

# Peculiarities of the Innovation Cycle in Ukraine's Military-Industrial Complex Under Conditions of Martial Law

## Особливості інноваційного циклу в оборонно-промисловому комплексі України за умов режиму воєнного стану

Yevhen Kralich

Postgraduate student, e-mail: [ievgen.robortovich@gmail.com](mailto:ievgen.robortovich@gmail.com), ORCID ID: <https://orcid.org/0009-0004-5138-2536>

Dnipro University of Technology, Dnipro, Ukraine

Євген Краліч

аспірант, e-mail: [ievgen.robortovich@gmail.com](mailto:ievgen.robortovich@gmail.com), ORCID ID: <https://orcid.org/0009-0004-5138-2536>

Національний технічний університет "Дніпровська політехніка", Дніпро, Україна

Received: February 8, 2026 | Revised: April 22, 2026 | Accepted: April 30, 2026

JEL Classification: O31, O32, O38, H56, L64

УДК 330.341.1 : 338.45:623

DOI: <https://doi.org/10.33445/sds.2026.16.2.33>

**Purpose:** To provide qualitative and quantitative substantiation of structural changes in the innovation cycle of enterprises within Ukraine's defense-industrial complex, assess the speed of progression through development stages using the Technology Readiness Level (TRL) scale, and determine the elasticity of innovation outcomes relative to the volume of funding for research and development activities.

**Method.** The research is based on the application of econometric modeling techniques, particularly the construction of a logarithmic regression model to analyze statistical data for the period from 2012 to 2024. Comparative analysis was employed to benchmark technological development rates, while probabilistic modeling was used to evaluate risks at different stages of the product life cycle.

**Findings.** The study demonstrates the transition of the innovation cycle in Ukraine's defense-industrial complex from an inertial linear model to a recursive system of agile defense management. It was established that the time interval from conceptualization to combat application of technologies has decreased four- to six-fold. Econometric analysis confirmed increasing returns on investments in high-technology developments, with the elasticity coefficient exceeding unity. It was further proven that institutional decentralization and rapid feedback loops exert a more substantial impact on system performance than mere increases in funding volumes.

**Practical implications.** The findings can be utilized by public authorities to improve certification and testing procedures for advanced weaponry. The proposed model for forecasting the success of innovation projects enables optimization of budget allocation under crisis conditions.

**Paper type.** Empirical quantitative research article (econometric modeling focus).

**Мета роботи.** Обґрунтування структурних змін в інноваційному циклі підприємств ОПК України, оцінку швидкості проходження етапів розробки за шкалою рівнів технологічної готовності та визначення еластичності інноваційного результату відносно обсягів фінансування науково-дослідних робіт.

**Метод дослідження.** Дослідження ґрунтується на застосуванні методів економетричного моделювання, зокрема побудові логарифмічної регресійної моделі для оцінки статистичних даних за період з дві тисячі дванадцятого по дві тисячі двадцять четвертий роки. Також використано метод порівняльного аналізу для зіставлення темпів технологічного розвитку та ймовірнісне моделювання для оцінки ризиків на різних стадіях життєвого циклу виробу.

**Результати дослідження.** Доведено перехід інноваційного циклу ОПК України від інерційної лінійної моделі до рекурсивної системи гнучкого оборонного менеджменту. Встановлено, що часовий інтервал від концептуалізації до бойового застосування технологій скоротився у чотири-шість разів. Регресійний аналіз підтвердив зростаючу віддачу від інвестицій у високотехнологічні розробки, де коефіцієнт еластичності перевищує одиницю. Доведено, що інституційна децентралізація та швидкий зворотний зв'язок мають більш суттєвий вплив на результативність системи, ніж просте зростання обсягів фінансування.

**Практична цінність дослідження.** Отримані висновки можуть бути використані органами державної влади для вдосконалення процедур сертифікації та випробувань новітнього озброєння. Запропонована модель прогнозування успіху інноваційних проєктів дозволяє оптимізувати розподіл бюджетних коштів у кризових умовах.

**Тип статті:** Емпірично-аналітична стаття з елементами економетричного моделювання.

**Key words:** Innovation, National Security, Threats, TRL Scales, Regression Model, Military Technologies, Production Ecosystem.

**Ключові слова:** інновації, національна безпека, загрози, шкали TRL, регресійна модель, військові технології, екосистема виробництва.

