

Development and implementation of a computational tool for the multi-criteria decision analysis method proppaga: case study of the sorting of hospital assistance ships of the brazilian navy to face the COVID-19 pandemic

Desenvolvimento e implementação de uma ferramenta computacional para o método multicritério de análise de decisão proppaga: estudo de caso da classificação dos navios de assistência hospitalar da marinha brasileira para enfrentar a pandemia de COVID-19

DOI:10.34117/bjdv7n10-211

Recebimento dos originais: 07/09/2021

Aceitação para publicação: 18/10/2021

Felipe Barbosa dos Santos

Graduado em Engenharia Naval - Universidade de São Paulo (USP)
Atualmente, mestrando em Engenharia de Defesa - Instituto Militar de Engenharia
R. Geraldo Irineo Jofilly, 200 - Recreio dos Bandeirantes - Rio de Janeiro - RJ
E-mail: felipe.barbosa@ime.eb.br

Marcos dos Santos

Pós-doutorado em Ciências e Tecnologias Espaciais (ITA)
Pós-doutorado em Engenharia de Produção (UFF)
Instituto Tecnológico de Aeronáutica (ITA)/ Universidade Federal Fluminense (UFF)
CASNAV - Rua da Ponte, Ed 23 do AMRJ – Centro - Rio de Janeiro - RJ
E-mail: marcos.santos@marinha.mil.br

Paulo César Pellanda

Dr. ENSAE
Instituto Militar de Engenharia (IME)
Pra General Tibúrcio, 80. URCA - Rio de Janeiro - RJ
E-mail: pellanda@ime.eb.br

ABSTRACT

The multi-criteria decision analysis (MCDA) methods seek to support the decision-maker in choosing the most preferable alternative among the various possible ones, considering the criteria that characterize this preference. However, this task can become very complex, depending on the method used. This is because the algorithms of the methods are not always of a simple application. In this way, it is indispensable to develop computational tools that apply the algorithms of MCDA methods, making it feasible to use them. In this context, the computational tool presented in this article was developed. It uses the PrOPPAGA method in the selection problem of the Brazilian Navy's Hospital Assistance Ship Class of (HAS) to cope with the COVID-19 pandemic. The main contribution of this article is to present a tutorial for using this tool, to make its use feasible by society.

Key-words: MCDA, COVID-19, Computational tool, Brazilian Navy, PrOPPAGA.

RESUMO

Os métodos de análise de decisão multicritério (MCDA) procuram apoiar o decisor na escolha da alternativa mais preferível entre as várias possíveis, considerando os critérios que caracterizam esta preferência. No entanto, esta tarefa pode tornar-se muito complexa, dependendo do método utilizado. Isto porque os algoritmos dos métodos nem sempre são de uma aplicação simples. Desta forma, é indispensável desenvolver ferramentas computacionais que apliquem os algoritmos dos métodos MCDA, tornando viável a sua utilização. Neste contexto, foi desenvolvida a ferramenta computacional apresentada neste artigo. Utiliza o método PrOPPAGA no problema de selecção da Classe de Navio de Assistência Hospitalar da Marinha do Brasil (HAS) para lidar com a pandemia de COVID-19. A principal contribuição deste artigo é apresentar um tutorial para a utilização desta ferramenta, a fim de tornar a sua utilização viável pela sociedade.

Palavras-chave: MCDA, COVID-19, Ferramenta computacional, Marinha do Brasil, PrOPPAGA.

1 INTRODUCTION

The methods of multi-criteria decision analysis (MCDA) seek to support the decision-taker in choosing the most preferable alternative among the various possible, considering the criteria that characterize this preference. Multi-criteria problems can be divided into continuous (as linear programming) or discrete (Kodikara, 2008). Within discrete problems, some methods define the concept of “indifference relationship” ($a_i \sim a_j$) and “preference relationship” ($a_i \succ a_j$) between alternatives. Others add the concepts of incomparability between alternatives, weak preference, and strict preference of one alternative concerning another (Bana and Costa and Vincke, 1990), using, for their application, their respective thresholds of indifference and preference.

MCDA methods are also influenced by the nature and characteristics of the data used. The nature of the data is closely linked to the measurement scale. The data can be quantitative or qualitative and can be expressed on the cardinal scale (quantitative) or ordinal scale (qualitative) (Saaty, 1980). The human being is therefore obliged to make decisions, either from quantitative parameters or from qualitative measurement parameters, with strong subjective characteristics. Quantitative parameters are generally easier to measure than qualitative parameters. On the other hand, the characteristics of the data refer to the fact that the data are correct or uncertain (Öztürk et al., 2005). Currently, new methods, based on fuzzy set theory, express these uncertainties of the fuzzy data (Chen e Pan, 2021; Dong, 2021; Ji et al., 2021; Karagöz et al., 2021; Liu et al., 2021; Rudnik, 2021; Song et al., 2021; Tang et al., 2021; Tian et al., 2020; Zarei et al., 2021).

In this context, knowing how to structure the decision-making process becomes indispensable (Barrager, 2016). As a rule, in multi-criteria problems, the simpler the analytical tool, the better. Starting from this premise, seeking modeling with simplifications becomes salutary, and understanding the behavior of alternatives helps in this task. The simplification proposed in this approach is the presumption that the alternatives have Gaussian behavior, that is, the data of the alternatives (sample of values), in each of the criteria considered, present a histogram in the form of a bell (normal curve). From this, the data of the alternatives are normalized, having as reference the mean and the standard deviation of the sample.

Cinelli et al., (2020) emphasize that especially the newer methods, usually more advanced and allowing more complex evaluations, because they do not have software that enables a trivial implementation, are detrimental to their applicability in several areas. With this, we can conclude that the use of a given method is often linked to the availability of software that allows the implementation of the method in a given case. The main contribution of this article is to present a computational tool for the application of the PrOPPAGA method, making it feasible for society to use the method.

