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Article

Interactive Internet Framework Proposal of WASPAS Method: A Computational Contribution for Decision-Making Analysis

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Abstract: Concerning the development of computational tools and solutions as a decision-making aid, this paper presents the results of the waspasWEB project, which strives to provide decision-makers with a readily accessible mechanism to employ the weighted aggregated sum product assessment (WASPAS) method. The social contribution of the project encompasses the development of a user-friendly and publicly accessible internet tool, as well as a package launched on the Comprehensive R Archive Network (CRAN) to serve the community of users of the R language. The use of operational research methodologies is crucial to justify decisions, and this effort seeks to advance the adoption of such methodologies, offering managers, researchers, and the general public an intuitive and easily accessible multi-criteria decision-making tool. In this way, we present the technical specifications, usability, and interactivity of the user with the computational platform, being validated its viability through a hypothetical case study. At the end of the research, it exposes the limitations and feasibility of the proposed computational model along with future research.

Keywords: CRAN; decision theory; operational research; R language; shiny

MSC: 90-04

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1. Introduction

The scientific community has been actively involved in the exploration and dissemination of methodologies, procedures, and algorithms aimed at enhancing the field of decision-making [1]. Decision-making, a fundamental aspect of human society since ancient times, holds profound implications for both individuals and organizations. As elucidated in [2], the discipline of multi-criteria decision analysis (MCDA) [3] is currently experiencing accelerated growth within the realm of operational research (OR), manifesting in a proliferation of diverse methods and their practical implementations [4].

The study [5] reflects the paramount importance of OR in the realm of decision-making, tracing its significant role back to the aftermath of the Second World War. Technological advancements have ushered in transformative changes in the business landscape, introducing elements of uncertainty and complexity [6]. Consequently, decision-making processes have become increasingly intricate. Organizations have devised strategies to identify, evaluate, mitigate, and monitor events and conditions that exert influence on their operational frameworks [7]. These strategies heavily rely on decision-making procedures that encompass multiple criteria, often derived from extensive multidimensional data sources [8].

Drawing inspiration from the field of OR, this research proposes a solution to the challenges posed by MCDA problematic, employing a range of analytical techniques such as AHP [9,10], ANP [11], PROMETHEE [12–14], THOR [15], SAPEVO [16], TOPSIS [17], and WASPAS [18], among others. In this environment, some new studies of areas have been proposed, integrating consensus reaching for ordinal classification-based group decision-making with heterogeneous preference information, where a group of decision-makers with different preferences and heterogeneous information aims to reach a consensus on the ranking or classification of alternatives based on ordinal data [19].

In MCDA, criteria weights reflect the importance or priority assigned to each criterion in the decision-making process. The weights are typically determined based on the decision-maker's preferences, and they influence how the alternatives are evaluated and compared [20,21]. Strategic weight manipulation refers to a strategy employed in MCDA where decision-makers strategically manipulate the weights assigned to criteria to influence the overall decision outcome or ranking of alternatives. This strategy involves adjusting the relative importance of criteria to achieve a desired result, often driven by personal biases or preferences [22].

Regarding the popular literature in MCDA, the WASPAS method may have limited available literature, but it exhibits promising potential for both academic research and practical applications in the public and private management environment [23]. As expressed in [24,25], the credibility of WASPAS concerns the integration of two prominent MCDA approaches, namely, the weighted sum model and the weighted product model.

This method enhances the analytical depth by evaluating the sensitivity of each underlying approach in response to the criteria weighting system, thereby incorporating various perspectives for decision-makers [26]. The practical efficacy of the aggregate method is demonstrated in [24] through its application as an effective MCDA tool to address eight decision-making problems in industrial manufacturing processes [11]. The proposed methodology has made numerous practical contributions, such as [27] utilizing the method for single and multiple response optimization in non-traditional machining processes [28]. These processes are employed in industries such as aerospace, nuclear, missile, turbine, automobile, and tool-and-die manufacturing, which impose stringent requirements [29].

The method's applicability extends to all multi-criteria decision processes. For instance, in the realm of healthcare [30], the study employs the WASPAS method to prioritize patient care in the Ghanaian health system, where population growth surpasses the availability of medical resources, leading to constraints that often result in treatment delays and increased probabilities of complications and mortality. In a distinct context, a study conducted in India [31] utilizes WASPAS to propose an integrated weighting approach for essential factors affecting client satisfaction with the care experience, aiming to enhance their overall level of satisfaction. The study employed real data collected from the largest health service provider in Calcutta and addressed the demands arising from the sector's economic growth and increased competition in the private healthcare domain in the region.

To substantiate the implementation of the proposed approach, a recent publication [18] serves as an illustrative example, addressing a critical public security issue in Rio de Janeiro: determining the optimal choice for the acquisition of a helicopter by the State Military Police. This study presents a highly intricate decision problem characterized by various constraints, including the high cost and advanced nature of the equipment, the requirement for operational versatility and precision, and the necessity to adhere to stringent safety criteria. The research provides a comprehensive investigation and rigorous application of the proposed method, thus serving as an invaluable resource for information and validation of the implemented algorithms and developed systems [32].

In this scenario, as a motivational character, in the search to enable the dissemination of knowledge within the scope of the MCDA, the study aims to provide tangible products to the community by offering a publicly accessible mechanism on the internet that empowers decision-makers to utilize the WASPAS method as a supporting mechanism. The mechanism is user-friendly and intuitive and abstracts the computational intricacies involved in the calculation algorithms from the user, thereby eliminating the need for programming or mathematical expertise.

Embedded within the context, the modest contribution of this study aims to concretize and offer a tangible product to the academic community. The product takes the form of a publicly accessible mechanism on the internet, ensuring unrestricted access [33]. The intention is to empower decision-makers with the capability to utilize the WASPAS method as a supporting mechanism without requiring programming or mathematical expertise [34]. The computational intricacies involved in the calculation algorithms are abstracted from the user, who only needs to input the relevant information pertaining to the problem through a user-friendly and intuitive graphical interface.

This paper is structured into six sections. After the contextualization in the introduction section, the second sections describe the concepts of the WASPAS methodology and computational development through material and methods. The third section approaches the technological framework proposal. Exploring the feasibility of the computational model, a case study is presented in Section 4, exposing the main concepts of the technological proposal. Section 5 presents the discussion within the limitations and gains of the framework. Finally, Section 6 concludes the study along with future study proposals.

2. Materials and Methods

This section is divided into three subtopics: "The WASPAS Method", "Used Infrastructure", and "Delivered Results". These subtopics serve as an organizational framework for presenting the key aspects of the research. Notably, the emphasis is placed on the topic of "The WASPAS Method", as it holds significant importance within this study. While references to individual publications related to the WASPAS theme exist in this paper, direct quotations from these works will be avoided to ensure a clear and coherent presentation.

2.1. The WASPAS Method

In the context of intricate decision-making processes involving extensive sets of alternatives and criteria, the application of multi-criteria decision-making (MCDA) systems has proven to be effective. It has been established that combining multiple methods yields higher accuracy compared to applying each method individually. the weighted aggregated sum product assessment (WASPAS) method implements this principle by aggregating the well-known weighted sum model (WSM) and weighted product model (WPM) methods. WSM is widely recognized and extensively used in MCDA for addressing problems of this nature, while WPM is a variation that replaces the sum of multiplications (rating x weight) with the exponentiation of product weights [35].

It is important to note that the WSM and WPM methods are applicable exclusively to quantitative data. It is advisable to refrain from employing criteria with qualitative ratings. If the inclusion of qualitative data is deemed necessary, it is crucial to employ appropriate methods capable of converting qualitative information into numerical rating without introducing arbitrary weighting, whether directly or indirectly.

