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Use of the WASPAS Method to Select Suitable Helicopters for Aerial Activity Carried Out by the Military Police of the State of Rio de Janeiro

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Abstract: Using a multi-criteria decision support method (WASPAS) to analyze and rank alternatives, this article proposes a method to assist in the selection of helicopter models that are the most suitable for police air activity in the State of Rio de Janeiro. A robust technical basis for defining the essential requirements of an aircraft is established, and solutions that can ensure the effective and safe execution of missions are indicated. Helicopter models were evaluated by considering predefined criteria, and the weights of these criteria were attributed using a questionnaire that was administered to pilots and aerostatic operators of Public Air Units (UAP) in several states of the federation. As a result of the evaluation of the 15 helicopter models used by police services in the State of Rio de Janeiro, the modeling with the WASPAS method ranked the Sikorsky UH-60 (Black Hawk) model in first place, the Leonardo AW 139 model in second place, and the Bell 412 model in third place. Based on the available data, we suggest that a comparative study integrating the Entropy and CRITIC methods be conducted to measure the weights of the criteria associated with the application of other multi-criteria techniques, such as COMET, MACAB, SPOTIS, VIKOR, SAPEVO, and PROMETHEE.

Keywords: operations research; multi-criteria decision aid; WASPAS method; aviation; helicopters; police; public safety

MSC: 90B50; 91B06

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1. Introduction

Helicopters are sophisticated machines capable of multi-directional flight and hovering. These aircraft were initially developed to meet many military demands, such as rescue, surveillance, cargo transport, anti-submarine warfare, and troop transport. These characteristics allow for the insertion of ready-made fighters to battlefields. Civil use is also relevant, highlighting activities such as firefighting, crop spraying, civil defense, and civilian transport.

In public safety, using helicopters is fundamental for police organizations, as it is a tool that increases operational capacity, given that it allows for rapid displacement and a broad view of an entire region. Thus, it is considered a multi-mission vector of high importance, with applicability in police transport missions, troop insertion in conflict areas, patrolling, rescue, determining appropriate guidance and the approximate coverage of personnel in operations, data collection in intelligence activities, regional mapping, providing lighting for places of interest using search beacons, the pursuit of fugitives, the transport of high-risk prisoners, and providing assistance in areas of difficult access in public calamities. They can also be used to monitor roads, significant events, and demonstrations using cameras that transmit images in real time to strategic level agents, who as a result can have improved technical conditions for decision making regarding such tasks as planning, displacement, and policing support.

As an example of evidence of the effectiveness of helicopters in the interest of public safety, we highlight Schnelle et al. [1], who verified that the use of aircraft for patrolling regions with a high rate of residence theft led to a significant reduction in that particular crime and found that the costs linked to the implementation of that vehicle were outweighed by the benefits generated.

A more detailed analysis of public security in Rio de Janeiro reveals regions with a large number of conflict areas. In this context, it is worth noting that the presence of organized crime in poor communities is widespread and that criminal factions related to drug trafficking exert firm control through the use of firearms, information networks, and private rules [2]. This social picture causes police operations to be carried out routinely to curb criminal activity, comply with judicial orders, preserve public order, and guarantee the individual rights of citizens.

However, the action of the police in some locations can be hampered by outlaws resisting arrest if they have geographical knowledge of the land, have weapons of high destructive potential, and collaborate with local inhabitants. They may use barricades to prevent police access, elevate sites, and build interiors with holes for firearm use, putting police and citizens at risk. In this scenario, the use of a helicopter is essential for the support of operations because, in addition to the ability to monitor the terrain with a camera and guide the police, the aircraft can perform overflight near the ground, an action that has a strong deterrent effect because it puts criminals at a disadvantage, causing resistance to be overcome faster, and, consequently, reducing the likelihood of confrontation and the resulting damage.

Basilio et al. [3] state that human activities require decision making. All such decisions are based on an evaluation of individual decision options, typically based on the decision-makers preferences, experience, and other data. Some decisions are simple, while others are complex. According to [3–7], some decisions are relatively simple, especially if the consequences of making the wrong decision are minor, whereas others are highly complex and have significant effects. In most cases, real-life problem solving involves several competing points of view that must be considered to reach a reasonable decision. A decision can be defined formally as a choice based on available information or a method of action to solve a specific problem. In practice, multiple-criteria decision analysis (MCDA) evaluates possible courses of action or options by selecting a preferred option or sorting the options from best to worst. In everyday practice, using MCDA is critical in signaling the best rational alternative to the decision maker so that he can allocate finite resources between competing and alternative interests. Whether in an organizational or domestic setting, the decision maker is constantly confronted with multiple paths and limited resources. Researchers refer to multiple-criteria methods in various ways.

Over the last 50 years, experts have been solving multi-criteria problems in various fields of knowledge, such as information and communication technology, business intelligence, environmental risk analysis, environmental impact assessment and environmental sciences, water resource management, solid waste management, remote sensing, and public security. The AHP is the most used method, followed by TOPSIS, VIKOR, PROMETHEE, and ANP. However, the literature reports the growth of new techniques and the integration with fuzzy sets and associations to reduce the decision maker's discretion regarding weight elicitation. Thus, decision makers have at their disposal a myriad of methods such as MAUT, SMART, UTA, MACBETH, ELECTRE, NAIADE, ORESTE, REGIME, ARGUS, TACTIC, MELCHIOR, PAMSSEM, EVAMIX, QUALIFLEX, PCCA, MAPPAC, PRAGMA, PACMAN, IDRA, DRSA, SPOTIS, SIMUS, COMET, DARIA-TOPSIS, MABAC, MAIRCA, WASPAS, and SAPEVO-M [8–16].

When a particular MCDM method is finally recommended for a specific application, it is observed that its solution accuracy and ranking performance are seriously influenced by the value of its control parameter, as stated by Kahraman et al. [17]. In this paper, the applicability and usefulness of the weighted aggregated sum product assessment (WASPAS) method were used to answer the following question: Which mobile rotorcraft is best suited for use in support of police service? As a result of the application of WASPAS for evaluating 15 helicopter alternatives, the alternative A15-Sikorsky UH-60 aircraft (Black Hawk) was ranked in first place as the most suitable for supporting the police service.

This paper is structured into six sections. In addition to the Introduction, where aspects related to the use of helicopters in the police service, concepts and multi-criteria methods, and the justification for the choice of the WASPAS method are presented to readers, Section 2 details the problem and the context of the action of the police organization studied. In the third section, we present the literature review; in the fourth section, we describe the methodology; in the fifth section, the model is numerically applied; and in the sixth section, the authors discuss the results and present the final considerations.

