

# Selection of unmanned aerial vehicle systems for border monitoring using the MPSI-SPOTIS method

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## Abstract

**Purpose** – The present paper assesses the decision problem of selecting Unmanned Aerial Vehicle Systems (SARP) by the hybrid MPSI-SPOTIS approach for deployment in border control and transborder illicit combat.

**Design/methodology/approach** – By the hybrid MCDA MPSI-SPOTIS approach, and from the database available in Gettinger (2019), models were filtered by Endurance, Range, Maximum Take-Off Weight (MTOW), and Payload, fitting within the classification of Categories EB 0 and 2. Category EB 1 was not considered in this study due to the limited number of models in the data source.

**Findings** – The use of the Multi-Criteria Decision Analysis (MCDA) tool MPSI-SPOTIS allowed the determination of weights by stochastic criteria, applied in a ranking method resistant to reverse ordering. The application of the method identified the Raybird-3 (Cat EB 0) and Searcher (Mk3) (Cat EB 2) models as the best alternatives. From a proposed clustering, other selection possibilities with close performance in the evaluation were presented. The cost criterion was not taken into consideration due to the absence of information in the data source employed. Future studies are suggested to include criteria related to the life cycle and acquisition cost of the models.

**Research limitations/implications** – The cost criterion was not taken into consideration due to the absence of information in the data source used. Future studies are suggested to include criteria related to the life cycle and acquisition cost of the models.

**Originality/value** – This paper aims to propose a technology selection method applied to complex defense acquisitions when multiple factors influence the decision makers and it is hard to obtain a major optimum solution in multitask and multi-mission platform.

**Keywords** MCDA, MPSI, SPOTIS, UAV, Drone, SISFRON

**Paper type** Research paper

## 1. Introduction

### 1.1 Practical and methodological aims of the study

This paper aims to explore the use of the Multi-Criteria Decision Analysis (MCDA) method MPSI-SPOTIS for the selection of UAVs (in Brazilian Portuguese – *Sistemas de Aeronaves*



*Remotamente Pilotadas* - SARP) intended for border monitoring, considering the various demands associated with their use. This study is based on the framework proposed by the Center for the Study of the Drone – Bard College (Gettinger, 2019), which encompasses technical data on SARPs from various countries.

To achieve this goal, this paper approaches the research problem in an attempt to identify a proper MCDA method to evaluate SARPs in the context of board control in Brazil, satisfying the following objectives: provide a description of the problem context; identify MCDA methods applied to similar problems; describe the MPSI-SPOTIS method; and rank the SARPs by the application of MPSI-SPOTIS.

### *1.2 Motivation for conducting research*

The United Nations (UN), aiming to drive global development, established the Sustainable Development Goals (SDGs), of which Brazil is a signatory (UN, 2023). This set of goals encompasses 17 development axes, with SDG 16 - Peace, Justice, and Strong Institutions - including the combat against transborder crimes (UN Brazil, 2015).

In this context, the Brazilian National Defense Policy, the Brazilian National Defense Strategy (Brazil, 2020a), and Complementary Law No. 97 and its amendments (Brazil, 1999) assign to the Armed Forces the responsibility of defending the national territory, ensuring sovereignty, maintaining law and order, as well as operating on the border. These documents established National Defense Objectives and oriented the participation of the Armed Forces in the fight against transborder crimes.

The Brazilian Army instituted the Strategic Program of the Army Integrated Border Monitoring System (SISFRON), part of the Integrated Border Protection Program. Its purpose is to promote “the integration and coordination of public security, intelligence, customs control, and the Armed Forces’ actions with the actions of states and municipalities located in the border strip and neighboring countries” (Brazil, 2017).

SISFRON is a system composed of Systems and Materials for Military Use (SMEM), which aim to monitor, sense, and provide decision support in the Brazilian border strip. The use of technological solutions allows “enhancing the current Operational Capabilities of troops already deployed in this area of the national territory, whether in fulfilling their constitutional mission or acting in subsidiary assignments through cooperation with different agencies” (Brazil, 2017).

Among the essential components of SISFRON, the use of Unmanned Aerial Vehicle Systems (SARP) stands out. SARPs must have features such as the ability to communicate with other systems, support sensing and monitoring activities, and potentially transport cargo (Brazil, 2020b).

The Unmanned Aerial Vehicle Systems project (Brazil, 2020c) aims to establish the life cycle management of SARPs within the scope of the Brazilian Army. This document regulates the conditions for acquisition and logistics for the maintenance of SMEMs of Categories EB (Cat EB) 0 to 2 until the year 2035, within the context of the Army Strategic Program for Full Operational Capability Acquisition (Prg EE OCOP) (Brazil, 2020c, 2023).

Among the challenges outlined in the project initiation directive (Brazil, 2020c), the following stands out: the possibilities and the impacts of financing systems and materials obtained for the project, considering the life cycle of SMEM; obtaining SMEM, seeking to prioritize the national Defense Industrial Base (BID); reduction of technological gaps and external dependence on SMEM to be obtained; constant need for system replacement due to obsolescence, discontinuation, or wear and tear from use; and continuous study of the evolution of doctrine and new materials that can be adopted.

The main risks identified regarding the material include (Brazil, 2020c): acquisition of SMEM whose production line is closed or obsolete, leading to future difficulties in obtaining

supplies; lack of capacity of Science, Technology, and Innovation (STI) institutions and/or national companies to develop or produce the material properly, making deliveries dependent on foreign technologies; discontinuity and/or insufficient budgetary resources for investment and financing; interruption of the supply of SARP's materials or loss of qualification of suppliers; and costs arising from frequent replacements of systems, especially in categories 0 and 1, due to wear and rapid obsolescence.

The Brazilian Land Operations Command (COTER), an organ of the Brazilian Army, established the guidelines for the use and responsibilities in SARPs (Brazil, 2023). In this document, an Unmanned Aerial Vehicle (UAV) is defined as “an airborne vehicle in which the operator is not on board (unmanned), being controlled remotely from a pilot station, for the execution of a specific activity or task” (Brazil, 2023).

### 1.3 The contributions of the study

This paper offers a MCDA approach to the assessment of technological solutions, particularly SARP systems, through the application of MPSI-SPOTIS methods. The MPSI weight definition method allows a suitable approach for the context of research based on the alternatives' performance in each criterion, and the SPOTIS ranking method has the feature of reverse ranking resistance. Therefore, a novel viewpoint to tackle the complexity of military systems' selection is proposed that considers the possibility of allowing the decision-maker to insert or withdraw alternatives without modifying the previous ranking.

### 1.4 Organization of the paper

This paper is divided into the following sections: Introduction (Section 1) provides initial insights of the problem context; Problem Description (Section 2) depicts essential aspects of SARPs systems; Literature Analysis (Section 3) presents a literature overview of MCDM methods applied to military technology solutions assessment; Methodology (Section 4) describes the MPSI-SPOTIS method approach; Solution of the Problem (Section 5) shows the application of MPSI-SPOTIS in SARP ranking, compares with others MCDA approaches and offers a sensitivity test; Results (Section 6) discusses the major insights of the obtained ranking; and Conclusion (Section 7) debates the research goals, insights, contributions, limitations and future researches.

## 2. Problem description

An Unmanned Aerial Vehicle System is a “set of means necessary for the accomplishment of a specific task using UAVs” (Brazil, 2023), composed of the parts presented in Figure 1.