The underlying steps of WASPAS, namely WSM and WPM, share initial procedures. The first step involves constructing the decision matrix, as MCDA problems are defined by sets of m alternatives and m criteria. Consequently, a matrix is created, containing a known rating of the m criteria for each of the n alternatives, as illustrated in matrix b (1).

$$X_{ij} = \begin{bmatrix} c_j a_i & a_1 & a_2 & \dots & a_n \\ c_1 & x_{11} & x_{21} & \dots & x_{1n} \\ c_2 & x_{21} & x_{22} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots & \dots \\ c_m & x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \quad (1)$$

where x is the algebraic matrix formed by the rating of the set of criteria associated with each of the alternatives under analysis in the study of the MCDA problem, where $a_i = 1, \dots, n$, and $c_i = 1, \dots, m$. The variable x_{ij} represents the performance of alternative a_i bbbbin the criterion c_j.

In the second step, the matrix rating is normalized due to their tendency to be highly disparate. It is common for one criterion to vary by thousands while another varies by units, resulting in difficulty when comparing and evaluating alternatives. Criteria can also be either monotonic of cost or benefit. For example, in the above case, price is a cost criterion, where lower ratings are preferred, and warranty is a benefit criterion, where higher ratings are desired. Thus, a distinct normalization formula is employed for each criterion type.

For benefit criteria, the normalization process involves dividing the rating of each alternative by the maximum rating of the set of ratings for that specific criterion. The performance rating of alternatives with respect to each criterion is normalized such that, for the criterion vector of rating. x_{ij}. Equation (2) below illustrates the normalization function for monotonic benefit criteria.

$$x_{ij} = \frac{x_{ij}}{max_i(x_{ij})} \quad (2)$$

where x_{ij}: represents the normalized rating for a specific tuple (alternative, criterion); x_{ij} is the original rating that needs to be normalized; $max(x_{ij})$ denotes the largest rating within the set of rating for a specific monotonic benefit criterion across all alternatives.

For monotonic cost criteria, the vector of performance rating associated with the specific criterion is normalized by dividing each rating obtained for the criterion by the smallest rating within the set of ratings. In this case, the normalization of the alternatives' performance rating with respect to the criterion involves applying a function to the vector of rating. x_{ij} for the criterion. This function divides the minimum rating of the criterion's rating vector by the rating of the *i*th alternative. The formula for this normalization process is represented by Equation (3).

$$x_{ij} = \frac{min_i(x_{ij})}{x_{ij}} \quad (3)$$

where x_{ij}: is the normalized rating for a specific tuple (alternative, criterion); x_{ij} is the original rating to be normalized; $min(x_{ij})$ represents the smallest rating within the set of rating for a specific monotonic cost criterion across all alternatives, and the index i ranges from 1 to m, representing the number of alternatives.

In the subsequent step, the criteria are assigned weights based on their relative importance in the decision-making process, with these weights being determined by the decision-maker. The WSM and WPM methods differ in their approach to determining the best alternatives based on the weighting function.

Some MCDA methods have as objective the construction of ranking based on alternative performance in multiple criteria. This ranking provides decision support and serves as a means of communication to stakeholders affected by the decision-making process. The classification process in the WSM method is as follows: w_j represents the relative importance (weight) assigned to the criterion, and IR_i denotes the calculated relative importance of the alternative. The relative importance rating is obtained by summing the normalized rating of the set of criteria assigned to the alternative being evaluated.

Since there are *m* criteria involved, the formula for calculating the relative importance (IR_i) according to the WSM method is as follows in Equation (4).

$$IR_i = \sum_{j=1}^{m} x_{ij} w_j \tag{4}$$

where IR_i: is the relative importance of alternative *i* obtained by the sum of normalized rating x_{ij} weighted by the arbitrated weight of criterion w_j ranging from 1 to *m*, where *m* is the number of criteria in the problem.

In the case of the WPM method, we follow a similar approach by obtaining the normalized rating of the set of criteria assigned to the alternatives (x_{ij}), where *i* ranges from 1 to *n*. These normalized ratings are then raised to the power of the weight assigned to the relative importance of the *j* criterion, as indicated in the weights vector. Equation (5) represents the classification function used in the WPM method.

$$IR_i = \prod_{j=1}^{n} \left(x_{ij}\right)^{W_j} \tag{5}$$

where IR_i: is the relative importance of alternative *i* obtained by the product of the normalized rating x_{ij} raised to the arbitrated weight of the criterion w_j ranging from 1 to *m*, and *m* is the number of criteria in the problem.

The WASPAS method incorporates the relative importance derived from the *WSM* and *WPM* methods to assess the sensitivity of the alternatives and criteria. To achieve this, a lambda (λ) parameter, ranging from 0 to 1, is introduced and applied to the alternatives versus criteria set. The objective is to determine the total relative importance by combining the weighted relative importance of *WSM* and *WPM* based on lambda. This weighting is obtained by multiplying the relative importance obtained from the *WSM* method by lambda and adding it to the relative importance obtained from the *WPM* method multiplied by the complement of lambda (1 − λ). This approach allows for different emphasis on the *WSM* and *WPM* relative importance based on the rating of lambda. When lambda is set to 1, the *WSM* relative importance is fully utilized, while the *WPM* relative importance is disregarded. Conversely, when lambda is set to 0, only the *WPM* relative importance is considered for the determination of the total relative importance. For lambda rating of 0.5, the total relative importance is computed as the arithmetic mean of the *WSM* and *WPM* relative importance. In a simplified explanation, the total relative importance of the criterion (IRT_j) can be calculated as the sum of lambda multiplied by the relative importance from the *WSM* method (*WSM*) and the complement of lambda (1 − λ) multiplied by the relative importance from the *WPM* method (*WPM*):

$$IRT_j = \lambda \times IR_j(WSM) + (1 - \lambda) \times IR_j(WPM) \tag{6}$$

where IRT_j is the total relative importance of alternative *i*, obtained by the WASPAS method; $IR_j(WSM)$ is its relative importance obtained by the *WSM* method, and $IR_j(WPM)$ is its relative importance obtained by the *WPM* method; λ (lambda) is a rating ranging from 0 to 1.

By substituting the weighted sum (*WSM*) and weighted product (*WPM*) formulas, we arrive at Equation (7), which is commonly encountered in the relevant technical literature:

$$IRT_j = \lambda \times \sum\nolimits_{j=1}^{m} \overline{X}_{ij} W_j + (1 - \lambda) \prod\nolimits_{j=1}^{n} \left(\overline{X}_{ij}\right)^{W_j}, \lambda_j \in [0, 1] \tag{7}$$

where IRT_j is the total relative importance of alternative *i*, obtained through the WASPAS method, is calculated using the formula above, where the lambda factor multiplies the sum indicated in Equation (4), and its complement (1 − λ) multiplies the product indicated in Equation (5).

The high-level software (IDEs and web portals) used in the production of the work are listed and briefly described in Table 1, more detailed explanations of their functionality and use are presented throughout this topic.

Table 1. List of IDEs and web portals used.

System	Description
RStudio 2022.07.2	RStudio is a graphical development environment that provides productivity tools for systems development in the R language. It is distributed by Posit Software company, PBC, and is licensed under version 3 of the GNU General Public License.
posit.cloud	Posit Cloud is a cloud-based solution or web service that offers a browser-based experience similar to RStudio. It serves as an alternative IDE for R users and developers.
Shiny	Shiny is a free and open-source R package used for developing web applications (Apps). It is integrated with RStudio and posit.cloud, allowing for enhanced productivity in application prototyping.
shinyapps.io	shinyapps.io is a web portal that provides free services for hosting and publishing applications developed in the R language on the internet. It is part of the suite of solutions offered by Posit Software.
GitHub	GitHub is a file repository hosting platform that is integrated with the Git version control system. It can be used with various IDEs, including Rstudio, offering a graphical interface for interacting with the web service.
CRAN	CRAN (Comprehensive R Archive Network) is the central repository of packages for R language development. Supported by the R Foundation, it includes package source codes and precompiled binary files for Windows and macOS. CRAN was created in 1997 by Kurt Hornik and Friedrich Leisch.