The rest of this article is organized as follows. Section 2 presents the PrOPPAGA method. In section 3 is presented the tool developed through a case study for the application of the method. In section 4, the conclusion is performed.

2 PROPPAGA METHOD

The PrOPPAGA method (Priority Observed from the Presumption of Gaussian Attitude of Alternatives) was developed to be simple and effective compared to the methods enshrined in the literature, specifically in problems with many alternatives (more than 30), where some methods that perform pairwise comparisons become exhaustive for the decision-taker, and may still incur in inconsistencies, which generate reworking.

According to Rezaei, (2015), an MCDA problem is usually presented according to the matrix (1).

$$P = \begin{matrix} & c_1 & c_2 & \cdots & c_n \\ \begin{matrix} a_1 \\ a_2 \\ \vdots \\ a_m \end{matrix} & \begin{pmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ p_{21} & p_{22} & \cdots & p_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ p_{m1} & p_{m2} & \cdots & p_{mn} \end{pmatrix} \end{matrix} \quad (1)$$

Where $\{a_1, a_2, \dots, a_m\}$ is the set of alternatives analyzed, $\{c_1, c_2, \dots, c_n\}$ is the set of criteria considered, and p_{ij} is the score obtained by the alternative a_i in criterion c_j . The goal is to select the alternative with the larger overall value. The general value v_i , of alternative a_i , is calculated through (2), assuming a weight w_j for criterion c_j ($w_j \geq 0, \sum w_j=1$).

$$v_i = \sum_{j=1}^n w_j \cdot p_{ij} \tag{2}$$

In the next section, we will see that PrOPPAGA uses the same matrix (1) and equation (2) in its step-by-step.

2.1 PROPPAGA STEP-BY-STEP

In this section, the steps of the method will be displayed.

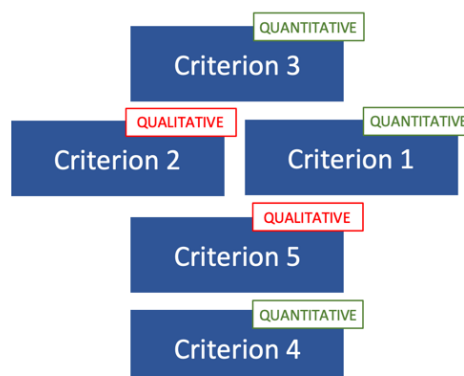
2.1.1 Step 1. Determine the set of decision criteria

In this step is defined the set $C = \{c_1, c_2, \dots, c_n\}$, which will be used for the decision-making. For quantitative criteria, it is important to observe which are monotonic of cost. In criteria monotonic of cost, the alternatives will have the values of the parameters multiplied by (-1) to express the negative impact of these values.

2.1.2 Step 2. Sort the criteria by importance

Once defined C , the criteria must be ordered in order of importance (Figure 1), and may even be matched.

Figure 1 - Example of sorting with five criteria.



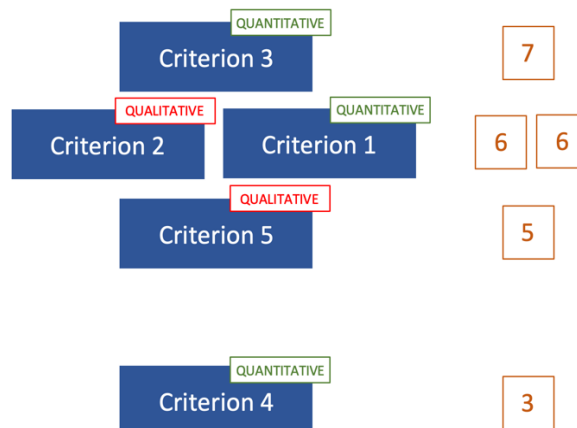
2.1.3 Step 3. Assign the degree of importance (sj) and weights (wj) of the criteria

According to the ordering carried out in the previous step, a degree of importance sj will be assigned to each criterion cj. The maximum value of sj obeys the relation (3).

$$(s_j)_{max} = \begin{cases} n, & \text{se } n > 7 \\ 7, & \text{se } n \leq 7 \end{cases} \quad (3)$$

Where n is the number of elements of the set C. At the most important criterion, must be assigned (sj)max. The other criteria will be assigned a lower degree of importance, according to the order made, as we can see in the example in Figure 2.

Figure 2 - Ordering example, with five criteria.

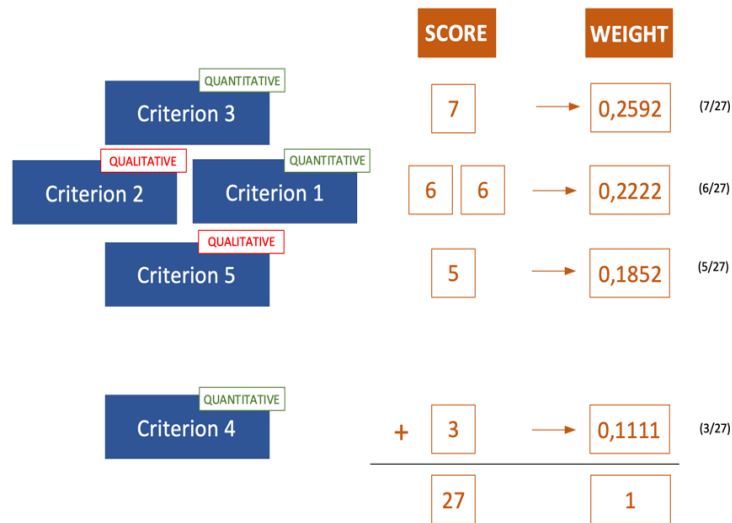


W is defined as the set of weights of the criteria, where $W = \{w_1, w_2, \dots, w_j\}$ and w_j the weight of criterion c_j . From the weighted average (4), we get the value of w_j .

$$w_j = \frac{s_j}{\sum_{k=1}^n s_k} \quad (4)$$

With this, $\sum w_j = 1$, as can be seen in the example in Figure 3.

