Decision Science Letters 10 (2021) 487–496

Contents lists available at GrowingScience

Decision Science Letters

homepage: www.GrowingScience.com/dsl

Evaluation of the operational viability of forensic units in Brazil: A hybrid approach based on the BWM and R-TOPSIS

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C H R O N I C L E

Article history:
Received February 2, 2021
Received in revised format: June 2, 2021
Accepted July 4 2021
Available online July 4, 2021

Keywords:
Public Security
Criminalistics
Multicriteria Decision
BWM
R-TOPSIS

A B S T R A C T

Public security is an area of increasing importance in Brazil, as society requires that public resources are managed more efficiently and effectively. Criminalistics is an integral and vital part of the Brazilian public security system and requires new management tools to optimize human resources, equipment, and facilities allocation. Faced with a challenging scenario of budgetary constraints in several areas in public administration, the search for innovative methods should be a priority for the forensic service sector managers. The current article presents a multicriteria decision model to evaluate the operational viability of 23 forensic units within the Federal Police of Brazil (PF). The framework used the hybrid approach BWM and R-TOPSIS. The proposed model led to the complete ranking of 23 local forensic units. Amongst the last positions in the ranking, it was possible to recommend merging or shutting down some units. The sensitivity analysis performed did not show abrupt variations in the original positions, confirming the robustness of the proposed solution. It was concluded that the model allowed resources optimization whilst not compromising the quality of the services provided to society.

1. Introduction

Criminalistics can be described as the part of forensic science that is operated within laboratories focused on criminal cases, usually in parallel with police investigations or lawsuits. The popularity of criminalistics issues has been boosted by the growing audience of television programs that address crime scene investigations and the constant improvement of the methods employed in the resolution of cases, boosting the confidence of the judicial system (Huey, 2010). Houck et al. (2015) present a general review of the literature involving management issues in the forensic science area between 2009 and 2013 and begin by pointing out that one of the greatest difficulties encountered was the establishment of a cut-off point to distinguish between scientific and managerial oriented articles, reinforcing the maladaptation of the forensic scientist to management issues. The above-mentioned authors divide the review into three major categories that affect forensic sciences: i) the external factors faced by the sector; ii) leadership issues and sector organization; and iii) competitive reality. One of public management's major challenges is the evaluation of criteria or parameters that support the allocation of material and personnel resources in a more efficient and effective manner. Society increasingly demands a modern and professional public administration that decides objectively and adopts methodologies or protocols that enable the traceability of the decisions taken. The greater rationalization in the use of public resources justifies the adoption of tools that guide public managers to take complex decisions in strategic, tactical, or operational levels. Thus, Multiple Criteria Decision Methods (MCDM) support greater objectivity in the construction of possible solutions based on the alternatives and criteria available. According to Almeida et al. (2015) Multi-Criteria Decision Methods (MCDM) consider the preference structure of a decision maker (DM) and involve value judgments. The DM's preferences will be incorporated into the decision model to support the alternative choices, thus analysing multiple decision criteria simultaneously.

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doi: 10.5267/j.dsl.2021.7.001

Accordingly, the contribution of the current research lies in the application of a multicriteria hybrid approach based on the Best-Worst Method (BWM) and R-TOPSIS methods to perform the ranking of 23 local forensic units (FUs) within the Federal Police of Brazil, thus contributing to public security management.

2. Literature review

2.1 Management of forensic science services

De Kinder (2017) analyses the different forensic structures between some European countries as to implement the European Forensic Science Area 2020 (EFSA 2020). The countries evaluated were Belgium; Finland; France; Germany; Netherlands; and Sweden. Different government structures were observed, ranging from centralized structures to more decentralized systems, all of them presenting the permanence of crime scene units within the police forces, whilst other forensic disciplines may be organized into non-police structures; the structures focused on legal medicine also present variation between state and private service. Similar analyses in relation to stakeholders, private forensic science service providers and the attendance of high-impact cases also show a diversity of organizational structures amongst countries. McAndrew and Houck (2019) present a comprehensive review of research work involving the management of forensic science services carried out between 2016 and 2019 around the world. The authors detect the occurrence of a specific change in the main themes addressed by the researchers, so that less attention was paid to issues involving accreditation of laboratories and a greater emphasis was applied on the themes of decision-making processes, transparency and application of information technology.