The R language [36] serves as the foundation for all the development in this work. It was initially created in 1993 by Robert Gentleman and Ross Ihaka, statisticians from the University of Auckland in New Zealand. R was specifically designed to be a high-performance language for statistical analysis, data mining, machine learning, and database exploration to identify patterns. Being an open-source language, it benefits from numerous packages available primarily through the CRAN repository. The extensive collection of free packages enables R to be widely used across various domains beyond statistics and data science. R is recognized as one of the most popular languages for statistical analysis, statistical graphing, and data science projects. Moreover, it has been gaining popularity in general terms as well.

The prominence of R is attributed not only to its extensibility, robustness, and versatility but also to the active support from a large community of volunteers who contribute to frequent updates of the language. For instance, the development of this work was carried out using version 4.2.2 of R, released on 31 October 2022. As of the time of writing, the current version is 4.2.3 (“Shortstop Beagle”), released on 15 March 2023, with version 4.3.0 (“Already Tomorrow”) scheduled for release on 21 April 2023. The progress of R is driven by a core group of developers supported by contributions from the community.

This community is primarily manifested through the “R Foundation,” which holds the copyright and oversees the management of the R software and documentation. Established as a non-profit public interest organization, the foundation was founded by members of the core development team with the goal of providing support for the R Project (www.r-project.org, accessed on 16 January 2023) and fostering innovation in statistical computing. With R having reached a high level of maturity, the R Foundation strives to ensure its ongoing development through continuous advancements in statistical and computational research software. The foundation also serves as a reference point for individuals, institutions, and companies seeking to support or engage with the R development community, including organizing meetings and conferences in the field of statistical computing.

The R Foundation serves as the maintainer of the CRAN package repository, which currently hosts 19,312 packages (source: Contributed Packages) as of the time of writing. The R Package developed within the scope of this work was accepted and added to CRAN on 9 March 2023, making it globally available for use by the entire R community.

2.2. RStudio and Posit Cloud IDEs

In this study, the RStudio integrated development environment (IDE) played a crucial role. Developed using Java, C++, and JavaScript, the IDE is compatible with Linux, macOS, and Windows operating systems. It is distributed under the GNU Affero General Public License v3 by Posit Software PBC. This organization holds significant prominence within the R community, offering essential resources widely utilized in the field of data science. Therefore, it is pertinent to provide an overview of this organization, as their free products played an exceptional role in the completion of this work [37].

Originally established in 2009 as RStudio, Inc., the organization began distributing free and open-source products. In February 2011, they released the IDE bearing the same name. Over time, they continued to introduce significant contributions to the R community, including the launch of Shiny in 2012, RStudio and Shiny SERVER PRO versions in 2014, and the Spark and tidyverse packages in 2016. In 2020, RStudio, Inc. transformed into Posit PBC, expanding its business to include the Python community with the release of Shiny for Python. Posit PBC is classified as a public benefit corporation (PBC) and holds B-Corp certification. PBC companies are profit-oriented entities with a defined social mission. They are legally structured to prioritize societal well-being alongside shareholder rating maximization. This framework enables companies to focus on both profits and social benefits while also necessitating transparency in demonstrating how the public benefit purpose is served and how member interests are promoted [38].

Since March 2018, several US states have enacted legislation to support PBC companies. These companies must demonstrate a commitment to social good, conduct activities responsibly and transparently without generating adverse environmental, social, or economic impacts, and empower management to make decisions in the public interest, even if they may affect profitability. While pursuing profit is an objective, PBC companies are not required to obtain B-Corp certification. However, Posit Software PBC has earned this certification from B-Lab, which independently assesses the company's social and environmental performance, responsibility, and transparency based on rigorous standards.

Posit Software PBC fulfills a significant public purpose by creating and distributing high-quality open-source software for data scientists while also providing various free resources to the data science community. In the course of this study, posit.cloud (https://posit.cloud/, accessed on 16 January 2023) was initially employed on an experimental basis to facilitate seamless integration with the web platform where the web application was hosted. Initial development and initial deployments were carried out using this tool. However, posit.cloud aims to provide an online environment nearly identical to the RStudio IDE, eliminating the need for downloads, installations, and configurations. Once the integration with the shinyapps.io web platform was complete, the standalone IDE was reverted to for usage. It is worth noting that the free version of the web IDE has certain usage limitations, including a maximum of 50 projects, 25 h of computation per month, 1 GB of RAM, and no support. To utilize posit.cloud, users are required to create an account, thereby gaining access to their designated work area.

2.3. shinyapps.io the Web Hosting Platform

The web service developed in this study is made accessible to the community through the shinyapps.io portal (www.shinyapps.io, accessed on 16 January 2023). This portal offers a free membership plan with certain limitations, including the ability to host up to 5 apps and a maximum of 25 h of availability per month. If the allotted hours of usage are exceeded, the application becomes temporarily unavailable under the free plan. However, paid plans offer extended availability, and if usage exceeds the allocated hours, additional charges may apply, but the service remains accessible [39].

To utilize the shinyapps.io portal, users are required to create an account, granting them access to the application hosting platform. This platform offers all the necessary resources for hosting a web application developed in R using the shiny package. Upon accessing the service, users are presented with a dashboard (Figure 1) that provides convenient hyperlinks to the application's management.

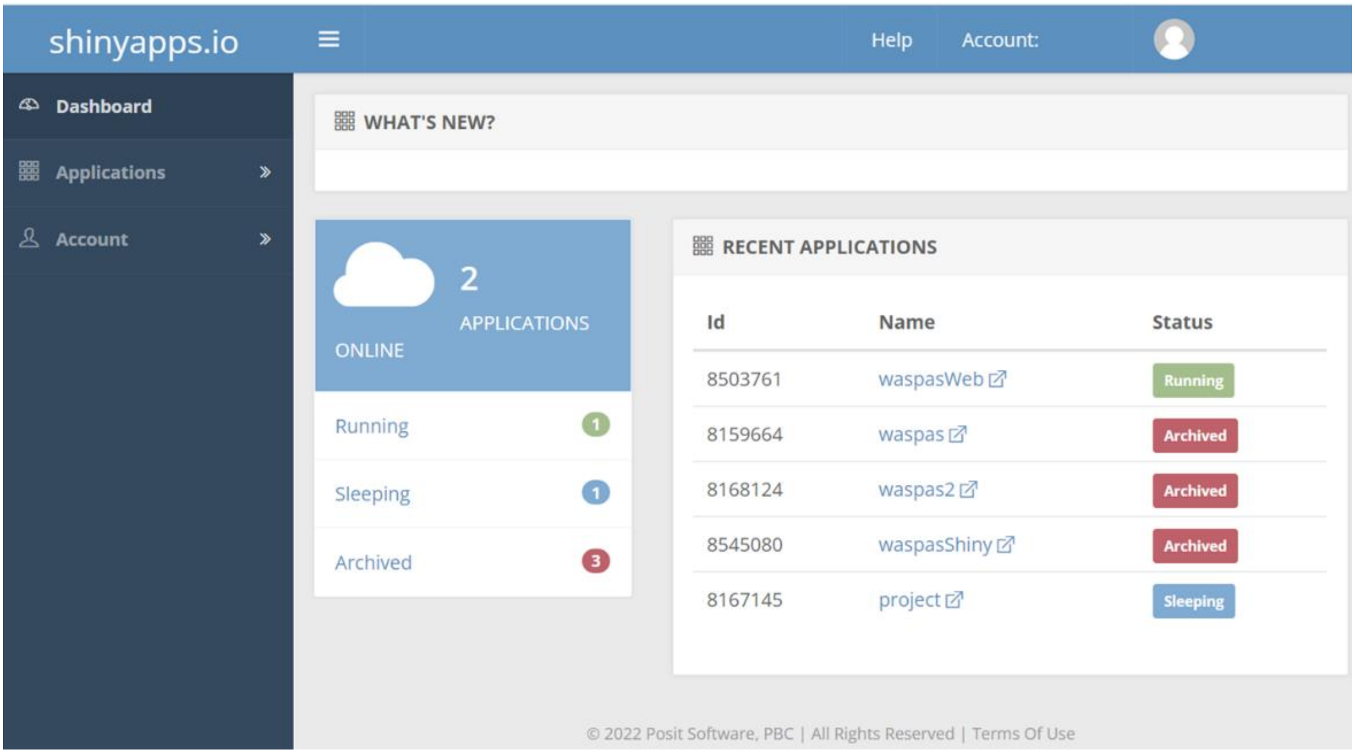


Figure 1. "Dashboard" screen, which showcases a list of web applications hosted on the shinyapps.io platform. This screen serves as a centralized hub for managing and monitoring the various applications.