Figure 3 - Example of calculating the weight of the criteria.



2.1.4 Step 4. Take the alternatives

$A=\{a_1, a_2, \dots, a_m\}$ is defined as the set of alternatives analyzed for decision making. In each criterion, the alternatives have an attribute d_{ij} . These attributes form the decision matrix M .

$$M = \begin{bmatrix} d_{11} & \dots & d_{1n} \\ \vdots & d_{ij} & \vdots \\ d_{m1} & \dots & d_{mn} \end{bmatrix} \quad (5)$$

It is expected that the attributes of quantitative criteria have their values well defined, linked to a unit of measure. However, it is important to observe the criteria monotonic cost, because, in these criteria, the attributes will be represented by negative values. For qualitative criteria, where it is not possible to use a unit of measure, the attributes will be defined by a seven-point scale, where the performance of each alternative is evaluated according to Table 1.

Table 1 - Seven-point scale of PrOPPAGA

score	definition
1	The alternative does not meet the demands
2	The alternative meets the demands well below expected
3	The alternative meets the demands slightly below expected
4	The alternative meets the demands within the expected
5	The alternative meets the demands slightly above expectations
6	The alternative meets the demands well above expectations
7	The alternative exceeds all expectations about these criteria

2.1.5. Step 5. Normalization

Once the attributes are defined, their values will be normalized based on the presumption that they behave gaussianly within each criterion. Then, for each $c_j \in C$ criterion the mean μ_j and the standard deviation σ_j of the attribute d_{ij} are calculated.

The P probability of an attribute any x being less than or equal to d_{ij} represents element p_{ij} of the normalized decision matrix N .

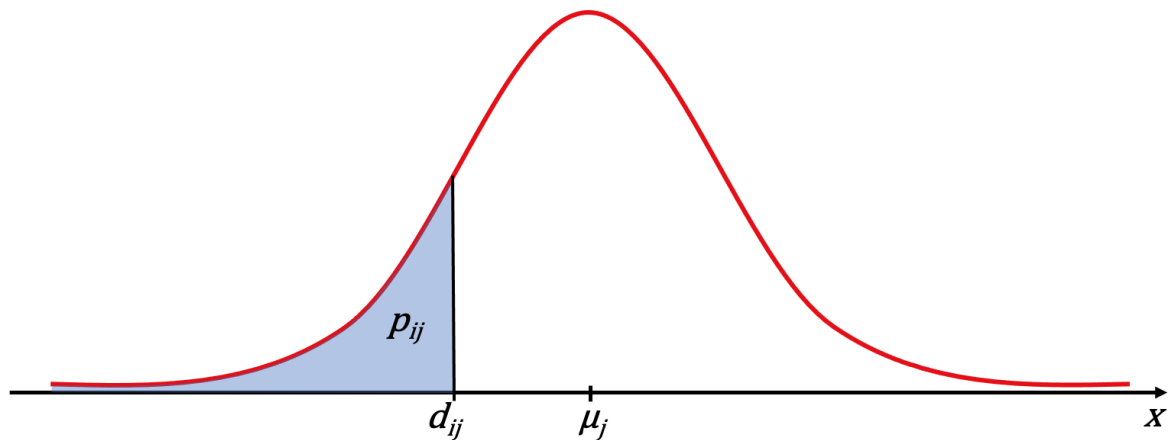
$$N = \begin{bmatrix} p_{11} & \dots & p_{1n} \\ \vdots & p_{ij} & \vdots \\ p_{m1} & \dots & p_{mn} \end{bmatrix} \quad (6)$$

According to Albuquerque et al. , (2008),

$$p_{ij} = P(x \leq d_{ij}) = \int_{-\infty}^{d_{ij}} \frac{1}{\sqrt{2\pi}\sigma_j} e^{-\frac{(x-\mu_j)^2}{2\sigma_j^2}} dx \quad (7)$$

Despite the complex look, with the aid of electronic spreadsheets, this equation is easily solved. Graphically, p_{ij} it is the area below the Gaussian curve (defined by the mean μ_j and the standard deviation σ_j), limited to the right by d_{ij} (Figure 4).

Figure 4 - Graphic representation of p_{ij} .



2.1.6 Step 6. Aggregation

The general value v_i is calculated by equation (2), where v_i represents the cardinality of i -th alternative. Another way to interpret this aggregation is through the relationship, $N \cdot w = v$, or even:

$$\begin{bmatrix} p_{11} & \dots & p_{1n} \\ \vdots & p_{ij} & \vdots \\ p_{m1} & \dots & p_{mn} \end{bmatrix} \cdot \begin{bmatrix} w_1 \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} v_1 \\ \vdots \\ v_m \end{bmatrix} \quad (8)$$

3 COMPUTATIONAL TOOL

An MCDA method, in essence, is an algorithm that is applied, returns a result for the data entered in it. However, the calculations/steps that are performed throughout this process are not always trivial, or even the domain of those who employ it. Thus, the development of computational tools allows a user who does not master the algorithm of a given method to use it, without incurring conceptual errors, since the interactivity with the user causes he/she to be guided throughout the process of using the method. In this context, even if the algorithm of a determined approach is relatively simple, the development of a computational tool becomes essential for the dissemination of this MCDA method in society.

The computational tool developed for the application of the PrOPPAGA method can be accessed at www.proppaga.com.br. It was developed in PHP language, through the Apache NetBeans IDE 12.2. To present the tool, an application of it will be shown in a real problem, to observe the step-by-step to be followed.