2. Description of the Problem

The State of Rio de Janeiro has an area of 43,750 km^2 and a population of approximately 17.5 million inhabitants [18,19]. There are numerous conflicted regions where crime practices, such as drug trafficking and vehicle theft, are commonly carried out in territories. Such criminal activities require efficient action of the state through intelligence and policing efforts to curb the execution of crimes and maintain public order [20].

Given the characteristics of crime practices and events that occur in the region, it is necessary to map the conflicted areas and monitor various locations in real time, especially when operations are taking place, to curb criminal actions, provide police officers involved in operations with greater security, and enable managers to make better decisions [21,22].

It is noteworthy that, due to the clashes resulting from operations in conflagrated locations, citizens, police, and criminals are often injured, which requires urgent help and rapid transport to specialized hospitals. However, several circumstances compromise these actions because the transit of land vehicles is not favorable, few hospitals are referenced in treating those wounded by firearm projectiles, and access to operating sites is extremely risky and challenging for health agencies.

In addition to the factors mentioned above, the State of Rio de Janeiro has essential characteristics that give it relevance nationally and globally and, therefore, was recently home to major events such as the Soccer World Cup, the Olympic Games, the World Youth Meeting, and political demonstrations, which required significant investments and performance in the area of public security.

For planning and action in public security to be carried out efficiently and effectively, the tools used must allow the agencies involved to act safely and intelligently, mainly through monitoring and gathering information [23].

One of these tools is the use of helicopters, which play a role in the development of police activities, as was already evidenced in the introduction of this work. It is essential to highlight that the Military Police of the State of Rio de Janeiro also operates with aircraft in situations that exceed their primary duties of the policing and preservation of public order, as well as civil defense, especially in cases of public calamity.

However, this model of air activity must meet specific requirements to be considered efficient, effective, and safe, as it preserves the lives of the police officers who crew the aircraft, and to ensure that those who receive the support and contribute to the reduction in crime rates have enough access to the fleet to meet the demands; these specific requirements include, the capacity for prompt response, justifying the high public investment in aircraft, as well as having machines with high reliability and safety, which reduces the probability of accidents during the overtaking of inhabited places.

An ideal fleet should also have aircraft with other characteristics necessary for the development of special missions: (1) sufficient autonomy to operate in locations far from the base of origin, in view of the small amount of refueling points in the state territory, (2) enough internal capacity to transport the crew members required for each type of operation, as well as tactical intervention teams from other special units, (3) space that allows for a safe landing in restricted areas, such as clearings in forest areas for rescues, calamitous locations on humanitarian missions, and sites surrounded by obstacles for troop landing, (4) sufficient engine power, a maximum take-off weight, and a payload that allow for take-off with the necessary amount of equipped crew members, fuel, and assistance equipment from any location, either at sea level or in places at high elevation, regardless of weather, (5) the possession of equipment such as winches and hooks, needed in rescue missions, (6) an ability to install and operate cameras with a quality suitable for imaging services, (7) an ability to carry medical stretchers, and (8) an ability to operate water baskets (Bambi Bucket) for firefighting missions.

It is essential to highlight that the support of helicopters in police operations in conflicted areas is loaded with high risk because, in addition to the obstacles existing in operations, such as the presence of high voltage cables, antennas, and towers, there is a factor related to the war power of criminal factions, notoriously observed in hostile manifestations, usually practiced through the firing of firearms against aircraft. This has already caused several malfunctions, injuries to crew members, and, in 2009, an emergency landing of a helicopter of the Military Police of the State of Rio de Janeiro when it was active in a complex of communities known as Macacos and São João, with an extension to the neighborhoods of Tijuca and Méier. Three crew members died, exemplifying the referenced impacts on military police human resources. Thus, it is perceived that high levels of ballistic protection and survivability, which is a helicopter's capacity to avoid and withstand a hostile environment [24], are essential requirements for selecting a helicopter destined for police activity.

Currently, the aircraft fleet of the Airmobile Unit of the Military Police of the State of Rio de Janeiro (GAM) consists of seven helicopters, one Airbus Helicopter EC 145 (BK 117 C2), one Bell Helicopter UH-1H II (Huey II), two Airbus Helicopters H125 B2 (Squirrel), two Airbus Helicopters H125 B3 (Squirrel), and one Sikorsky Schweizer 300 CBi. The latter is used only for flight instruction. There is a diversification of the Unit's fleet, which directly impacts pilot training, maintenance service contracts, and the flight service scale of pilots, considering that piloting a particular helicopter model is necessary for the respective qualification granted by the National Civil Aviation Agency (ANAC).

In the fleet referenced above, only the UH-1H II model has armor. The aircraft was manufactured in 1968, based on a 1959 project, and was supplied with a new engine and new systems and avionics. However, the Huey II has a maintenance program established by the manufacturer that performs preventive inspections and maintenance every 25 h of flight, a factor that directly affects availability, which is the ratio between the number of days the aircraft was in flight condition and the period of one year. Another relevant factor is that few helicopters of this model are operating in the country, which is reflected in the low number of spare parts in the stocks of companies that provide maintenance services. These factors, together with the recurrent corrective maintenance performed due to the damage caused by firearm projectiles, contributed to an average availability of 52.37% in the last 10 years, considered very low.

The legislation in force recommends that special public aviation operations should be carried out by public civil aircraft. In other words, the use of any aircraft by a military police organization is not authorized unless the Brazilian agency can register them.

Hence, the definition of a helicopter model is justified. A helicopter must have sufficient attributes and characteristics for the performance of certain activities in a legal, optimized, and protected way. GAM takes into account the features related to the missions developed as well as the particularities of the region of operation and legal aspects.

The rich picture methodology, representing a system and its interactions through graphic diagrams, was used to understand and describe the problem, allowing for a more precise and accurate visualization of the theme addressed. Figure 1 depicts the real world experienced by the actors using rotorcrafts in police activities. The rich picture is one of the stages of Soft System Methodology (SSM) developed by Professor Peter Checkland [16], and one of the characteristics is the freehand production of the problem situation studied. In Figure 1, we depict the various daily activities faced by police organizations in the city of Rio de Janeiro, Brazil, such as air support for police teams fighting drug traffickers in the slums of Rio de Janeiro, the air patrol of overpopulated areas, the rescue of people in distress, the pursuit of fugitives, and the transport of troops for incursions into conflict areas. In summary, Figure 1 illustrates the need for mobile wing aircraft to support police activities.