The process of publishing the developed web application involves utilizing the available functionalities within the IDEs (posit.cloud or Rstudio), which offer a streamlined publishing option specifically designed for Shiny applications. This option is automatically displayed when the project is created as a Shiny. Throughout the development process, the application can be run in a browser or within the IDE's runtime viewer, which also provides the capability to command the publication of the application on the web.

2.4. GitHub

GitHub, Inc. is a prominent internet company that exemplifies the success story of young visionary founders starting in a garage and experiencing exponential growth to become a technology giant. Originally established in 2008 as Logical Awesome LLC (Limited Liability Company), it introduced a collaborative software version control platform based on Git. Presently, the company boasts a revenue of approximately USD one billion and a workforce of 2500 employees as of 2022. In 2012, Microsoft became a significant user of GitHub's services, and in October 2018, it acquired the company, assuming its current ownership. As highlighted on its official website, GitHub offers a comprehensive and scalable platform that enables development teams to securely create and deploy their products. It presently serves over 100 million developers across more than 4 million organizations and hosts over 330 million repositories [40].

The utilization of GitHub in this context is motivated by its integration with RStudio and its widespread adoption within the Information Technology community, encompassing both academic and commercial spheres. This choice allows for the broad accessibility of the software developed in this project to these diverse communities. The entire material developed as an R library (package) is publicly available in a repository on GitHub [41].

The waspasR package can be obtained directly from CRAN or through GitHub through the link www.github.com/flavio-barbara/waspasR (accessed on 16 January 2023), and the application code can be retrieved through the link www.github.com/flavio-barbara/waspasWeb (accessed on 16 January 2023).

2.5. CRAN, Package Building, and Submission Process

Building a software package offers significant advantages, including componentization, code reuse, context isolation, improved code readability, and standardized design. Additionally, it facilitates sharing functions with other developers, fostering an engaged community. In the case of this study, the R language was chosen for implementation, and the package was promoted through CRAN [42].

CRAN is a vast repository of R packages supported by a global network of FTP servers or mirrors. These mirrors store updated versions of component packages, providing sophisticated resources for R development. CRAN serves as the primary instrument for the R Project, which aims to support the continuous development of the R language and explore new methodologies in statistical computing and data science. The R Project is maintained by the R Foundation, located at the Institute of Statistics and Mathematics of the University of Economics and Business in Vienna, Austria. The CRAN network consists of 94 servers, with the main server, 0-Cloud, automatically routing to the other servers worldwide. Rstudio organization maintains the 0-Cloud server.

All packages available on CRAN undergo a rigorous certification process to ensure compliance with strict standards. CRAN has a set of policies that must be adhered to for package submission. The repository emphasizes hosting quality packages and requires contributors to make relevant contributions. Compliance with legal requirements for code and documentation distribution is also essential, considering CRAN operates in multiple jurisdictions. The policies aim to ensure that mirror server distributors fulfill their legal obligations without overloading their work. The CRAN Repository Policy page provides submission instructions, an online form for package submission, and a checklist to aid contributors in meeting submission requirements.

The development process of the package followed a prototyping approach, which is widely recognized in software engineering. As an individual project, communication was ad hoc, based on the needs of the CBT project and the availability of the advisor and student. The process involved analyzing requirements, designing the package structure, implementing the code, thorough testing, creating comprehensive documentation, submitting the package to CRAN, addressing feedback, and continuously improving the package. It is important to note that activities overlapped and proceeded in parallel during the development process.

1. Agreement between the authors on the topic to be developed.
2. Initial guidance provided to the development team regarding objectives, deliverables, and deadlines.
3. Study of the WASPAS method based on recorded classes taught by one of the co-authors.
4. Implementation of functions:
    a. Selection of a validation database.
    b. Construction of functions.
    c. Validation of results.
    d. Correction of defects.

   e. Iteration between steps 4c and 4d until optimization is achieved.
5. Development of the Shiny application.
   a. Debugging process following the steps outlined in 4.
6. Publication of the application on shinyapps.io.
7. Software registration with the INPI.
8. Structuring of the package for submission to CRAN:
   a. Re-engineering of functions to meet the required requirements.
   b. Application of verification programs.
   c. Adjustments to meet the required standards.
   d. Iteration between steps 8b and 8c until optimization is achieved.
9. Submission of the package to CRAN.
   a. Re-submission with necessary cosmetic corrections until accepted.
10. Re-engineering of the Shiny application:
   a. Integration of the waspasR package.
   b. Replacement of functions with calls to package functions.
   c. Deletion of the original functions.

3. Interactive Framework Proposal

The R package, which includes functions for implementing various solutions based on MCDM (multiple criteria decision-making), also makes a small contribution to the R community. It has been accepted in CRAN and is readily available worldwide through the simple installation command "install.packages("waspasR")" in any R environment. The package is also publicly available on GitHub.

As the main product, the waspasWEB project is an academic scientific research project that proposes to implement a decision-making support tool using the WASPAS method, proposed by Zavadskas [35]. The implementation was performed in the R language using the Shiny package for internet publishing and the shinyapps.io hosting service.

The "WASPAS for Dummies" service is a tool to support multi-criteria decision-making, or MCDM, which stands for "Multi-Criteria Decision Making". This type of problem involves a set of alternatives, from which one wants to select the best choice, and a set of evaluation criteria, weighted according to the relative importance that the decision maker considers to be applicable in the decision-making process. There are many methods developed to solve MCDM problems. The study [18] cites more than 25 different methods, including AHP, MACBETH, ELECTRE, MELCHIOR, PAMSSEM, EVAMIX, QUALIFLEX, SAPEVO-M, WASPAS, and several others. Rani et al. [2] point out that multi-criteria decision-making processes are one of the areas of OR that grows the most, both in terms of method diversification and their application in the market [43].

Considering an example of real application, if one decision maker wants to choose the best automobile that will satisfy his needs; based on these needs, a set of criteria is established: economy, power, transport capacity, comfort items, safety items, price, etc., once the criteria are defined, a degree of importance must be assigned to each one of them, that is, the price may be a more relevant criterion than engine power, but this may be considered more relevant than autonomy. For the mathematical calculations of the method, it is also essential to determine whether the criterion regards cost or benefit, that is, if the higher is better or if the lower is better. The algorithms need to know whether the maximization or minimization of rating is intended, for example, price is a cost criterion, that is, the lower, the better, and autonomy is a benefit criterion, the higher, the better. With this information in hand, it is possible to apply mathematical models that classify the most appropriate alternatives for any problem that has this structure.

The software waspasWEB can be accessed by [44]. The first page is divided into two areas, as Figure 2 exposes.

