigned to him" (*Kikalishvili, 2019*). This problem not only did not lose its relevance but also gained new opportunities and expanded the scope of its application, ultimately contributing to the fall of such powerful empires as the Roman, Ottoman, Spanish and French.

Corruption at the highest levels of government poses a serious threat to state sovereignty, destroying all democratic and social institutions. It also leads to a significant violation of the rule of law, which can eventually cause constitutional collapse. Therefore, the fight against corruption should be one of the highest state priorities. Reducing and ideally eliminating corruption is a necessary task.

An effective fight against corruption requires three key factors: political will, public support, and proper implementation of the internal policies of state structures. The first legislative act that contained these principles was the French Declaration of Human and Civil Rights of 1789 (*Zinchenko, 2013*). In particular, Article XV of this declaration states: "The company has the right to demand a report from any civil servant for the area of management entrusted to him." At the same time, the leading international documents of a normative and criminal nature do not provide an exact definition of corruption but list corruption offences subject to criminalisation.

The Strasbourg Convention on criminal liability for corruption (1999) defines specific measures for the national level in the fight against corruption. It covers the bribery of civil servants, including international judges, and granting intangible benefits in exchange for undue benefits. In addition, the convention criminalises corruption among civil servants who knowingly accept or offer illegal benefits to themselves or others. The convention's text also criminalises abuse of influence for profit, similar to mediation in corruption schemes and money laundering obtained by criminal means in accounting. The Strasbourg Convention provides a broader list of corruption offences and definitions than national legislation and provides for criminal liability for legal entities for corruption offences. Other necessary international instruments, such as the European Union Convention on Civil Liability for Corruption and the UN Convention against organised transnational criminal offences, also propose measures to criminalise corruption offences. However, they do not establish special liability for civil servants for preparing extortion or obtaining illegal benefits, leaving these issues to the discretion of member states (*Trepak, 2015*).

When planning methods to combat corruption offences, it is crucial to consider the causes of their occurrence and latent factors caused by both objective and subjective reasons. The socio-political environment of the state, including low salaries and high taxes, is a significant factor in the spread of corruption. Different countries use different methods to fight corruption, and the results vary: some countries succeed at minimal cost, while others do not have significant results despite significant resources.

From the point of view of criminal law, in the legislation, the term "corruption" is not singled out as a separate criminal wrongful act but is a collective concept that covers various types of official offences, such as abuse of office and obtaining illegal benefits. The same concept is reflected in the UN documents on the international fight against corruption, including undue profit, nepotism and embezzlement of public funds (*United Nations Convention…, 2007*). Therefore, it is necessary to strengthen the fight against criminal offences that contribute to the development of corruption. Corruption actors include civil servants and other persons who intend to benefit.

The new approach to the definition of corruption confirms that the international community does not identify corruption only with undue profit and bribery of public and private officials. Corruption is a transaction between a person who provides an illegal benefit and one who receives it. The European Commission provides a broader definition of corruption, including not only undue benefit from officials of various sectors, independent agents and individuals with different statuses but also any illegal act that violates official duties and is aimed at obtaining illegal benefit for an individual or third party (*Zadvornykh, 2015*).

According to Article 1 of the law of Ukraine of 14.10.2014, "On Prevention of Corruption", corruption is "the use of official powers or opportunities by a person specified in part one of Article 3 to obtain undue benefits for himself or others. This also includes accepting or offering such a benefit and promising to receive it. Corruption covers cases where a person offers or attempts to provide undue benefits to influence official decisions. An undue benefit is any money or other property, services, benefits or benefits offered, provided or received without legal grounds" (*On Preventing Corruption, 2014*). According to the Criminal Code of Ukraine, corruption offences are offences committed by abusing their official position to obtain illegal