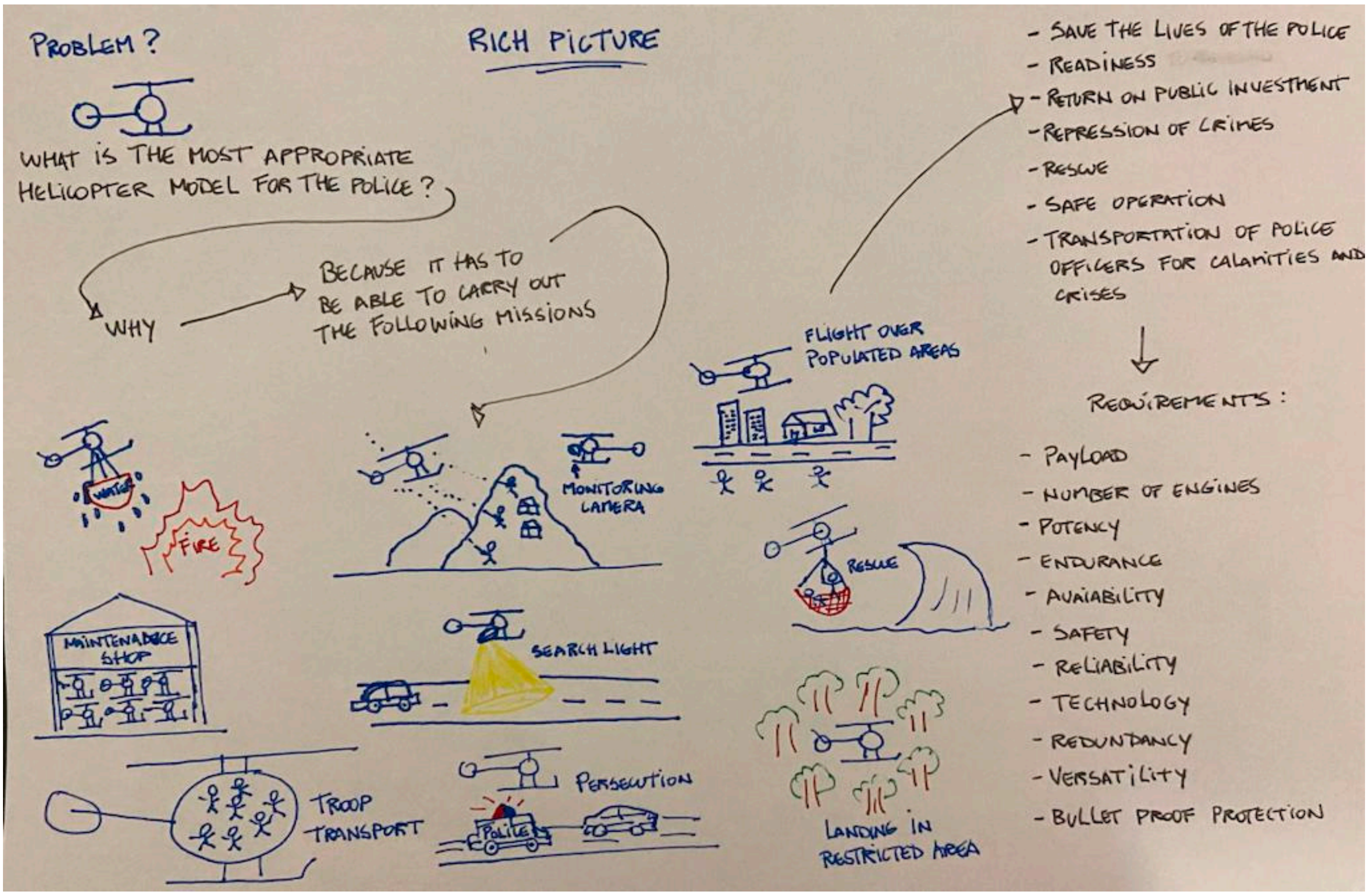

Figure 1. Rich picture illustrating the various applications of helicopters to police activity in a significant metropolis. **Source:** The authors. **Note:** This figure has been produced by Soft System Methodology (SSM) [25].

3. Literature Review

To evidence the construction of knowledge, the Scopus database was used to designate scientific articles related to multi-criteria decision support methods, with the research conducted in November 2022, limiting itself to the survey of scientific production of the last five years (2017–2022) and being restricted to journal articles. The researchers used the following search key: TITLE-ABS-KEY ((“Weighted Aggregated Sum Product Assessment” OR “WASPAS” OR “Multicriteria Analysis” OR “Multicriteria Decision Making” OR “MCDM” OR “MCDA”) AND (“Aircraft” OR “Helicopter” OR “Unmanned Aircraft” OR “Drones”)) AND (LIMIT-TO (PUBYEAR, 2022) OR LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2018) OR LIMIT-TO (PUBYEAR, 2017)) AND (LIMIT-TO (DOCTYPE, “ar”)). The search returned 59 articles.

Decision-making problems usually involve a plurality of criteria, which can often be divergent or have more or less influence on a given analysis but are fundamental for the classification of available alternatives for the solution of a given problem [19].

According to Aires and Ferreira [26], multi-criteria decision making is considered one of the most commonly used methodologies to increase the quality of decision-making processes in science, government, business, and engineering.

Multi-criteria decision analysis (MCDA) is an expression used to describe a set of formal approaches that consider several criteria designed to help stakeholders evaluate decisions that matter. It has been of great value to the Brazilian Navy in determining the most appropriate attack helicopter model for the performance of their duties [27].

According to Moreira et al. [28], a method based on MCDA concepts requires a set of techniques to assess the real problem, which usually consists of a lack of data, risk, uncertainty, and conflicting opinions. Thus, the modeling considers the subjectivity of the decision maker, e.g., always considering the preference for an alternative or the importance of criteria for selecting an attack helicopter for the Brazilian Navy. The evaluation based on the PROMETHEE-SAPEVO-M1 method allowed for the overcoming of alternatives, not only considering the best option but also taking into account other choices favorable to it, allowing the decision maker to consider the use of multiple aircraft.

According to Krishankumar et al. [29], MCDA provides a systematic approach for decision makers, who will deliberate based on alternative assessments, considering a predetermined set of criteria according to the preferences of the decision makers involved.

In several everyday situations, it is necessary to evaluate a group of alternatives through a multiplicity of criteria, and this applies to the military context, e.g., in an aircraft acquisition process by an air force, which requires the consideration of a wide variety of criteria, such as service ceilings, operational ranges, cruising speed, and the rate of ascent, making the multi-criteria decision-making theory (MCDM) appropriate for this type of decision [3,30,31].

A study employing a hybrid method of multi-criteria analysis, BWM-Fuzzy TOPSIS, for the selection of a modern training aircraft for the Vietnam Popular Air Force, which was still able to perform light attack and reconnaissance tasks, also identified a model that better met the predetermined criteria: the Yak-130 [32].

Another study used the AHP to select an appropriate cargo helicopter model for the Turkish Armed Forces, considering quantitative and qualitative criteria, such as performance, avionics systems, maintenance, and cost, presenting consistent results favorable to an optimal choice [33].