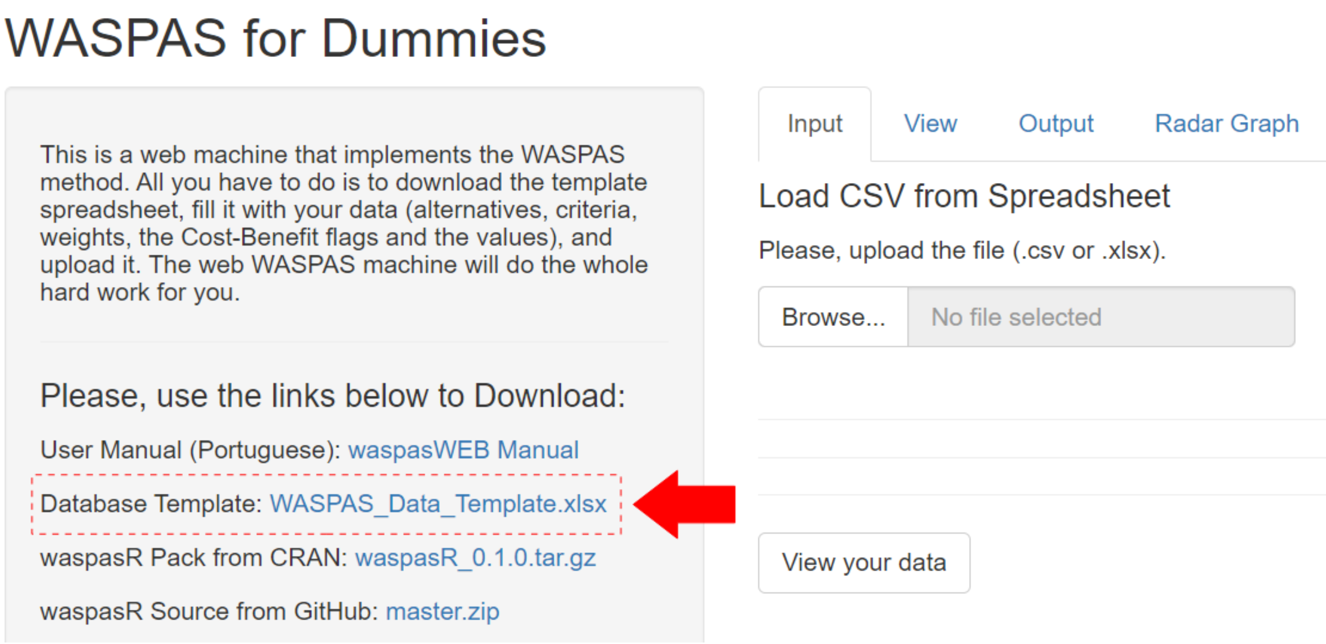


Figure 2. The first page of waspasWEB.

On the right side, there is a presentation column with important information and links to supporting files (e.g., this operation manual). To the left of this display column is the workspace with four tabs, such as: Input, containing the field for uploading the database to be analyzed; View, with visualization of input data and button to command the calculation; Output, presenting the list of alternatives properly ranked; and Radar Chart, exposing radar-type graphic with classification.

The first step is to download the spreadsheet with the database model. To do so, just click on the Database Template link: WASPAS_Data_Template.xlsx (Figure 2), follow the well-known dialog for choosing the folder (directory) where you want to save the file and click on save.

Once the spreadsheet with the data model has been downloaded, edit the file using MS Excel or LibreOffice Calc, for example, and save it with a name you deem appropriate. We will explain later how to fill in the worksheet with data from the multi-criteria decision-making problem. The system will validate the format of the loaded data and show a brief report of what was imported. If there is no formatting error, the screen that will be displayed is the one shown below (Figure 3).

There are scroll bars on the right and bottom that allow you to view all the loaded data. After applying the WASPAS method to the database, the "Output" tab opens automatically and shows the classification made by the WASPAS method and by the two underlying methods, WSM and WPM. There is a "Slider" object on the screen that allows you to very quickly change the lambda rating that weigh the relative rating of each of the underlying methods. The closer to 0 (zero) the lambda rating is, the greater the weight of the WPM method, and the closer to 1, the greater the relative weight of the ranking obtained by WSM. The screen shown in the Output tab contains the rankings by the WSM (summation) and WPM (product) methods and the WASPAS ranking, which changes dynamically according to the change in the lambda rating in the "slider" object, as Figure 4 presents.

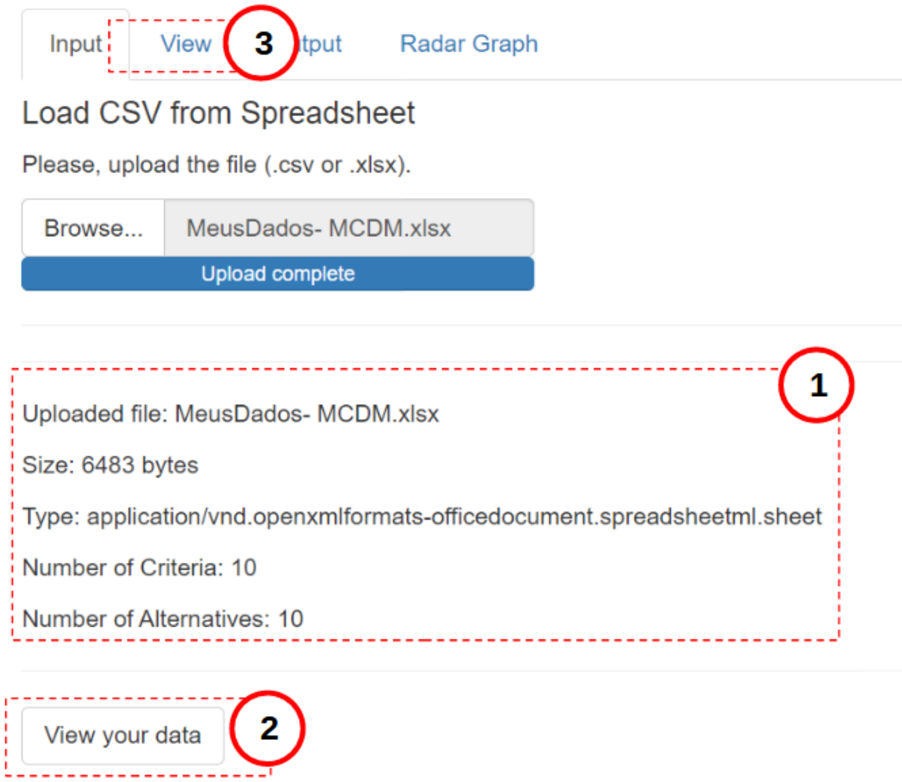
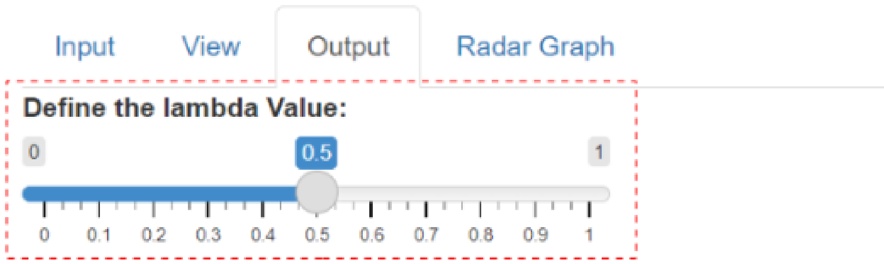


Figure 3. Database load result presentation screen, where: (1) Report on the loading process: file name and size, number of criteria, and database alternatives; (2) A button that directs to the visualization tab of the imported data (One can click directly on the "View" (3) tab to view the data).



Alternative	WSM_Rank	WPM_Rank	WASPAS_Rank
Alternative 4	0.638	0.605	0.622
Alternative 1	0.719	0.498	0.609
Alternative 2	0.617	0.469	0.543
Alternative 3	0.569	0.452	0.511
Alternative 5	0.526	0.429	0.478

Figure 4. Slider that allows dynamic visualization of the lambda.

