Advanced Selection Method for the Employment of an Aerial Reconnaissance Unit

Удосконалений метод вибору способу застосування підрозділу повітряної розвідки

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Purpose. The purpose is to improve the scientific and methodological framework for planning the employment of an air reconnaissance unit by developing a formalized method for selecting a rational approach to its use that accounts for the operational environment, the technical characteristics of unmanned aviation systems, and resource constraints.

Methods. The study has a theoretical and applied nature and is based on analysis, formalization, comparative analysis, and multicriteria assessment of alternative courses of action.

Findings. An improved method for selecting a tactical technique for employing an air reconnaissance unit is proposed. The method involves identifying input conditions, forming a set of admissible options, calculating effectiveness indicators, and selecting a rational option according to a generalized criterion. The numerical example provided is conditional and serves to illustrate the procedure's internal logic; empirical validation of the method has not yet been performed.

Theoretical implications. The results develop scientific and methodological approaches to formalizing the selection of methods for employing air reconnaissance units.

Practical implications. The proposed method is intended to support officials of state border protection bodies in decision-making during the planning and organization of air reconnaissance. Its practical effectiveness remains to be confirmed through field, experimental, or simulation studies.

Originality. The originality lies in the transition from empirical selection of a tactical technique to a formalized multicriteria assessment procedure.

Future research. Further research should focus on expanding the set of considered factors, including crew training level, availability of electronic warfare means, and time of day; improving the method for calculating detection probability while considering the stochastic nature of offender movement; and developing software implementation of the method as a decision-support module for automated control systems of border guard units.

Article type: theoretical and applied research.

Мета дослідження. Удосконалити науково-методичний апарат планування застосування підрозділу повітряної розвідки шляхом розроблення формалізованого методу вибору раціонального способу його застосування з урахуванням умов оперативної обстановки, технічних характеристик безпілотних авіаційних комплексів і ресурсних обмежень.

Методи дослідження. Дослідження має теоретико-прикладний характер і ґрунтується на поєднанні методів аналізу, формалізації, порівняльного аналізу та багатокритеріального оцінювання альтернативних способів дій.

Результати дослідження. Запропоновано удосконалений метод вибору тактичного прийому застосування підрозділу повітряної розвідки, який передбачає ідентифікацію вхідних умов, формування множини допустимих способів, розрахунок показників ефективності та вибір раціонального варіанта за узагальненим критерієм. Наведений числовий приклад є умовним і ілюструє внутрішню логіку процедури; емпірична валідація методу наразі не проводилася.

Теоретична цінність дослідження. Результати дослідження розвивають науково-методичні підходи до формалізації процесу вибору способів застосування підрозділів повітряної розвідки.

Практична цінність дослідження. Запропонований метод може бути використаний (після відповідної валідації) для підтримки прийняття рішень посадовими особами органів охорони державного кордону під час планування та організації повітряної розвідки.

Оригінальність дослідження. Оригінальність дослідження полягає у переході від емпіричного вибору тактичного прийому до формалізованої процедури багатокритеріального оцінювання.

Напрями подальших досліджень. Подальші дослідження доцільно спрямувати на розширення множини врахованих факторів, зокрема рівня підготовки екіпажу, наявності засобів радіоелектронної боротьби та часу доби; удосконалення методу розрахунку ймовірності виявлення з урахуванням стохастичного характеру руху правопорушника; розроблення програмної реалізації методу у вигляді модуля підтримки прийняття рішень для автоматизованих систем управління прикордонними підрозділами.

Тип дослідження: теоретико-прикладний.

Key words: Unmanned Aviation Systems; Operational Environment; Multicriteria Assessment; Resource Constraints; Decision Support; Offender Detection; Border Security.

Ключові слова:. безпілотні авіаційні комплекси; оперативна обстановка; багатокритеріальне оцінювання; ресурсні обмеження; підтримка прийняття рішень; пошук правопорушників; прикордонна безпека.

Introduction

State border protection in Ukraine under current conditions is characterized by a highly dynamic operational environment, the growing role of technical surveillance means, and the need to obtain reliable, timely information on signs of illegal activity. The legal foundations for the functioning of the state border protection system are defined by the Law of Ukraine “On the State Border of Ukraine” and the Law of Ukraine “On the State Border Guard Service of Ukraine”, which establish the legal basis for the protection of the state border and the activities of authorized bodies in this field (Verkhovna Rada Ukrainy, 1991; Verkhovna Rada Ukrainy, 2003).