benefits. These may include actions related to misappropriation or embezzlement of property, bribery, abuse of power, misuse of budget funds, and violation of the rules and regulations governing the circulation of various resources and services. Corruption offences also include taking illegal benefits and abuse of influence, performed directly by officials or through bribery or fraud. they include a wide range of offences related to abuse of official position. This covers offences under such articles as misappropriation or embezzlement of property (Art. 191), theft of weapons or narcotic drugs (Art. 262, 308, 312, 313), violation of the rules of drug trafficking (Art. 320), and other similar actions. Corruption criminal offences are also considered misuse of budget funds (Art. 210), bribery of employees (Art. 354), abuse of power or official position (Art. 364, 3641, 3652), acceptance of illegal benefits (Article 368), illegal enrichment (Art. 3682), and abuse of influence (Art. 369, 3692). The jurisdiction of these criminal offences is determined depending on the nature of the offence. It is divided between the National Police and the National Anti-Corruption Bureau of Ukraine (*Criminal Code of Ukraine, 2001*).

The Criminal Code defines liability for corrupt transactions and criminal offences in Georgia. Article 339 of the Criminal Code of Georgia provides penalties for providing undue benefits, including promises or provision of money, securities, other property or illegal benefits to officials. Changes in the legislation have increased the penalty for providing illegal benefits from two to three years in prison. The concept of "influence trafficking" was also introduced, defined as a criminal offence, a promise or offer of illegal benefits to influence an official's decisions. In Georgia, the concept of "influence trafficking" is defined as a criminal offence involving a promise, offer or provision of illegal benefits in order to influence the decisions of an official or person performing public functions. This concept includes cases where any form of benefits, whether tangible (money, securities, property) or intangible (influence, support), are offered or promised in order to influence a person's decisions within the limits of their official duties (*Kikalishvili, 2019*). The legislation of Georgia provides for the punishment of such an offence in the form of fines, restriction of liberty or deprivation of Liberty, depending on the gravity of the offence and the specific circumstances of the case, thus contributing to the fight against practices that harm integrity and transparency in the public sector. The amendments to the new law on civil service are aimed at modernising the public sector and introducing innovative approaches. A model for monitoring declarations of official property status was introduced. In October 2015, the Georgian parliament adopted a draft law on amendments to the law on incompatibility of interests and corruption in the civil service. An automatic human resource management system has been implemented in 18 ministries. In April 2015, the Georgian government approved the updated anti-corruption strategy and action plan for 2015-2016. The Anti-corruption Council approved the assessment and monitoring methodology in February 2015. International organisations rated Georgia's progress as positive in 14 15 recommendations (*Korulya, 2014*).

In countries like Georgia, criminal legislation does not define corruption as a separate criminal offence. For example, in Italy, despite the detailed regulation of penalties for bribing officials, no criminal offence is defined as corruption. The Italian Criminal Code provides liability for obtaining undue benefits and incitement to do so, distinguishing between these actions and applying different penalties.

Ukraine, focusing on European integration and facing the transnational nature of corruption, should adhere to international standards and practices to combat this phenomenon when developing anti-corruption legislation. It is significant not only to formally integrate international legal norms into national legislation but also to master the methodology, concepts and approaches to solving the problem of corruption and develop effective ways to implement international standards in national practice. An effective fight against corruption requires a global approach. That is why in the last decades of the 20th century, UN bodies, particularly the General Assembly and specialised agencies, began to actively work on forming an international consensus on the recognition of corruption as a criminal offence of an international nature. This includes concluding multilateral international treaties and facilitating countries' collective efforts to fight corruption at the global level (*Roshchina, 2022*).

Many countries, such as Austria, the Czech Republic, and Sweden, do not have separate laws dedicated exclusively to the fight against corruption. On the other hand, corruption issues are regulated through various legislative acts and specific provisions of criminal law. The activities of public authorities in these countries are often based on standard criminal codes or carried out within the framework of international cooperation, for example, with Interpol and Europol. For example, in Finland, the Anti-Corruption System includes detailed rules in the Criminal Code, where corruption acts are punishable by fines or up to four years in prison. In Finland, corruption acts are often qualified not as criminal offences but as administrative offences, and criminal liability occurs only in cases of particular severity of violations (*Chernikov, 2015*). This approach demonstrates that the fight against corruption can be effective through individual laws, integrating anti-corruption norms into the general legal context, and close cooperation with international organisations.