The same result is displayed on the "Radar Chart" tab in a graphic format also known as spider web chart, Kiviat diagram, and other names. In this tab, there is also a "Slider" object that allows changing the lambda rating dynamically (Figure 5). The Radar Chart slider is synchronized with the Output tab object. When modifying the lambda rating in this component, the slider on the "Output" tab is also changed to the same rating, updating the WASPAS ranking.

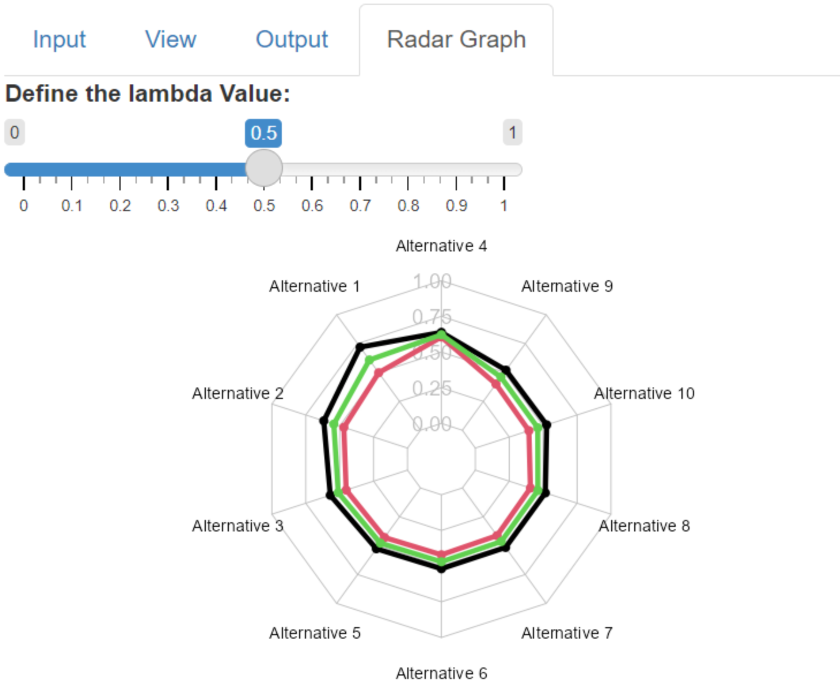


Figure 5. Slider and radar chart (spider web).

After downloading the spreadsheet (WASPAS_Data_Template.xlsx), open it in MS Excel, LibreOffice Calc, or the application of your choice. The worksheet will be the one shown in (Figure 6), but without any color, the colors are merely for didactic purposes.

F	Cost	Benefit	Cost	Benefit	Cost	Benefit	Cost	Benefit	Cost	Cost
W	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
C	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Criterion 6	Criterion 7	Criterion 8	Criterion 9	Criterion 10
Alternative 1	1	2	3	4	5	6	7	8	9	10
Alternative 2	2	3	4	5	6	7	8	9	10	11
Alternative 3	3	4	5	6	7	8	9	10	11	12
Alternative 4	4	123	6	7	8	9	10	11	12	13
Alternative 5	5	6	7	8	9	10	11	12	13	14
Alternative 6	6	7	8	9	10	11	12	13	14	15
Alternative 7	7	8	9	10	11	12	13	14	15	16
Alternative 8	8	9	10	11	12	13	14	15	16	17
Alternative 9	9	10	11	12	13	14	15	16	17	18
Alternative 10	10	11	12	13	14	15	16	17	18	19

Figure 6. Template spreadsheet for structuring input data.

The spreadsheet that structures the database of the multi-criteria decision-making problem that will be submitted to the WASPAS calculation provided by the "WASPAS for Dummies" page must respect the above structure. Separated by colors, there are six areas in the worksheet: indicators, flags, weights, criteria, alternatives, and alternative criterion rating.

Detailing each of them, we have in cells (1,1), (2,1), and (3,1) the indicators (Figure 6) of lines 1, 2, and 3 are informed, which must be "F" for "Flags", "W" for weights, and "C" for "Criteria". That is, "F" means the Cost or Benefit flag, "W" is the weight (importance of each criterion), this information (metadata) allows the user of the "WASPAS for Dummies" service to inform the data of criteria, weights, and cost–benefit in the line that suits you, the service will process each line according to the indicator in the cell.

With the indicator properly defined, it is necessary that the data in the referred rows are appropriate. The "F" indicator line should contain only "Flags" that indicate whether the criterion is cost or benefit. For this, the cells must contain words starting with "C" (cost) or "B" (Benefit).

The row whose indicator is the "W" (weight) must contain the weights arbitrated by the decision maker in relation to the relative importance of each of the criteria. The sum of the weights in the "W" row must add up to 1 (100%). And the indicator line "C" should contain the problem criteria. These are brief descriptions such as price, weight, size, capacity, etc.

The area in red is the part where the alternatives to the problem are introduced. There are no limits to the number of alternatives, just as there are no limits to the number of criteria. We suggest that in these cells (column 1, rows 4 to n, last alternative), brief descriptions of the alternatives be introduced, as well as in row "C" (criteria).

And the most important part is the one that has the rating. The ratings are, in general, obtained in the market and refer to the performance of that alternative in relation to the criterion. For example, the price rating of product X, the maximum speed of alternative Y, and the boiling temperature of element Z. The gray hatched ratings in Figure 6 are those that will be submitted to the decision support algorithm that is determined by criteria alternatives.

For a better understanding of the interactive internet-based model, Figure 7 presents a flowchart exposing the main steps of analysis using the computational framework.

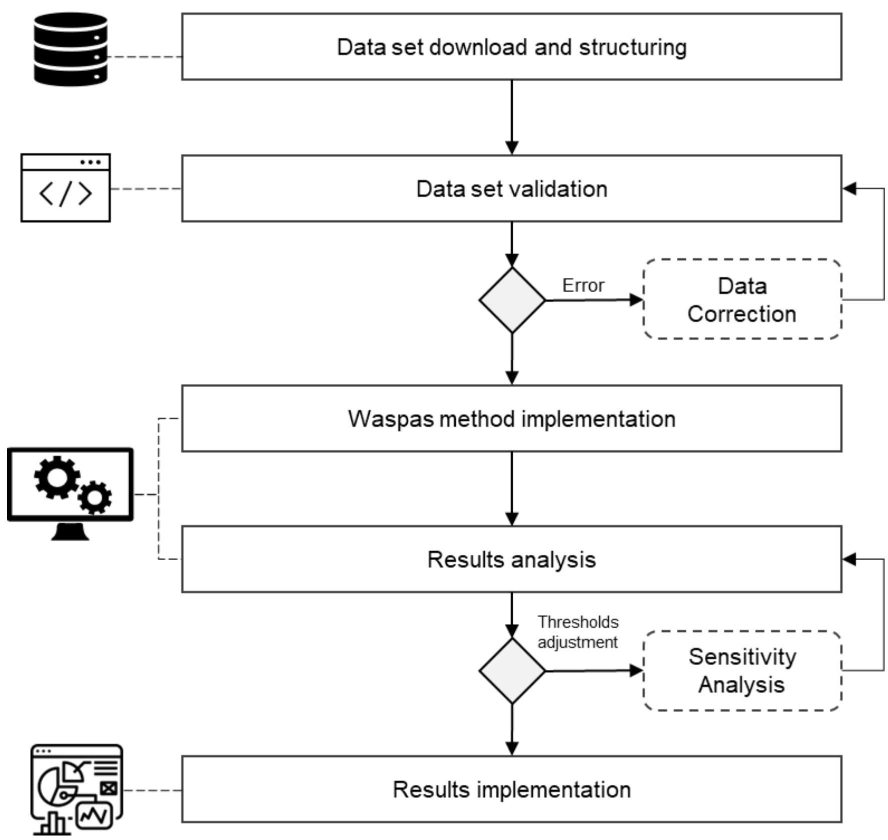


Figure 7. Computational analysis flowchart.