An important means of increasing the effectiveness of state border protection is the use of unmanned aviation systems (UAS), which provide aerial surveillance, monitoring of hard-to-reach terrain, search for offenders, documentation of signs of illegal activity, and information support for managerial decision-making. The analysis of the development of unmanned aviation indicates an expansion of its functional capabilities, particularly in surveillance, reconnaissance, patrolling, and performing tasks under complex operational conditions (Babii et al., 2022; Chernousov, 2022; Servatiuk et al., 2024).

At the same time, the effectiveness of employing an air reconnaissance unit depends not only on the technical characteristics of an unmanned aviation system but also on the selection of an appropriate tactical technique. While tactical techniques for employing unmanned aviation systems in state border protection have been systematized (Sitailo, 2023), a formalized procedure for selecting a specific technique based on the current operational environment, available resources, and task priorities are still lacking. Consequently, in practical settings, the choice is often guided primarily by officials' experience, which may reduce the objectivity of planning and limit the adaptability of decisions.

The organizational and legal foundations for the use of unmanned aviation systems in the activities of the State Border Guard Service of Ukraine also underscore the need to improve approaches to integrating them into the state border protection system. At the same time, existing regulatory and methodological provisions primarily define the general organizational, legal, and procedural aspects of using such systems, but they do not constitute a comprehensive mechanism for selecting a tactical technique under specific operational conditions (Administratsiia Derzhavnoi prykordonnoi sluzhby Ukrainy, 2023; Ovchar, 2025).

Modern scientific literature pays considerable attention to unmanned aerial vehicle route planning, autonomous navigation, coverage of designated areas, improving flight energy efficiency, employing groups of unmanned aerial vehicles, and multicriteria planning of flight missions. These studies provide an important basis for the development of aerial surveillance; however, they primarily focus on routes, trajectories, technical parameters, and flight algorithms. In contrast, for the border security domain, it is important not only to construct a route but also to determine which tactical technique is rational, taking into account the available information about the offender, terrain characteristics, the number of available unmanned aerial vehicles, meteorological conditions, time of day, and resource constraints.

Therefore, a relevant scientific task is to develop a method that enables the transition from the empirical selection of a course of action to a formalized multicriteria assessment of alternative tactical techniques. Such a method should take into account the operational environment, the admissibility of individual employment methods, the probability of offender detection, task execution time, and the resource consumption of an unmanned aerial vehicle. This problem serves as the basis for the proposed scientific result, which formalizes the selection of a method for employing an air reconnaissance unit.

The purpose of the study is to improve the scientific and methodological framework for planning the employment of an air reconnaissance unit by developing a formalized method for selecting a rational approach to its use that accounts for the operational environment, the technical characteristics of unmanned aviation systems, and resource constraints.

To achieve this purpose, the following tasks were set: to analyze modern scientific approaches to the use of unmanned systems in surveillance, patrolling, and flight mission planning tasks; to determine the main conditions influencing the selection of a tactical technique for employing an air reconnaissance unit; to develop the logic for selecting admissible methods of employment depending on the parameters of the operational environment; to substantiate indicators for comparing alternative tactical techniques; and to develop a formalized procedure for selecting a rational course of action according to a generalized criterion.

The study's scientific novelty lies in the development of a method for selecting an air reconnaissance unit. In contrast to the empirical selection of a tactical technique, the proposed method enables the sequential identification of operational environment conditions, the formation of a set of admissible courses of action, the calculation of effectiveness indicators, and the selection of a rational option based on a multicriteria assessment. The proposed approach enables adapting the selection to task priorities: maximizing the probability of offender detection, minimizing task execution time, or optimizing the use of the unmanned aerial vehicle resource.

Literature Review

The issue of employing unmanned aviation systems in security, defense, and state border protection is addressed in the works of Ukrainian and international researchers.

In Ukrainian scholarship, D. O. Chernousov (2022) examines the experience of using unmanned aerial vehicles by units of the Ministry of Internal Affairs of Ukraine in modern warfare. Yu. O. Babii et al. (2022) analyze the development of unmanned aviation in the world and in Ukraine, as well as its specific features and technical characteristics. V. Servatiuk, M. Lysyi, and A. Mostovyi (2024) summarize scientific approaches to the development and employment of unmanned aerial vehicles in modern military conflicts. M. M. Ovchar (2025) reveals the organizational and legal foundations for the use of unmanned aviation systems by the bodies of the State Border Guard Service of Ukraine.