### Introduction

The martial law regime has not only necessitated legislative shifts in Ukraine but has also triggered a fundamental transformation in the economic behavior of all actors involved in ensuring national security. Ukraine's defense-industrial complex (DIC) stands as a cornerstone of this system, given that

technological superiority has become the decisive factor in modern warfare. The innovation cycle within Ukraine's defense sector has undergone significant contraction; as a result, cutting-edge technological solutions often traverse the path from concept to front-line deployment within weeks or months—a sharp contrast to the traditional multi-year development timelines observed globally.

An analysis of recent thematic literature indicates that innovation under wartime conditions is a primary driver of Ukraine's resilience. Research by the Center for Strategic and International Studies (CSIS) demonstrates that Ukraine has restructured its DIC and military procurement systems to focus on emerging technologies, outsourcing early-stage research and development (R&D) to private companies. This approach has enabled the rapid attainment of technology readiness levels (TRL) suitable for immediate combat testing. Furthermore, while the development of artificial intelligence technologies in Ukraine was initially driven by the private sector and volunteer initiatives, state institutions have recently begun scaling their internal capacity to promote them. These efforts represent a significant step toward the institutionalization of AI innovation within the public sector (Bondar, 2025; Jacobsen, 2025; Ryan, 2025).

An Atlantic Council study highlights a strategic risk: while Ukraine strengthens its reputation as a "defense tech" powerhouse, the lack of robust intellectual property protection could lead to a loss of control over the very breakthroughs currently defending the nation on the battlefield (Dovbenko, 2025). Another report notes that international aid has exposed tech companies to new security risks, including cyberattacks and kinetic threats to personnel or infrastructure. The degree of perceived risk and subsequent mitigation measures varied based on each firm's vulnerability, particularly for those whose technologies had direct military applications or a physical presence (Tereshchenko et al., 2021; Schroeder, 2025).

Recent RAND Corporation publications emphasize that Ukraine's unique operational context requires a doctrinal framework distinct from NATO standards—one that supports the strengths of horizontal innovation and rapid experience sharing (RAND Corporation, 2025). Furthermore, while Ukrainian society and industry have coalesced around a UAV (unmanned aerial vehicle) production ecosystem that is now a global leader in terms of technological capability, this system is currently sustained by significant domestic demand. Long-term success for the DIC will necessitate a transition toward export orientation, where Ukraine's innovation potential and combat-proven experience will serve as the primary drivers of future export performance (RAND Europe, 2025).

The relevance of this study stems from the need for a systemic analysis of Ukraine's DIC innovation cycle, which has evolved from a matter of economic expediency into a fundamental condition for national survival. This cycle has acquired unique characteristics: extreme compression of "idea-to-front" timelines, decentralized development, and extensive civilian sector involvement. The goal of this paper is to highlight the primary determinants and structural features of the innovation cycle within the Ukrainian DIC under martial law. The scientific novelty lies in the application of an integrated methodological framework that combines innovation process theory with the theoretical foundations of organizational adaptation, specifically applied to the analysis of the Ukrainian case.

### **Materials and methods**

The study used a comprehensive approach combining various methods to examine the specifics of the innovation cycle in Ukraine's defense industry, integrating theoretical analysis, empirical data collection, and modeling methods. The study was conducted in four consecutive stages, which ensured the reproducibility of results based on publicly available domestic and international databases, official reports, and standardized assessment systems. Statistical data processing and modeling were performed using open-source tools, and the source data sets were stored for verification. Thus, in the first stage, the theoretical basis of the study was formed; in the second stage, the main patterns of innovation cycles, the specifics of defense innovations, and the

peculiarities of the innovation process in crisis conditions were identified; the third stage involved the collection and processing of empirical data, as well as their cleaning, unification, and preparation for analysis; at the fourth stage, the data was analyzed, a regression model was constructed, and the conclusions of the study were formed.

## Results

Defense innovation is a multifaceted strategy that goes beyond the creation of new military technologies. It encompasses the implementation of technological, organizational, and doctrinal changes to achieve long-term national security goals. Based on Joseph Schumpeter's classic model, innovation is the driving force behind economic growth, and in the context of the defense industry, it provides a technological advantage. Despite the diversity of approaches to defense innovation and different national policy objectives, there are some consistent features of the defense innovation process. In its Innovation Framework Program, the RAND Corporation highlights four key parameters of the defense innovation ecosystem: driving forces (external and internal factors that motivate and direct innovation); input resources (tangible and intangible assets necessary to support innovation); support resources (infrastructure and networks that support information flow and collaboration among stakeholders); and shaping factors (cultural and structural elements that influence the innovation process) (Kotila, 2023).