Unmanned Aerial Vehicles (UAVs), or aerial platforms, include the propulsion system, electrical system, and embedded navigation and control system. The payload consists of

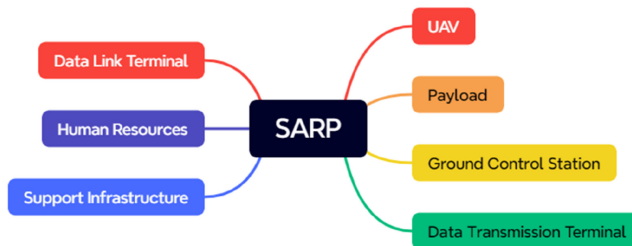


Figure 1.  
Components of a SARP

Source(s): Figure adapted from Brazil (2023)

sensors and equipment onboard for the fulfillment of the assigned mission, which may encompass electro-optical sensors, infrared sensors, radars, pointers, and laser systems, and Electronic Warfare (EW) systems (Brazil, 2023).

The Ground Control Station (GCS) serves as the interface between the operator, UAV, and payload. Depending on the category of the UAV, it can be portable or installed in vehicles or shelters. The GCS typically comprises the command for the UAV and the command for the payload. The Data Transmission Terminal (DTT) consists of equipment linking the aircraft to the GCS, combining both telemetry and coordination with air control (Brazil, 2023).

The Data Link Terminal (DLT) is composed of equipment that enables data flow between the GCS and the command-and-control center of the military unit of interest. Finally, the support infrastructure brings together resources and means to sustain logistical and maintenance aspects of the operation (Brazil, 2023).

To classify UAVs into groups, COTER proposed classes based on payload capacity called Categories EB (Cat EB), as outlined in Table 1.

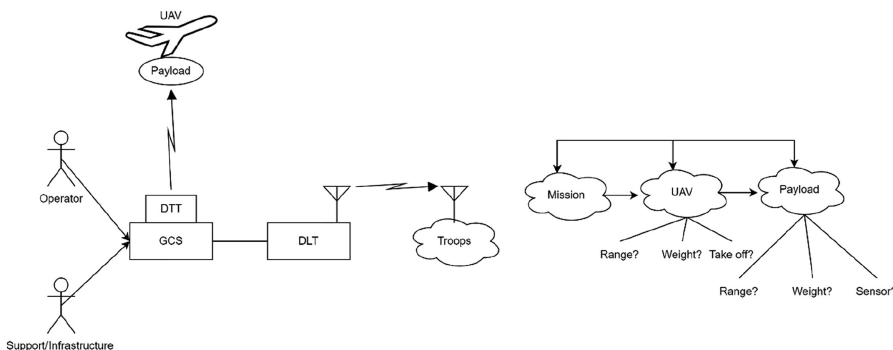
The Brazilian Army's need to acquire the capability to operate UAV-type aerial vehicles and the complexity associated with the selection of systems based on various criteria constitute a complex problem, suitable for the use of Multi-Criteria Decision Analysis (MCDA) methods. In this context, the MPSI-SPOTIS method emerges as a decision support tool applicable to a project of relevance to Brazil.

The center of the decision problem lies in the complexity of selecting from many alternatives of aerial platforms capable of fulfilling various missions they will be subjected to. The specific nature of a given task implies variations in the selection of payload, takeoff characteristics (MTOW), and the required flight time and distance. Figure 2 provides a rich picture of the inherent complexity of this decision-making process.

Class	Category EB	Payload (kg)	Deployment force	Deployment level
III	5	>600	MD/EMCFA	Strategic
III	4		C Cj/FTC	Operational
II	3	150–600	FTC (Division/C Ex)	Tactical
I	2	15–150	Brigade/Division	
	1	<15	U/Brigade (Light)	
	0	<10	até SU	

Source(s): Table adapted from Brazil (2023)

Table 1.  
SARP categories



Source(s): Figure by authors

Figure 2.  
Rich picture of SARP  
selection for a  
deployment

### 3. Literature analysis

In a broad approach, the application of MCDM methods in defense sciences has been the subject of many studies. Among the most recent, it is noteworthy the trending topics of evaluation of life cycle management (Girardi *et al.*, 2022); selection of weapon systems (Radovanović *et al.*, 2023, 2024), selection of  $4 \times 4$  vehicles (Gavião *et al.*, 2024), fighter aircraft (Rajukar *et al.*, 2023); combat helicopters (Kurnaz *et al.*, 2023); optimization of anti-aircraft missile system (Akram *et al.*, 2024), anti-UAV systems selection (Moreira *et al.*, 2023); defense supplier selection (Desticiglu Tasdemir and Asilogullari Ayan, 2024; Güneri and Deveci, 2023; Rasmussen *et al.*, 2023); cybersecurity systems (Al-Hchaimi *et al.*, 2023; Belal and Sundaram, 2023); strategy selection (Tešić *et al.*, 2023) and technology evaluation (Girardi and Santos, 2023).

The main MCDA methods found were: AHP (Gavião *et al.*, 2024), AHP-VIKOR (Radovanović *et al.*, 2023), AHP-MOORA-VIKOR (Rajukar *et al.*, 2023), AHP-TOPSIS-SECA (Rasmussen *et al.*, 2023), AHP-TOPSIS-2N (Girardi and Santos, 2023), AHP-FTOPSIS (Desticiglu Tasdemir and Asilogullari Ayan, 2024), AHP-EDAS (Güneri and Deveci, 2023), LMAW-G-EDAS (Radovanović *et al.*, 2024), ELECTRE III (Akram *et al.*, 2024), F-FDOSM-CRITIC (Al-Hchaimi *et al.*, 2023), MEREC-VIKOR (Belal and Sundaram, 2023), Grey SWARA (Kurwaz *et al.*, 2023), DIBR-DOMBI-Fuzzy MAIRA (Tešić *et al.*, 2023), and SAPEVO-H2 (Moreira *et al.*, 2023).

Particularly, when analyzing the literature regarding SARP selection, the search descriptors (“unmanned aerial vehicles” OR “uav” OR “drone”) AND (“selection” OR “evaluation” OR “prioritization”) AND (“multicriteria” OR “multi-criteria”) were utilized in the Scopus database, retrieving 91 documents. The inclusion and exclusion criteria applied were: the time period between the years from 2018 to 2023; only papers, conference papers and journals as the source; English language; and a filter based on the title and abstract of documents related to the topic.

Figure 3 summarizes the literature search and filtering process, highlighting the stages of identification and selection of documents.

The bibliometric analysis conducted using the Biblioshiny software (Aria and Cuccurullo, 2017) provided general data from the field, as shown in Figure 4. Noteworthy is the growth trend in the subject’s interest (annual growth rate of 14.87%) and the significant international collaboration (35% co-authorship), indicating the global interest and relevance of the selection of SARPs.

Figure 5 describe the temporal evolution of the number of publications per year, with the trend line indicating the growth in the number of documents. The year 2021 exhibited the highest number of publications.

Table 2 presents the top 10 publication sources found, ordered by the number of documents and their H-index. Procedia Computer Science stood out with two publications. Overall, no clear prevalence of one source over another was demonstrated.

