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INTEGRAL INDICATOR OF THE EFFECTIVENESS OF RADIO-CONTROLLED MUNITION COUNTERMEASURE SYSTEMS ON ARMOURED AND AUTOMOTIVE VEHICLES OF SECURITY AND DEFENCE FORCES

The article substantiates the relevance of improving the effectiveness of systems for countering radio-controlled explosive devices deployed on automotive and armored vehicles of Ukraine's security and defense forces under the conditions of modern combat operations. It is shown that existing approaches do not adequately account for the combined impact of operating modes of radio-technical equipment and the formation of multispectral demasking signatures, which reduce the counter-intelligence protection of military equipment.

An integral indicator for evaluating the effectiveness of radio-controlled explosive device countermeasure systems is proposed, based on normalized criteria and the Euclidean metric, which enables comparison of alternative solutions according to their degree of proximity to an ideal system. The obtained results provide a scientific basis for enhancing the combat survivability of automotive and armored vehicles and for increasing the overall level of state security of Ukraine.

Keywords: *state security, security mechanism, armoured and automotive vehicles, counter-reconnaissance protection, radio-controlled munitions countermeasures, unmanned aerial vehicles, detection, coefficient, monitoring, radio-technical visibility, effectiveness enhancement, integral indicator, normalised criterion, Euclidean metric.*

Statement of the problem. The experience gained from combat and special operations conducted during the repulsion of the armed aggression of the Russian Federation has demonstrated that radio-controlled explosive devices (RCEDs) are among the most widespread and dangerous means of attack actively employed by the adversary under contemporary combat conditions. The primary targets of such devices are automotive and armored vehicles (AAVs) of the security and defense forces, which directly affects unit combat capability, the level of personnel protection, and the ability to accomplish assigned operational and combat tasks. This, in turn, has a significant impact on the effectiveness of mechanisms for ensuring the state security of Ukraine.

Electronic warfare (EW) systems intended to detect and block RCED control channels have proven their effectiveness; however, assessing the overall effectiveness of their application remains a complex task. Existing methodologies predominantly consider only individual parameters — such as the probability of signal detection, the probability of neutralization, or system reaction time — which does not provide a comprehensive assessment of the protection level under diverse tactical conditions and varying resource constraints. At the same time, the employment of EW assets and RCED countermeasure systems generates additional multispectral demasking signatures (radio-frequency, thermal, acoustic, and vibrational), which directly affect the counter-intelligence (reconnaissance) protection of AAVs by increasing the probability of their detection by adversary technical reconnaissance assets.

Thus, a scientific and practical problem arises due to the absence of a comprehensive methodology that would allow simultaneous assessment of the effectiveness of RCED countermeasure systems, the impact of operating modes of radio-technical equipment, and the level of counter-intelligence protection of AAVs as a determining factor of combat survivability and as an element of the state security assurance mechanism.

Analysis of recent research and publications. Issues related to countering RCEDs and electronic warfare consistently remain at the center of attention in NATO and U.S. military doctrines and standards, which emphasize the necessity of a comprehensive assessment of the effectiveness of actions in the electromagnetic spectrum (see doctrinal materials FM 3-36 and the updated FM 3-12) [6–9]. NATO review publications also highlight the role of electromagnetic operations in ensuring mission accomplishment and force resilience in modern operations [13].

Practical approaches to the validation of RCED countermeasure systems (e.g., CREW / vehicular jammers) in open technical literature are primarily based on field trials and empirical effectiveness metrics, as reflected in studies and reports by JHU/APL [11]. Market and technology reviews emphasize typical architectures of automotive and armored jamming systems; however, they do not provide a generalized multicriteria metric of performance effectiveness [12]. At the same time, standards and guidelines for testing the impact of the electromagnetic environment (AECTP-500 / STANAG 4370) establish a regulatory framework for replicable measurements and verification of results on military equipment [8–10].