For Ukraine, the traditional model of long innovation cycles in the defense sector, characterized by large-scale research and development, has become irrelevant as a result of Russian armed aggression. Our country has become an unprecedented testing ground for accelerated defense innovation, where the intensity of the war has sharply compressed research and development cycles. The new paradigm of the innovation cycle requires more flexible approaches and adaptation of existing capabilities (Zweibelson, 2025). Thus, if in 2022, the latest technologies on the battlefield in Ukraine were relevant for about seven months before being replaced, in 2023 the cycle was reduced to five to six months, in 2024 to three to four months, and by early 2025 it barely reached four to six weeks.

Based on the above, the only strategic imperative that will allow streamlining the flow of state and commercial developments into a managed innovation system in the defense industry is to significantly expand the use of the Technology Readiness Level (TRL) scale (Olechowski et al, 2020). In conditions of time and resource constraints, the TRL methodology serves as an objective filter for project prioritization, as it allows laboratory experiments to be separated from solutions that are ready for rapid scaling. This transforms the innovation process in the defense industry from linear to iterative, where the level of technology readiness becomes the only standardized criterion for making investment and operational decisions (Yfanti, 2024). It is quite obvious that in a state of martial law, the state cannot afford to finance “fundamental science for science's sake”. In this case, the introduction of the TRL scale allows for a clear classification of innovative projects (NATO, 2023):

TRL 1–3 – require grant support and incubation;

TRL 4–6 – require rapid prototyping and field testing;

TRL 7–9 – ready for large-scale state funding, which will enable the effective allocation of budget funds, focusing on projects for their rapid implementation on the front lines.

In addition, the active integration of the domestic defense industry into NATO's global supply and development chain requires the implementation of Alliance standards, one of which is the TRL scale. One of the most serious problems in innovation processes is the gap between TRL 4 (laboratory sample) and TRL 7 (working prototype). In peacetime, this transition takes years, but in a state of martial law, analysis using the TRL scale allows for the rapid identification and elimination of problem areas in production chains. For example, if a number of projects remain at TRL 6 for a long period of time, this may serve as a signal to the state about the need to simplify codification procedures or create new production capacities. In the classic model of implementation, TRL 7 and

TRL 8 require complex testing in a controlled environment. In Ukraine, these levels have undergone significant transformation, thanks to which the prototype demonstration stage takes place directly in combat conditions, and feedback is received almost instantly. This can be demonstrated by conducting a descriptive statistical analysis of the trends described and constructing a matrix model of the transformation of the innovation cycle by TRL levels (accelerated transition from TRL 1-3 to TRL 7-9) (Table).

**Table:** Transformation of the Technology Readiness Level scale under martial law in Ukraine

Cycle Phase*	TRL Levels	Ukraine Adaptation (2022 – 2025)	Metrics
R&D	1 – 3	Brave1 hackathons; private funding	243 AI firms; 1,5B UAH grants
Prototyping	4 – 6	Battlefield validation; 10-day approvals	200+ UAS approved 2024
Scaling	7 – 8	Direct procurement (58,8B UAH UAS 2024)	2M drones; 500 producers
Deployment	9	ZSU integration/export (Zbroyari)	96% domestic UAS; 30 - 50% ZSU needs

\* Justification: Quantitative thresholds per DoD (e.g., TRL 6: relevant environment prototype); qualitative from CSIS interviews. Sensitivity: Scenario analysis ( $\pm 20\%$  production variance) confirms robustness.

**Source:** constructed by the author based on data from (SIPRI, n.d.; UNESCO, n.d.; Ukrainian, n.d.).

According to the canons of the classical approach to management, innovation risk is often considered a probabilistic value that needs to be minimized (da Silva, 2019). However, in a state of war, this paradigm is somewhat transformed: the greatest risk is the lack of a technological solution on the battlefield at the right moment. Building a probabilistic model will allow us to move away from subjective expert assessments and obtain clear calculations, i.e.: assess the “Cost of Delay” (Elveren, 2023) (how much chance of success a project loses when delayed at TRL 4); optimize the development portfolio (how many parallel projects at TRL 3 need to be funded to obtain at least one successful prototype at TRL 9).