3.1 CASE STUDY

To present the computational tool developed for the PrOPPAGA method, it will be used in the sorting of four Brazilian Navy Hospital Assistance Ships to support the fight against the COVID-19 pandemic. The problem was exposed by Costa et al., (2020), which applied the THOR 2 method to solve it.

Faced with the scenario of the pandemic of COVID-19, the health system of several localities in the country was pushed to the limit. In this context, the Brazilian Navy emerges as an ally in coping with the pandemic. The Brazilian Navy has Hospital Assistance Ships (HAS) based in the North and Midwest regions of the country. These

ships play the function of floating hospitals that normally already operate in the Amazon region, bringing health support to the riverside communities.

On the selected ship would be implanted a Field Hospital to treat patients affected by non-contagious diseases. It would relieve hospitals in Manaus and nearby cities, or even more distant cities, depending on the worsening of the pandemic in the region.

Ship classes analyzed were: "Oswaldo Cruz", "Dr. Montenegro", "Soares Meirelles" and "Lieutenant Maximiano". The criteria used for decision-making were:

Maneuverability: Ability of the ship to move when entering and docking in low-depth ports, common in riverside regions. This is a qualitative criterion.

Crew (unit): Number of personnel boarded to operate the ship. A large crew decreases comfort on board. It is understood that the smaller the crew, the better.

The radius of action (nautical miles): Maximum distance that the ship can reach, leaving its headquarters and returning to it, without the need for refueling.

Maximum Speed (nodes): Self-explanatory criterion, where the higher the maximum speed, the better.

Patient evacuation capacity: Another qualitative criterion. Consideration is given to the possibilities of means for the transfer of patients, for medical reasons, to other health units.

Hospital capacity: Considers the types of medical care possible, as well as the number of beds available and the possibility of a possible expansion of this number, through the installation of any Field Hospital on board.

The degree of importance attributed to each criterion is shown in Table 2.

Table 2 - Degree of the importance of each criterion

critierion	Degree of importance
Maneuverability	3
Crew	2
Radius of action	3
Maximum Speed	6
Patient evacuation capacity	7
Hospital capacity	7

The operative data of the analyzed Navios can be observed in Table 3. This data will be used in the future to define the Decision Matrix.

Table 3 (Continua) - Ship operating data analyzed

critierion	characteristic	Dr. Montenegro	Oswaldo Cruz	Soares Meirelles	Lieutenant Maximiano
Maneuverability	Length (m)	42	47.2	63	31.06
	Width (m)	11	8.45	12	6.5
	Draught (m)	2.4	1.75	2.1	1.02
	Maximum displacement (ton)	347	490	1338	160
crew	Number of people	60	27	47	23
Radius of action	Nautical miles	3200	3000	6000	1100
Maximum Speed	knots	10	12	12	12

Ability to the evacuation of patients	Patient evacuation capabilities	2 speedboats for personnel transport	Flight deck capable of operating a Bell Jet Ranger IH-6 or Squirrel UH-12 helicopter, plus 2 speedboats for personnel transport	2 speedboats for personnel transport	2 speedboats for personnel transport
--	---------------------------------	--------------------------------------	---	--------------------------------------	--------------------------------------

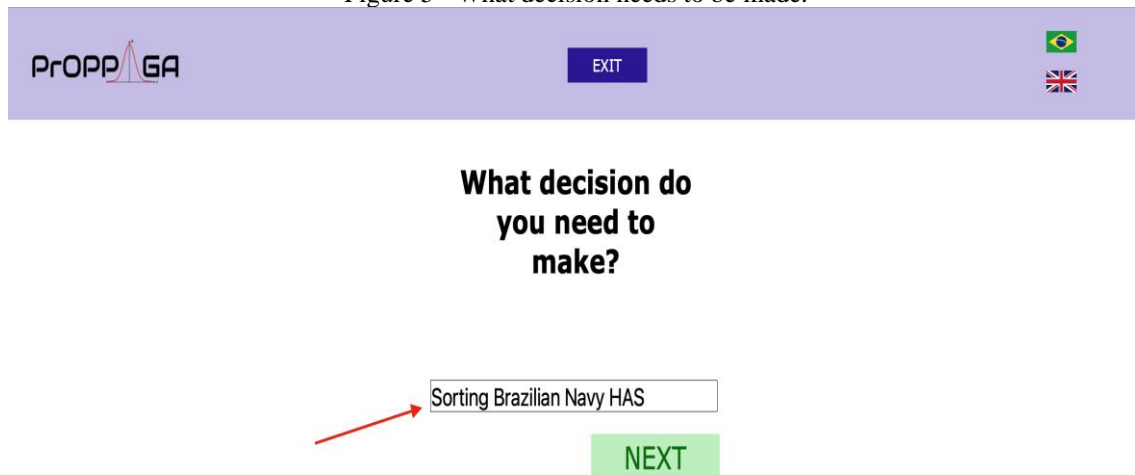
Table 3 (Conclusion) - Ship operating data analyzed

critierion	characteristic	Dr. Montenegro	Oswaldo Cruz	Soares Meirelles	Lieutenant Maximiano
Hospital capacity	Number of hospital beds available	6	6	6	3
	Medical care available	3 offices, 2 dental offices, 1 laboratory, 1 pharmacy, 1 X-ray room, 2 wards, 1 operating room, 1 emergency room, ICU	2 outpatient clinics, 2 dental offices, 1 laboratory, 1 pharmacy, 1 X-ray room, 2 wards, 1 operating room	Medical and dental office, pharmacy, vaccination room, X-ray room, operating room, ward, clinical analysis laboratory	Operating room, ward, sterilization room, purge room, pharmacy, laboratory, doctor's office, dental offices, 1 compartment equipped with an X-ray machine

Source: Costa et al (2020)