Let us talk about the results of Georgia's anti-corruption policy. It can be an example of a successful fight against corruption, which has attracted widespread attention inside and outside the country. During the 1990s crisis that engulfed post-Soviet countries, Georgia, like other states, faced increased corruption. Government positions became the subject of trade, which led to the flourishing of criminal business and corruption. The lack of political will, low officials' salaries, and non-compliance with legal structures and new realities have created favourable conditions for corruption development. Since the early 2000s, Georgia has embarked on significant reforms, including controlling employees' income, reforming the police, tax and customs system, liberalising the economy, and reforming the judicial system. These changes have made significant progress: the country has risen in the corruption ranking from 110th place in 2004 to 51st place in 2012. The number of people convicted of corruption offences increased by 300%. The main conditions for the success of Georgian reforms are the restriction of state functions and the manifestation of political will. An active civil sector plays a significant role in the process, which helps maintain trust in government agencies and ensure participation in the development of state projects. The main conditions for the success of the Georgian government in the fight against corruption were due to two key factors: the reduction of the state's role in the economy and the manifestation of strong political will. Georgia has achieved significant results thanks to the reduction of state intervention in economic processes and radical reform of the state apparatus. An important aspect was the implementation of comprehensive reforms, such as the privatisation of state property, the modernisation of the tax and customs systems,

and the creation of Free Economic Zones. This has significantly improved the investment climate and stimulated the development of the private sector.

However, the success of anti-corruption measures in Georgia was made possible by state policy changes and civil society's active role. Supporting the civil sector and ensuring transparency in governance are critical to achieving lasting results. Civil society, which should actively participate in policy-making and the implementation of significant projects, should ensure control over the activities of state bodies and support politicians aimed at increasing confidence in the state. This interaction contributes to the formation of effective coalitions and support for anti-corruption initiatives, which makes Georgia a valuable experience for other countries, including Ukraine (*Khalkovsky, 2011*).

The primary anti-corruption strategy in Germany is to destroy criminal groups' material base, particularly their financial resources. This is achieved by confiscating property and creating a legal environment that makes it impossible to launder funds obtained by criminally illegal means. A significant part of Germany's anti-corruption strategy is maintaining a register of companies involved in corruption, which prohibits them from participating in public procurement and attracts close attention from law enforcement agencies.

The UK has a rather complex and extensive system of anti-corruption legislation. National norms concerning corruption offences are not concentrated in one code or act but distributed among legal documents, including criminal and other branches of law. This makes it difficult for law enforcement agencies to apply the law. The UK Home Office has developed an anti-corruption bill to address these concerns. This new bill summarises pre-existing anti-corruption legislation, including provisions that eliminate parliamentary immunity from liability for corruption. This means that even high-ranking officials can now be held accountable for corruption, which previously could have been complicated by their privileges. The UK also has an effective mechanism for administrative control over the activities of civil servants. Although the country is considered one of the least corrupt compared to other states, especially developing countries, this does not mean that the system does not need to be constantly improved. In British law, corruption is defined rather narrowly, covering only practices related to obtaining illegal benefits in exchange for favourable solutions. The UK is constantly improving its anti-corruption measures, responding to new challenges and adapting them to changes in international practice. This flexibility and adaptability contribute to maintaining high transparency and integrity in public administration and business (*Ilienok, 2012*).

Singapore is another striking example of a fight against corruption based on well-defined principles. The first principle is to minimise opportunities for officials to act on their initiative. This is achieved by simplifying decision-making procedures and reducing the many signatures required for document approval. The country has created a transparent and understandable legal system without the possibility of double interpretation of laws, eliminating unnecessary administrative barriers and simplifying economic development conditions. The second principle includes unconditional punishment for corruption. For this purpose, a specialised body was created in Singapore – the Bureau. It investigated corruption in the highest-power echelons. The head of this bureau reports directly to the prime minister, which guarantees the independence and transparency of investigations, and any external interference in the process is impossible. The third principle focuses on matching officials' salaries to the market level. In

addition, civil servants are required to report annually on their property and assets. Prosecutors have the right to check the bank accounts of persons suspected of corruption, which adds a level of control and prevention of corruption (*Grishova, 2015*). These strategies have become the basis for creating an effective anti-corruption system that ensures high transparency and accountability in governance. They also demonstrate how an integrated approach to fighting corruption can significantly improve the overall situation in the country by providing precise control mechanisms and increasing public confidence in state institutions.