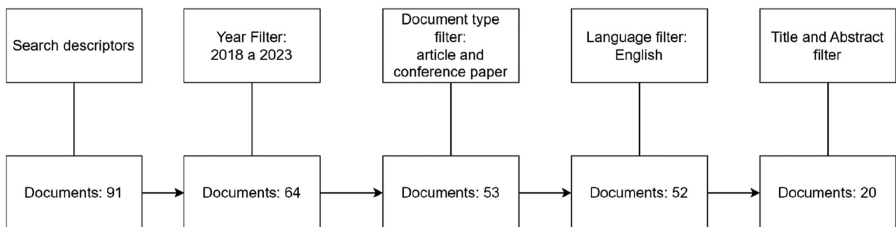
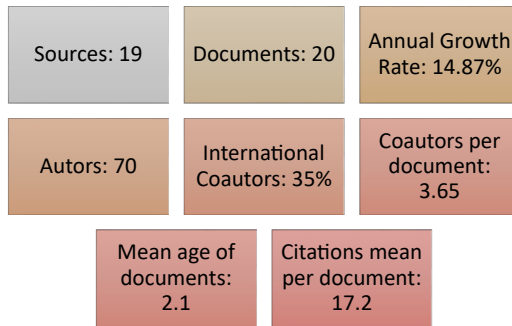


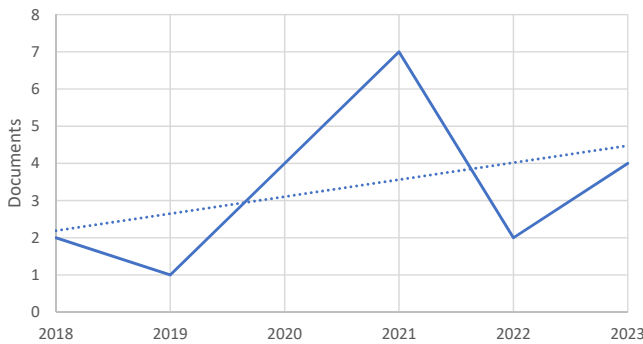
Figure 3. Search steps

Source(s): Figure by authors



**Figure 4.**  
Research field  
overview

**Source(s):** Figure by authors



**Figure 5.**  
Publications per year

**Source(s):** Figure by authors

Sources	Documents	H index
Procedia Computer Science	2	109
Expert Systems with Applications	1	249
Information Sciences	1	210
IEEE Access	1	204
Computers and Industrial Engineering	1	148
Industrial Management and Data Systems	1	117
Soft Computing	1	102
Mathematical Problems in Engineering	1	78
Complexity	1	72
Advances in Intelligent Systems and Computing	1	58

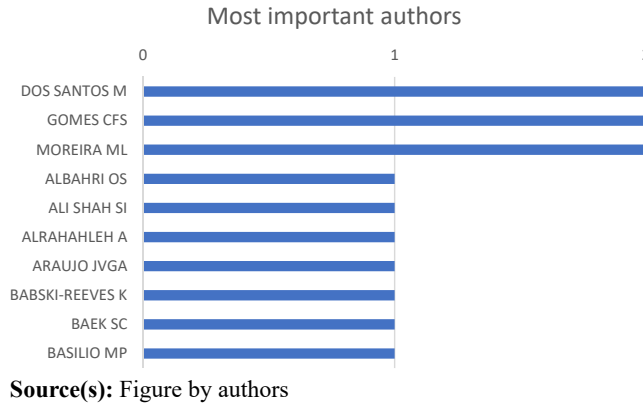
**Table 2.**  
Relevant sources

**Source(s):** Table by authors

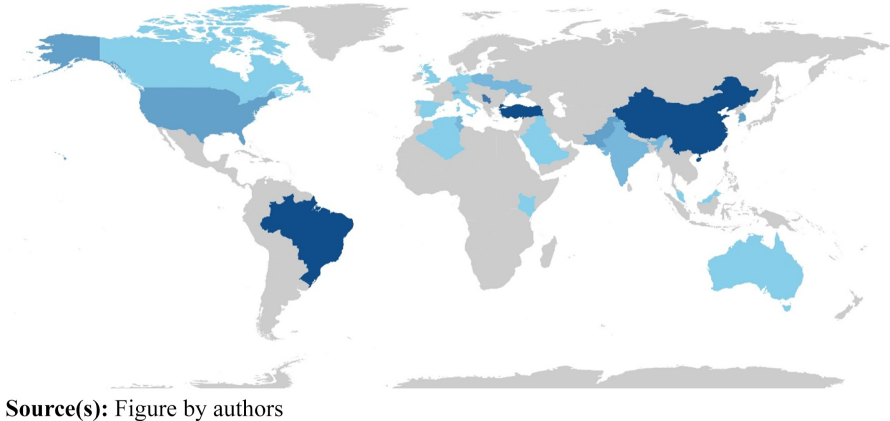
Figure 6 displays the most important authors, and Figure 7 shows the most relevant countries. Authors dos Santos, Gomes, and Moreira emerged as prominent figures, combined with Brazil's leadership in scientific production in the field, indicating the formation of a significant research group.

Table 3 presents the top 15 publications in the field, ordered by Total Citations (TC). Notably, *Moreira et al. (2020)* and *Moreira et al. (2021)* appears twice, which, when combined

**Figure 6.**  
Most relevant authors



**Figure 7.**  
Most relevant countries



with [Figures 6 and 7](#), underscores the importance of Brazilian institutions in the field of MCDA.

Analyzing the history of the seminal paper on the SPOTIS method ([Dezert et al., 2020](#)) using the [LITMAPS tool \(n.d.\)](#), there is a substantial volume of related papers, indicating the consolidation of the MCDA method ([Figure 8](#)).

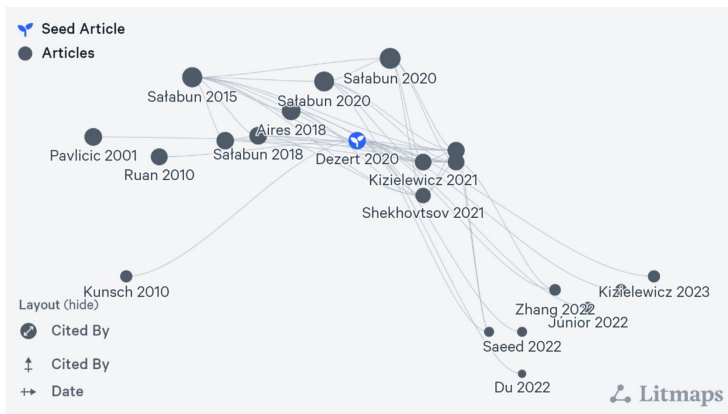
The MCDA methods used in the relevant publications ([Table 3](#)) include: AHP ([Canetta et al., 2018](#)), AHP-ANP-DEMATEL ([Zhang et al., 2023](#)), AHP-TOPSIS ([Hamurcu and Eren, 2020](#); [Dukić et al., 2022](#)), TOPSIS ([Karaşan and Kaya, 2020](#)), Fuzzy TOPSIS ([Topaloglu et al., 2018](#); [Nur et al., 2020](#)), DEMATEL ([Raj and Sah, 2019](#)), WASPAS ([Simić et al., 2021](#)), PROMETHEE-SAPEVO-MI ([Moreira et al., 2020, 2021](#)), Spherical Fuzzy MARCOS ([Kovač et al., 2021](#)), CoCoSo ([Pamucar et al., 2023](#)), and SAGA ([Mohamadi et al., 2021](#)).

As for the types of problems addressed, 5 focused on UAV for military applications ([Dukić et al., 2022](#); [Hamurcu and Eren, 2020](#); [Karaşan and Kaya, 2020](#); [Moreira et al., 2020, 2021](#)), 4 addressed drone product delivery ([Kovač et al., 2021](#); [Nur et al., 2020](#); [Raj and Sah, 2019](#); [Simić et al., 2021](#)), 2 dealt with transportation systems and control ([Mohamadi et al., 2021](#);

Document	Total citations (TC)	TC mean/year	Normalized TC
RAJ A, 2019, COMPUT IND ENG	73	14.60	1.00
SIMIĆ V, 2021, EUR TRANSP RES REV	45	15.00	2.74
MOREIRA ML, 2020, SPRINGER PROC MATH STAT	42	10.50	1.81
MOREIRA ML, 2021, PROCEDIA COMPUT SCI	39	13.00	2.37
HAMURCU M, 2020, J MATH	33	8.25	1.42
TOPALOGLU M, 2018, SOFT COMPUT	28	4.67	1.87
KOVAČ M, 2021, COMPLEXITY	22	7.33	1.34
PAMUČAR D, 2023, INF SCI	17	17.00	2.83
NUR F, 2020, J COMPUT DES ENG	13	3.25	0.56
DUKIĆ D, 2022, YUGOSL J OPER RES	8	4.00	1.78
MOHAMADI HE, 2021, EXPERT SYS APPL	7	2.33	0.43
KARAŞAN A, 2020, ADV INTELL SYS COMPUT	5	1.25	0.22
ZHANG JZ, 2023, IND MANAGE DATA SYS	5	5.00	0.83
CANETTA L, 2018, INT CONF ENG, TECHNOL INNOV: ENG, TECHNOL INNOV MANAG BEYOND: NEW CHALLENGES, NEW APPROACHES, ICE/ITMC - PROC	2	0.33	0.13
SOHAIB KHAN M, 2021, PROC INT BHURBAN CONF APPL SCI TECHNOL, IBCAST	1	0.33	0.06

Source(s): Table by authors

**Table 3.**  
Most relevant documents



Source(s): Figure adapted from Litmaps ([n.d.])