2.2 Best-Worst Method (BWM)

BWM was presented by Rezaei (2015) and it is used to obtain the weights of the criteria involved in a multicriteria decision problem. It is a multicriteria method that uses linear programming techniques and is considered subjective, because it considers the preferences of the decision maker, expressed through pairwise comparison between criteria.
The BWM was presented as an alternative to the Analytic Hierarchy Process - AHP (SAATY, 2013) and according to Mi et al. (2019) presents as a differential the need for a smaller number of pairwise comparison, because only reference comparisons are required by the decision maker (DM), that is, those that include the most important and least important element of the set of criteria. The literature presents BWM applications in several areas such as: evaluation of electricity supply companies (You et al. 2017); sustainable technology assessment (Ren et al. 2017); performance evaluation of firms in the research and development sector (Salimi & Rezaei, 2018); performance evaluation of solar batteries (Zhao et al. 2018); and key factors affecting university-industry collaboration (Mosayebi et al. 2019).

The steps required to use the method are presented below (Rezaei, 2015, 2016):

Step 1: Selection of criteria to solve the proposed problem, allowing the creation of a set C that represents the relevant criteria, according to Eq. (1):

$$C = \{c_1, c_2, \dots, c_n\} \tag{1}$$

Step 2: Choice of the most important criterion, considered Best (c_B), and the least important criterion, considered Worst (c_W), from the set of available criteria. In the event of a tie between criteria in the best or worst nomination, the decision maker can choose arbitrarily between them.

Step 3: The Best criterion (c_B) is compared to each of the other criteria, always using a scale of integers from 1 to 9 derived from AHP. The preference of the decision maker is represented by a_{Bj}, indicating how c_B is more relevant than c_j. Eq. (2) expresses the vector. It should be remembered that $a_{BB} = 1$:

$$BO = (a_{B1}, a_{B2}, \dots, a_{Bn}) \tag{2}$$

Step 4: The other criteria are compared to the Worst (c_W), always using integers from 1 to 9. The decision maker's preference is represented by a_{jW}, indicating how much c_j is more relevant than c_W. The vector represented by Eq. (3) is formed. It should be remembered that $a_{WW} = 1$:

$$OW = (a_{1W}, a_{2W}, \dots, a_{nW})^T \tag{3}$$

Step 5: The optimal criteria weights are found ($w_1^*, w_2^*, \dots, w_n^*$).

In order to avoid multiples optimal solutions, the linear model of BWM presented by Rezaei (2016) was applied in the current research as follows:
min ξ^L

s.t.

$$
\begin{aligned}
&|w_B - a_{Bj}w_j| \leq \xi^L \\
&|w_j - a_{jW}w_W| \leq \xi^L \\
&\sum_{j=1}^{n} w_j = 1, w_j \geq 0, for\ all\ j
\end{aligned}
\tag{4}
$$

According to Rezaei (2016) the above linear problem (4) has a unique solution. The optimal criteria weights $(w_1^*, w_2^*, \ldots, w_n^*)$ and $\xi^{L*}$are obtained. Values of ξ^{L*}close to zero display a high level of consistency.