The Netherlands is a prime example of an effective fight against corruption through its approach at the procedural and institutional levels. One of the key measures is to ensure transparency and accountability in corruption issues. The Dutch interior minister reports annually to Parliament on the uncovered corruption cases and the results of their investigation. This approach, which involves openness and discussion of the consequences, helps reduce corruption and increase public confidence in anti-corruption measures. Ukraine should learn from this experience by introducing a similar practice of reporting the Ministry of Internal Affairs to the Verkhovna Rada, contributing to a more transparent and effective fight against corruption (*Shvidky, 2020*). Israel is also demonstrating success in the fight against corruption through multi-stage monitoring. There are government organisations, special police units and a state controller that monitor corruption manifestations regardless of ministries and government departments. They identify potential corruption cases and transmit information for further investigation.

Discussion

The author believes that the punitive function of responsibility cannot be the main one in a democratic society since it will lead to responsibility for the sake of responsibility. Punishing the offender is not an end in itself; the primary purpose of liability is to prevent wrongdoing. Liability rules, including corruption offences, should be part of a system that encourages lawful behaviour. If this goal is not achieved, the second goal of liability is to correct the person who committed the offence. Therefore, the humanisation and individualisation of legal responsibility, especially in corruption offences, should be a trend of legal regulation in a democratic state. To create this positive trend, lawmakers must explain to citizens the importance of humanising responsibility and building their political will based on a strategic vision to overcome corruption rather than meeting changing public demands. The legislator needs to form the political will to introduce and change the forms of responsibility for corruption offences based on a strategic vision, statistical indicators, and expert research, and not just based on public opinion.

Conclusion

Success in the fight against corruption cannot be achieved only by mechanically transferring international norms to the national level. Specific legal measures and tools for their implementation should be adapted to each country's political, economic and socio-cultural development. This involves considering the specifics of local legislation, administrative traditions and economic realities, which can significantly affect the effectiveness of anti-corruption reforms. Countries seeking to achieve actual results in the fight against corruption

should adopt international standards and ensure their effective implementation and adaptation to their specific conditions. This includes developing and supporting an active civil society and increasing the level of accountability of state bodies, like creating a system of control and monitoring to ensure that the announced reforms correspond to fundamental changes. Only an integrated approach that combines international standards with local adaptations can deliver significant and sustainable results in the fight against corruption.

By analysing anti-corruption practices in foreign countries, we can identify several key ways to implement an effective anti-corruption strategy in Ukraine.

(1) Develop a strong political will to fight corruption by providing support from senior officials and developing a comprehensive public policy that includes legal, economic, and social measures. This policy should provide for criminal sanctions for corruption, clearly defined elements of criminal offences, and effective mechanisms for criminal prosecution.

(2) Activate civil society in monitoring the activities of state bodies and ensuring transparency. This includes allowing citizens to initiate criminal cases against officials suspected of corruption. An effective mechanism to investigate such cases, including independent investigating authorities and courts, is needed.

(3) Guarantee the judicial system's independence and integrity, critical to ensuring a fair hearing of criminal cases. For this purpose, an independent mechanism for monitoring the judicial system should be introduced, including the involvement of international experts.

(4) To improve criminal legislation, including the definition of clear criminal elements for various types of corruption offences, the celebration of corruption abuses and misconduct, and the provision of strict criminal sanctions for those criminal offences. This includes not only punishment but also confiscation of illegally acquired property.

(5) Ensure fair and transparent governance, simplify bureaucratic procedures, and ensure their transparency. Introduce fair tax and social systems that reduce the need for corruption schemes.

(6) Establishing high standards of ethics for civil servants and conducting regular ethics training is critical to preventing corrupt practices. Ensuring competitive salaries and social guarantees for civil servants is also necessary.