**Figure 8.**  
Most relevant documents of SPOTIS method

Pamucar *et al.*, 2023), and 1 focused on value chain analysis (Canetta *et al.*, 2018), and environmental solutions (Topaloglu *et al.*, 2018).

#### 4. Methodology

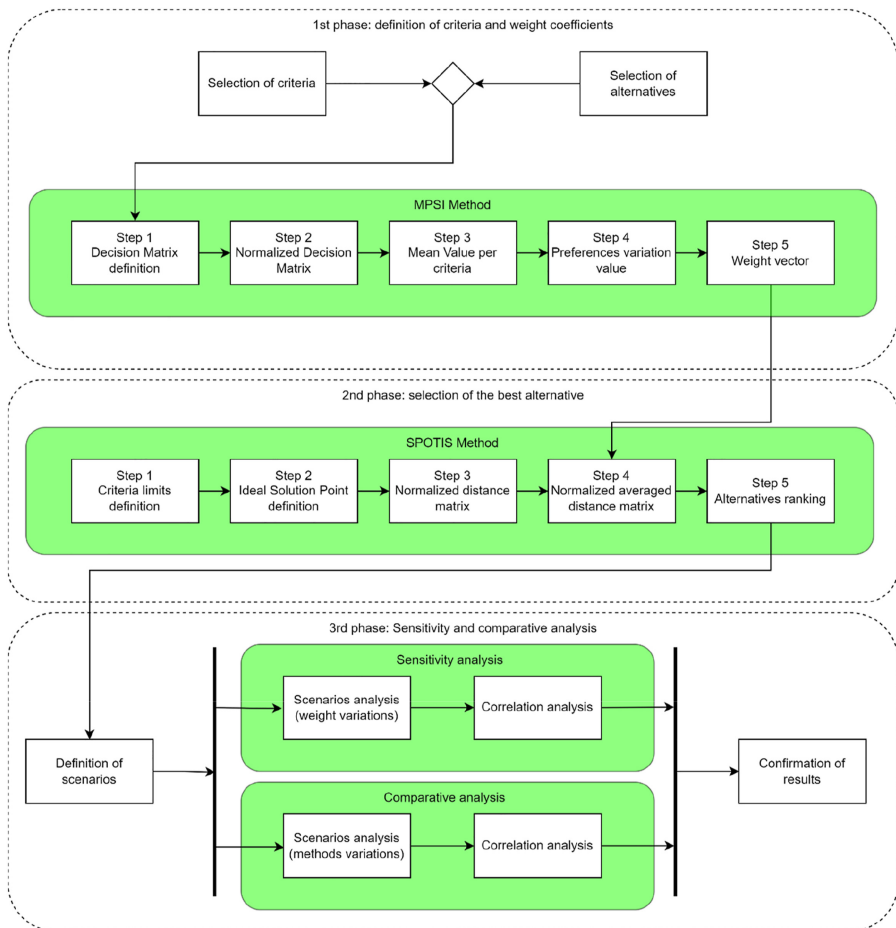
This paper proposes a case study with a hybrid MCDA approach, combining the Modified Preference Selection Index (MPSI) (Gligorić *et al.*, 2022) and the Stable Preference Ordering Towards Ideal Solution (SPOTIS) (Dezert *et al.*, 2020). The choice of the MPSI method aims to obtain weights, eliminating the need to define the relative importance between criteria since it

is calculated using stochastic concepts without the expression of criteria preferences by decision-makers. SPOTIS stands out for being a method designed to avoid reverse ordering, allowing the inclusion or exclusion of alternatives without altering the previous result.

The MPSI-SPOTIS hybrid approach explores the calculation of criterion weights through statistical measures of preference values from the MPSI method (Gligorić *et al.*, 2022) and ranks the results obtained by SPOTIS. This approach allows flexibility to change the decision environment without causing reverse ordering due to changes in expressed preferences (Dezert *et al.*, 2020). The constituent steps of this process are schematically presented in Figure 9.

#### 4.1 MPSI method steps

The MPSI method proposed by Gligorić *et al.* (2022) comprises five steps. In Step 1, the definitions of objectives, criteria, alternatives, and preference values take place. Considering the set of alternatives  $A = \{A_i\}$  for  $i = \{1, 2, 3, \dots, m\}$ , the set of criteria  $C = \{C_j\}$  for



**Figure 9.**  
MPSI-SPOTIS steps

Source(s): Figure by authors

Model	Cat EB 0				Cat EB 2						
	Country	Endurance	Range	MTOW	Payload	Model	Country	Endurance	Range	MTOW	Payload
Orbiter 3	Israel	7	150	30	5.5	Searcher (Mk 3)	Israel	18	250	450	120
Ptero-5F	Russia	8	75	30	5	Seeker 400	South Africa	16	250	450	100
Raybird-3	Ukraine	15	240	21	5	Falco	Italy	14	200	490	70
FlyEye	Peru	2.5	30	11	4	Burevestnik-MB	Belarus	10	290	400	60
Fulmar X	Spain	8	80	20	4	Bayraktar-TB2	Turkey	20	150	630	55
FT-100 Horus	Brazil	2	20	7	3	CamCopter S-100	Austria	10	200	200	50
IT180-3EL-1	France	0.8	10	21	3	ASN-206	China	8	150	222	50
Orbiter-1K	Israel	2.5	100	11	2.6	ASN-209	China	10	200	320	50
MicroFalcon	Israel	4	40	10	2	Shahpar	Pakistan	7	250	480	50
Spectator-M	Ukraine	2	50	5.5	2	Horlytsya	Ukraine	7	1,050	200	50
Observer-S	Ukraine	5	100	6.5	1.5	RQ-7 Shadow	USA	9	125	212	43
SpyRanger	France	3	30	14.5	1.2	Aludra (Mk1)	Malaysia	3	100	200	25
Skylark I-LEX	Israel	3	40	7.5	1.2	PGZ-19R	Peru	12	150	90	20
Serce-1	Turkey	0.5	3	6.5	1						
XeFI	South Korea	0.5	3	3	0.5						
Mosquito	Belarus	0.75	12	2.8	0.35						
InstantEye Gen3	USA	0.5	2	0.5	0.3						
Aladin	Germany	1	15	3.2	0						

Source(s): Table adapted from [Gettinger \(2019\)](#)