4. Case Study

After validating the algorithm implemented by comparing all the results obtained (partial and final) by the work [18], several other exercises were applied. We will report one of them. The most important thing is that the public tool derived from this work can be used for any MCDM study based on the methods presented here (WSM, WPM, and WASPAS), which can be accessed through the link www.flaviob.shinyapps.io/waspasWeb, accessed on 16 January 2023.

For this case study, we used the interactive software proposal using a step-by-step guide that serves as a drive for any further study that uses the tool.

First, we download the database template and edit it using the application of your choice. Then, we download a public database available on Kaggle [45] with various models of cell phones presenting technical specifications and prices in USD. Regarding the base used and the computational processing capacity of the mathematical and computational model, a limit between the number of criteria and alternatives is not identified. However, it should be noted that the use of heterogeneous and non-redundant criteria becomes validated, allowing a more accurate assessment in the application of a given real case.

In the sequence, the analysis and data preparation were conducted on the CSV file obtained in the previous step. This process involved data scrubbing, which entailed removing non-numeric entries and unnecessary columns that were not relevant to the MCDM process. The original dataset has 22 columns, as can be seen in Figure 8. The first cleansing operation involved removing non-numeric columns (highlighted in yellow). Next, column "A" was removed as it served only as an indexer (highlighted in gray). Then, it was observed that column "B" was a combination of columns "C" and "D" (highlighted in green), hence they were also eliminated.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
	Name	Brand	Model	Battery capacity (mAh)	Screen size (inches)	Touchscreen	Resolution x	Resolution y	Processor	RAM (MB)	Internal storage (GB)	Rear camera	Front camera	Operating system	Wi-Fi	Bluetooth	GPS	Number of SIMs	3G	4G/ LTE	Price
0	OnePlus	OnePlus	7T Pro M	4085	6.67	Yes	1440	3120	8	12000	256.0	48.0	16.0	Android	Yes	Yes	Yes	2	Yes	Yes	58998
1	Realme	Realme	X2 Pro	4000	6.5	Yes	1080	2400	8	6000	64.0	64.0	16.0	Android	Yes	Yes	Yes	2	Yes	Yes	27999
2	iPhone 1	Apple	iPhone 1	3969	6.5	Yes	1242	2688	6	4000	64.0	12.0	12.0	iOS	Yes	Yes	Yes	2	Yes	Yes	106900
3	iPhone 1	Apple	iPhone 1	3110	6.1	Yes	828	1792	6	4000	64.0	12.0	12.0	iOS	Yes	Yes	Yes	2	Yes	Yes	62900
4	LG G8X	LG	G8X Thi	4000	6.4	Yes	1080	2340	8	6000	128.0	12.0	32.0	Android	Yes	Yes	Yes	1	No	No	49990
5	OnePlus	OnePlus	7T	3800	6.55	Yes	1080	2400	8	8000	128.0	48.0	16.0	Android	Yes	Yes	No	2	Yes	Yes	34930
6	OnePlus	OnePlus	7T Pro	4085	6.67	Yes	1440	3120	8	8000	256.0	48.0	16.0	Android	Yes	Yes	Yes	2	Yes	Yes	52990
7	Samsun	Samsun	Galaxy N	4300	6.8	Yes	1440	3040	8	12000	256.0	12.0	10.0	Android	Yes	Yes	Yes	2	Yes	Yes	79699
8	Asus RO	Asus	ROG Ph	6000	6.59	Yes	1080	2340	8	8000	128.0	48.0	24.0	Android	Yes	Yes	Yes	1	Yes	Yes	37999
9	Xiaomi P	Xiaomi	Redmi K	4000	6.39	Yes	1080	2340	8	6000	128.0	48.0	20.0	Android	Yes	Yes	Yes	2	No	No	23190
10	Oppo K3	Oppo	K3	3765	6.5	Yes	1080	2340	8	6000	64.0	16.0	16.0	Android	Yes	Yes	Yes	2	Yes	Yes	23990
11	Realme	Realme	X	3765	6.53	Yes	1080	2340	8	4000	128.0	48.0	16.0	Android	Yes	Yes	Yes	2	Yes	Yes	14999
12	Xiaomi P	Xiaomi	Redmi K	4000	6.39	Yes	1080	2340	8	6000	64.0	48.0	20.0	Android	Yes	Yes	Yes	2	Yes	Yes	19282
13	OnePlus	OnePlus	7 Pro	4000	6.67	Yes	1440	3120	8	6000	128.0	48.0	16.0	Android	Yes	Yes	Yes	2	Yes	Yes	39995
14	Oppo Re	Oppo	Reno 10	4065	6.6	Yes	1080	2340	8	6000	128.0	48.0	16.0	Android	Yes	Yes	Yes	2	Yes	Yes	36990

Figure 8. The original dataset was loaded in a spreadsheet tool.

So, the prepared dataset at the end has the following list of criteria: battery capacity (mAh), screen size (inches), resolution x, resolution y, processor, RAM (MB), internal storage (GB), rear camera, front camera, number of SIMs, and price.

Assign weights to the criteria. At this point, the decision maker is required to assign weights to each criterion in such a manner that the summation of weights is equal to 1 (or 100%). Since there are eleven criteria, and the main one is the price, some exercises of criteria importance powering can be easily performed. For example, a weight of 0.2 or 20% can be assigned to the price criterion, and the remaining ten criteria can be equally divided into a weight of 0.08 or 8% each (Figure 9). Similarly, if a weight of 50% is assigned to the price criterion, the other ten criteria will have a weight of 0.05 or 5% to fit the sum of 100% (Figure 10). Alternatively, a specific weight rating can be assigned for each criterion, provided that the sum of the weights equals 1. These types of exercises have been performed and will be described in more detail later on.

Assign and specify for each criterion whether it is a cost or benefit criterion. It is important to bear in mind that such a definition can be subjective. For instance, a specific criterion may be considered a benefit by one decision-maker, while it may be viewed as a cost by another. In the case being studied, the screen size, which is typically regarded as a benefit by most individuals, will be considered a cost criterion by someone seeking an exceptionally small phone for whatever reason. In other words, the smaller the screen, the better it is perceived as a cost criterion in their case. This classification is also performed in the spreadsheet editor and can be seen in Figure 11.

	A	B	C	D	E	F	G	H	I	J	K	L
1	**Weights**	**0.08**	**0.08**	**0.08**	**0.08**	**0.08**	**0.08**	**0.08**	**0.08**	**0.08**	**0.08**	**0.20**
2	**Criteria**	Battery capacity (mAh)	Screen size (inches)	Resolution x	Resolution y	Processor	RAM (MB)	Internal storage (GB)	Rear camera	Front camera	Number of SIMs	Price
3	OnePlus 7T P	4085	6.67	1440	3120	8	12000	256.0	48.0	16.0	2	58998
4	Realme X2 Pr	4000	6.5	1080	2400	8	6000	64.0	64.0	16.0	2	27999
5	iPhone 11 Pro	3969	6.5	1242	2688	6	4000	64.0	12.0	12.0	2	106900
6	iPhone 11	3110	6.1	828	1792	6	4000	64.0	12.0	12.0	2	62900

Figure 9. Weight assignments (highlighted in light yellow) were used in the first exercise.

	A	B	C	D	E	F	G	H	I	J	K	L
1	**Weights**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.50**
2	**Criteria**	Battery capacity (mAh)	Screen size (inches)	Resolution x	Resolution y	Processor	RAM (MB)	Internal storage (GB)	Rear camera	Front camera	Number of SIMs	Price
3	OnePlus 7T P	4085	6.67	1440	3120	8	12000	256.0	48.0	16.0	2	58998
4	Realme X2 Pr	4000	6.5	1080	2400	8	6000	64.0	64.0	16.0	2	27999
5	iPhone 11 Pro	3969	6.5	1242	2688	6	4000	64.0	12.0	12.0	2	106900
6	iPhone 11	3110	6.1	828	1792	6	4000	64.0	12.0	12.0	2	62900

Figure 10. Weight assignments are used in the second example mentioned.