(7) Involve the most independent media and public organisations in the fight against corruption, including ensuring freedom of the press and supporting the media in covering corruption cases. Strengthening legislation and its implementation and increasing the risk of punishment for corrupt officials is necessary to ensure an effective fight against corruption.

(8) Developing economic mechanisms to legally increase civil servants' incomes and developing markets and competition will also help reduce opportunities for corruption. Society's moral and psychological attitude toward intolerance to corruption, educational campaigns, and information about its rights and obligations are significant for forming anti-corruption consciousness.

These measures should contribute to creating an effective anti-corruption system in Ukraine, adapting the positive experience of European countries to Ukrainian realities and ensuring the criminal law aspect of the fight against corruption.

Conflict of interest

The author declares that there is no conflict of interest.

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Anastasiia M. Mernyk [23]

Artificial intelligence as a subject of law: Development prospects [11]

Abstract: The article notes that robots that can recognise objects, perceive and analyse information, make decisions and learn are likely to be able to become aware of their selves. All this causes new legal and ethical problems. Therefore, the legal status of work with artificial intelligence is relevant in modern conditions. Within the framework of the article, the purpose is to study the issue: the need to regulate the status and use of "end" products of artificial intelligence and robotics technologies. The study subject is a set of theoretical and practical issues related to the recognition of artificial intelligence as a subject of law, the analysis of the legal consequences of such recognition and the prospects for developing the corresponding legal regulation. The study object is artificial intelligence as a technology (nature, possibilities, limitations, development rates) and its potential impact on society, like moral and ethical aspects of social life. To aim the study, the author uses a system of methods of scientific knowledge, including general scientific (analysis, synthesis), private (comparative, quantitative and qualitative analysis), and exceptional legal (formal-legal, comparative-legal) methods. The leading researchers studying the mentioned problems are M. Weiner, D. Gudyma, D. Hrytsai, L. Brodbeck, M. Rubenstein and others.

Keywords: artificial intelligence, subject of law, robots, information technologies.

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Анастасія Муслімівна Мерник

Штучний інтелект як суб'єкт права: перспективи розвитку

Анотація: У статті наголошується на тому, що роботи, які матимуть здатність розпізнавати об'єкти, сприймати й аналізувати інформацію, ухвалювати рішення та навчатися, ймовірно, зможуть усвідомити власне «Я». Все це спричиняє нові юридичні й етичні проблеми. Тому питання щодо правового статусу роботу зі штучним інтелектом є актуальним в умовах сучасності. У рамках статті ставиться ціль вивчити питання: необхідності врегулювання статусу та використання «кінцевих» продуктів технологій штучного інтелекту та робототехніки. Предметом дослідження є комплекс теоретичних та практичних питань, пов'язаних з визнанням штучного інтелекту як суб'єкта права, аналіз правових наслідків такого визнання та перспективи розвитку відповідного правового регулювання. Об'єктом дослідження виступає штучний інтелект як технологія (природа, можливості, обмеження, а також темпи розвитку) та його потенційний вплив на суспільство, моральні та етичні аспекти суспільного буття. Для досягнення поставленої мети у роботі використовується система методів наукового пізнання, зокрема загальнонаукові (аналізу, синтезу), приватні (порівняльний, кількісного й якісного аналізу), а також спеціально-юридичні (формально-юридичний, порівняльно-правовий). Основні дослідники, що досліджували зазначену проблематику: М. Вейнер, Д. Гудима, Д. Грицай, Л. Бродбек, М. Рубенштейн та інші.

Ключові слова: штучний інтелект, суб'єкт права, роботи, інформаційні технології.