Whereas the selection of military defense equipment significantly affects the readiness of an organization responsible for ensuring the sovereignty of a country's airspace, as in the case of the Indonesian Air Force, the use of an MCDA method using both the Methods of Order of Preference for Similarity to an Ideal Solution (TOPSIS) and the AHP was instrumental in the proposal for an effective and appropriate fighter jet for an air combat operation [34].

For Dhara et al. [35], the MCDA method also ensures the selection of a light executive aircraft for civil aviation that is more suitable and preferred by passengers based on effectiveness and aesthetic comfort, in addition to criteria such as reach, technological equipment, comfortable seating arrangements, and sanitary facilities on board.

A methodology that applies two MCDA methods, such as the TOPSIS and the AHP, is considered adequate for analyzing aircraft reliability, maintainability, availability, and costs [36,37], and for training aircraft classification. Torğul et al. [38] proposed an approach based on the Fuzzy BWM method to select more suitable training aircraft in government universities in Turkey. Bakır et al. [39] used an integrated fuzzy Pivot Pairwise Relative Criteria Importance Assessment (F-PIPRECIA) and fuzzy Measurement Alternatives and Ranking according to the Compromise Solution (F-MARCOS) for aircraft selection.

Even though MCDA is considered an exceptional tool with applicability in various real-world decision problems that require determining the optimal alternative when considering various competing requirements, incomplete or uncertain input data characteristics are a prominent issue that has caused researchers to search for modern techniques when modeling the data in complex decision-making problems. One of these techniques is the weighted aggregate sum product evaluation (WASPAS) [40].

A WASPAS approach integrated with type-2-range hesitant diffuse assemblies (IT2HFS) was used in a study to select a more suitable type of aircraft for a given route, given that it is one of the crucial issues that airline decision makers have to face under uncertainty, based on various commercial and operational criteria. The results showed that the Airbus 32C was the appropriate alternative for a given route between the airports of Kuwait and Istanbul [41].

In a distinct area of aviation, but pertinent to a multi-criteria decision problem, a study conducted to select a more appropriate last-mile delivery mode confirmed the high reliability of the WASPAS method due to its high robustness and consistency. The model was said to improve delivery methods in urban areas around the world [42,43].

Finally, consonant with Aktas and Kabak [44], an analytical decision-making model based on the Diffuse Method of Pythagoras with Range Value (IVPF) combined with the WASPAS method was influential in choosing one of the most suitable unmanned aircraft alternatives for delivery operations.

4. Methodology

The data were collected through a questionnaire, which was applied to helicopter pilots and aerostatic operators of Public Air Units (UAP) from several states of the federation to obtain evaluations of helicopter models concerning predefined criteria, as well as for establishing the weight of each criterion. The data were then anonymized and arranged in open and closed questions.

The helicopter models used in the research were defined based on the aircraft used by police forces in Brazil and referencing types specified in recent technical studies prepared by GAM to acquire helicopters. The criteria were determined according to the characteristics necessary for developing police aerial activities. The research participants could only evaluate the subjective criteria related to aircraft characteristics, such as versatility, system redundancy, instrument flight capacity, autopilot capability, embedded technology, engine power, after-sales, availability, and protection, considering that the other criteria are immutable technical data regarding manufacturing, such as autonomy, maximum speed, the maximum number of people on board, the number of engines, maximum take-off weight, payload, and length, which were obtained in consultation with manufacturers, along with prices.

For analysis of the obtained data, the WASPAS method was used. This method combines two other methods to increase the accuracy in the ordering of the solutions: the weighted sum method (WSM) and the weighted product method (WPM).

The WASPAS method's application first requires the development of a decision/evaluation matrix, $X = \left[x_{ij}\right]_{m \times n}$, where x_{ij} is the performance of the ith alternative concerning the jth criterion, m is the number of alternatives, and n is the number of criteria. To make the performance measures comparable and dimensionless, all the elements in the decision matrix are normalized using the following two equations:

$$\overline{x}_{ij} = \frac{x_{ij}}{max_i x_{ij}} \tag{1}$$

for beneficial criteria, and

$$\overline{x}_{ij} = \frac{min_i x_{ij}}{x_{ij}} \tag{2}$$

for non-beneficial criteria. $\overline{x}_{ij}$ is the normalized value of x_{ij}.

In the WASPAS method, a joint criterion of optimality is sought based on two criteria of optimality. The first criterion of optimality, i.e., the criterion of a weighted mean success, is similar to the WSM method. It is a popular and well-accepted MCDM approach applied for evaluating a number of alternatives concerning a set of decision criteria. Based on WSM, the total relative importance of the ith alternative is calculated as follows:

$$Q_i^{(1)} = \sum_{j=1}^{n} \overline{x}_{ij} w_j, \tag{3}$$

where w_j is the weight (relative importance) of the jth criterion.

On the other hand, according to the WPM method, the total relative importance of the ith alternative is evaluated using the following equation:

$$Q_i^{(2)} = \prod_{j=1}^{n} (\overline{x}_{ij})^{w_j}, \tag{4}$$

In order to have increased ranking accuracy and effectiveness of the decision-making process, in the WASPAS method, a more generalized equation for determining the total relative importance of the ith alternative is developed [45–47]:

$$Q_i = \lambda Q_i^{(1)} + (1-\lambda) Q_i^{(2)} = \lambda \sum_{j=1}^{n} \overline{x}_{ij} w_j + (1-\lambda) \prod_{j=1}^{n} (\overline{x}_{ij})^{w_j},\ \lambda = 0,\ 0.1, \ldots,\ 1. \tag{5}$$

In Equation (5), when the value of λ is 0, the WASPAS method is transformed to WPM, and when λ is 1, it becomes the WSM method. The feasible alternatives are now ranked based on the Q values, and the best alternative has the highest Q value. It has been applied for solving MCDM problems to increase ranking accuracy, and it can reach the highest accuracy of estimation [48–54].

5. Numerical Application

This section should provide a concise and precise description of the experimental results, their interpretation, and the experimental conclusions that can be drawn.

The problem under analysis aims to select helicopter models more suitable for police air activity in the State of Rio de Janeiro through the WASPAS method proposed by Zavadskas et al. [45]. A questionnaire was applied for the evaluation and definition of the variables. A consultation was made with Air Units and technical data provided by aircraft manufacturers, resulting in a set of 15 alternatives and 17 criteria, as detailed in Table 1.

Table 1. Alternatives and criteria established for analysis.