2.3 R-TOPSIS

TOPSIS (Technique of Order Preference Similarity to the Ideal Solution) is a multicriteria method developed by Hwang & Yoon (1981) and is considered the second most widely used MCDM, second only to AHP, according to Çelikbilek & Tüysü (2020). Aires and Ferreira (2019) clarify that TOPSIS considers that the best alternative is the one closer to the positive ideal solution (PIS) and further from the negative ideal solution (NIS). PIS is a hypothetical alternative that maximizes benefit criteria whilst minimizing cost criteria. On the other hand, NIS acts in reverse, maximizing costs and minimizing benefits. The steps necessary for the application of TOPSIS involve the normalization of the initial decision matrix; the aggregation of the values of the weights to the normalized matrix; the determination of positive and negative ideal solutions; the calculation of the distances or separations of the alternatives in relation to the PIS and NIS; the calculation of the proximity coefficients of each alternative; and finally, the obtainment of the ranking of the alternatives from the decreasing ordering of the values of the corresponding proximity coefficients. According to Aires and Ferreira (2019), Yang (2020) and Çelikbilek and Tüysüz (2020), despite the wide use of TOPSIS in problems involving multicriteria, the phenomenon of ranking reversal is a reason for strong criticism of the method and is consisted of the change in the position of alternatives from the addition or subtraction of a criterion or alternative from the original sets. Some changes in the original TOPSIS were proposed to overcome the problem of ranking reversal, allowing the use of the method more reliably. The proposals use modifications in the normalization methods of the original decision matrix and in the rule to obtain PIS and NIS. A modified version of TOPSIS known as R-TOPSIS was presented by Aires & Ferreira (2019). The authors demonstrated through computational simulations the stability of the proposed solution in relation to the phenomenon of ranking reversal. The authors presented the steps required to use the method as follow:

Step 1: Define a set of alternatives (A):

$$A = [a_i]_m \tag{5}$$

Step 2: Define a set of criteria (C), and a subdomain of real numbers (D), where $d_j \in R$, evaluate the rating of the alternatives, where d_{1j} is the minimum value of D_j and d_{2j} is the maximum value of D_j:

$$C = [c_i]_n \tag{6}$$

$$D = [d_j]_{2\times n} \tag{7}$$

Step 3: Estimate the performance rating of the alternatives as (X):

$$X = [x_{ij}]_{m\times n} \tag{8}$$

Step 4: Elicit the criteria weights as (W), where $w_j > 0$ and $\sum_{j=1}^{n} w_j = 1$:

$$W = [w_j]_n \tag{9}$$

Step 5: Calculate the normalized decision matrix (n_{ij}) by using Max or Max-Min as:

Step 5.1: Max

$$n_{ij} = \frac{x_{ij}}{d_{2j}}, i = 1,2,\cdots,m; j = 1,2,\cdots,n \tag{10}$$

Step 5.2: Max-Min

$$n_{ij} = \frac{x_{ij} - d_{1j}}{d_{2j} - d_{1j}}, i = 1,2,\cdots,m; j = 1,2,\cdots,n \tag{11}$$

Step 6: Calculate the weighted normalized decision matrix (r_{ij}) as:

$$n_{ij} = \frac{x_{ij} - d_{1j}}{d_{2j} - d_{1j}}, i = 1,2,\cdots,m; j = 1,2,\cdots,n \quad (12)$$

Step 7: Set the positive (PIS) and negative (NIS) ideal solutions as:

$$PIS = \{r_1^+,\cdots,r_n^+\}, where\ r_j^+ = w_j\ if\ j\ \in B\ e\ r_j^+ = \frac{d_{1j}}{d_{2j}} w_j\ if\ j \in C \quad (13)$$

$$NIS = \{r_1^-,\cdots,r_n^-\}, where\ r_j^- = \frac{d_{1j}}{d_{2j}} w_j\ if\ j\ \in B\ e\ r_j^+ = w_j\ if\ j \in C \quad (14)$$

Step 8: Calculate the distances of each alternative i in relation to the ideal solutions as:

$$S_i^+ = \sqrt{\sum_{j=1}^{n} \left(r_{ij} - r_j^+\right)^2}, i = 1,\cdots,m \quad (15)$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} \left(r_{ij} - r_j^-\right)^2}, i = 1,\cdots,m \quad (16)$$

Step 9: Calculate the closeness coefficient of the alternatives (CC_i) as:

$$CC_i = \frac{S_i^-}{S_i^- + S_i^+} \quad (17)$$

Step 10: Sort the alternatives in descending order. The highest CC_i value indicates the best performance in relation to the evaluation criteria.

3. Methodology

Within the context of multicriteria decision-making, there are several approaches in the literature that recommend phases or steps that must be followed in the process of formulating models to solve multicriteria problems according to Pomerol & Barba-Romero (2000), Belton & Stewart (2002), Tsoukiàs (2007), Dodgson et al. (2009), De Almeida (2013) and Ferretti (2016).