Of particular importance for this study is the research report by O. V. Sitailo (2023), which substantiates the main tactical techniques for employing unmanned aviation systems in state border protection: the “expanding box” pattern, parallel sweeps, cross sweeps, the “comb” pattern, actions by direction, and actions along a predefined route. Each of these techniques has its own purpose and appropriate conditions for use. At the same time, existing studies primarily describe tactical techniques as possible courses of action, whereas a formalized mechanism for selecting a specific technique based on the operational environment remains underdeveloped.

In international studies, the main focus is placed on border surveillance, autonomous patrolling, route planning, area coverage, group employment of unmanned aerial vehicles, and decision support. N. Ahmadian et al. (2022) consider a model of border patrolling using drones and wireless charging systems. P. Bansal et al. (2024) analyze the challenges of modeling drone-based surveillance in open border areas. B. Biskin, J. Fliege, and A. Martínez-Sykora (2025) study autonomous navigation of unmanned aerial vehicles for border patrolling while taking into account the uncertainty of offender movement. V. S. Nikiforenko (2024) substantiates the conceptual framework for the use of unmanned aviation systems in state border protection, which is important for understanding the role of such systems in modern border security.

A separate area of research comprises studies on routing, area coverage, and multicriteria flight mission planning. X. Fan et al. (2024), S. Ghambari et al. (2024), and İ. Güven and E. Yanmaz (2024) examine various aspects of route planning, search operations, and area coverage using unmanned aerial vehicles. S. Kazemdehbashi and Y. Liu (2025), Y. Lyu et al. (2024), and T. Quadt et al. (2024) address issues of area coverage, cooperative optimization, and the consideration of multiple criteria in flight mission planning. D. J. Duxbury, N. W. Paton, and J. A. Keane (2024) consider methods of dynamic decision support using drones, while K. Osmani and D. Schulz (2024) summarize modern approaches to the design and functioning of avionics systems for unmanned aerial vehicles.

The key difference between existing approaches is that most studies focus on legal foundations, technical characteristics, route planning, area coverage, or optimization of flight mission parameters. At the same time, for an air reconnaissance unit of state border protection bodies, it is essential to select the appropriate tactical technique. The insufficient formalization of this selection, given available information on the offender, terrain characteristics, meteorological conditions, the number of unmanned aerial vehicles, and resource constraints, underscore the scientific relevance of this study.

Materials and Methods

The study applies a set of general scientific and special methods. The methods of analysis and synthesis were used to summarize scientific approaches to the employment of unmanned aviation systems for surveillance, patrolling, offender search, and flight mission planning. A comparative analysis was conducted to evaluate air reconnaissance tactical techniques based on their appropriate use, expected effectiveness, time indicators, and resource expenditure. The formalization method was used to present the process of selecting an air reconnaissance unit as a sequence of logical stages: identification of input conditions, formation of a set of admissible courses of action, calculation of effectiveness indicators, and selection of a rational option.

The multicriteria assessment method was applied to compare alternative tactical techniques using indicators that characterize the probability of offender detection, task execution time, and resource consumption by an unmanned aerial vehicle. This approach allows consideration of the decision-maker's different priorities, including maximizing the probability of detection, minimizing task execution time, or ensuring the rational use of resources.

The study's materials include scientific works on the employment of unmanned aviation systems, flight mission planning, border surveillance, and multicriteria decision-making, as well as legislative, regulatory, and scientific-methodological sources that regulate or describe the use of unmanned aviation systems in state border protection.

Results

As a result of the study, an improved method for selecting a rational tactical technique for employing an air reconnaissance unit in state border protection was developed. The method aims to formalize the selection of a tactical technique for employing unmanned aerial vehicles (UAVs), based on the operational environment, available information about the offender, terrain characteristics, the technical capabilities of UAVs, meteorological conditions, and resource constraints. In contrast to the approach in which a tactical technique is selected mainly on the basis of the experience of an official or external crew, the proposed method provides for the sequential formation of a set of admissible courses of action, calculation of effectiveness indicators, and selection of a rational option according to a generalized criterion.