Alternatives		Criteria	
A1	Airbus H125 B3 (Squirrel)	C1	Price (US$)
A2	Airbus H125 B2 (Squirrel)	C2	Autonomy (minutes)
A3	Airbus H355 (Twin-Engine Squirrel)	C3	Speed VNE (Knots)
A4	Airbus EC 145 (BK-117 C2)	C4	Maximum number of people on board
A5	Airbus EC 135	C5	Versatility
A6	Airbus EC 120 (Hummingbird)	C6	Number of engines
A7	Bell UH-1H (Huey II)	C7	System redundancy
A8	Bell 206 (Long Ranger)	C8	Maximum take-off weight (Kg)
A9	Bell 412	C9	Payload (Kg)
A10	Bell 429	C10	Capacity for instrument flights
A11	Leonardo AW 119 Kx	C11	Autopilot
A12	Leonardo AW 139	C12	Embedded technology
A13	Robinson 44	C13	Length (meters)
A14	Robinson 66	C14	Engine power
A15	Sikorsky UH-60 (Black Hawk)	C15	Aftermarket
		C16	Availability
		C17	Protection

5.1. Evaluation of Alternatives

For the evaluation of alternatives about each subjective criterion related to aircraft characteristics, such as versatility, system redundancy, the capacity for instrument flights, autopilot capability, embedded technology, engine power, after-sales, availability, and protection, the questionnaire established the following values: 1 (very bad), 2 (bad), 3 (reasonable), 4 (good), and 5 (very good). The final value inserted in Table 1 is the result of the arithmetic mean referring to the amount of each value assigned and the total evaluations performed.

The values of the other criteria, such as autonomy, maximum speed, the maximum number of people on board, the number of engines, maximum take-off weight, payload, length, and weight, were obtained in consultation with the manufacturers.

5.2. Normalization of Variable Values

By analyzing Table 2, it is observed that the values are in different units. Therefore, normalization is required to standardize this data.

Initially, the monotonic benefit criteria and the monotonic cost criteria were defined.

Criteria 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 15, 16, and 17 were defined for the monotonic benefit. According to Zavadskas et al. [45], Equation (1) was used for normalization.

For the monotonic disadvantage, Criteria 1 and 13 were defined. According to Zavadskas et al. [45], Equation (2) was used for normalization.

After applying Equations (1) and (2), Table 3 was elaborated with the normalized values.

5.3. Definition of Criteria Weights

For the attribution of the criteria weights, the researchers designed a questionnaire distributed to 50 helicopter pilots active in police organizations working in 10 states of the Brazilian territory. Thirty-two questionnaires were answered. The participants of the survey were asked, based on their respective flight experiences in police activity, to answer a total of 21 questions, 17 of which referred to the evaluation of the criteria registered in Table 1. The researchers developed a four-point scale to measure the pilot's perception of the importance of the criteria. The pilots had to mark whether they believed the criterion was (1) irrelevant, (2) not important, (3) important, or (4) very important for aircraft selection.

Table 4 records the data used for determining the weights per criterion. Column 1 shows the value scale points (VSPs), which are the points of the evaluation scale used to collect the perception of the pilots who participated in the survey. Columns 2–18 show the number of answers that each point on the value scale received. From the data described above, in Row 6, the scores of the scale of values were calculated according to the following equation:

$$Score_j = \sum_{i=1}^{n} VSP_{i1} C_{ij}\ ,\ \forall\ j = 1, \ldots,\ m. \tag{6}$$

After calculating the scores, the next step was to calculate the weights of each criterion according to the following equation:

$$W_j = \frac{Score_j}{\sum_{j=1}^{m} Score_j}\ ,\ \forall\ j = 1, \ldots,\ m. \tag{7}$$

5.4. Weighted Sum Method (WSM)

Given the decision matrix (Table 3) and the weights and criteria matrix (Table 4), the relative importance of the alternatives was calculated, called Qi, applying Equation (3). The results obtained are shown in Table 5.

5.5. Weighted Product Method (WPM)

Given the decision matrix (Table 3) and the weights and criteria matrix (Table 4), the relative importance of the alternatives was calculated, called Qi, applying Equation (4). The results obtained are shown in Table 6.

Table 2. Matrix of evaluation of the aircraft concerning the criteria.

Alternatives	Criteria																
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
A1	4,826,857	200	155	6.0	4.7	1.0	3.0	2250	976	1.8	2.0	3.6	10.9	4.5	4.0	4.0	1.7
A2	1,500,000	200	155	6.0	4.6	1.0	2.7	2250	1000	1.8	1.6	2.8	10.9	3.9	3.9	3.9	1.8
A3	1,500,000	200	150	6.0	4.5	2.0	3.2	2600	930	2.2	3.0	3.2	11.0	3.5	3.5	3.7	1.7
A4	9,000,000	210	150	11.0	3.8	2.0	4.0	3585	1905	3.5	3.5	3.8	13.0	3.3	3.3	4.0	1.3
A5	6,000,000	216	136	8.0	3.8	2.0	4.0	2980	1418	3.5	3.5	3.8	12.3	3.3	3.3	5.0	1.3
A6	795,000	312	150	6.0	3.0	1.0	2.0	1715	755	2.0	1.0	3.0	9.6	2.5	3.0	4.0	1.5
A7	8,420,000	120	130	13.0	4.2	1.0	2.4	4772	2300	2.4	2.2	2.8	13.3	3.9	2.3	2.1	4.3
A8	2,000,000	222	130	7.0	3.0	1.0	1.0	1451	600	1.0	1.0	2.0	8.7	2.0	3.0	3.0	1.0
A9	6,000,000	228	124	15.0	4.0	2.0	4.0	5400	2327	3.0	4.0	4.0	14.2	4.0	3.0	3.0	3.0
A10	7,000,000	270	155	8.0	5.0	2.0	4.0	3402	1476	3.0	4.0	4.0	13.0	4.0	3.0	4.0	2.0
A11	3,600,000	312	152	8.0	5.0	1.0	3.3	2850	908	3.0	3.0	4.3	13.0	4.0	4.0	4.0	4.0
A12	12,000,000	260	167	17.0	5.0	2.0	5.0	6800	2300	4.5	5.0	4.5	16.6	4.0	4.0	4.5	3.0
A13	450,000	200	130	4.0	2.5	1.0	1.0	1134	320	1.0	1.0	1.0	9.0	2.0	4.0	4.5	1.0
A14	1,260,000	180	140	5.0	3.0	1.0	1.0	1225	420	1.0	1.0	3.0	9.0	3.0	3.0	4.0	1.0
A15	25,000,000	468	159	14.0	5.0	2.0	4.7	10,660	4100	4.6	3.8	4.4	20.0	5.0	4.3	4.8	5.0

Table 3. Aircraft evaluation matrix concerning criteria with normalized values.