From the perspective of mathematical tools, the most relevant class of methods for constructing an integral indicator is multicriteria decision-making (MCDM). The concept of an "ideal point" or "utopia point," which underlies the TOPSIS method, makes it possible to measure the proximity of an alternative to the ideal solution and its distance from the anti-ideal within a normalized criteria space [1–3]. A key element in the correct construction of such assessments is the normalization of heterogeneous criteria (benefit-type and cost-type), which significantly affects the stability of the final ranking. This issue is examined in detail in comparative studies of normalization techniques and MCDM methods [4, 5].

Thus, the methodological conclusions derived from the literature review can be summarized as follows:

there is a need for a harmonized integral indicator for RCED countermeasure systems deployed on automotive and armored vehicles;

the application of MCDM/TOPSIS logic with normalization of heterogeneous characteristics and measurement of Euclidean distance to the ideal point is methodologically justified;

regulatory and testing documents provide a basis for the verification of such integral indicators under field and proving-ground conditions [1–5, 10–13].

In open publications and analytical materials on countering UAVs/RCEDs, additional emphasis is placed on the need for rapid adaptation of EW operating modes and consideration of tactical and technical variability of threats – factors that make the use of adaptive weighting schemes and sensitivity analysis important in the construction of integral indices [14]. In socio-security literature (reviews on IED and IED threats), it is emphasized that the protection of equipment and personnel is directly related to state security, which further substantiates the applied orientation of the developed integral indicators [15].

Therefore, based on the analyzed sources, the application of the proposed approach (normalization – determination of the ideal solution – measurement of the weighted Euclidean distance → transformation into an integral index) is substantiated for constructing an integral indicator of the effectiveness of RCED countermeasure systems as a tool for assessment and decision-making in the context of ensuring state security.

The purpose of the article. The purpose of this study is the theoretical substantiation of an integral indicator for evaluating the effectiveness of radio-controlled explosive device countermeasure systems deployed on automotive and armored vehicles of security and defense force units as a key mechanism for enhancing the level of state security of Ukraine, taking into account their impact on the counter-intelligence (reconnaissance) protection of AAVs and overall combat survivability.

Summary of the main material. The indicators used to evaluate radio-controlled explosive device (RCED) countermeasure systems can be divided into several groups, structured according to the operational needs of the troops. The list of these indicators may be modified and expanded depending on the specific characteristics of RCED countermeasure systems.

1. Threat detection indicators.

1.1. Probability of detecting the RCED control signal. The higher the probability of initial signal detection, the shorter the reaction time and the lower the risk of vehicle damage; therefore, the degree of influence is critical.

1.2. Selectivity of receiver chains. The ability to separate RCED control signals from interference and non-hostile channels determines the accuracy of threat classification; thus, the degree of influence is high.

1.3. Scanning bandwidth. A wider spectrum enables detection of diverse RCEDs, including FPV drones and IEDs with non-standard control channels; therefore, the degree of influence is high.

1.4. Resistance to adversary signal masking. If the system is capable of identifying signals masked as radio noise or civilian frequencies, the probability of threat penetration is reduced; hence, the degree of influence is critical.

2. Control channel neutralization (jamming) indicators.

2.1. Probability of successful suppression. This is a decisive factor directly affecting the actual neutralization of the threat; the degree of influence is critical.

2.2. Interference stability under dynamic conditions. The ability to maintain jamming during drone maneuvering or frequency changes determines EW effectiveness; the degree of influence is high.

2.3. Countering multi-target attacks. Simultaneous response to multiple drones or control channels ensures unit survivability; the degree of influence is critical.

2.4. Universality with respect to RCED types. The ability to operate against various FPV models, improvised devices, and standardized munitions provides operational advantage; the degree of influence is high.

3. Temporal parameters.

3.1. System reaction time. The faster the transition from detection to suppression, the lower the probability of a successful strike; the degree of influence is critical.

3.2. Continuous operation duration. The ability to operate without overheating determines suitability for prolonged operations; the degree of influence is medium.

3.3. Mode switching speed. Rapid adaptation between detection and suppression modes increases effectiveness in a changing tactical environment; the degree of influence is high.

3.4. Control command latency. Any delays may reduce system accuracy; the degree of influence is medium.

4. Spatial parameters.

4.1. Maximum jamming range. Greater range enables earlier loss of adversary control over the munition; the degree of influence is critical.