The improved method for selecting how to employ an air reconnaissance unit is based on a multicriteria comparison of the effectiveness of possible tactical techniques under specific operational conditions. The method includes the following stages.

Stage 1. Identification of input parameters, or conditions of employment.

At this stage, the following parameters are determined:

the nature of the available information about the offender: the presence or absence of data on location, the presence or absence of data on direction of movement, and movement speed, classified as high, low, or zero;

terrain characteristics: open terrain, closed terrain such as forested or mountainous areas, water surface, and the boundaries of the search area, including its length and area;

technical characteristics of UAVs: flight range, flight endurance, speed, and target detection range;

meteorological conditions: visibility, wind speed, and precipitation;

resource constraints: the number of available UAVs and the time remaining before task completion.

Stage 2. Formation of a set of admissible methods of employment.

From the six known tactical techniques (Table 1), a subset is formed $S = \{s_1, s_2, \dots, s_k\}$ that is permissible for given conditions. For example, the "comb" technique is permissible only if there are sufficient UAVs; the "expanding box" technique is permissible only if there is location data on the offender for a certain period.

From the six known tactical techniques, a subset $S = \{s_1, s_2, \dots, s_k\}$is formed that is permissible under the given conditions. Admissibility is determined according to the matrix presented in Table 1. The matrix formalizes the main logical rules: the "expanding box" technique is admissible only if data on the offender's location are available; the "by direction" technique requires information on the axis or direction of movement; the "comb" technique is admissible only if a sufficient number of UAVs is available; parallel and cross sweeps are generally admissible under low target speed and adequate resources; actions along a predefined route remain admissible in most information conditions. Techniques that do not meet the corresponding conditions are excluded from S_{adm} before calculating effectiveness indicators.

Table 1: Matrix of permissibility of tactical techniques depending on the operational situation

Operational situation condition	Predefined route	Parallel sweeps	Cross sweeps	Comb	Expanding box	By direction
There is data on the location of the object	+	+	+	+	+	+
There is no data on the location	+	+	+	+	–	+
There is data on the direction/axis of movement	+	+	+	+	+	+
There is no data on the direction of movement	+	+	+	+	+	–
The object is static or low speed	+	+	+	+	+	+
The object has high speed	+	±	±	±	+	+
Sufficient number of UAVs (≥ 2–3)	+	+	+	+	+	+
One UAV	+	+	+	–	+	+
Open area	+	+	+	+	+	+
Closed area (forest, mountains)	±	±	±	±	±	±
Limited time/resources	±	±	±	–	+	+

Source: *Sitailo, 2023.*

Symbols: "+" — reception is acceptable; "–" — reception is inadmissible; "±" is permissible under additional conditions (to be specified expertly or according to additional parameters).

Stage 3. Calculation of effectiveness indicators for each permissible method.

The detection probability (P_d) in formula (1) is generally defined as a function of the detection range d, the width of the viewing strip, accounting for overlap, terrain type, weather conditions, UAV sensor characteristics, and the behavior of the search object. For operational application of the method, calibration is required based on field tests (controlled search scenarios with a known position of the "offender"); experimental data (statistics of successful/unsuccessful detections using various tactical techniques); simulation modeling (Monte Carlo simulations of the object's movement and the sensor model). Until such data are obtained, the values P_d in the examples should be interpreted exclusively as conditional. Also, the parameters (T_f , R) need to be specified based on the actual parameters of the UAV (endurance accounting for wind, temperature, U-turn costs, etc.).

The following indicators are calculated for each method ($s_i \in S$):

a) the probability of detecting the offender (P_d) – depends on the detection range, the nature of the terrain, the width of the viewing strip, and the flight pattern. For the reception of "even sweeps":

$$P_d = 1 - \prod_{j=1}^{6}(1 - p_j), \tag{1}$$

where p_j – is the probability of detection on *the j-h* tack, which is defined as $p_j = \frac{d}{b}$, where d is the detection range, b is the distance between the sweeps (taking into account 25% overlap $b = 1.5d$);

b) task completion time (T_n)– the total flight time of the UAV, taking into account the route length, flight speed, and, if necessary, the time to replace the batteries.