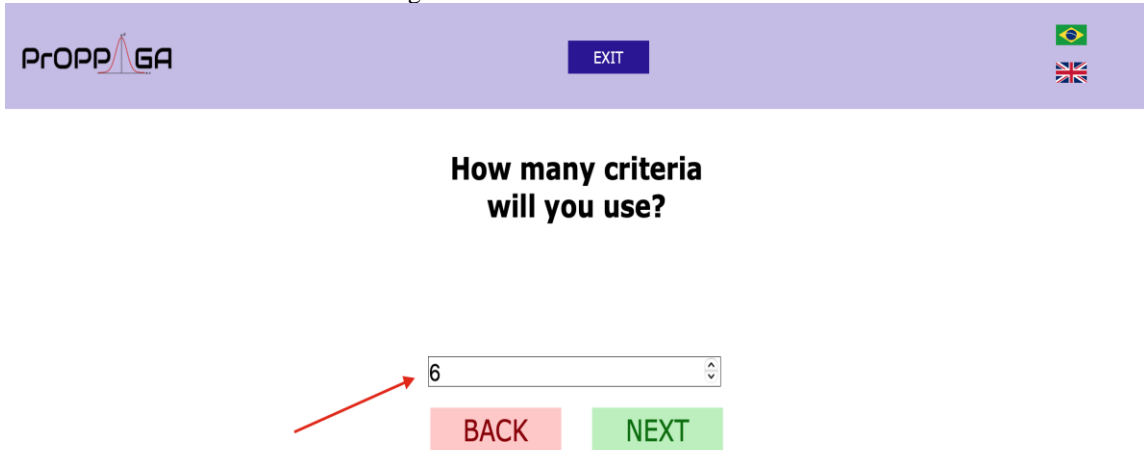
To use the computational tool of the “PrOPPAGA” it is necessary, after accessing the electronic address, to inform which decision needs to be taken (Figure 5) and click on "NEXT".

Figure 5 - What decision needs to be made.



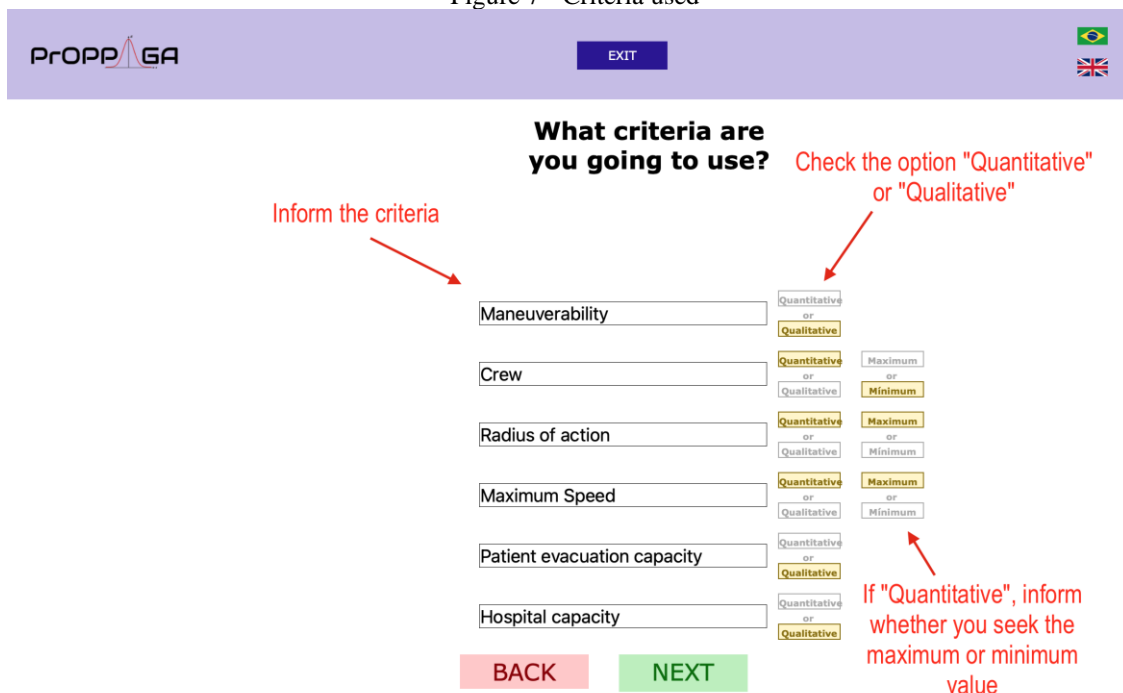
You will then be asked to inform how many criteria will be used for this decision-making (Figure 6).

Figure 6 - Wetcriteria will be used.



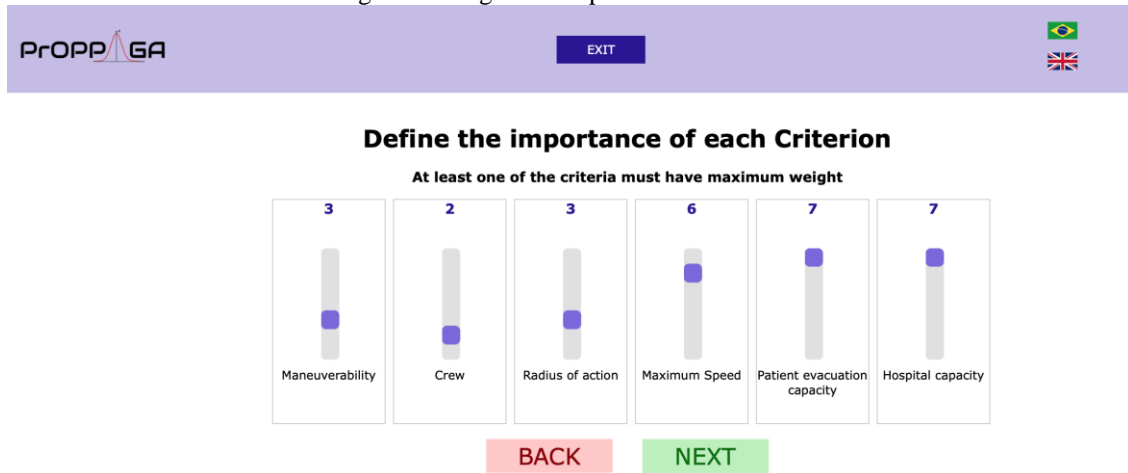
After that, it will be necessary to inform the criteria used (Figure 7). Each informed criterion should be classified as "QUANTITATIVE" or "QUALITATIVE", depending on the nature of the criterion. For criteria classified as "QUANTITATIVE", it will still be requested to be informed if the values sought in each of these criteria are "Maximums" or "Minimums". Criteria monotonic of cost seek the minimum values, while monotonic profit criteria look for the maximum values.