4.2. Angular coverage sector. Full (360°) coverage minimizes blind zones; the degree of influence is high.

4.3. Altitude coverage range. Essential for countering FPV drones attacking from different altitude layers; the degree of influence is high.

4.4. Stability in complex terrain conditions. Terrain obstacles degrade jamming effectiveness; system compensation is required; the degree of influence is medium.

5. Spectral capabilities.

5.1. Operating frequency range. A broader spectrum increases the likelihood of detecting non-standard control systems; the degree of influence is high.

5.2. Capability to track frequency hopping. Since adversaries actively use frequency hopping, the ability to follow it is critical.

5.3. Adaptive spectrum scanning algorithms. Automatic adaptation to emerging threats improves reaction speed; the degree of influence is high.

5.4. Compatibility with friendly communication systems. Preventing suppression of friendly channels is essential; the degree of influence is critical.

6. Demasking signatures (impact on reconnaissance protection).

6.1. Electromagnetic emissions. Active EW operation increases radio-frequency visibility of AAVs; the degree of influence is critical.

6.2. Thermal signature. Component heating affects thermal reconnaissance; the degree of influence is high.

6.3. Acoustic and vibrational noise. Generator noise and vibrations may be detected by seismic sensors; the degree of influence is high.

6.4. Optical manifestations. Reflections from surfaces and indicators may be visible to reconnaissance drones; the degree of influence is medium.

7. Impact Indicators on the Reconnaissance Protection Coefficient (RPC).

7.1. Increase in radio-frequency visibility. Active transmitters significantly reduce RPC; the degree of influence is critical.

7.2. Increase in thermal visibility. Especially relevant at night or during winter; the degree of influence is high.

7.3. Enhancement of acoustic and vibrational background. This increases vulnerability to counter-artillery and acoustic reconnaissance systems (e.g., Penicillin); the degree of influence is high.

7.4. Reduction of the integral RPC. RCED countermeasure systems may simultaneously protect and demask vehicles; the degree of influence is critical.

8. Operational indicators.

8.1. Mean Time Between Failures (MTBF). Fewer failures ensure operational stability; the degree of influence is high.

8.2. Resistance to climatic conditions. Rain, dust, and frost may reduce system effectiveness; the degree of influence is medium.

8.3. Resistance to vibration and shock. AAVs operate under harsh conditions; the degree of influence is high.

8.4. Operation under partial damage. Maintaining functionality after damage is crucial in combat; the degree of influence is critical.

9. Energy and logistics indicators.

9.1. Power consumption. High loads increase the risk of vehicle system failures; the degree of influence is medium.

9.2. Mass and dimensions. Excessive size may limit maneuverability; the degree of influence is high.

9.3. Requirement for additional power sources. Increases logistical complexity; the degree of influence is medium.

9.4. Maintainability. The speed of module replacement determines combat readiness; the degree of influence is high.

10. Tactical and operational indicators.

10.1. Compatibility with standard communication systems. Operation must not block friendly radio channels; the degree of influence is critical.

10.2. Effectiveness while moving and during firing. The system must operate reliably under combat dynamics; the degree of influence is high.

10.3. Performance in various combat scenarios. Versatility increases overall unit effectiveness; the degree of influence is high.

10.4. Safety for friendly forces. Interference must not affect friendly UAVs; the degree of influence is critical.

The selection of effectiveness indicators for RCED countermeasure systems and the assessment of their degree of influence were conducted using an expert-based method involving specialists in electronic warfare, combat employment of AAVs, RCED countermeasures, and technical reconnaissance. The expert evaluation was carried out in several stages: preliminary identification of factors affecting system performance; assessment of their relative importance under various combat scenarios; and ranking of indicators according to their impact on overall protection levels. Each indicator was evaluated based on frequency of manifestation in real conditions, magnitude of impact on the probability of AAV damage, interdependence with other parameters, and optimization potential. The resulting expert assessments were aggregated using weighted averaging, enabling the formation of a coherent indicator set and quantitative determination of their influence within the developed methodology.