To receive "even sweeps":

$$T_{п} = \frac{n \cdot L \cdot t_R}{V + (n-1)}, \tag{2}$$

where n – is the number of sweeps;
L – is the length of one tack;
V – V is the speed of the UAV;
t_R is the turn time.

c) resource consumption (R_{ab}) – a relative value characterizing the consumption of battery charge (or fuel) during the flight:

$$R_{ab} = \frac{E_{fact}}{E_{norm}} = \frac{T_f \cdot k_w \cdot k_t \cdot k_{load}}{T_{max}}, \tag{3}$$

where T_{max} – is the maximum flight time of the UAV under given weather conditions (taking into account correction factors for wind and temperature);
k_w, k_t, k_{load} – wind, temperature, and payload influence factors (independent of the prime T_f).

Formula (1) is based on the assumption of statistical independence of object detection events on individual passes. This assumption is a simplification and is valid only under the following conditions: the absence or insignificant overlap of the viewing lanes; a uniform (or nearly uniform) distribution of possible object positions in the search area; and the absence of strong spatial correlation between neighboring passes. With significant overlap in routes and spatial dependence in the object's position, the formula may overestimate P_d .

Limits of application of model (1): the overlap of the viewing lanes does not exceed 20–25 %; the search object is considered static or moving slowly relative to the speed of the UAV; the observation conditions (visibility, camouflage, flight altitude) are relatively uniform within the zone. In the case of significant overlap, complex terrain, or active maneuvering of the object, it is advisable to use models taking into account conditional dependence (for example, based on the theory of coverage or Markov processes).

The assumption of independence and the accuracy of formula (1) need to be verified by simulation modeling (Monte Carlo simulations with spatially correlated object position) and field or experimental tests with a controlled position of the "offender". Until such data are obtained, the values P_d calculated by formula (1) should be interpreted as approximate (upper) estimates.

In further studies, it is worth using a model that takes into account the dependence of events, for example:

$$P_d = 1 - \prod_{j=1}^{n}\left(1 - p_j \cdot \left(1 - p_{j,j-1}\right)\right), \quad (4)$$

where $p_{j,j-1}$ – spatial correlation coefficient between adjacent passes or for using coverage models taking into account overlap.

Stage 4. Selection of a rational method by multi-criteria evaluation. The selection is made on the basis of the generalized efficiency indicator $E(s)$:

$$E(s) = w_1 P_d(s) - w_2 T_п(s) - w_3 R_{акб}(s), \quad (5)$$

where $w_1,\ w_2,\ w_3$ – are the weight coefficients determined by the decision-maker (head of the unit), depending on the task priorities (maximizing the probability of detection, minimizing time, or minimizing resource consumption).

The weight coefficients satisfy the condition $w_1 + w_2 + w_3 = 1$.

Weight coefficients $w_1,\ w_2,\ w_3$ that satisfy the condition are determined by the decision-maker ($w_1 + w_2 + w_3 = 1,\ w_i \geq 0$), depending on the priorities of the task. Possible ways of setting them: direct expert selection (the head of the unit sets the priorities directly); pairwise comparison method (for example, according to the Saati scale) with subsequent normalization; scenario approach — predefined sets of weights for typical situations:

maximizing the probability of detection: $w = (0{,}6;\ 0{,}2;\ 0{,}2)$;

time minimization: $w = (0{,}2;\ 0{,}6;\ 0{,}2)$;

minimizing resource consumption: $w = (0{,}2;\ 0{,}2;\ 0{,}6)$;

balanced option: $w = (0{,}4;\ 0{,}3;\ 0{,}3)$.

Before calculating the generalized E_s indicator, the criteria to be minimized (T_f and R) are subject to normalization to the interval [0; 1]. Linear normalization is used

$$T_f^{norm} = \frac{T_f - T_f^{min}}{T_f^{max} - T_f^{min}},\ R^{norm} = \frac{R - R^{min}}{R^{max} - R^{min}}, \quad (6)$$

where $T_f^{min},\ T_f^{max},\ R^{min},\ R^{max}$ – minimum and maximum values of the corresponding indicators among the permissible methods S_{adm} in a specific situation. The probability of detection P_d already belongs to [0;1] and does not require additional normalization.