3.1 Applied framework

De Almeida (2013) proposes a procedure for constructing the model with three main phases that are divided each into 12 steps. The process described admits recursive refinements and is shown on Table 1. Given the other approaches available in the literature for the construction of models already presented, the framework chosen allows successive refinements to be applied throughout the development of the model and provides greater reflection to the users regarding the most significant aspects in the problem examined.

Table 1
Framework proposed by De Almeida (2013)

Phase	Step
Preliminary	1. Characterizing the DM and Other Actors. 2. Identifying Objectives. 3. Establishing Criteria. 4. Establishing the Set of Actions and Problematic. 5. Identifying uncontrolled factors.
Modelling preferences and method choice	6. Preference Modelling. 7. Conducting an Intra-Criterion Evaluation. 8. Conducting an Inter-Criteria Evaluation.
Finalization	9. Evaluating Alternatives. 10. Conducting a Sensitivity Analysis. 11. Analysis of results and preparation of recommendations. 12. Implementing the decision.

4. Results

This section examines the results obtained from the application of the framework to the case study, which involves the evaluation of operational viability of 23 local forensic units within the Federal Police of Brazil (PF). Within the PF, the delivery of forensic science services is the role of the Technical-Scientific Directorate (DITEC/PF). Both The headquarters of DITEC/PF and the National Institute of Criminalistics (INC/DITEC/PF), a central unit that performs forensic science activities within that agency, are located in Brazil's capital, Brasília/DF. The Forensic science services structure within DITEC/PF is composed of the INC/DITEC/PF, as the central unit; 27 forensic science sections (SETECs), inserted in the Federal Police state offices, located in the capitals cities of each Brazilian state; and 23 FUs, inserted in local Federal Police stations. Fig. 1 illustrates the hierarchical structure.

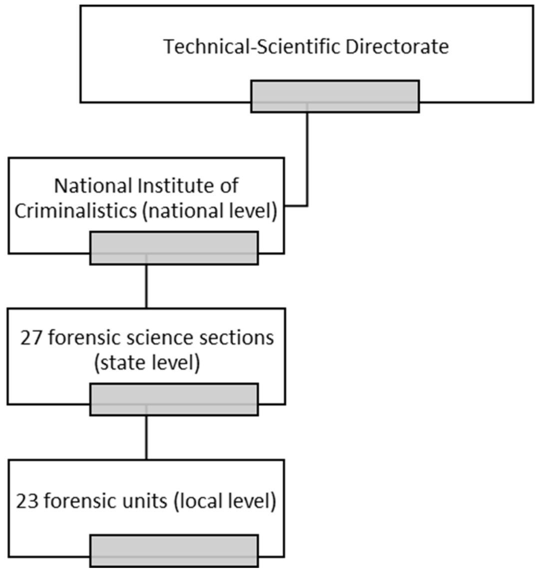

Fig. 1. Forensic science services structure in the Brazilian Federal Police

The framework applied the ranking problematic related to the 23 FUs is explained in the following sections:

4.1. Characterizing the DM and Other Actors

The first step aims at identifying the DMs and other relevant players, such as experts, analysts, advisors, and stakeholders. In this instance, the DM chosen was the Forensic Science Director of the Federal Police. The decision analyst was also from the institution's board, whose role was to clarify the methods and methodology employed. The experts consulted were forensic experts. According to De Almeida (2013) the expert has specialized knowledge of some parts of the system, which is the object of the decision process and who gives information to be incorporated within the model.

4.2. Identifying Objectives

Our fundamental objective is the improvement of the management of federal forensic services, regarding FUs, thus allowing better use of public resources invested in public security, in face of a scarcity scenario.

4.3. Establishing Criteria

The group of experts, composed of forensic experts working at the National Institute of Criminalistics, elaborated a set of metrics aimed at evaluating the operational viability of FUs (Table 2).