Alternatives	Criteria																
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
A1	0.093	0.427	0.928	0.353	0.940	0.500	0.600	0.211	0.238	0.391	0.400	0.800	0.802	0.900	0.930	0.800	0.340
A2	0.300	0.427	0.928	0.353	0.920	0.500	0.540	0.211	0.244	0.391	0.320	0.622	0.802	0.780	0.907	0.780	0.360
A3	0.300	0.427	0.898	0.353	0.900	1.000	0.640	0.244	0.227	0.478	0.600	0.711	0.795	0.700	0.814	0.740	0.340
A4	0.050	0.449	0.898	0.647	0.760	1.000	0.800	0.336	0.465	0.761	0.700	0.844	0.672	0.660	0.767	0.800	0.260
A5	0.075	0.462	0.814	0.471	0.760	1.000	0.800	0.280	0.346	0.761	0.700	0.844	0.713	0.660	0.767	1.000	0.260
A6	0.566	0.667	0.898	0.353	0.600	0.500	0.400	0.161	0.184	0.435	0.200	0.667	0.910	0.500	0.698	0.800	0.300
A7	0.053	0.256	0.778	0.765	0.840	0.500	0.480	0.448	0.561	0.522	0.440	0.622	0.657	0.780	0.535	0.420	0.860
A8	0.225	0.474	0.778	0.412	0.600	0.500	0.200	0.136	0.146	0.217	0.200	0.444	1.000	0.400	0.698	0.600	0.200
A9	0.075	0.487	0.743	0.882	0.800	1.000	0.800	0.507	0.568	0.652	0.800	0.889	0.615	0.800	0.698	0.600	0.600
A10	0.064	0.577	0.928	0.471	1.000	1.000	0.800	0.319	0.360	0.652	0.800	0.889	0.672	0.800	0.698	0.800	0.400
A11	0.125	0.667	0.910	0.471	1.000	0.500	0.660	0.267	0.221	0.652	0.600	0.956	0.672	0.800	0.930	0.800	0.800
A12	0.038	0.556	1.000	1.000	1.000	1.000	1.000	0.638	0.561	0.978	1.000	1.000	0.527	0.800	0.930	0.900	0.600
A13	1.000	0.427	0.778	0.235	0.500	0.500	0.200	0.106	0.078	0.217	0.200	0.222	0.971	0.400	0.930	0.900	0.200
A14	0.357	0.385	0.838	0.294	0.600	0.500	0.200	0.115	0.102	0.217	0.200	0.667	0.971	0.600	0.698	0.800	0.200
A15	0.018	1.000	0.952	0.824	1.000	1.000	0.940	1.000	1.000	1.000	0.760	0.978	0.437	1.000	1.000	0.960	1.000

Table 4. Matrix about the weights of the criteria.

VSP	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
1	4	1	2	1	1	2	1	1	1	4	3	1	4	1	3	1	2
2	12	2	4	2	1	5	4	1	3	12	18	5	10	1	3	2	2
3	12	11	24	16	4	13	14	11	7	13	11	16	14	10	12	6	6
4	4	18	2	13	26	12	13	19	21	3	0	10	4	20	14	23	22
Score	80	110	90	105	119	99	103	112	112	79	72	99	82	113	101	115	112
Weight	**0.047**	**0.065**	**0.053**	**0.062**	**0.070**	**0.058**	**0.060**	**0.066**	**0.066**	**0.046**	**0.042**	**0.058**	**0.048**	**0.066**	**0.059**	**0.068**	**0.066**

Note: VSP = value scale point; 1 = irrelevant; 2 = not important; 3 = important; 4 = very important.

Table 5. Matrix for the weighted sum method (WSM).

Alternatives	**Criteria**																	**WSM**
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**	**C15**	**C16**	**C17**	
A1	0.004	0.028	0.049	0.022	0.066	0.029	0.036	0.014	0.016	0.018	0.017	0.047	0.039	0.060	0.055	0.054	0.022	0.575
A2	0.014	0.028	0.049	0.022	0.064	0.029	0.033	0.014	0.016	0.018	0.014	0.036	0.039	0.052	0.054	0.053	0.024	0.557
A3	0.014	0.028	0.047	0.022	0.063	0.058	0.039	0.016	0.015	0.022	0.025	0.041	0.038	0.046	0.048	0.050	0.022	0.596
A4	0.002	0.029	0.047	0.040	0.053	0.058	0.048	0.022	0.031	0.035	0.030	0.049	0.032	0.044	0.046	0.054	0.017	0.638
A5	0.004	0.030	0.043	0.029	0.053	0.058	0.048	0.018	0.023	0.035	0.030	0.049	0.034	0.044	0.046	0.068	0.017	0.628
A6	0.027	0.043	0.047	0.022	0.042	0.029	0.024	0.011	0.012	0.020	0.008	0.039	0.044	0.033	0.041	0.054	0.020	0.516
A7	0.003	0.017	0.041	0.047	0.059	0.029	0.029	0.029	0.037	0.024	0.019	0.036	0.032	0.052	0.032	0.028	0.057	0.570
A8	0.011	0.031	0.041	0.025	0.042	0.029	0.012	0.009	0.010	0.010	0.008	0.026	0.048	0.027	0.041	0.041	0.013	0.424
A9	0.004	0.031	0.039	0.054	0.056	0.058	0.048	0.033	0.037	0.030	0.034	0.052	0.030	0.053	0.041	0.041	0.030	0.682
A10	0.003	0.037	0.049	0.029	0.070	0.058	0.048	0.021	0.024	0.030	0.034	0.052	0.032	0.053	0.041	0.054	0.026	0.662
A11	0.006	0.043	0.048	0.029	0.070	0.029	0.040	0.018	0.015	0.030	0.025	0.056	0.032	0.053	0.055	0.054	0.053	0.655
A12	0.002	0.036	0.053	0.062	0.070	0.058	0.060	0.042	0.037	0.045	0.042	0.058	0.025	0.053	0.055	0.061	0.039	0.799
A13	0.047	0.028	0.041	0.015	0.035	0.029	0.012	0.007	0.005	0.010	0.008	0.013	0.047	0.027	0.055	0.061	0.013	0.452
A14	0.017	0.025	0.044	0.018	0.042	0.029	0.012	0.008	0.007	0.010	0.008	0.039	0.047	0.040	0.041	0.054	0.013	0.454
A15	0.001	0.065	0.050	0.051	0.070	0.058	0.057	0.066	0.066	0.046	0.032	0.057	0.021	0.066	0.059	0.065	0.066	0.896

Table 6. Matrix for the weighted product method (WPM).