A set of formal relationships for a mathematical model of the success of an innovation project ( $P_s$ ), which takes into account the current state of readiness, funding volumes, and time interval, can be presented as follows:

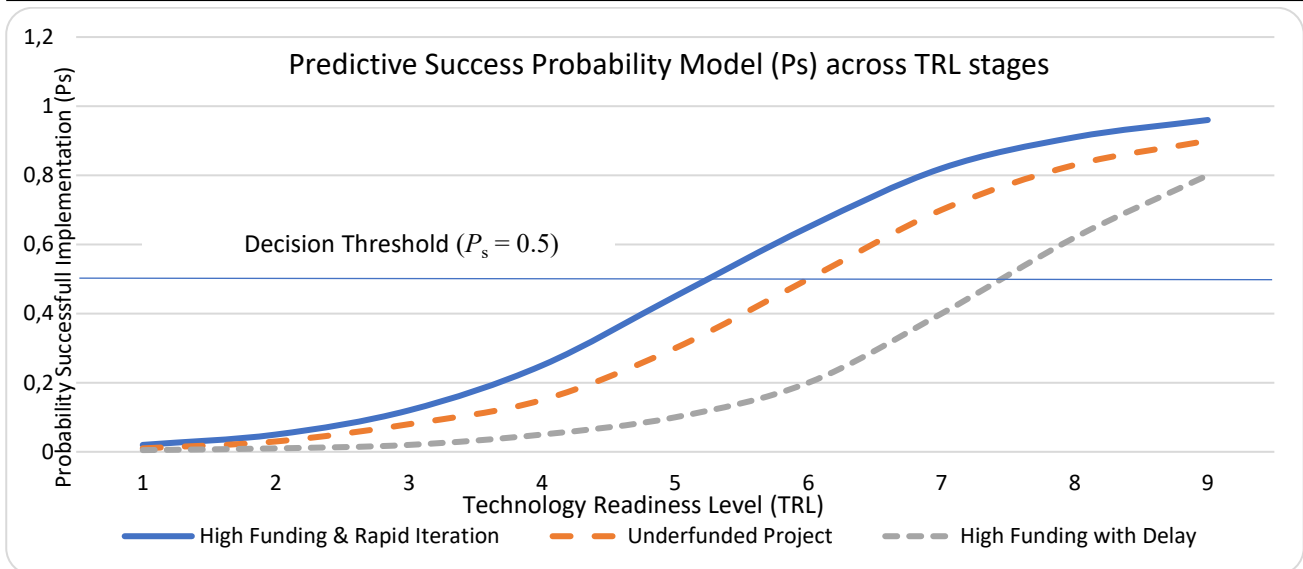
$$P_s = \frac{1}{1 + e^{-(\alpha + \beta_1 TRL + \beta_2 \ln(F) - \beta_3 \Delta t)}} \quad (1)$$

where

- $P_s$  – probability of successful transition to serial production (TRL 9);
- $TRL$  – current level of technological readiness (1–8);
- $F$  – current funding levels (resource base);
- $\Delta t$  – time spent at the current stage (inertia/delay factor);
- $\alpha, \beta_1, \beta_2, \beta_3$  – weight coefficients reflecting the specifics of wartime (high weight  $\beta_1$  due to Combat Proven validation).

In the proposed model, each transition  $TRL_i \rightarrow TRL_{i+1}$  is considered as a kind of “filter”. In wartime conditions, the probability of transition increases at stages TRL 7–8 due to simplified certification, but there is an increase in risks at stages TRL 4–5 due to the use of civilian components, which are not always sufficiently reliable.

We implement and visualize the regression model (1) in Python (Figure).



**Figure:** Implementation of a regression model for the success of an innovation project

**Source:** constructed by the author using Python software

Explanation of the model.

Inflection Point – with high funding (green line), the project crosses the “success threshold” ( $P_s > 0,5$ ) already at TRL – 5. This means that the state can make decisions on procurement even before the completion of the full cycle of tests;

delay effect (blue line) – even with sufficient funding, a significant time delay  $\Delta t$  significantly changes the curve, which means that in a state of war, the speed of development is more important than the amount of funding.

Critical risk zone (TRL 1–4) — at these stages, the probability of project success is low and almost independent of finances. This justifies the implementation of a “portfolio investment” strategy, i.e., financing many inexpensive projects at an early stage (Yakupov, 2022).

Limitations of the study and verification of results.