Table 2
Criteria set developed by the experts

Criteria	Type	Definition
C01 – Regional demand for forensic analysis (all areas)	Benefit	The quantity of forensic analysis requests in the region served by the FU weighted by request complexity. All areas of forensic analysis are included.
C02 – Regional demand for crime scene examination	Benefit	The quantity of crime scene analysis requests in the region served by the FU
C03 – FU capacity to face regional demand	Benefit	Percentage of forensic analysis requests performed in the region served by the FU
C04 – Workload per forensic expert	Benefit	The quantity of forensic analysis requests in the region served by the FU weighted by request complexity, divided by the quantity of forensic personnel (average)
C05 – Forensic personnel	Benefit	Number of Forensic personnel crew
C06 – Turnover net result	Benefit	Indicates the attractiveness of the FU. A positive number indicates that the local forensic team is increasing. On the other hand, a negative number indicates that the local forensic team is decreasing.
C07 - Road distance from the FU to the SETEC in the capital of the state.	Benefit	Units farther from the SETEC simplify the logistics of forensic service delivery, extending the criminalistics assistance capacity.

4.4. Establishing the Actions Set and the Problem

In this case, the actions set correspond to the discrete set of 23 FUs. According to Almeida et al. (2015) the concept of problem is related to the format of recommendation to be made for the alternatives set. As the alternatives set must be compared and ranked amongst them, the problem ranking indicates the most suitable choice. The consequence matrix is illustrated on Table 3. The following data was retrieved from the federal forensic database from 2018 to 2019.

Table 3
Consequence matrix

FU	C01	C02	C03	C04	C05	C06	C07
FU01	1684.4950	0.4583	0.5853	563.4171	3.0000	-1.0000	504.0000
FU02	1084.8100	0.7917	0.5380	259.3978	4.0000	-1.0000	500.0000
FU03	4083.4350	1.7917	0.7855	712.8033	9.0000	0.0000	273.0000
FU04	5101.0450	2.5833	0.7461	524.9834	14.0000	-1.0000	537.0000
FU05	6580.4400	1.2917	0.6228	964.3624	10.0000	3.0000	228.0000
FU06	1712.4950	0.7083	0.5355	611.3667	2.0000	-2.0000	215.0000
FU07	1050.4600	0.3333	0.6736	257.3236	6.0000	1.0000	481.0000
FU08	2071.8450	0.7083	0.4041	558.1900	3.0000	0.0000	1375.0000
FU09	6977.7800	1.4583	0.8430	619.2084	20.0000	2.0000	636.0000
FU10	4800.9350	1.1667	0.7891	1165.6092	7.0000	1.0000	643.0000
FU11	4422.7300	1.4583	0.6321	657.8153	8.0000	-1.0000	390.0000
FU12	1728.6250	0.3333	0.6110	528.1125	4.0000	0.0000	707.0000
FU13	3206.9800	2.0833	0.3803	375.3015	6.0000	-1.0000	289.0000
FU14	2381.9000	1.7083	0.8489	898.6756	5.0000	1.0000	260.0000
FU15	2465.6800	0.7917	0.2755	226.4133	5.0000	-2.0000	290.0000
FU16	4864.9800	2.8333	0.8861	749.7191	11.0000	-1.0000	95.0000
FU17	3538.0200	5.9167	0.8494	751.2700	9.0000	2.0000	80.0000
FU18	2399.3900	0.4167	0.3994	479.2175	4.0000	0.0000	520.0000
FU19	3507.3200	0.9583	0.4391	513.3383	7.0000	2.0000	450.0000
FU20	2314.9300	0.5417	0.7577	877.0425	4.0000	0.0000	560.0000
FU21	4791.6800	1.5417	0.7221	692.0540	10.0000	0.0000	320.0000
FU22	3123.7000	3.2083	0.7256	697.3908	7.0000	1.0000	90.0000
FU23	3353.2550	1.2500	0.7601	849.5567	6.0000	0.0000	100.0000

4.5. Identifying uncontrolled factors

It was considered that in the present problem UCIs ordering there are no relevant factors which are not under the DM control.