Alternatives	Criteria																	WPM
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	
A1	0.895	0.947	0.966	0.938	0.996	0.961	0.970	0.903	0.910	0.957	0.962	0.987	0.989	0.993	0.996	0.985	0.932	0.492
A2	0.945	0.947	0.966	0.939	0.994	0.961	0.963	0.903	0.911	0.957	0.953	0.973	0.989	0.984	0.994	0.983	0.935	0.499
A3	0.945	0.947	0.994	0.939	0.993	1.000	0.973	0.911	0.907	0.966	0.979	0.980	0.989	0.977	0.988	0.980	0.932	0.538
A4	0.869	0.950	0.994	0.974	0.981	1.000	0.987	0.931	0.951	0.987	0.985	0.990	0.981	0.973	0.984	0.985	0.915	0.558
A5	0.885	0.951	0.989	0.955	0.981	1.000	0.987	0.920	0.933	0.987	0.985	0.990	0.984	0.973	0.984	1.000	0.915	0.548
A6	0.974	0.974	0.994	0.938	0.965	0.961	0.946	0.887	0.895	0.962	0.934	0.977	0.995	0.955	0.979	0.985	0.924	0.457
A7	0.871	0.916	0.987	0.984	0.988	0.961	0.957	0.949	0.963	0.970	0.966	0.973	0.980	0.984	0.964	0.943	0.990	0.508
A8	0.932	0.953	0.987	0.947	0.965	0.961	0.907	0.877	0.881	0.932	0.934	0.954	1.000	0.941	0.979	0.966	0.900	0.359
A9	0.885	0.955	0.984	0.992	0.985	1.000	0.987	0.956	0.963	0.980	0.991	0.993	0.977	0.985	0.979	0.966	0.967	0.627
A10	0.879	0.965	0.996	0.955	1.000	1.000	0.987	0.928	0.935	0.980	0.991	0.993	0.981	0.985	0.979	0.985	0.942	0.584
A11	0.907	0.974	0.995	0.955	1.000	0.961	0.975	0.917	0.906	0.980	0.979	0.997	0.981	0.985	0.996	0.985	0.985	0.584
A12	0.857	0.963	1.000	1.000	1.000	1.000	1.000	0.971	0.963	0.999	1.000	1.000	0.970	0.985	0.996	0.993	0.967	0.704
A13	1.000	0.947	0.987	0.915	0.953	0.961	0.907	0.863	0.846	0.932	0.934	0.916	0.999	0.941	0.996	0.993	0.900	0.345
A14	0.953	0.940	0.991	0.927	0.965	0.961	0.907	0.867	0.861	0.932	0.934	0.977	0.999	0.967	0.979	0.985	0.900	0.368
A15	0.828	1.000	0.997	0.988	1.000	1.000	0.996	1.000	1.000	1.000	0.988	0.999	0.961	1.000	1.000	0.997	1.000	0.769

5.6. Aggregation of WSM and WPM Methods

According to Zavadskas et al. [45], to increase the classification accuracy and effectiveness of the decision-making process, a generalized equation, Equation (5), aggregates the two methods used in the analysis. To calculate the relative importance of the methods, the variable λ, whose values range from zero to one ($0 \leq \lambda \leq 1$), is used. In the present study, to increase the accuracy of the results, three values were used for the variable λ: 0.25, 0.5, and 0.75. Table 7 summarizes the results generated for the set of $\lambda = \{0, 0.25, 0.50, 0.75, 1\}$. Considering that the best alternatives are those with the highest Qi value, alternatives were ranked by decreasing score. Figure 2 illustrates the ranking of the helicopters, where the first option is Alternative A15 (Sikorsky UH-60 (Black Hawk)).

Table 7. The overall ranking of the alternatives.

Ranking	Alternatives	Helicopters	$\lambda = 0$	$\lambda = 0.25$	$\lambda = 0.50$	$\lambda = 0.75$	$\lambda = 1$
1.	A15	Sikorsky UH-60 (Black Hawk)	0.769	0.801	0.832	0.864	0.896
2.	A12	Leonardo AW 139	0.704	0.727	0.751	0.775	0.799
3.	A9	Bell 412	0.627	0.641	0.654	0.668	0.682
4.	A10	Bell 429	0.584	0.604	0.623	0.643	0.662
5.	A11	Leonardo AW 119 Kx	0.584	0.602	0.620	0.637	0.655
6.	A4	Airbus EC 145 (BK-117 C2)	0.558	0.578	0.598	0.618	0.638
7.	A5	Airbus EC 135	0.548	0.568	0.588	0.608	0.628
8.	A3	Airbus H355 (Twin-Engine Squirrel)	0.538	0.552	0.567	0.581	0.596
9.	A7	Bell UH-1H (Huey II)	0.508	0.523	0.539	0.554	0.570
10.	A2	Airbus H125 B2 (Squirrel)	0.499	0.514	0.528	0.542	0.557
11.	A1	Airbus H125 B3 (Squirrel)	0.492	0.512	0.533	0.554	0.575
12.	A6	Airbus EC 120 (Hummingbird)	0.457	0.472	0.487	0.502	0.516
13.	A14	Robinson 66	0.368	0.389	0.411	0.432	0.454
14.	A8	Bell 206 (Long Ranger)	0.359	0.375	0.391	0.407	0.424
15.	A13	Robinson 44	0.345	0.372	0.399	0.425	0.452

Figure 2 graphically represents the ranking arranged on the set of λ values used. The order is arranged clockwise and decreasingly. The outermost layer of the radar corresponds to the first position in the ranking. The layers closer to the circle's center correspond to the lower ranks in order. The results of the application of each λ are arranged by color. We can see that the alternatives obtained the same position in the ranking for all values applied to λ.