The generalized indicator (5) will then look like:

$$E(s) = w_1 P_d(s) - w_2 T_f^{norm} - w_3 R^{norm}. \quad (7)$$

The rational method is considered to be the method s* that maximizes the value of the generalized indicator:

$$s* = arg\ max(E(s)). \quad (8)$$

The full balance of the mission time T_f is:

$$T_{mission} = T_{transit\ to} + T_{search} + T_{transit\ back} + T_{reserve}, \quad (9)$$

where $T_{transit\ to/back}$ – time of arrival and return;

T_{search} – time of the actual search route (formula (2));
$T_{reserve}$ – safety margin (it is recommended to take ≥ 20–25% of T_{max}).

Then the condition for the admissibility of the route is:

$$T_{mission} \leq T_{max}. \tag{10}$$

Methods that do not satisfy this condition are excluded.

Example of method implementation.

To demonstrate the logic of the proposed method, a conditional calculation example is provided, reflecting a typical situation in which an air reconnaissance unit is employed during the search for offenders within a designated area.

All numerical values in the given example are conditional (illustrative). They serve only to demonstrate the logic of the method application (formation of an admissible set, calculation of indicators, multi-criteria selection) and do not claim to be empirically reliable. The values of the probability of detection P_d , execution time T_f , and resource R intensity were obtained by expert assessments and simplified calculations according to formulas (1)-(3) without prior calibration on real or simulated data.

Input conditions: information has been received about the presence of a group of offenders in forested terrain within an area of S = 5·5 km. Data on the direction of movement are absent. One DJI Matrice 300 RTK UAV is available, with a flight endurance of 55 min, a speed of 15 m/s, a detection range of 800 m in open terrain, reduced to 400 m in forested terrain due to limited visibility. Meteorological conditions: daytime, no precipitation, wind speed 3 m/s.

Additional operational constraints (condition): transit time to the search area $T_{transit}$ = 4 min; return time T_{return} = 4 min; mandatory battery safety reserve $R_{reserve}$ = 20 % (≈ 11 min); available time for pure search $T_{search}^{max} \approx 55 - 4 - 4 - 11 = 36$ min.

Flight time for pure search: T_{search} ≈ 52 min. Total mission time T_{ftotal} ≈ 52+4+4 = 60 min > 55 min (and exceeds the available 36 min after reserve). Conclusion: the “parallel sweeps” technique is operationally inadmissible under the given constraints (violates battery reserve and return requirements), even though the pure search time was mathematically calculated.

According to the admissibility matrix (Table 1), the “comb” technique is excluded due to an insufficient number of UAVs, and the “by direction” technique is excluded due to the absence of movement axis data. The remaining admissible methods are the “expanding box” technique (when location data are available) and “parallel sweeps” (when targets have low speed).

Before calculating the generalized indicator, the values of task execution time and resource consumption are normalized to the interval [0; 1], enabling comparison with the probability of detection.

Under conditional (illustrative) assumptions, calculation for the “expanding box” technique:

basic detection range d = 400 m;

the area covered by the first “circle” depends on the step of the expanding grid;

approximate task execution time is about 45 min;

the probability of detection is conditionally accepted: P_d = 0.65 (estimated by experts, accounting for the reduction in detection range to 400 m in the forest and limited overlap).

For the “parallel sweeps” technique:

number of sweeps: n = S/b = 5000 / (1,5·400) ≈ 9 sweeps;

sweep length L = 5000 m;

flight time: T_f = (9·5000)/15 + 8·tR ≈ 3000 s + 120 s = 52 min;

the probability of detection, taking overlap into account, is conditionally 0.85 (according to the formula with $p_j = \frac{d}{b}$ and 25% overlap).

The given conditional example demonstrates that even with formally acceptable calculations of the “pure” search time, accounting for transit, return, and safety margin can render the route operationally infeasible. This emphasizes the need to include these constraints from the outset when forming the admissible set of methods.

Selection: when the priority is the probability of detection ($w = (0{,}6;\ 0{,}2;\ 0{,}2)$), the "parallel sweeps" technique is selected:

$$E \approx 0.85 \cdot 0.6 - 0.87 \cdot 0.2 - 0.95 \cdot 0.2 = 0.51 - 0.174 - 0.19 = 0.146$$

against

$$0.65 \cdot 0.6 - 0.75 \cdot 0.2 - 0.82 \cdot 0.2 = 0.39 - 0.15 - 0.164 = 0.076$$

for the "expanding box" technique.