The presented indicators describe heterogeneous aspects of RCED countermeasure system performance and counter-intelligence (reconnaissance) protection of AAVs. Many indicators differ in physical nature and dimensionality, making direct comparison impossible. Therefore, to correctly apply selection, ranking, and integration procedures into a single generalized criterion, adequate normalization is required, ensuring transformation of all variables into a unified dimensionless scale and eliminating the influence of heterogeneity [16, 17].

The normalization problem can be formalized as follows:

$$F' : \left\{ M_j \right\}_j J \rightarrow \left\{ M'_j \right\}_j J\,[0,1] \rightarrow \Re \,, \qquad (1)$$

where F' – is the mapping M_j in M'_j, to be determined;

M_j – is the characteristic of the j-th RCED countermeasure system;

M'_j – is the normalized characteristic of the j-th system;

J – is the index set of compared systems;

Â – is the set of real numbers.

The mapping F represents the first stage of the transformation process and implements the proportional selection method for evaluated RCED countermeasure systems.

The problem of evaluating and selecting alternatives based on a set of normalized metric characteristics can be interpreted as follows. In the R^n space of indicators, an ideal RCED countermeasure system is defined. It is represented by an ideal point or utopia point. Given the standardized form of normalized indicators, the coordinates of this point are a set of ones (1, 1, …, 1), i.e., n ones. The ideal system corresponds to one of the vertices of the n-dimensional unit hypercube G_1^n. Any real RCED countermeasure system can also be represented as an n-dimensional point within the same space; however, the probability that it coincides with the ideal point is negligible, meaning that real systems are always located inside the hypercube G_1^n.

Thus, RCED countermeasure systems can be compared based on their proximity to the ideal solution. In other words, the introduced distance (metric) between the ideal and real systems allows assessment of their quality: the closer a system is to the ideal point, the higher its quality as evaluated by the entire set of characteristics [18].

In this context $d\left(M_i,M_j\right)$, the distance (metric) is defined as a non-negative real-valued function satisfying the standard metric axioms:

$$d\left(M_i,M_j\right) \geq 0 \ \forall M_i,M_j \in G_1 \ ; \tag{2}$$

$$d\left(M_i,M_j\right) = 0 \Leftrightarrow M_i = M_j \ ; \tag{3}$$

$$d\left(M_i,M_j\right) = d\left(M_j,M_i\right) \ ; \tag{4}$$

$$d\left(M_i,M_j\right) \leq d\left(M_i,M_k\right) + d\left(M_k,M_j\right) \ , \tag{5}$$

where M_i,M_j,M_k – the vectors correspond to normalized metric characteristics of the i-th, j-th, and k-th RCED countermeasure systems, respectively, within the unit n-dimensional hypercube G_1^n.

For comprehensive evaluation of RCED countermeasure systems, the Euclidean distance is used as the metric definition, which determines the form of the composite indicator:

$$d\left(M_j,M_0\right) = \left[\sum_{i=1}^{n}\left(M_{ij} - M_0\right)^2\right]^{1/2} . \tag{6}$$

The selection criterion for the best alternative follows the rule that a smaller numerical value of the distance from the system representation point to the ideal point corresponds to a better RCED countermeasure system.

Expert assessments and contemporary studies on multispectral observation and masking [17, 18] indicate that radio-frequency manifestations associated with the operation of EW, RCED countermeasure, and communication systems have the most significant negative impact on reconnaissance protection. Therefore, the combined use of expert methods, mathematical relations (1) – (6), and the generalization of combat experience of the Defense Forces of Ukraine enabled the development of a scientifically grounded mechanism suitable for practical application—from optimizing EW/RCED operating modes to forecasting AAV vulnerability under various scenarios and forming management decisions that effectively contribute to ensuring and enhancing the level of state security.

Conclusions

The relevance of the study is determined by the fact that the effectiveness of radio-controlled explosive device (RCED) countermeasure systems directly affects the combat resilience and survivability of automotive and armored vehicles of Ukraine's security and defense forces and, consequently, their ability to successfully perform assigned tasks in ensuring national and state security. The conditions of modern high-technology warfare, characterized by the widespread use of remotely controlled means of attack, require a scientifically grounded integral approach to assessing the effectiveness of such systems. The level of their performance largely determines the degree of risk reduction for personnel, equipment, and critical infrastructure of the security and defense forces, thereby forming an important component of Ukraine's comprehensive state security assurance system.