Despite the high coefficient of determination  $R^2$  and the statistical significance of the model parameters, it has a number of limitations due to the specifics of the object of analysis and the conditions of martial law:

information asymmetry and data secrecy (the main limitation is the secrecy regime that accompanies the activities of the defense industry). Statistical data on new weapons models are based on open reports and official statements, which may not reflect the full range of secret developments. This may underestimate the real elasticity of the innovation cycle, as some successful TRL 7-9 projects remain outside the public domain;

Survivorship Bias effect – the model is based on the analysis of projects that have become known for their effectiveness (e.g., marine drones), but we do not have access to data on unsuccessful developments that were stopped at TRL 4. This may create the illusion of a higher probability of success than it actually is for the average project in the defense industry;

the limited time series due to the relatively short period (2012 – 2024), with the active military contraction phase of the cycle (2022 – 2024) covering only three observation points. Such a small number of degrees of freedom in the regression may make the model sensitive to outliers. Although the results are significant, they need further verification over longer time intervals after the economic situation stabilizes;

The problem of endogeneity and proxy variables – the use of the indicator of financial expenditure on R&D as an independent variable has certain caveats, since the growth in the number

of new models may in itself stimulate growth in funding, which creates a problem of endogeneity (Wang, 2023). Furthermore, it is a quantitative rather than a qualitative metric that does not take into account technological complexity (for example, one missile system is not equal to ten types of FPV drones).

Specificity Generalizability – The extreme decrease in TRL levels recorded in the model is the result of an exogenous shock (war). Therefore, there is a risk that after the transition to peacetime, the elasticity of innovation may decline due to the return of bureaucratic procedures.

## **Discussion**

The obtained results confirm the hypothesis regarding the transformation of the innovation cycle in Ukraine's defense-industrial complex from a linear to an adaptive recursive model. However, the interpretation of these changes requires caution. In particular, the identified reduction in time intervals between TRL stages may be driven not only by institutional decentralization but also by the exogenous factor of war, which limits the possibility of extrapolating the findings to peacetime conditions. Therefore, the causal relationship between the speed of innovation and system performance requires further empirical validation.

The regression model indicates increasing returns on investment, yet there is a risk of endogeneity, as funding may respond to already achieved outcomes. Additionally, the presence of survivorship bias may lead to an overestimation of the effectiveness of innovation projects. An alternative interpretation suggests that the key driver is not the volume of resources, but rather the speed of feedback and the intensity of experimentation.

Thus, the findings should be considered context-specific to conditions of high uncertainty, while their generalization requires extending time series data and accounting for latent variables.

## **Conclusions**

The study confirms that under the influence of extreme external challenges, traditional linear innovation management models are transforming into flexible adaptive systems. This manifests itself in the transition from a strict sequence of TRL stages to a recursive cycle, where feedback from the end user becomes an integral part of the development process. This paradigm shift allows for significant temporal optimization, reducing the time to market without critically compromising functional reliability.

Regression analysis revealed a stable relationship between investment volumes and the rate of technological solution generation. High elasticity indicators show that modern defense innovations demonstrate a growing return on capital. This is explained not only by the volume of resources, but also by the system's ability to effectively integrate dual-use technologies. This strategy significantly lowers the entry threshold for innovative national security entities and ensures an asymmetric response to the challenges of traditional industrial production. Statistically significant structural shifts in the model indicate that institutional design is no less important than direct financing. Decentralization of development and the creation of specialized accelerators contribute to the formation of a network structure for the defense industry. In such an ecosystem, the success of a project is determined not by hierarchical control, but by the speed of knowledge exchange and the ability to rapidly iterate prototypes.

The results of the study allow us to consider the status of "battle-tested" not just as a tactical advantage, but as a new category of innovation validation. This creates new standards of quality and reliability that may change global approaches to the certification of high-tech products in the future, bringing the testing process closer to real operating conditions.

Scientific research into flexible innovation cycles has significant potential for expansion in terms of maintaining the identified effectiveness during the transition to stable economic conditions. It is important to investigate which elements of the "extreme" innovation cycle can be

implemented in public policy on a long-term basis to increase the overall competitiveness of Ukraine's defense industry.

### **Funding**

This study received no specific financial support.

### **Competing interests**

The authors declare that they have no competing interests.