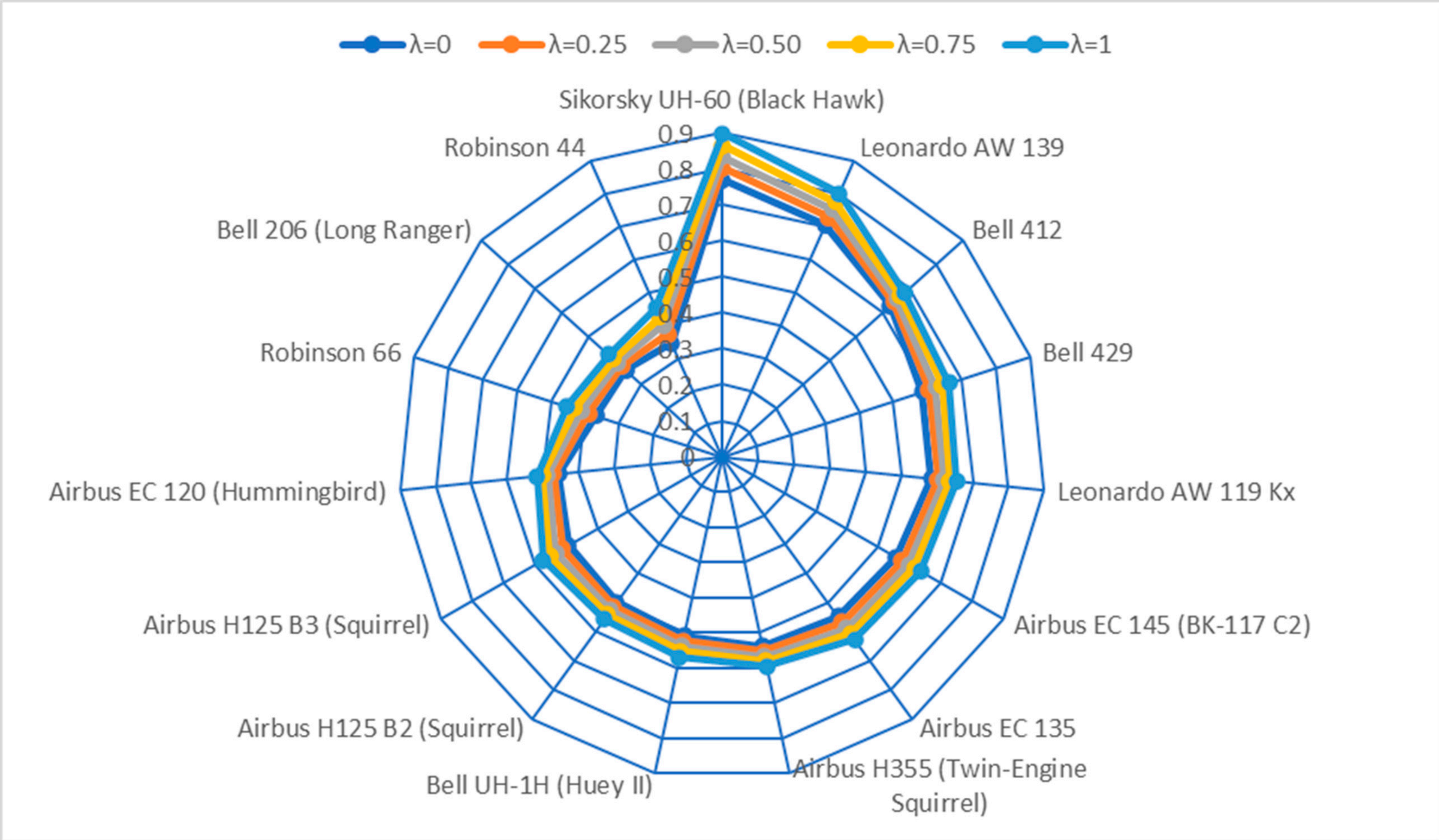

Figure 2. Illustration of the ranking of helicopters with the application of WASPAS.

6. Discussion and Final Considerations

By analyzing the classifications obtained, as evidenced in Table 7 and Figure 2, it is observed that the results are only slightly modified by the changes in the value of the variable λ, and the ordering of alternatives remained the same in the three tables up to the ninth position. There was a small alternation between the 10th and 11th positions and between the penultimate and ultimate positions, but the values remained very close.

It is noted that, mathematically, the helicopter model most suitable for police air activity in the State of Rio de Janeiro is the Sikorsky UH-60 (Black Hawk) because it is the aircraft that obtained the best result with the application of the method in all cases, isolating itself from the others in the classifications. This result reflects the ability of this aircraft to act effectively in different missions and to provide a higher level of protection to the crew in hostile environments, one of the most significant concerns of public safety aviators, as can be inferred from the data in Table 1, showing the model in question was the only one to obtain the maximum average evaluation among helicopters in the protection criterion, which was evaluated as the second largest weight. It is also noteworthy that, in the criterion availability, the one with the highest importance, the UH-60, obtained the best evaluation.

Another aspect that deserves to be considered is the proximity of the results obtained for the alternatives classified between the second and fifth position, demonstrating that these aircraft also meet the predefined requirements effectively, making them acceptable options.

Although the alternatives classified between the sixth and eleventh position in the three hypotheses occupied the intermediate zone of the classification, it is worth mentioning that the results were also close and that these alternatives are widely used by police forces in Brazil and several other countries, demonstrating that they are aircraft with applicability in certain types of police missions, even if they are not considered the best options.

Regarding the alternatives that occupy the last four positions in the classification, it is observed that the results obtained were very low and far from the others, so these aircraft are considered inadequate or limited in achieving the goals that are generally pursued.

This research aimed to solve a real problem faced by the Military Police of the State of Rio de Janeiro regarding determining a helicopter model that is more suitable for the effective and safe fulfillment of the missions developed by the Airmobile Unit. The UH-60 aircraft (Black Hawk) was indicated as the best model through the WASPAS method, confirming a perception that already prevails in the public and military security aviation sector. The final classification of alternatives is also relevant for discussing the use of each model. Thus, it is concluded that the WASPAS method proved efficient for solving the proposed problem.

The practical implications of applying the WASPAS multi-criteria method to select helicopters to be used by the police service consist of aiding in the decision making of police managers by reducing discretionary aspects that refute technical choices.

In future research, we can indicate the association of the Entropy or CRITIC methods for eliciting criteria weights. Based on the available data, other analyses can be carried out as a comparative study using other multi-criteria methods, such as COMET, MABAC, SPOTIS, VIKOR, SAPEVO-M, and PROMETHEE.

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Abbreviations

The following abbreviations are used in this manuscript:

AHP	Analytic Hierarchy Process
ANAC	Agência Nacional de Aviação Civil (Portuguese)
ANP	Analytical Network Process
COMET	Characteristic Objects METhod
COPRAS	Complex Proportional Assessment
CRITIC	CRiteria Importance Through Intercriteria Correlation
DARIA-TOPSIS	Data vARIability Assessment Technique for Order of Preference by Similarity to Ideal Solution
DRSA	Dominance-based Rough Set Approach
ELECTRE	ÉLimination et Choix Traduisant la REalité (French)
GAM	Grupamento Aereomóvel (Portuguese)
MACBETH	Measuring Attractiveness by a Categorical-Based Evaluation Technique
MABAC	Multi-Attributive Border Approximation Area Comparison
MAIRCA	Multi-Attributive Ideal-Real Comparative Analysis
MCDA	Multi-criteria decision analysis
MCDM	Multi-criteria decision making
MODM	Multi-Objective Decision Making
MOORA	Multi-Objective Optimization by Ratio Analysis
MULTIMOORA	MOORA plus the full Multiplicative Form
NAIADE	Novel Approach to Imprecise Assessment and Decision Environment
PCCA	Pairwise Criterion Comparison Approach
PROMETHEE	Preference Ranking Organization Method for Enrichment of Evaluation
SAPEVO-M	Simple Aggregation of Preferences Expressed by Ordinal Vectors Group Decision Making
SIMUS	Sequential Interactive Modelling for Urban Systems
SPOTIS	Stable Preference Ordering Towards Ideal Solution
WASPAS	Weighted aggregated sum product assessment
WPM	Weighted product model
WSM	Weighted sum model
TODIM	Tomada de Decisão Interativa Multicritério (Portuguese)
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
UAP	Unidade Aérea Pública (Portuguese)
VIKOR	VlseKriterijumska Optimizacija I Kompromisno Resenje (Serbian)

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