4.6. Preference Modelling

This stage deals with determining the most appropriate structure to represent the DM preferences. According to De Almeida (2013), an important issue to be evaluated in this step is the assessment of rationality regarding compensation amongst criteria. The question "Which type of rationality is the most adequate to the DM?" must be answered, resulting in non-compensatory methods or compensatory methods. Compensatory rationality was considered adequate for the problem and allowed the use of MADM based on the additive model. The approach chosen to face the problem of ordering the FUs involves the BWM method to calculate the values of the criteria weights and the R-TOPSIS method for the evaluation and ranking of FUs. The choice of methods followed the rational based on Dodgson et al. (2009), because it took into account the type of decision faced; the time available for decision making; the quantity and nature of the data available to support the decision-making process; the analytical skills of the actors who conduct the decision-making process; and the culture and organizational requirements of the institution.

4.7. Conducting an Intra-Criterion Evaluation

According to De Almeida (2013), this step consists of eliciting the value function, related to the value of different performances of outcomes in a specific criterion. For compensatory methods the elicitation procedure may produce linear or nonlinear value functions. For this application, the normalization method used by R-TOPSIS and expressed by Eq. (11) was considered appropriate due to its linear nature.

4.8. Conducting an Inter-Criteria Evaluation

In this step the values of the criteria weights were elicited via BWM. The DM received a spreadsheet form in which it was possible to express his preferences through pairwise comparison in relation to the criteria set. The pairwise comparison vectors for the best and worst criteria are shown on Table 4 and Table 5. The results shown on Table 6 were produced after solving the model represented by Eq. (4).

Table 4
Pairwise comparison vector for the best criterion

Criteria	C01	C02	C03	C04	C05	C06	C07
Best: C02	6	1	7	4	3	9	2

Table 5
Pairwise comparison vector for the worst criterion

Criteria	Worst: C06
C01	3
C02	8
C03	3
C04	5
C05	6
C06	1
C07	2

Table 6
Criteria weights calculated by BWM

Criteria	Weight
C01 – Regional demand for forensic analysis (all areas)	0.0778
C02 – Regional demand for crime scene examination	0.3889
C03 – FU capacity to face regional demand	0.0667
C04 – Workload per forensic expert	0.1167
C05 – Forensic personnel	0.1556
C06 – Turnover net result	0.0389
C07 - Road distance from the FU to the SETEC in state capital	0.1556
ξ^{L*}	0.0471

4.9. Evaluating Alternatives

This step applies the R-TOPSIS algorithm into the decision model to evaluate the alternatives set. The Table 7 shows the values of the input parameter "domain", a set of numeric values chosen by the DM, representing the range of possible values that each criterion can take, according to Aires & Ferreira (2019). The Table 8 shows the values of the ideal solutions (PIS and NIS), after the normalization step.

Table 7
Maximum (d_{2j}) and minimum (d_{1j}) values of "domain" (D_j)

	C01	C02	C03	C04	C05	C06	C07
d_{2j}	7000.00	6.00	1.00	1200.00	21.00	4.00	1400.00
d_{1j}	1000.00	0.00	0.00	200.00	1.00	-3.00	70.00

Table 8
Positive (PIS) and negative (NIS) ideal solutions

	C01	C02	C03	C04	C05	C06	C07
PIS	0.0778	0.3889	0.0667	0.1167	0.1556	0.0389	0.1556
NIS	0.0111	0.0000	0.0000	0.0194	0.0074	-0.0292	0.0078

The closeness coefficient is always between 0 and 1, where 1 is the preferred action. If an alternative is closer to the PIS than NIS, then CCi approaches 1, whereas if an action is closer to the NIS than to the PIS, CCi approaches 0. The final ranking is illustrated in Fig. 2 and was formed after sorting the FUs in descending order. The highest CCi value indicates the best performance in relation to the evaluation criteria. Table 9 illustrates the distances from each action (S_i^+ and S_i^-) to PIS and NIS. The closeness coefficients (CCi) for each action are also displayed. The ranking produced is illustrated in Fig. 2.