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Introduction

Developing robotics is closely linked to attempts to create artificial intelligence. Therefore, robots that can recognise objects, perceive and analyse information, make decisions, and learn will probably be able to understand their "I". All this leads to new legal and ethical problems. There is a question about the legal status of working with artificial intelligence. Therefore, this issue is relevant in modern conditions. The subject of the research is the legal regulation of artificial intelligence; the object is artificial intelligence as a technology and its legal regulation in modern legal systems. The study aims to provide a theoretical justification of legal mechanisms that will effectively regulate legal relations arising from the participation of artificial intelligence. The implementation of the goal determines the following tasks to conduct an analytical review of scientific literature studying the issues of artificial intelligence, analyse the international experience of legal regulation of artificial intelligence, identify general trends, determine the criteria that will distinguish artificial intelligence from other objects of legal relations and justify the possibility of granting it the status of a subject of law, develop proposals on the legal status of artificial intelligence, including the definition of its rights and obligations, like responsibility for its actions, and analyse the possible legal consequences of recognising artificial intelligence as a subject of law. To achieve this purpose, the work uses a system of methods of scientific knowledge, in particular general scientific (analysis, synthesis), private (comparative, quantitative and qualitative analysis), and notable legal (formal-legal, comparative-legal).

The results of the study

Today, many countries worldwide are actively working on the problem of the need to regulate the status and use of "final" products of artificial intelligence and robotics technologies. Modern legislation is not ready to actively introduce artificial intelligence technologies and systems into legal practice. As for the legal personality of robotics with artificial intelligence, this discussion continues in the scientific literature. The leading researchers who studied this problem are M. Weiner (*2021*), D. Gudyma (*2009, p. 66*), D. Gritsay (*2019, p. 72*), L. Brodbeck (*2016*), M. Rubenstein (*2014, p. 796*), etc. So, L. Brodbeck and his colleagues emphasise that adaptation of physical forms is a fundamental mechanism that allows biological systems to survive in various environments. Due to evolutionary adaptation, some animals have changed their morphology to live on land rather than underwater (*Moczek et al., 2011, p. 2705*). Modern machines, by contrast, are severely limited by their initial morphological configurations, and the question remains whether machines can achieve a similar level of adaptability by adjusting their morphologies (*Rubenstein et al., 2014, p. 796*).

One of the problems is that humanity still cannot accurately define the boundaries of what it means by the term "artificial intelligence". After all, who or what can or should be called "robots." Gradually, the line between people's abilities and carriers of so-called artificial intelligence is blurred. So, computers have long bypassed the human brain in indexing information and issuing data from memory based on simple queries. Researchers have already developed a machine that can learn and perform better than humans on intelligence quotient tests. Moreover, Microsoft specialists and scientists from the University of Science and Technology of China plan to give the machine the same thinking abilities humans have (*Wehner, 2021*). However, remember that computers have long outstripped the human mind when

indexing information and calling data based on simple queries. However, the soft processors inside our skulls have always had the upper hand regarding verbal reasoning and complex language problems. Scientists from the University of Hanover proposed to create a "nervous system" for robots that will allow them to feel pain. Regardless of whether a particular state invests resources in creation or supports the scientific search for artificial intelligence, it is obliged to predict the possible consequences of the development of robotics and use, in particular, legal means to determine the "rules of the game" in the relationship of people with such robots.

Therefore, the scientific community is interested in discussing the legal and moral aspects of the existence and activity of "artificial beings" in the world, like their rights and obligations concerning people and among themselves. Of interest are, in particular, the issues of the legal status of "smart machines", like responsibility for their failure and the negative consequences caused by them.

Discussion

The robotics industry and the development of information technologies are taking on unprecedented proportions today. If earlier robots and robotic equipment could only be found in factories and laboratories, now representatives of artificial intelligence appear everywhere in human life: in hospitals, on the roads, in offices and even at home. The man was at the centre of the robotics revolution. Robots surround us everywhere. Someone sees them as a carefree and comfortable future for humanity and someone – a threat to the existence of civilisation. Remember the 2020 Movie "Rise of the Robots" (artificial intelligence vs. humans).

Did you know that in 2021, robots "celebrate" their 100th anniversary? It was in 1921 that Karel Chapek, a Czech writer, coined the word "robot". Moreover, in 1942, the American writer Isaac Asimov, in the story "Round Dance", formulated 3 Laws of robotics. First, a robot cannot harm a person or, by its inaction, allow a person to be harmed. Secondly, the robot must obey all orders that a person gives, except in cases when these orders contradict 1 law, and thirdly, the robot must take care of its safety to the extent that it does not contradict 1 or 2 laws.