**Table 4.**  
Assessed models

**Table 5.**  
Normalized decision  
matrix

Objective Model	Cat EB 0					Cat EB 2					
	Country	Max Endurance	Max Range	Max MTOW	Max Payload	Objective Model	Country	Max Endurance	Max Range	Max MTOW	Max Payload
Orbiter 3	Israel	0.4667	0.6250	1.0000	1.0000	Searcher (Mk 3)	Israel	0.9000	0.2381	0.7143	1.0000
Ptero-5E	Russia	0.5333	0.3125	1.0000	0.9091	Seeker 400	South Africa	0.8000	0.2381	0.7143	0.8333
Raybird-3	Ukraine	1.0000	1.0000	0.7000	0.9091	Falco	Italy	0.7000	0.1905	0.7778	0.5833
FlyEye	Peru	0.1667	0.1250	0.3667	0.7273	Burevestnik-MB	Belarus	0.5000	0.2762	0.6349	0.5000
Fulmar X	Spain	0.5333	0.3333	0.6667	0.7273	Bayraktar-TB2	Turkey	1.0000	0.1429	1.0000	0.4583
FT-100 Horus	Brazil	0.1333	0.0833	0.2333	0.5455	CamCopter S-100	Austria	0.5000	0.1905	0.3175	0.4167
IT180-3EL-1	France	0.0533	0.0417	0.7000	0.5455	ASN-206	China	0.4000	0.1429	0.3524	0.4167
Orbiter-1K	Israel	0.1667	0.4167	0.3667	0.4727	ASN-209	China	0.5000	0.1905	0.5079	0.4167
MicroFalcon	Israel	0.2667	0.1667	0.3333	0.3636	Shahpar	Pakistan	0.3500	0.2381	0.7619	0.4167
Spectator-M	Ukraine	0.1333	0.2083	0.1833	0.3636	Horlytsya	Ukraine	0.3500	1.0000	0.3175	0.4167
Observer-S	Ukraine	0.3333	0.4167	0.2167	0.2727	RQ-7 Shadow	USA	0.4500	0.1190	0.3365	0.3583
Spy Ranger	France	0.2000	0.1250	0.4833	0.2182	Aludra (Mk1)	Malaysia	0.1500	0.0952	0.3175	0.2083
Skylark J-LEX	Israel	0.2000	0.1667	0.2500	0.2182	PGZ-19R	Peru	0.6000	0.1429	0.1429	0.1667
Serçe-1	Turkey	0.0333	0.0125	0.2167	0.1818						
XeFI	South Korea	0.0333	0.0125	0.1000	0.0909						
Mosquito	Belarus	0.0500	0.0500	0.0933	0.0636						
InstantEye Gen3	USA	0.0333	0.0083	0.0167	0.0545						
Aladin	Germany	0.0667	0.0625	0.1067	0.0000						

**Source(s):** Table by authors

$j = \{1, 2, 3, \dots, n\}$ , and the preference value  $x_{ij}$  for each alternative  $A_i$  concerning criterion  $C_j$ , the matrix given by  $M = [x_{ij}]_{m \times n}$  is defined as a decision matrix.

Step 2 involves normalizing the data by transforming values  $x_{ij}$  into a range from 0 to 1 while maintaining proportions. For the calculation, it is necessary to define the objective of the criteria as either benefit-monotonic or cost-monotonic. Benefit criteria aim for the highest possible value and are normalized using Equation (1), while cost criteria aim for minimization, described by Equation (2).

$$r_{ij} = \frac{x_{ij}}{x_j^{max}} \tag{1}$$

$$r_{ij} = \frac{x_j^{min}}{x_{ij}} \tag{2}$$

Steps 3 and 4 involve obtaining the values of the preferences  $p_j$  applying Equations (3) and (4).

$$v_j = \frac{1}{N} \sum_{i=1}^m r_{ij} \tag{3}$$

$$p_j = \sum_{i=1}^m (r_{ij} - v_j)^2 \tag{4}$$

In step 5, the vector of weights  $w_j$  is calculated using Equation (5), where  $w_j$  is used in step 4 of the SPOTIS method.

$$w_j = \frac{p_j}{\sum_{j=1}^n p_j} \tag{5}$$

Cat EB	–	Endurance	Range	MTOW	Payload	Cat EB	Endurance	Range	MTOW	Payload
0	$v_j$	0.2446	0.2315	0.3907	0.4258	2	0.5538	0.2465	0.5304	0.4763
	$p_j$	1.0759	1.1278	1.5647	1.7488		0.6923	0.6496	0.7699	0.6135
	$w_j$	0.1950	0.2044	0.2836	0.3170		0.2540	0.2384	0.2825	0.2251

Source(s): Table by authors

**Table 6.**  
Value of vectors  $v_j$ ,  $p_j$   
and  $w_j$

	$S_n^{min}$	Cat EB 0 $S_n^{max}$	ISP	$S_n^{min}$	Cat EB 2 $S_n^{max}$	ISP
$S_1$	0.5	15	15	3	20	20
$S_2$	2	240	240	100	1,050	1,050
$S_3$	0.5	30	30	90	630	630
$S_4$	0	5.5	5.5	20	120	120

Source(s): Table by authors

**Table 7.**  
Values of  $S_n$  and ISPs

**Table 8.**  
Normalized distance  
matrix

Model	Cat EB 0				Cat EB 2				Payload		
	Country	Endurance	Range	MTOW	Payload	Model	Country	Endurance		Range	MTOW
Orbiter-3	Israel	0.5517	0.3782	0.0000	0.0000	Searcher (Mk-3)	Israel	0.1176	0.8421	0.3333	0.0000
Pterop-E	Russia	0.4828	0.6933	0.0000	0.0909	Seeker-400	South Africa	0.2353	0.8421	0.3333	0.2000
Raybird-3	Ukraine	0.0000	0.0000	0.3051	0.0909	Falco	Italy	0.3529	0.8947	0.2593	0.5000
FlyEye	Peru	0.8621	0.8824	0.6441	0.2727	Burevestnik-MB	Belarus	0.5882	0.8000	0.4259	0.6000
Fulmar X	Spain	0.4828	0.6723	0.3390	0.2727	Bayraktar-TB2	Turkey	0.0000	0.9474	0.0000	0.6500
FT-100 Horus	Brazil	0.8966	0.9244	0.7797	0.4545	CamCopter S-100	Austria	0.5882	0.8947	0.7963	0.7000
IT180-3EL-1	France	0.9793	0.9664	0.3051	0.4545	ASN-206	China	0.7059	0.9474	0.7556	0.7000
Orbiter-1K	Israel	0.8621	0.5882	0.6441	0.5273	ASN-209	China	0.5882	0.8947	0.5741	0.7000
MicroFalcon	Israel	0.7586	0.8403	0.6780	0.6364	Shahpar	Pakistan	0.7647	0.8421	0.2778	0.7000
Spectator-M	Ukraine	0.8966	0.7983	0.8305	0.6364	Horlytsiya	Ukraine	0.7647	0.0000	0.7963	0.7000
Observer-S	Ukraine	0.6897	0.5882	0.7966	0.7273	RQ-7 Shadow	USA	0.6471	0.9737	0.7741	0.7700
Spy Ranger	France	0.8276	0.8824	0.5254	0.7818	Aludra (Mk1)	Malaysia	1.0000	1.0000	0.7963	0.9500
Skylark HLEX	Israel	0.8276	0.8403	0.7627	0.7818	PGZ-19R	Peru	0.4706	0.9474	1.0000	1.0000
Serçe-1	Turkey	1.0000	0.9958	0.7966	0.8182						
XeFI	South Korea	1.0000	0.9958	0.9153	0.9091						
Mosquito	Belarus	0.9828	0.9580	0.9220	0.9364						
InstantEye Gen3	USA	1.0000	1.0000	1.0000	0.9455						
Aladin	Germany	0.9655	0.9454	0.9085	1.0000						