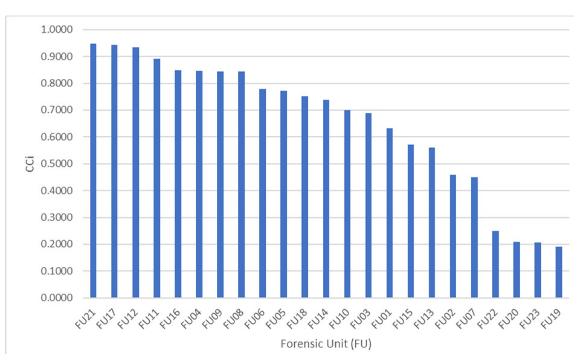

Fig. 2. Final ranking produced by R-TOPSIS (CCis in descending order)

Table 9
R-TOPSIS results

FU	S_i^+	S_i^-	CCi	Ranking
FU01	0.4140	0.7123	0.6324	15
FU02	0.4027	0.3411	0.4586	18
FU03	0.3253	0.7158	0.6875	14
FU04	0.2647	1.4642	0.8469	6
FU05	0.3474	1.1745	0.7717	10
FU06	0.4125	1.4595	0.7796	9
FU07	0.4229	0.3445	0.4489	19
FU08	0.3860	2.0892	0.8440	8
FU09	0.3155	1.7185	0.8449	7
FU10	0.3452	0.8046	0.6998	13
FU11	0.3425	2.8349	0.8922	4
FU12	0.4134	5.9174	0.9347	3
FU13	0.3303	0.4213	0.5605	17
FU14	0.3403	0.9638	0.7390	12
FU15	0.4076	0.5442	0.5718	16
FU16	0.2754	1.5461	0.8488	5
FU17	0.1938	3.2102	0.9431	2
FU18	0.4144	1.2521	0.7513	11
FU19	0.3755	0.0880	0.1898	23
FU20	0.3977	0.1046	0.2082	21
FU21	0.3346	6.0010	0.9472	1
FU22	0.2732	0.0912	0.2502	20
FU23	0.3690	0.0961	0.2065	22

4.10. Conducting a Sensitivity Analysis

According to Iooss & Saltelli (2017), the sensitivity analysis (SA) provides tools to investigate the dependence between output and input data; it also allows studying the degree of importance of input data on the solution offered by the model. The sensitivity analysis allows the decision maker the chance to see which parameter, data and component in the decision problem is effective or critical to the solution (Aytekin & Durucasu, 2021). In the current research, the one-way sensitivity analysis was used due to its simplicity, intuitive nature, and simple implementation (Clemen, 1996; Diaby & Goeree, 2013). The algorithm proposed by Xu et al. (2017) was used as follows:

Step 1: Choose the criterion to be evaluated.
Step 2: Change the original value of the weight of the chosen criterion (ω_j) between -20%, -10, 10% and 20%, resulting in $\omega_j' = \delta\omega_j$, where the values of δ are 80%, 90%, 110% and 120%;
Step 3: Recalculate the changes in the values of the other criteria's weights through $\omega_k' = \varphi\omega_k, k \neq j, k = 1,2,\cdots,n$ and considering the Eq. (18):

$$\delta\omega_j + \sum_{k=1,k\neq j}^{n} \varphi\omega_k' = 1 \tag{18}$$

where: $\varphi = (1-\delta\omega_j)/(1-\omega_j)$
Step 4: Apply the new values to R-TOPSIS, generating a new ranking.
Step 5: Repeat the process until all criteria have been evaluated.

In the current research, four variations were applied to the seven criteria, resulting in 28 experiments. The following graphs illustrate the impacts observed in the values of the closeness coefficients (CCi) of each alternative and the possible changes in the original ranking proposed by the model, thus allowing evaluating its robustness within the range of variation proposed by the sensitivity analysis. The robustness of the solution provided by the hybrid approach was demonstrated because only a few changes in the ranking positions were observed for criteria C02 and C07, as illustrated in Fig. 3 and Fig. 4.

4.11. Analysis of results and preparation of recommendations

This step is used in the analysis of the results and for the preparation of recommendations. Hence, the ranking generated by the proposed model allowed identifying the FUs which are more and less viable in operational terms, considering the set of criteria used and the preferences expressed by the DM. Table 10 summarizes the recommendations related to the least viable FUs.