Well-known companies specialising in the development of artificial intelligence are now investing in creating so-called human assistants.

As we know from forecasts in robotics, in 2022, artificial intelligence will reach the level of human mental abilities by 10%, somewhere in 2040 – by 50%. After 2070, the robot's thinking will not be distinguishable from a human's. That is, robots endowed with artificial intelligence at the level of human intelligence will be able to understand the significance of their actions and will be able to control them. Therefore, if robots gradually become on the same level as humans in their development, they will be able to have rights and obligations. This raises the question: Do I need to grant robots rights? Let us think about it.

If the behaviour of so-called deterministic robots can be programmed and controlled, then cognitive robots are capable of perception, using language, interacting and solving problems, learning and creativity. Such robots' decisions are unpredictable, and actions depend on the experience gained and random conditions. Such actions can affect people's behaviour and lead to social and cultural changes, which can be both positive and negative. This is where the issues of security, privacy and protection of a person's dignity arise. Moreover, who will be responsible

for such actions, the developer or user of a specific robotics object or artificial intelligence that is self-aware?

Cognitive robots with artificial intelligence of the human level and above can be self-aware. They will defend their rights, so to speak. Which ones? And at least for existence. Who would want people to take it apart for "spare parts", turn it off at any time, and throw it away? There is a threat of confrontation between people and their equal intelligence or even more intelligent creatures (robots). Moreover, the forecast of such a confrontation for humanity can be pretty tragic.

Of course, you can prevent the development of such a scenario. To do this, you need to program robots so that they do not have the appropriate intentions and set their artificial intelligence below the level of human intelligence. However, despite the pace of robotics development, companies' interest in creating a high-quality product, and competition, humanity is unlikely to implement this option.

Therefore, we may need another way to regulate such a confrontation. One of the options for ensuring the coexistence of humans and robots can be to grant robots the status of subjects of Civil Relations, which will be endowed with appropriate rights and obligations. When determining the scope of rights and obligations of robots, you need to consider the purpose for which the corresponding robots will be created. In other words, the legal capacity of robots at the initial stage will be special. Gradually, the set of rights and obligations of robots will be compared with those that previously belonged only to humans. Moreover, of course, the leading rights of robots should be the right to existence (life) and personal inviolability. However, among the responsibilities that robots should rely on, they are worth obligating to compensate for the damage they cause.

We are not talking about programmed hardware but about the mass use of self-aware robots. Perhaps now, we seem to be on the verge of understanding the script of some science fiction film. However, let us turn to world practice.

Discussion

Considering the legal status of robots in the future, as soon as the robot has an awareness of the subjective "I" when it can independently make decisions and give itself orders, from that moment on, this robot must bear some responsibility for the decisions it makes. On February 16, 2017, the European Parliament approved a resolution of the European Parliament with recommendations of the Civil Law Commission on robotics (*European Parliament…, 2019*). The resolution notes that the current trend is to develop intelligent and autonomous machines to learn and make their own decisions in the long run. This creates economic benefits and many problems regarding artificial intelligence's direct and indirect impact on society. The document emphasises that there is a possibility that, in the long run, artificial intelligence will surpass human intellectual capabilities. The European Parliament, in particular, proposed recognising robots as "electronic persons" and creating a European agency for robotics and artificial intelligence, which will conduct technical and ethical examinations of robots.

Determining the legal status of "smart robots" is still quite challenging. However, we can already predict that robots will still be able to become subjects of law when they have artificial intelligence on par with human intelligence: they will have the ability to recognise objects,

perceive and analyse information, make decisions and learn. However, if attempts at any such definition are avoided, serious enforcement problems may arise over time. Recall the work of Sofia, who was granted citizenship in Saudi Arabia (*Alloway, 2017*); it is hardly possible to define what causes legal uncertainty clearly). Ravina Shamdasani, a spokeswoman for the Office of the United Nations High Commissioner for Human Rights, expressed that if the Universal Declaration of Human Rights says that all people are born free and equal, then a robot can be a citizen, but not a human.