**Source(s):** Table by authors

Model	Cat EB 0				Cat EB 2						
	Country	Endurance	Range	MTOW	Payload	Model	Country	Endurance	Range	MTOW	Payload
Orbiter 3	Israel	0.1076	0.0773	0.0000	0.0000	Searcher (Mk-3)	Israel	0.0299	0.2008	0.0942	0.0000
Ptero-5F	Russia	0.0941	0.1417	0.0000	0.0288	Seeker-400	South Africa	0.0598	0.2008	0.0942	0.0450
Raybird-3	Ukraine	0.0000	0.0000	0.0865	0.0288	Falco	Italy	0.0896	0.2133	0.0732	0.1126
FlyEye	Peru	0.1681	0.1804	0.1827	0.0865	Burevestnik-MB	Belarus	0.1494	0.1907	0.1203	0.1351
Fulmar X	Spain	0.0941	0.1374	0.0961	0.0865	Bayraktar-TB2	Turkey	0.0000	0.2259	0.0000	0.1463
FT-100 Horus	Brazil	0.1748	0.1889	0.2211	0.1441	CamCopter S-100	Austria	0.1494	0.2133	0.2250	0.1576
IT180-3EL-1	France	0.1910	0.1975	0.0865	0.1441	ASN-206	China	0.1793	0.2259	0.2134	0.1576
Orbiter-1K	Israel	0.1681	0.1202	0.1827	0.1671	ASN-209	China	0.1494	0.2133	0.1622	0.1576
MicroFalcon	Israel	0.1479	0.1718	0.1923	0.2017	Shahpar	Pakistan	0.1942	0.2008	0.0785	0.1576
Spectator-M	Ukraine	0.1748	0.1632	0.2355	0.2017	Horlytsya	Ukraine	0.1942	0.0000	0.2250	0.1576
Observer-S	Ukraine	0.1345	0.1202	0.2259	0.2305	RQ-7 Shadow	USA	0.1644	0.2321	0.2187	0.1733
SpyRanger	France	0.1614	0.1804	0.1490	0.2478	Aludra (Mk1)	Malaysia	0.2540	0.2384	0.2250	0.2138
Skylark I-LEX	Israel	0.1614	0.1718	0.2163	0.2478	PGZ-19R	Peru	0.1195	0.2259	0.2825	0.2251
Serce-1	Turkey	0.1950	0.2035	0.2259	0.2594						
XeFI	South Korea	0.1950	0.2035	0.2596	0.2882						
Mosquito	Belarus	0.1916	0.1958	0.2615	0.2968						
InstantEye Gen3	USA	0.1950	0.2044	0.2836	0.2997						
Aladin	Germany	0.1883	0.1932	0.2576	0.3170						

Source(s): Table by authors

**Table 9.**  
Normalized average  
distance matrix

4.2 SPOTIS method steps

The SPOTIS method, proposed by [Dezert et al. \(2020\)](#), presents five steps starting from the decision matrix  $M$  defined in step 1 of the MPSI method.

In step 1, the definition of criterion limits takes place, which is a subjective stage. Decision-makers must establish value intervals that meet the problem's solution. For each criterion  $C = \{C_j | j = 1, 2, \dots, n\}$ , an interval  $[S_n^{min}, S_n^{max}] = [x_1, x_2]$  is defined, constituting the set of limits to be used. This definition should not be too restrictive, as it would make it difficult to find a suitable quantity of alternatives, and it should not be too broad either, as it would make the distinction between alternatives difficult.

In step 2, the Ideal Solution Points are defined, where the extreme value of each interval is selected based on the criteria's objective. For monotonically benefit criteria, the highest value is selected, and for monotonically cost criteria, the lowest value is selected. Thus, each Ideal Solution Point  $S_n^*$  (ISP) makes up the set of ISPs  $S^* = \{S_n^*\}$ .

From  $S^*$ , the normalized distance matrix is calculated (step 3). Using the values from the initial matrix  $M$ , the new value  $d_{ij}$  of each element in the new matrix  $D$  is obtained using [Equation \(6\)](#).

$$d_{ij} = \frac{|a_{ij} - S_j^*|}{|S_j^{max} - S_j^{min}|} \tag{6}$$

with the values from the matrix  $D$ , the normalized average distance is obtained in step 4, using the vector of weights  $w_j$  obtained from [Equation \(5\)](#), according to [Equation \(7\)](#).

$$d(A_i, S^*) = \sum_{j=1}^N w_j d_{ij} \tag{7}$$

At last, the ranking is obtained by ascending order of each  $d(A_i, S^*)$  obtained from [Equation \(7\)](#).

5. Solution of the problem

[Gettinger \(2019\)](#) provides technical data for 168 SARPs currently in use or under development. As the scope of the SARP project in the Brazilian Army covers only Categories 0 to 2 ([Table 1](#)), this is the only alternative selection criteria in the database provided by [Gettinger \(2019\)](#) in this paper. The evaluated criteria chosen in this paper are Endurance, Range, Maximum Take-Off Weight (MTOW), and Payload. These criteria were selected since they were the parameters available for most UAVs in the database.

The Endurance criterion, measured in hours, is related to the work hours that an UAV can last in operation, where the more it endures, the better (monotonic benefit). The Range criterion, as a monotonic benefit and measured in kilometers, describes the maximum distance that an UAV can travel while in operation. The MTOW criterion, a monotonic benefit measured in kilograms, expresses the maximum weight that an UAV can have to take off from an airbase. The Payload criterion, also a monotonic benefit measured in kilograms, represents the maximum cargo weight that an UAV can carry as additional equipment, such as sensors.

After filtering the UAVs in the database (alternatives) using the aforementioned criteria, 18 models from Category EB 0, 2 models from Category EB 1, and 13 models in Category EB 2 were selected, as shown in [Table 4](#). Since only 2 models were found in Category EB 1, these models were not evaluated in this study.

Cat EB 0				Cat EB 2			
Model	Country	$d(A_i, S^*)$	Rank	Model	Country	$d(A_i, S^*)$	Rank
Raybird-3	Ukraine	0.1153	1°	Searcher (Mk 3)	Israel	0.3248	1°
Orbiter 3	Israel	0.1849	2°	Bayraktar-TB2	Turkey	0.3722	2°
Ptero-5E	Russia	0.2647	3°	Seeker 400	South Africa	0.3997	3°
Fulmar X	Spain	0.4141	4°	Falco	Italy	0.4887	4°
FlyEye	Peru	0.6176	5°	Horlytsya	Ukraine	0.5768	5°
IT180-3EL-1	France	0.6191	6°	Burevestnik-MB	Belarus	0.5955	6°
Orbiter-1K	Israel	0.6381	7°	Shahpar	Pakistan	0.6310	7°
Observer-S	Ukraine	0.7112	8°	ASN-209	China	0.6825	8°
MicroFalcon	Israel	0.7137	9°	CamCopter S-100	Austria	0.7452	9°
FT-100 Horus	Brazil	0.7290	10°	ASN-206	China	0.7762	10°
SpyRanger	France	0.7386	11°	RQ-7 Shadow	USA	0.7885	11°
Spectator-M	Ukraine	0.7753	12°	PGZ-19R	Peru	0.8530	12°
Skylark I-LEX	Israel	0.7973	13°	Aludra (Mk1)	Malaysia	0.9312	13°
Serçe-1	Turkey	0.8838	14°				
Mosquito	Belarus	0.9458	15°				
XeFI	South Korea	0.9463	16°				
Aladin	Germany	0.9562	17°				
InstantEye Gen3	USA	0.9827	18°				

Source(s): Table by authors

Table 10.  
Final ranking

Cat EB	Criteria	Scenarios					
		S0	S1	S2	S3	S4	S5
Cat EB 0	C1	0.1950	0.2500	0.4000	0.2000	0.2000	0.2000
	C2	0.2044	0.2500	0.2000	0.4000	0.2000	0.2000
	C3	0.2836	0.2500	0.2000	0.2000	0.4000	0.2000
	C4	0.3170	0.2500	0.2000	0.2000	0.2000	0.4000
Cat EB 2	C1	0.2540	0.2500	0.4000	0.2000	0.2000	0.2000
	C2	0.2384	0.2500	0.2000	0.4000	0.2000	0.2000
	C3	0.2825	0.2500	0.2000	0.2000	0.4000	0.2000
	C4	0.2251	0.2500	0.2000	0.2000	0.2000	0.4000

Source(s): Table by authors

Table 11.  
Weight coefficients in  
sensitivity analysis

From the data in Table 4, the decision matrix  $M$  is formed. The criteria aim for maximization (monotonic benefit), and Equation (1) is applied to obtain the normalized decision matrix (Table 5).