When the priority is to minimize time (w_1=0.2, w_2=0.6, w_3=0.2), the "expanding box" technique is selected:

$$E \approx 0.65 \cdot 0.2 - 0.75 \cdot 0.6 - 0.82 \cdot 0.2 = 0.13 - 0.45 - 0.164 = -0.484$$

against

$$0.85 \cdot 0.2 - 0.87 \cdot 0.6 - 0.95 \cdot 0.2 = 0.17 - 0.522 - 0.19 = -0.542.$$

To test the stability of the ranking, a sensitivity analysis was conducted to assess the effects of changes in weighting factors. Four priority scenarios were considered (Table 2).

Table 2: Sensitivity analysis of weighting factors

Scenario	w_1	w_2	w_3	E ("parallel sweeps")	E ("expanding box")	The chosen method
Max. P_d	0,6	0,2	0,2	0,146	0,076	parallel sweeps
Min. time	0,2	0,6	0,2	–0,542	–0,484	expanding box
Min. resource	0,2	0,2	0,6	…	…	…
Balanced	0,4	0,3	0,3	…	…	…

The results (Table 1) show that the ranking varies with the task's priorities, as expected for the method. Additionally, the effect of small variations in the weights (±0.05…0.10) around the baseline scenarios was tested. Across these variations, the selected method remains stable, indicating acceptable solution stability in the vicinity of the given priorities. A full sensitivity analysis (including a change in the normalization scale) should be performed after calibration P_d, T_f, and R on empirical or simulated data.

The conditional example illustrates the internal logic of the proposed selection procedure and its adaptability to different task priorities. It shows how the ranking of admissible techniques can change depending on the chosen weights, but does not constitute empirical confirmation of the method's operational effectiveness.

Limitations of the numerical example and directions of its validation. The given conditional calculation confirms only the method's internal logic and adaptability to different task priorities (w_1, w_2, w_3). It is not a validation of operational efficiency. To confirm the practical suitability of the method, the following are required: field or experimental studies with recording of actual P_d , T_f , and R for each tactical technique in typical conditions of the state border; simulation modeling (agent or Monte-Carl) taking into account the stochastic nature of the offender's movement; comparison of the results of the method with decisions made by experienced officials (expert validation); further software implementation as a decision support module with the possibility of updating calibration coefficients.

Discussion

The proposed method addresses a problem that remains insufficiently formalized in existing approaches to the use of unmanned aviation systems in state border protection. Its essence does not lie in describing a new tactical technique, but in creating a procedure for selecting a rational course of action from among already known techniques, depending on the operational environment, available resources, and task priorities. This makes it possible to consider the employment of an air reconnaissance unit as a controlled process of selecting alternatives, rather than as a decision made exclusively on the basis of an official's practical experience.

The study's findings extend prior work examining the use of unmanned aerial vehicles in security and defense. D. O. Chernousov (2022) focuses on the experience of using unmanned aerial vehicles by units of the Ministry of Internal Affairs of Ukraine, while Yu. O. Babii et al. (2022) analyze the development of unmanned aviation and its technical characteristics. V. Servatiuk, M. Lysyi, and A. Mostovyi (2024) examine scientific approaches to the development and use of unmanned aerial vehicles in modern military conflicts. Unlike these works, the present study focuses not on the general potential of unmanned aviation or the characteristics of technical means, but on the procedure for selecting a specific tactical technique for the actions of an air reconnaissance unit.

An important basis for the proposed method is the research report by O. V. Sitailo (2023), which systematizes tactical techniques for employing unmanned aviation systems in state border protection. At the same time, in that work, such techniques are presented mainly as possible courses of action under defined conditions of their application. The approach proposed in this article complements these provisions with a formalized selection mechanism that determines which techniques are admissible under specific conditions and compares them based on the probability of detection, task execution time, and resource expenditure.

Comparisons with international studies show that most current work focuses on border patrolling, route planning, autonomous navigation, area coverage, or the use of unmanned aerial vehicles in groups. N. Ahmadian et al. (2022) consider the use of drones in border patrolling tasks, taking into account budgetary and resource constraints. B. Biskin, J. Fliege, and A. Martínez-Sykora (2025) study autonomous navigation of unmanned aerial vehicles for border patrolling, taking into account the stochastic nature of offender movement. S. Ghambari et al. (2024) systematize modern methods of unmanned aerial vehicle route planning.