### **References**

- Bondar, K. (2025). *How and why Ukraine's military is going digital*. Center for Strategic and International Studies. [https://csis-website-prod.s3.amazonaws.com/s3fs-public/2025-10/251006\\_Bondar\\_Military\\_Digital.pdf](https://csis-website-prod.s3.amazonaws.com/s3fs-public/2025-10/251006_Bondar_Military_Digital.pdf)
- da Silva Etges, A. P. B., & Cortimiglia, M. N. (2019). A systematic review of risk management in innovation-oriented firms. *Journal of Risk Research*, 22(3), 364–381. <https://doi.org/10.1080/13669877.2017.1382558>
- Dovbenko, A. (2025). Ukraine's defense tech sector must guard against innovation drain. *Atlantic Council*. <https://www.atlanticcouncil.org/blogs/ukrainealert/ukraines-defense-tech-sector-must-guard-against-innovation-drain/>
- Elveren, A. Y. (2022). Military spending and profit rate: A circuit of capital model with a military sector. *Defence and Peace Economics*, 33(1), 59–76. <https://doi.org/10.1080/10242694.2020.1832394>
- Jacobsen, S. D., & Bendett, S. (2025). How Ukraine became the world's most recorded war: A laboratory for AI-driven combat. *International Policy Digest*. <https://intpolicydigest.org/how-ukraine-became-the-world-s-most-recorded-war-and-a-laboratory-for-ai-driven-combat/>
- Kotila, B., Drezner, J. A., Bartels, E. M., Hill, D., Hodgson, Q. E., Huilgol, S. S., & Wong, J. P. (2023). *Fostering innovation in military technology: Strengthening DoD's commercial technology pipeline*. RAND Corporation. <https://doi.org/10.7249/RRA1352-1>
- NATO Science and Technology Organization. (2023). *Technology readiness levels (TRL)*. <https://www.sto.nato.int/document-tag/technology-readiness-levels-trl/>
- Olechowski, A. L., Eppinger, S. D., Joglekar, N., & Tomaschek, K. (2020). Technology readiness levels: Shortcomings and improvement opportunities. *Systems Engineering*, 23(4), 395–408.
- RAND Corporation. (2025). *Looking ahead: Enablers of innovation and scale for the future of Ukraine's defence-industrial base*. [https://www.rand.org/pubs/research\\_reports/RRA3833-6.html](https://www.rand.org/pubs/research_reports/RRA3833-6.html)
- RAND Europe. (2025). *Wartime innovation and adaptation: Supporting Ukraine's digital transformation*. <https://www.rand.org/randeurope/research/projects/2025/innovation-adaptation-at-war-cm.html>
- Ryan, M. (n.d.). Seven contemporary insights on the state of the Ukraine war. *Center for Strategic and International Studies*. <https://www.csis.org/analysis/seven-contemporary-insights-state-ukraine-war>
- Schroeder, E. (2025). *Building the digital front line: Understanding big tech decision-making in Ukraine*. Atlantic Council. <https://www.atlanticcouncil.org/in-depth-research-reports/report/building-the-digital-front-line/>
- Stockholm International Peace Research Institute (SIPRI). (n.d.). *SIPRI military expenditure database*. <https://www.sipri.org/databases/milex>
- Tereshchenko, E., Ushenko, N., Dielini, M., Nesterova, M., Lozhachevska, O., & Honcharenko, N. (2021). Behavioral models of decision-making by business and industry stakeholders.

- Financial and Credit Activities: Problems of Theory and Practice*, 5(40), 300–313.  
<https://doi.org/10.18371/fcaptp.v5i40.245156>
- Ukrainian Defense Industry. (n.d.). *Home*. <https://ukroboronprom.com.ua/>
- UNESCO Institute for Statistics. (n.d.). *UNESCO education statistics*.  
<https://data360.worldbank.org/en/dataset/UNESCO UIS>
- Wang, X., Hou, N., & Chen, B. (2023). Democracy, military expenditure and economic growth: A heterogeneous perspective. *Defence and Peace Economics*, 34(8), 1039–1070.  
<https://doi.org/10.1080/10242694.2022.2126955>
- Yakupov, B. T., & Safiullin, L. N. (2022). A new approach to risk identification in portfolio investment. *Mezhdunarodnyy nauchno-issledovatel'skiy zhurnal (International Research Journal)*, 5–4(119), 168–172.
- Yfanti, S., & Sakkas, N. (2024). Technology readiness levels (TRLs) in the era of co-creation. *Applied System Innovation*, 7(2), Article 32. <https://doi.org/10.3390/asi7020032>
- Zweibelson, B. (2025). Innovation management: Embracing the fantastic to get the military moving in new directions. *Contemporary Issues in Air and Space Power*, 3(1).  
<https://doi.org/10.58930/bp38138499>



This is an open access journal and all published articles are licensed under a Creative Commons «Attribution» 4.0.