Based on the normalized decision matrix (Table 5), the process of obtaining the weights is started by the calculation of the vectors  $v_j$  (Equation 3) and  $b_j$  (Equation 4) using the UAV data from Gettinger (2019) in each criterion, resulting in the weight vector  $w_j$  (Equation 5) of the MPSI method, whose values are found in Table 6.

Returning to the decision matrix  $M$  (Table 4), minimum, maximum limits, and ISPs are defined (step 1 of the SPOTIS method). In this case study, the extremes found were used as the limits of the intervals  $S_{ij}$ , and considering the monotonic benefit objective of the

criteria, the points  $S_n^*$  are composed of the upper limits of  $S_n$ . Table 7 summarizes the values found.

Using the values of  $S^*$ , the normalized distance matrix was calculated (Table 8) using Equation (6).

With the data from Table 8, the values of  $w_j$  (Table 6) were used, resulting in the normalized average distance matrix as presented in Table 9.

Using the values calculated in Table 9 and applying Equation (7), ranking was performed in ascending order, resulting in the final ordering presented in Table 10.

5.1 Sensitivity and comparative analysis

Sensitivity Analysis is an important step in the application of MCDA methods, in order to validate the obtained results. The SPOTIS method was assessed by Azevêdo Junior et al. (2023) and Więckowski et al. (2022), presenting a robust performance when compared to other approaches, credited to the characteristic of ranking reversal resistance.

As stated by Radovanović et al. (2023, 2024), in this paper the sensitivity analysis is followed by the evaluation of the impact of criteria weights changing. This approach implies that the weight vector  $w_j$  obtained from the MPSI method (Table 6) is not applied in the analysis.

This analysis is built on six scenarios. The scenario S0 comprehends the original weights at Table 6; the scenario S1 assesses an equal weights scenario; and the S2 to S5 scenarios

Alternatives	Cat EB 0 Scenarios						$\sigma$	Alternatives	Cat EB 2 Scenarios						$\sigma$
	S0	S1	S2	S3	S4	S5			S0	S1	S2	S3	S4	S5	
Raybird-3	1	1	1	1	1	1	0.0	Searcher (Mk 3)	1	1	1	1	2	1	0.4
Orbiter 3	2	2	2	2	2	2	0.0	Bayraktar-TB2	2	2	2	4	1	3	1.0
Ptero-5E	3	3	3	3	3	3	0.0	Seeker 400	3	3	3	3	3	2	0.4
Fulmar X	4	4	4	4	4	4	0.0	Falco	4	4	4	5	4	4	0.4
FlyEye	5	6	7	7	7	5	1.0	Horlytsya	5	5	6	2	7	5	1.7
IT180-3EL-1	6	7	9	8	5	7	1.4	Burevestnik-MB	6	6	5	6	5	6	0.5
Orbiter-1K	7	5	5	5	6	6	0.8	Shahpar	7	7	8	7	6	7	0.6
Observer-S	8	8	6	6	10	9	1.6	ASN-209	8	8	7	8	8	8	0.4
MicroFalcon	9	9	8	9	9	10	0.6	CamCopter S-100	9	9	9	9	9	9	0.0
FT-100	10	11	11	12	11	8	1.4	ASN-206	10	10	11	10	10	10	0.4
Horus															
Spy'Ranger	11	10	10	10	8	12	1.3	RQ-7	11	11	10	11	11	11	0.4
Spectator-M	12	12	13	11	13	11	0.9	Shadow							
Skylark	13	13	12	13	12	13	0.5	PGZ-19R	12	12	12	12	12	12	0.0
I-LEX								Aludra (Mk1)	13	13	13	13	13	13	0.0
Serçe-1	14	14	14	14	14	14	0.0								
Mosquito	15	15	15	15	15	16	0.4								
XeFI	16	17	17	17	17	15	0.8								
Aladin	17	16	16	16	16	17	0.5								
InstantEye	18	18	18	18	18	18	0.0								
Gen3															

Table 12. Alternatives rankings in different scenarios

Source(s): Table by authors

evaluate the predominance of one criterion over the others. Table 11 depicts the weights applied in the sensitivity analysis.

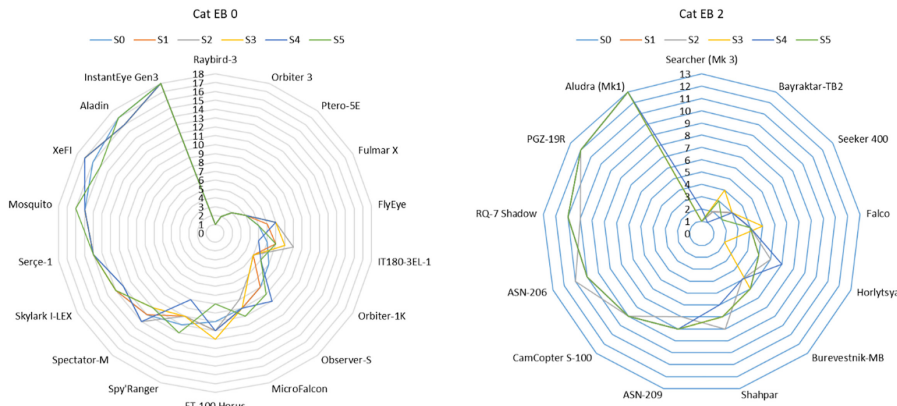
Applying the coefficients in the Table 11, the obtained rankings of alternatives are shown in Table 12.

The deviation obtained in the Table 12 suggests that the initial and final ranked alternatives in Cat EB 0 did not suffer major ranking changes (1st to 5th positions and 12th to 18th). In Cat EB 2, there was more ranking fluctuation, but with a minor magnitude, except for the Horlytsya UAV model. The overall behavior of the ranking is depicted in Figure 10.

Applying the Spearman's correlation coefficient (Table 13), it can be stated that the difference between the scenarios does not represent a major change in the decision-making process. The obtained values are above 0.8, which is considered satisfactory and reinforces that the MPSI-SPOTIS approach is suitable for the research problem context.

For a Comparative Analysis, TOPSIS (Zavadskas et al., 2016), Gaussian AHP (Santos et al., 2021), and MEREC-WISP (Keshavarz-Ghorabae et al., 2021; Stanujkic et al., 2021) were chosen since they are consolidated MCDA methods in the literature. Table 14 depicts the ranking obtained with these methods.

Assessing the correlation by the Spearman's coefficient (Table 15), no relevant differences were found between MPSI-SPOTIS and TOPSIS, AHP-G, and MEREC-WISP, since the coefficients obtained were above 0.8.