Figure 7 - Criteria used



The next step is to define the degree of importance of each criterion (Figure 8). Here the information was entered according to Table 2.

Figure 8 - Degree of import of each criterion



Define the importance of each Criterion

At least one of the criteria must have maximum weight

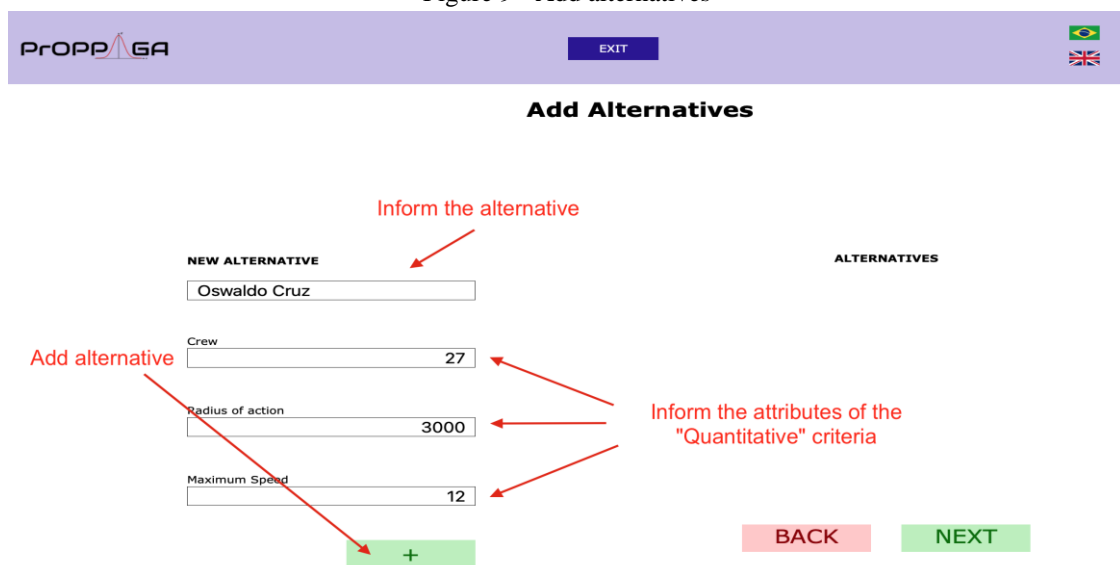
Criterion	Importance Degree
Maneuverability	3
Crew	2
Radius of action	3
Maximum Speed	6
Patient evacuation capacity	7
Hospital capacity	7

BACK NEXT

With the degree of importance of the defined criteria, the tool itself calculates the weight of each criterion. However, this information will only be displayed to the user in the last step, which is the display of the result.

The next step is to add the alternatives (Figure 9). The alternatives are inserted one by one. It is important to note that the attributes of the quantitative criteria are requested at this stage. After entering the information for an alternative, click the "+" button to add the alternative to the list of alternatives.

Figure 9 - Add alternatives



Add Alternatives

NEW ALTERNATIVE

Oswaldo Cruz

ALTERNATIVES

Crew: 27

Radius of action: 3000

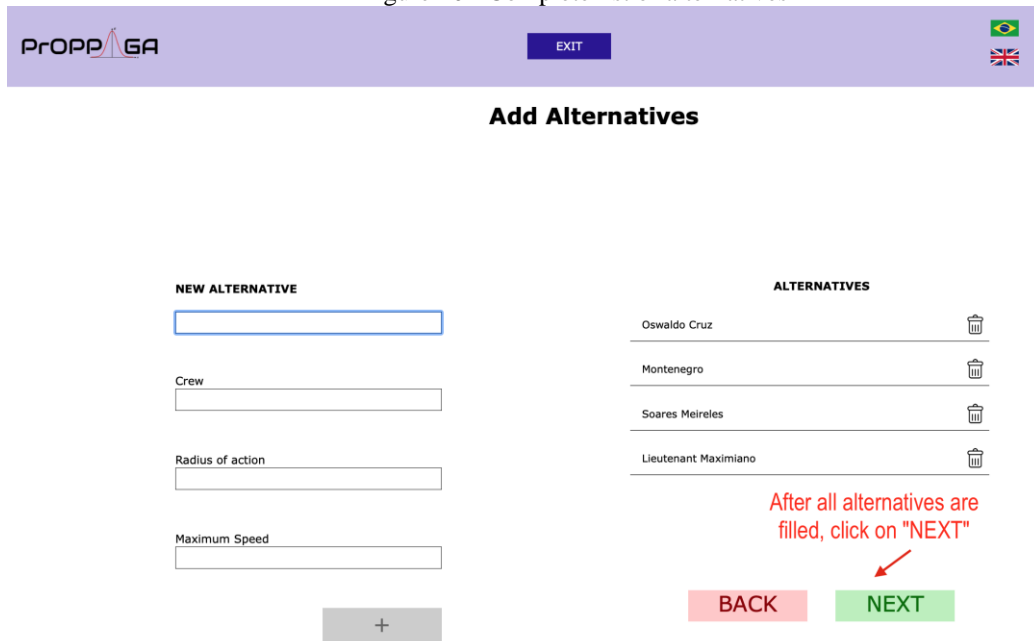
Maximum Speed: 12



+

BACK NEXT

Alternatives are being added to the list of alternatives, which is to the right of the screen. After all the alternatives are inserted, you must click "NEXT" (Figure 10) to go to the next step.