The European Union proposes to create a European agency for artificial intelligence, introduce a legal definition of the concept of "smart autonomous robot", introduce new rules for reporting companies on the development of robots, and adopt insurance rules for companies in case their work causes harm.

After analysing the research of scientists devoted to the problem of legal status, namely, determining the legal personality of robots with artificial intelligence in our time, we can conclude that the norms of civil law can regulate their role, Place and status. The legal basis is Article 177 of the Civil Code of Ukraine (*2003*), which defines the types of objects of civil rights. The list of objects is not exhaustive and is subject to an expanded interpretation. Accordingly, we conclude that today, the legal status of robots is regulated by the provisions on objects of civil rights. The Civil Code of Ukraine and other acts of civil legislation of Ukraine do not contain the concept of "robot" or "artificial intelligence", and therefore, for further definition and specification of the legal status of a robot as an object of legal relations, it is necessary to apply by analogy the norms that relate to objects of civil rights, based on the definition's "work", "artificial intelligence", formulated in the scientific literature. In particular, today, the status of work most corresponds to the provision of Article 1187 of the Civil Code of Ukraine, which defines that the source of increased danger is activities related to the use, storage or maintenance of vehicles, mechanisms and equipment, creating an increased danger for the person who carries out this activity, and other persons.

Of course, giving robots the status of subjects of civil legal relations will satisfy the interests of robots with self-awareness. There is no practical need to grant this status to robots that are not self-aware. Thus, whether robots whose artificial intelligence is at the level of human intelligence or higher should have rights remains a rhetorical question of the future.

Conclusion

If natural beings are capable of evolution, we can assume by analogy a similar evolutionary adaptation to life and artificial intelligence (*Bongard, 2013, p. 74*). Joint optimisation of the body and mind has already been demonstrated by scientists using simulations of the evolution of virtual animal-like creatures (*Bongard, 2011, p. 1234*). At the same time, we live in a time when robotics has become an integral part of the life of each of us. it is worth agreeing that science is progressing in the 21st century. At this stage of development, robots gradually leave the places of their creation, various factories and laboratories, and become part of our everyday life. Moreover, of course, the day will come when robots will become not just created devices but also members of society.

It is significant to understand that technical sciences divide robots into several categories: robots that perform only the same type of primitive actions aimed at meeting human household

needs (e.g., robot vacuum cleaners), the second category includes robots that can analyse and evaluate the environment and partially adjust their actions to the nature of such an environment (combat robots), and the last category consist of robots endowed with artificial intelligence, which is understood as the technology of creating computer programmes that work and systematically learn, accumulate experience, they collect information, can analyse and evaluate environmental conditions and apply the accumulated knowledge in everyday life. Artificial intelligence, according to many experts, is a set of complex mechanisms that are designed to solve problems to bring benefits and help to humans; at the same time, the concept of artificial intelligence and a robot are not identical: a robot is a kind of shell of artificial intelligence, which sometimes has the shape of a human body, but artificial intelligence is a computer inside a robot.

Summing up, it is worth noting that there are lively discussions around the legal regulation of the creation and operation of artificial intelligence; interested states, individual scientists and developers of artificial intelligence, however, express different positions on the further regulation of artificial intelligence activities. So, some scientists and lawyers believe that artificial intelligence should get rights for many signs, such as the ability to think independently and analyse information, the ability to self-develop, the ability to make independent decisions, etc. Despite this, it can be argued that such positions today remain a minority. The dominant opinion is still about the responsibility of owners or developers of artificial intelligence for the damage caused by the latter (it can be assumed that the prevalence of this opinion is caused by the lack of awareness of legal experts in the technical aspects of artificial intelligence activities, which causes distrust of the latter). Also, in the scientific literature at the moment, there is not even a clear understanding of the terminological apparatus – the most repeated are the concepts of "electronic person" and "digital person", and the category of "persons" itself gives grounds to discuss the subjectivity of artificial intelligence, because traditionally individuals are called subjects – which indicates that science has not developed the question of the legal personality of mechanisms that have artificial intelligence.

Conflict of interest
The authors declare that there is no conflict of interest.

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European Scientific e-Journal

EU, Czech Republic, Ostrava