An integral expression for evaluating the effectiveness of RCED countermeasure systems deployed on automotive and armored vehicles of security and defense force units has been further developed. Unlike existing approaches that primarily account for individual parameters (probability of detection, probability of suppression, or reaction delay), the proposed expression is based on a multifactor metric that integrates spectral, tactical-technical, radio-technical, and counter-intelligence protection parameters into a single integral indicator. This enables quantitative determination of the overall protection level of vehicles under different combat employment conditions and supports evidence-based decision-making regarding the optimization of RCED countermeasure systems, thereby strengthening a key component of the comprehensive state security assurance system of Ukraine.

Further research should focus on developing a mathematical model for the rational allocation of financial resources within the RCED countermeasure system. This would contribute to the formation of specific elements of Ukraine's comprehensive state security assurance system, particularly by enhancing the resilience of the security and defense forces to high-technology threats, improving defense resource planning, and advancing integrated RCED countermeasure capabilities.

References

1. Roszkowska E. (2014). Multi-criteria decision making models by applying the TOPSIS method. Multiple Criteria Decision Making. Katowice: University of Economics in Katowice. Retrieved from: http://www.mcdm.ue.katowice.pl (accessed 19 September 2025) [in English].
2. Lai Y. J., Liu T. Y., Hwang C. L. (1994). TOPSIS for MODM. *European Journal of Operational Research*, vol. 76, iss. 3, pp. 486–500. DOI: https://doi.org/10.1016/0377-2217(94)90282-8 [in English].
3. Madanchian M. (2020). A comprehensive guide to the TOPSIS method. *Semantic Scholar.* Retrieved from: https://www.semanticscholar.org (accessed 19 September 2025) [in English].
4. Malefaki S. (2020). Comparative Analysis of MCDM Methods and Normalization Techniques. *Mathematics,* vol. 8, no. 11. DOI: https://doi.org/10.3390/math8111863 [in English].
5. Normalization Techniques for MCDM: A comparative study. (2019). *ResearchGate.* Retrieved from: https://www.researchgate.net/publication/334267234 (accessed 15 September 2025) [in English].
6. Headquarters Department of the Army. (2009). FM 3-36. *Electronic Warfare in Operations.* Washington, DC. 180 p. [in English].
7. Headquarters Department of the Army (2017). FM 3-12. Cyberspace and Electronic Warfare Operations. Washington, DC. 210 p. [in English].
8. NATO Allied Tactical Publication (ATP 3-36 / FM 3-36) (2010). Electronic Warfare. Bonn: BITS. Retrieved from: https://www.bits.de (accessed 15 September 2025) [in English].
9. Headquarters Department of the Army (2009). FM 3-36. Electronic Warfare in Operations. Early edition. Washington, DC. 170 p. Retrieved from: https://www.bits.de (accessed 19 September 2025) [in English].
10. NATO Standardization Agreement (2014). AECTP-500 / STANAG 4370. Electromagnetic Environmental Effects Tests and Verification. Bonn: IB-Lenhardt AG. Retrieved from: https://www.ib-lenhardt.com (accessed 03 September 2025) [in English].
11. Pesci M. E. (2018). Controlled IED Electronic Warfare (CREW) testing methodology. Johns Hopkins Applied Physics Laboratory. Laurel, MD. Retrieved from: https://www.jhuapl.edu (accessed 10 September 2025) [in English].
12. IntelMarketResearch (2022). Vehicle bomb jamming systems overview. IntelMarketResearch Blog. Retrieved from: https://www.intelmarketresearch.com (accessed 28 September 2025) [in English].
13. NATO (2023). Electromagnetic warfare. NATO Official Topic Page. Brussels: NATO. Retrieved from: https://www.nato.int (accessed 19 September 2025) [in English].
14. Counteroffensive Pro (2025). Ukraine countermeasures vs Shahed threats. Counteroffensive News Analysis. Retrieved from: https://www.counteroffensive.pro (accessed 12 September 2025) [in English].
15. Social Science Research Network (2021). Security Aspects of IEDs. Retrieved from: https://www.socialscienceresearch.org (accessed 23 September 2025) [in English].
16. Sakovych V. I., Lopatin O. V. (2021). *Metody ekspertnoho otsiniuvannia u viiskovykh doslidzhenniakh: teoriia, praktyka, modeli* [Methods of expert evaluation in military research: theory, practice, models]. Kyiv: *NUOU named after I. Cherniakhovskyi.* 184 p. [in Ukrainian].
17. Kravchuk S. V., Bondarenko P. P. (2020). *Metody otsiniuvannia efektyvnosti radioelektronnykh zasobiv ta system REB u bahatospektralnomu seredovyshchi* [Methods for assessing the effectiveness of electronic warfare equipment and EW systems in a multispectral environment]. Kharkiv: KhNUPS. 212 p. [in Ukrainian].
18. Milanovic J., Petrović D., Kovač M. (2023). Multispectral Detection of Armored Vehicles under Battlefield Conditions: Models, Metrics and Counter-Measures. Defense Technology, vol. 19, no. 4, pp. 1121–1137. DOI: 10.1016/j.dt.2023.02.014 [in English].