Figure 10 - Complete list of alternatives



PrOPP GA EXIT  

Add Alternatives

NEW ALTERNATIVE





Crew

Radius of action

Maximum Speed

+

ALTERNATIVES

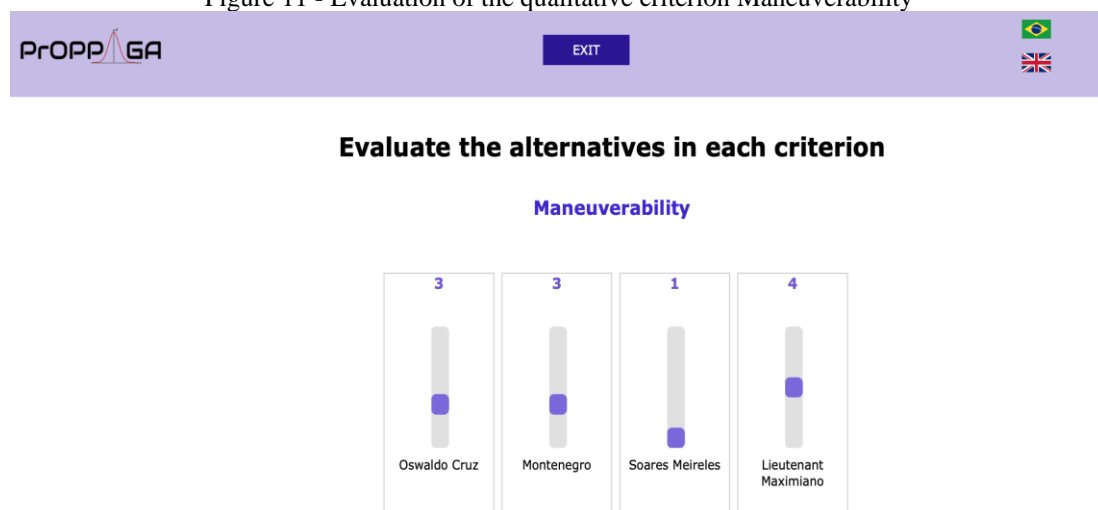
Oswaldo Cruz	
Montenegro	
Soares Meireles	
Lieutenant Maximiano	



After all alternatives are filled, click on "NEXT"

BACK
NEXT

Once all the alternatives have been inserted, with the respective information in the quantitative criteria, it will be requested to evaluate the alternatives in the qualitative criteria (Figures 11,12, and 13), according to the seven-point scale (Table 1).

Figure 11 - Evaluation of the qualitative criterion Maneuverability




PrOPP GA EXIT  

Evaluate the alternatives in each criterion


Maneuverability

3




Oswaldo Cruz

3




Montenegro

1



Soares Meireles

4



Lieutenant Maximiano

Figure 12 - Evaluation of the qualitative criterion Evacuation capacity

Patient evacuation capacity

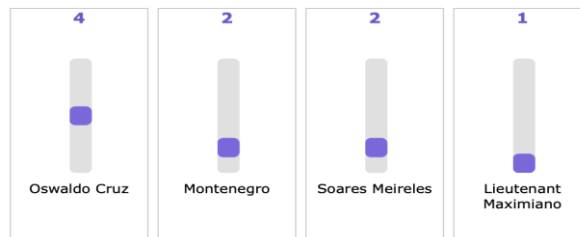
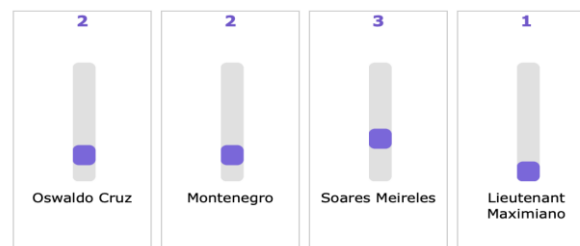


Figure 13 - Evaluation of the qualitative criterion Hospital capacity

Hospital capacity




BACK

NEXT

The criteria are displayed in sequence. Below the last criterion appears the "NEXT" button, which must be triggered after all criteria have been filled. Then the found result will be displayed (Figure 14). In addition to this result, are also displayed all the values used by the PrOPPAGA method during the process.

Figure 14 - PrOPPAGA Result

PrOPPAGA							EXIT	
RESULTS FOR Sorting Brazilian Navy HAS								
CRITERION	Patient evacuation capacity	Hospital capacity	Maximum Speed	Maneuverability	Radius of action	Crew		
GRADES	7	7	6	3	3	2		
WEIGHT	0,25	0,25	0,21	0,11	0,11	0,07		
AVERAGE	2,25	2,00	11,50	2,75	3.325,00	39,25		
STANDARD DEVIATION	1,09	0,71	0,87	1,09	1.748,39	15,04		
Values Reported								
Oswaldo Cruz	4	2	12	3	3000	27		
Soares Meireles	2	3	12	1	6000	47		
Lieutenant Maximiano	1	1	12	4	1100	23		
Montenegro	2	2	10	3	3200	60		
Grades by Criterion							Final Grade	
Oswaldo Cruz	9,46	5,00	7,18	5,91	4,26	7,92	6,80	
Soares Meireles	4,09	9,21	7,18	0,54	9,37	3,03	6,14	
Lieutenant Maximiano	1,26	0,79	7,18	8,74	1,02	8,60	3,70	
Montenegro	4,09	5,00	0,42	5,91	4,72	0,84	3,56	

BACK

Corroborating what was proposed by Costa et al. , (2020), using the THOR 2 method, the result obtained by PrOPPAGA presents the same ordering of the alternatives. Indicating that the best alternative is the HAS Oswaldo Cruz. The cardinality exposed by the tool presents the values found by the PrOPPAGA method multiplied by 10, to emphasize the differences in general values between the alternatives. The result is exposed in descending order of these values.