**Figure 10.**  
Alternatives rankings  
network in different  
scenarios

Source(s): Figure by authors

Cat EB 0						Cat EB 2							
S0	S1	S2	S3	S4	S5	S0	S1	S2	S3	S4	S5		
S0	1					S0	1						
S1	0.990	1				S1	1.000	1					
S2	0.971	0.988	1			S2	0.984	0.984	1				
S3	0.975	0.992	0.992	1		S3	0.962	0.962	0.929	1			
S4	0.975	0.983	0.961	0.963	1	S4	0.978	0.978	0.973	0.896	1		
S5	0.988	0.975	0.953	0.957	0.953	1	S5	0.995	0.995	0.978	0.967	0.967	1

Source(s): Table by authors

**Table 13.**  
Spearman's correlation  
of scenarios

**Table 14.**  
Comparative analysis  
of MPSI-SPOTIS

Alternatives	MPSI-SPOTIS	TOPSIS	AHP-G	MEREC-WISP	$\sigma$	Alternatives	MPSI-SPOTIS	TOPSIS	AHP-G	MEREC-WISP	$\sigma$
Raybird-3	1	1	1	1	0.0	Searcher (Mk-3)	1	2	2	1	0.6
Orbiter 3	2	2	2	2	0.0	Bayraktar-TB2	2	4	4	3	1.0
Ptero-5E	3	3	3	3	0.0	Seeker 400	3	3	3	4	0.5
Fulmar X	4	4	4	4	0.0	Falco	4	5	5	5	0.5
FlyEye	5	6	7	7	1.0	Horlytsya	5	1	1	2	1.9
IT180-3EL-1	6	5	10	5	2.4	Burevestnik-MB	6	6	6	9	1.5
Orbiter-IK	7	7	6	6	0.6	Shahpar	7	7	7	10	1.5
Observer-S	8	8	5	8	1.5	ASN-209	8	8	8	8	0.0
MicroFalcon	9	10	8	9	0.8	CamCopter S-100	9	9	9	7	1.0
FT-100 Horus	10	9	13	10	1.7	ASN-206	10	10	10	6	2.0
Spy Ranger	11	11	9	11	1.0	RQ-7 Shadow	11	12	11	11	0.5
Spectator-M	12	12	11	12	0.5	PGZ-19R	12	11	12	13	0.8
Skyhawk HLEX	13	13	12	13	0.5	Aludra (Mk1)	13	13	13	12	0.5
Serçe-1	14	14	14	14	0.0						
Mosquito	15	17	16	15	1.0						
XeFl	16	15	17	16	0.8						
Aladin	17	16	15	17	1.0						
InstantEye Gen3	18	18	18	18	0.0						

**Source(s):** Table by authors

**6. Results**

The application of the MPSI-SPOTIS method identified the UAV model Raybird-3 as the most suitable in Category EB 0 and the Searcher (Mk3) model in Category EB 2. Observing the values of the distances  $d(A_i, S^*)$ , it is suggested to form 5 clusters for Category EB 0 (Figure 11) and 5 clusters for Category EB 2 (Figure 12).

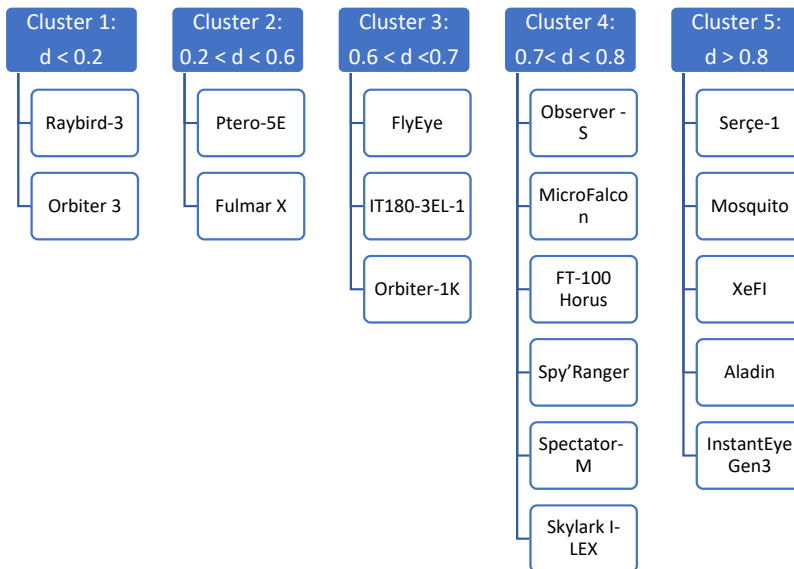
From Figure 11, there is a greater dispersion, with only 4 models falling within the interval  $d(A_i, S^*) < 0.6$ , indicating a greater restriction on alternatives that exhibit the best performance in the evaluation. The median of distances for Category EB 0 is 0.7213, confirming the dispersion in performance.

For Category EB 2 (Figure 12), there was a greater concentration of models in the clusters, representing a more balanced division. This facilitates decision-making as there are more options with similar performance in the evaluation. The median of distances found was 0.6310, indicating a greater centralization of alternatives.

	Cat EB 0					Cat EB 2			
	MPSI-SPOTIS	TOPSIS	AHP-G	MEREC-WISP		MPSI-SPOTIS	TOPSIS	AHP-G	MEREC-WISP
MPSI-SPOTIS	1				MPSI-SPOTIS	1			
TOPSIS	0.990	1			TOPSIS	0.934	1		
AHP-G	0.946	0.930	1		AHP-G	0.940	0.995	1	
MEREC-WISP	0.994	0.990	0.942	1	MEREC-WISP	0.857	0.868	0.879	1

Source(s): Table by authors

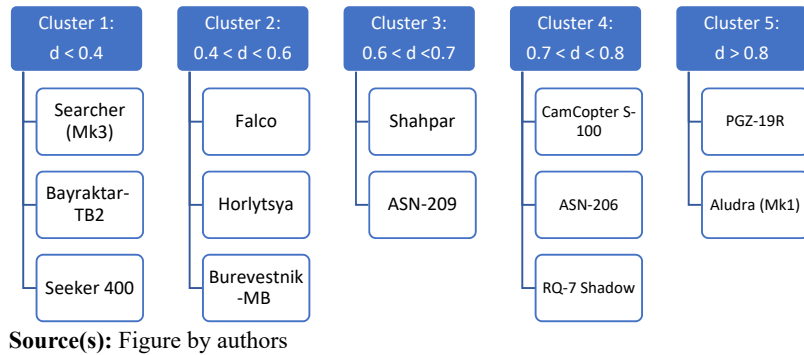
**Table 15.**  
Spearman's correlation  
of methods



Source(s): Figure by authors

**Figure 11.**  
Category EB 0 clusters

**Figure 12.**  
Category EB 2 clusters



From the analysis conducted in the paper, it was identified that the recommended SARP model in Category EB 0 is the Raybird-3, while for Category EB 2, the Searcher (Mk3) model stood out. However, it is emphasized that the evaluation of cost was not possible due to the unavailability of data from the used source (Gettinger, 2019). The clustering proposal suggested the possibility of considering other models beyond those highlighted. For Category EB 0, the Orbiter 3 model proved to be relevant. In Category EB 2, the Bayraktar – TB2 and Seeker 400 models were identified as alternatives to be considered.

## 7. Conclusion

In this paper, the evaluation of SARP systems was performed by the MCDA method MPSI-SPOTIS. The MPSI method proved to be an adequate approach to obtain the weight vectors, reinforced by the sensitivity and comparative analysis performed. The ranking of SARPs was performed by the SPOTIS method, which presents the feature of rank reversal resistance and adds to the decision-making process the capability to assess new alternatives or remove some without changing the overall scenario.

The sensitivity and comparative analysis performed showed that the weights obtained in MPSI methods satisfactorily described the importance grade of each criterion. Even when some criteria were privileged, the overall ranking did not suffer major changes in the top and bottom alternatives. It was observed that there was a higher deviation only in the middle of the ranking. The SPOTIS method performed statistically equivalent to other established methods, as described by the Spearman's coefficients above 0.8. Therefore, SPOTIS presents the rank reversal feature and stability, which have been considered suitable to assess defense systems.

It is recommended that future research incorporate cost as an additional criterion in the analysis. Furthermore, the evaluation of criteria related to the life cycle of SARPs can provide a more comprehensive view, including aspects of maintenance, updates, and sustainability.

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