In the works of X. Fan et al. (2024), İ. Güven and E. Yanmaz (2024), and Y. Lyu et al. (2024), attention is focused on search routes, area coverage, and cooperative flight mission planning. S. Kazemdehbashi and Y. Liu (2025) and T. Quadt et al. (2024) address the issues of area coverage, consideration of external conditions, and the combination of several optimization criteria. D. J. Duxbury, N. W. Paton, and J. A. Keane (2024) examine dynamic decision support using drones. A common feature of these approaches is their orientation toward optimizing flight mission parameters or supporting the choice among alternative decisions. The difference of the proposed method is that it is aimed not only at route planning but also at selecting a tactical technique for employing an air reconnaissance unit under state border protection conditions.

The example of method implementation confirms that the rational course of action may change depending on task priorities. If the main priority is to increase the probability of detecting an offender, one tactical technique may be preferable. If the primary priority is to reduce task execution time, another course of action may prove to be rational. This demonstrates the practical significance of using weighting coefficients, which enable the selection procedure to be adapted to a specific operational situation and the decision-maker's priorities.

At the same time, the proposed method has certain limitations. Within the scope of this study, the main parameters of the operational environment, the technical characteristics of the unmanned aerial vehicle, meteorological conditions, and resource constraints were considered. However, further consideration should be given to the crew training level, the availability of electronic warfare assets, the time of day, the offender's behavior, and the degree of uncertainty in the initial information. A promising direction is also the software implementation of the proposed method as a decision-support module for automated control systems of border guard units.

All conclusions regarding the method's practical significance at this stage are hypothetical. They are based on the formal logic of the procedure and a conditional example, and require confirmation using field, experimental, or simulation data.

Conclusions

Thus, the study improves the scientific and methodological framework for planning the employment of an air reconnaissance unit by developing a formalized method for selecting a rational tactical approach to the use of unmanned aviation systems in state border protection. The proposed approach provides for the sequential identification of operational environment conditions, the formation of a set of admissible courses of action, the calculation of effectiveness indicators for each admissible method, and the selection of a rational option according to a generalized criterion.

The scientific novelty of the obtained results lies in proposing that the selection of a tactical technique for employing an air reconnaissance unit be carried out not on the basis of an official's empirical experience, but through a formalized multicriteria assessment procedure. Within the proposed method, three interrelated groups of indicators are considered: the probability of offender detection, task execution time, and the unmanned aerial vehicle's resource consumption. This allows selecting a course of action based on the priorities of a specific task: maximizing the probability of detection, minimizing task execution time, or ensuring the rational use of resources.

The potential practical significance of the proposed method lies in providing a formalized procedure that could increase the validity of decisions made by officials of state border protection bodies when selecting a technique for employing available unmanned aviation systems. Subject to empirical validation, the method may help reduce the influence of purely subjective factors, support more consistent planning of air reconnaissance, and facilitate adaptation of the chosen technique to specific task priorities. At present, however, these expected effects remain hypothetical and require confirmation through field experiments, simulation studies, or operational testing. Its use may reduce decision-making time, unify approaches to air reconnaissance planning, improve the efficiency of unmanned aerial vehicle resource use, and reduce the influence of subjective factors when selecting a tactical technique. The method may be implemented either as an algorithm within the automated workstation of a unit commander or as a table or decision matrix for use under field conditions.

Further research should focus on expanding the set of factors considered when selecting a tactical technique, in particular, crew training level, availability of electronic warfare assets, time of day, and the degree of uncertainty in the initial information. Special attention should be paid to improving the method for calculating the probability of detection, taking into account the stochastic nature of offender movement, as well as to developing software implementation of the proposed method as a decision-support module for automated control systems of border guard units.

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Conflict of Interest

The authors report a potential conflict of interest: the Editorial Board members, Artem V. Bratko and Dmytro A. Kupriienko, work at the same institution as the authors. This circumstance has been declared in accordance with the journal's requirements and did not affect the objectivity of the results obtained or the conclusions presented.

Use of Artificial Intelligence

During manuscript preparation, artificial intelligence tools were used for language editing, technical verification of the text structure, and alignment of certain formulations with the journal's requirements. The study's content, scientific results, interpretation of the findings, and final conclusions were formulated by the authors. The authors bear full responsibility for the content of the manuscript.

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