4 CONCLUSION

The computational tool presented in this article enables decision-makers to apply the PrOPPAGA method to assist them in complex problems. The fact that it is available on the internet, allows the user its use at any time, anywhere, without the need to install any files for this and without limitations of operating systems. Such availability, combined with a user-friendly and easy-to-understand graphical interface makes the use of the PrOPPAGA method feasible, even for those who are unaware of their algorithm.

PrOPPAGA proves effective as its results have been validated compared to the THOR 2 method. This also corroborates the work of Costa et al., (2020), bringing robustness to the proposal of indication of the HAS Oswaldo Cruz for coping with the pandemic of the COVID-19.

This tool has no restrictions on use and can be used both in the civil environment and in the military environment. It can also be used both in the public and in the private environment. Thus, it is understood that the objective of this article had been achieved, making available to society a computational tool for the application of the PrOPPAGA method.

REFERENCES

- Albuquerque, J. P., Fortes, J.M., and Finamore, W. (2008) Probability, Random Variables and Stochastic Processes. Interscience.
- Bana and Costa, C., and Vincke, P. (1990) Multiple Criteria Decision Aid: An Overview. Readings in Multiple Criteria Decision Aid. Springer Berlin Heidelberg.
- Barrager, S.M. (2016) A new engineering profession is emerging: decision coach. IEEE Engineering Management Review, 44(2), 33–40. Presented in IEEE Engineering Management Review. doi:10.1109/EMR.2016.2568765
- Chen, L., and Pan, W. (2021) Review fuzzy multi-criteria decision-making in construction management using a network approach. Applied Soft Computing, 102, 107103. doi:10.1016/j.asoc.2021.107103
- Cinelli, M., Kadzinski, M., Gonzalez, M., and Slowinski, R. (2020) How to support the application of multiple criteria decision analysis? Let us start with a comprehensive taxonomy. Omega, 96,102261. Doi:10.1016/j.omega.2020.102261
- Costa, I. P. de A., Maêda, S.M. do N., Teixeira, L. F. H. de S. de B., Gomes, C. F. S., and Santos, M. D. (2020) Choosing a hospital assistance ship to fight the covid-19 pandemic. Public Health Magazine, 54, 79. doi:10.11606/s1518-8787.2020054002792
- Dong, J. (2021) Fuzzy best-worst method based on triangular fuzzy numbers for multi-criteria decision-making. Information Sciences, 25.
- Ji, Y., Xu, Y., Qu, S., Xu, Z., Wu, Z., and Nabe, M. (2021) A Novel Two-Stage Multi-Criteria Decision-Making Based on Interval-Valued Pythagorean Aggregation Fuzzy Operators with Self-Confidence Levels. Arabian Journal for Science and Engineering, 46(2), 1561–1584. doi:10.1007/s13369-020-04681-6
- Karagöz, S., Deveci, M., Simic, V., and Aydin, N. (2021) Interval type-2 Fuzzy ARAS method for recycling facility location problems. Applied Soft Computing, 102, 107107. doi:10.1016/j.asoc.2021.107107
- Kodikara, P. N. (2008) Multi-Objective Optimal Operation of Urban Water Supply Systems. Victoria University, Australia.
- Liu, P., Zhu, B., and Wang, P. (2021) A weighting model based on best–worst method and its application for environmental performance evaluation. Applied Soft Computing, 103, 107168. doi:10.1016/j.asoc.2021.107168
- Öztürk, M., Tsoukiàs, A., and Vincke, P. (2005) MODELLING PREFERENCE. MULTIPLE CRITERIA DECISION ANALYSIS, 45.
- Raiffa, H. (2002) Decision Analysis: A Personal Account of How It Got Started and Evolved. Operations Research, 50(1), 179–185. doi:10.1287/opre.50.1.179.17797

Rezaei, J. (2015) Best-worst multi-criteria decision-making method. *Omega*, 53, 49–57. doi:10.1016/j.omega.2014.11.009

Rudnik, K. (2021) Ordered fuzzy WASPAS method for selection of improvement projects. *Expert Systems With Applications*, 18.

Saaty, T. L. (1980) *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation*. McGraw-Hill International Book Company. Obtained from <https://books.google.com.br/books?id=Xxi7AAAAIAAJ>

Song, Y., Thatcher, D., Li, Q., McHugh, T., and Wu, P. (2021) Developing sustainable road infrastructure performance indicators using a model-driven fuzzy spatial multi-criteria decision making method. *Renewable and Sustainable Energy Reviews*, 138, 110538. doi:10.1016/j.rser.2020.110538

Tang, C., Xu, D., and Chen, N. (2021) Sustainability prioritization of sewage sludge to energy scenarios with hybrid-data consideration: a fuzzy decision-making framework based on full consistency method and fusion ranking model. *Environmental Science and Pollution Research*, 28(5), 5548–5565. doi:10.1007/s11356-020-10544-2

Tian, G., Hao, N., Zhou, M., Pedrycz, W., Zhang, C., Ma, F., e Li, Z. (2020) Fuzzy Grey Choquet Integral for Evaluation of Multicriteria Decision Making Problems With Interactive and Qualitative Indices. *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, 1–14. doi:10.1109/TSMC.2019.2906635

Zarei, E., Ramavandi, B., Darabi, A. H., and Omidvar, M. (2021) A framework for resilience assessment in process systems using a fuzzy hybrid MCDM model. *Journal of Loss Prevention in the Process Industries*, 69, 104375. doi:10.1016/j.jlp.2020.104375