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ІНТЕГРАЛЬНИЙ ПОКАЗНИК ЕФЕКТИВНОСТІ СИСТЕМИ ПРОТИДІЇ РАДІОКЕРОВАНИМ БОЄПРИПАСАМ НА АВТОБРОНЕТАНКОВІЙ ТЕХНІЦІ ПІДРОЗДІЛІВ СИЛ БЕЗПЕКИ ТА ОБОРОНИ

У статті запропоновано методологію оцінки ефективності систем знешкодження радіокерованих боєприпасів (РКБП) як критичного елементу системи безпеки підрозділів Національна гвардія України. Мета дослідження – розробити формалізовану математичну модель, яка дозволяє порівнювати різні зразки технічних та організаційно-технічних рішень за сукупністю критеріїв, ураховуючи як бойову, так і економічну доцільність їх використання. Основні завдання: 1) визначити ключові технічні, тактико-експлуатаційні, інформаційно-аналітичні, управлінські, підготовчі, економічні, стандартизаційні та надійнісні показники як складові інтегрального показника ефективності; 2) сформалізувати алгоритм нормування, зважування і агрегування показників; 3) запропонувати формулу обчислення питомої ефективності «ефективність/витрати»; 4) показати процедуру відсіву неефективних зразків; 5) побудувати модель розподілу ресурсів між зразками та стадіями життєвого циклу із урахуванням бюджетних обмежень; 6) продемонструвати на прикладі декількох альтернатив розрахунок інтегрального показника та питомої ефективності; 7) обґрунтувати управлінські рішення щодо пріоритезації фінансування; 8) продемонструвати гнучкість моделі для адаптації до змінених умов; 9) оцінити практичну допустимість моделі для військової практики.

Як методи дослідження обрано багатокритеріальний аналіз (MCDM), формалізацію та нормування показників, побудову інтегральних та питомих індексів ефективності, а також імітаційний розрахунок на умовних прикладах. У результаті проведеного дослідження було встановлено, що розроблена модель дозволяє кількісно порівнювати різні зразки систем захисту та обґрунтовано приймати рішення щодо їхнього фінансування, модернізації або виводу з експлуатації. Конкретний приклад демонструє, що зразок із найвищим абсолютним рівнем ефективності може мати нижчу питому ефективність ніж дешевший комплекс, – це відкритий шлях до оптимізації витрат без значного зниження захисних якостей.

Запропонована методика може бути використана для стратегічного планування у секторі безпеки та оборони, формування бюджету на озброєння та спеціальну техніку, оцінювання реальних загроз, а також для адаптивного управління ресурсами підрозділів НГУ.

Ключові слова : *державна безпека, механізм забезпечення, автобронетанкова техніка, розвідувальна захищеність, протидія радіокерованим боєприпасам, безпілотні летальні апарати, виявлення, коефіцієнт, моніторинг, радіотехнічна помітність, підвищення ефективності, інтегральний показник, нормований критерій, евклідова метрика.*

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