Table 10
Recommendations summary for least viable FUs

FU	Ranking	Recommendations summary
FU02	18	Shutting down the FU transferring equipment and personnel to the state capital.
FU07	19	Shutting down the FU transferring equipment and personnel to the state capital.
FU22	20	Keeping the current FU, due its small distance from the state capital and good performance in C02.
FU20	21	Merging with FU19, transferring equipment and personnel to FU19 location due its better localization in the state.

FU23	22	Shutting down the FU following a personnel transfer to another unit in the state.
FU19	23	Merging with FU20, keeping the current location due the good performance in C05 and C06.

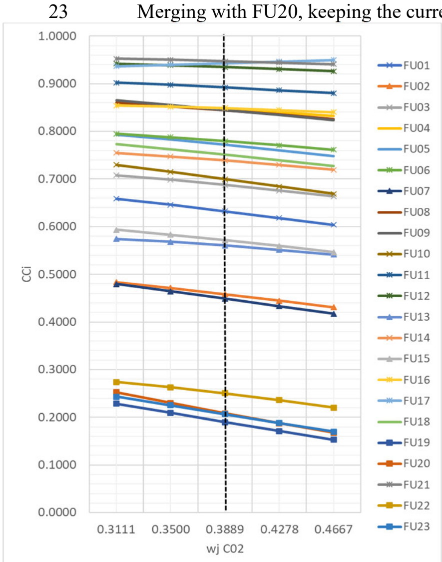

Fig. 3. Sensitivity analysis for criterion C02

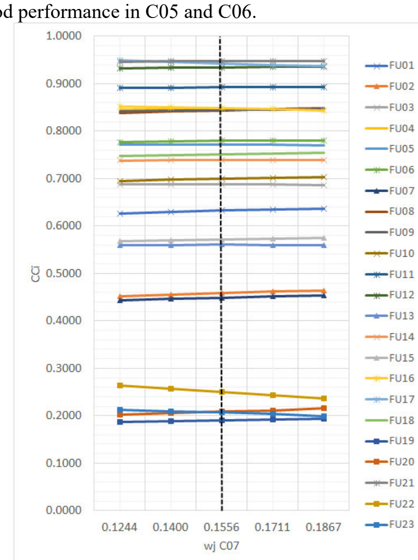

Fig. 4. Sensitivity analysis for criterion C07

4.12. Implementing the decision

The recommendations produced here are addressed to the Technical-Scientific Directorate, which in turn will carry out an intermediate process of analysis that will evaluate them. In case of acceptance, with or without modifications, the recommendations should be forwarded for consideration by the other boards involved, thus adding more levels to the decision-making process, and then their referral to the General Directorate (DG/PF) for its effective implementation.

5. Conclusion

The development of a multicriteria decision model aiming at evaluating the operational viability of 23 local forensic units within the Police Federal of Brazil was tackled in this paper. The model was built according to the three main phases divided in a 12-step framework proposed by De Almeida (2013) and applied a hybrid approach with BWM and R-TOPSIS. First, a preliminary phase was conducted, in which the main elements of the problem were approached to obtain the problem structure: actors, objectives, criteria, set of actions, problematic, and uncontrolled factors. In the second phase the preference modelling was conducted, BWM was chosen to elicit the weight of criteria due the compensatory rationality demonstrated by the DM. The final phase, finalization, allowed the evaluation of the 23 alternatives by R-TOPSIS, and performed a sensitivity analysis to check the robustness of the ranking provided as a solution. Finally, the recommendations were drawn, and sent to implementation. The model was fully implemented in spreadsheets, which allowed detailed monitoring of the steps and greater control of necessary adjustments during the process. The research results were satisfactory as they delivered an evidence-based solution to a real complex problem within a critical area such as public security. Considering that the problem was structured with only a single DM, future work can investigate a group decision approach, allowing the elicitation of another range of criteria considered relevant according to the clients of Federal forensic science services and that may involve the elements related to the expectations, consequences and the production process of the service itself, based on Rodrigues et al. (2010).

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