	A	B	C	D	E	F	G	H	I	J	K	L
1	**Flags**	**Benefit**	**Benefit**	**Benefit**	**Benefit**	**Benefit**	**Benefit**	**Benefit**	**Benefit**	**Benefit**	**Benefit**	**Cost**
2	**Weights**	**0.08**	**0.08**	**0.08**	**0.08**	**0.08**	**0.08**	**0.08**	**0.08**	**0.08**	**0.08**	**0.20**
3	**Criteria**	Battery capacity (mAh)	Screen size (inches)	Resolution x	Resolution y	Processor	RAM (MB)	Internal storage (GB)	Rear camera	Front camera	Number of SIMs	Price
4	OnePlus 7T P	4085	6.67	1440	3120	8	12000	256.0	48.0	16.0	2	58998
5	Realme X2 Pr	4000	6.5	1080	2400	8	6000	64.0	64.0	16.0	2	27999
6	iPhone 11 Pro	3969	6.5	1242	2688	6	4000	64.0	12.0	12.0	2	106900
7	iPhone 11	3110	6.1	828	1792	6	4000	64.0	12.0	12.0	2	62900

Figure 11. Flags cost–benefit defined. Screen size as benefit.

The import of the data and the result of the upload is then displayed as shown in Figure 12, Encircled with a dotted orange dashed line. Since it is not possible to edit the data after it is loaded, the criterion weighting exercises should be performed using a spreadsheet editing tool (such as Excel, LibreOffice, etc.), and reloading the data, which means going back to the previous Step 4 and repeating the exercises. It is recommended to refresh the page by clicking the "Reload this Page" button in the browser whenever a new load is performed. Additionally, it is important to remember to save the spreadsheet after making any changes.

In the sequence of software implementation, we visualize the data and submit it to the WASPAS algorithm. After loading the data, you can click on the "View your data" button or the "View" tab for a visualization of the imported dataset's contents, as shown highlighted in red in Figure 13.

Once the data loading results have been reviewed and confirmed to be successful, click on the "Calculate WASPAS" button to apply the method's algorithms to the imported database. The user will be automatically directed to the "Output" tab screen (as shown in Figure 14), where only the top 20 ranked items, with the application of lambda = 0.5, will be displayed. Limiting the number of observations to 20 is very useful in this case, given the thousands of options. Once we surpass a dozen of alternatives, it is better to create a shortlist and work with it. This is due to the presence of a set of "losers" that do not deserve attention and would burden the computational effort required for applying the algorithms.

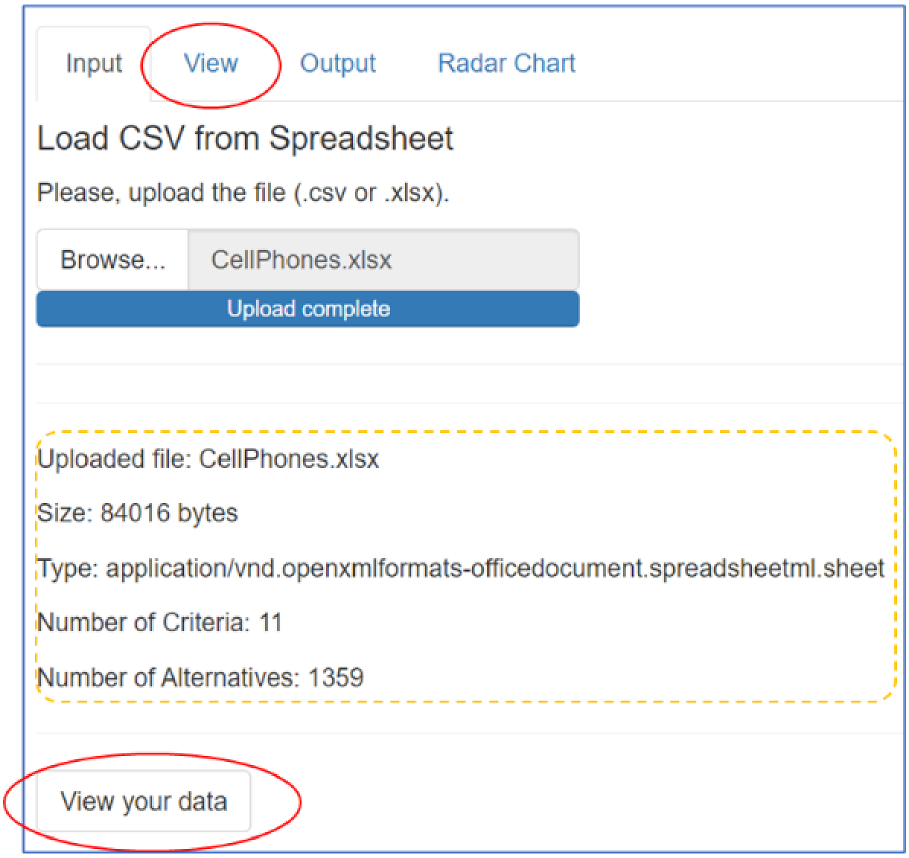


Figure 12. A dataset with 1359 cell phones with 11 criteria was successfully uploaded.

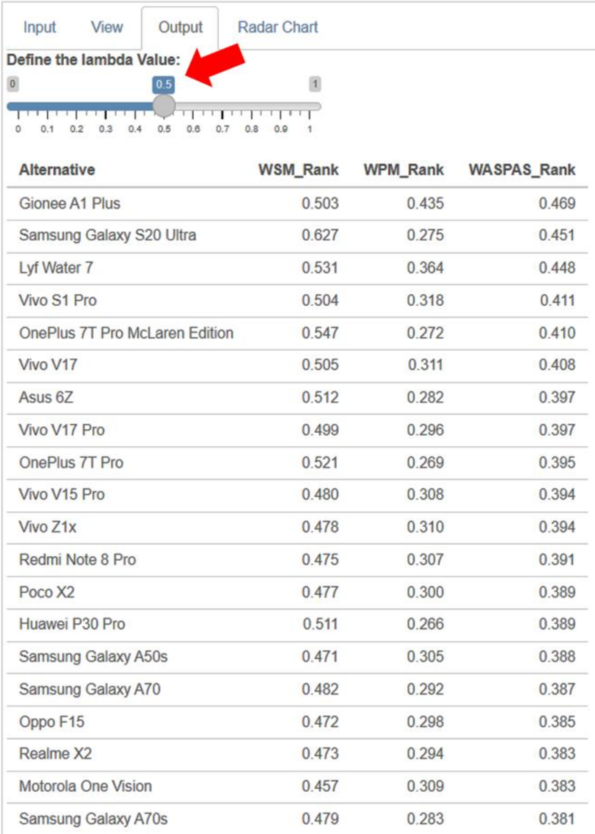
Input View Output Radar Chart

Calculate WASPAS

...1	...2	...3	...4	...5	...6	...7	...8	...9	...10	...11	...12
Flags	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit	Cost
Weights	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.2
Criteria	Battery capacity (mAh)	Screen size (inches)	Resolution x	Resolution y	Processor	RAM (MB)	Internal storage (GB)	Rear camera	Front camera	Number of SIMs	Price
OnePlus 7T Pro McLaren Edition	4085	6.67	1440	3120	8	12000	256.0	48.0	16.0	2	58998
Realme X2 Pro	4000	6.5	1080	2400	8	6000	64.0	64.0	16.0	2	27999
iPhone 11 Pro Max	3969	6.5	1242	2688	6	4000	64.0	12.0	12.0	2	106900
iPhone 11	3110	6.1	828	1792	6	4000	64.0	12.0	12.0	2	62900

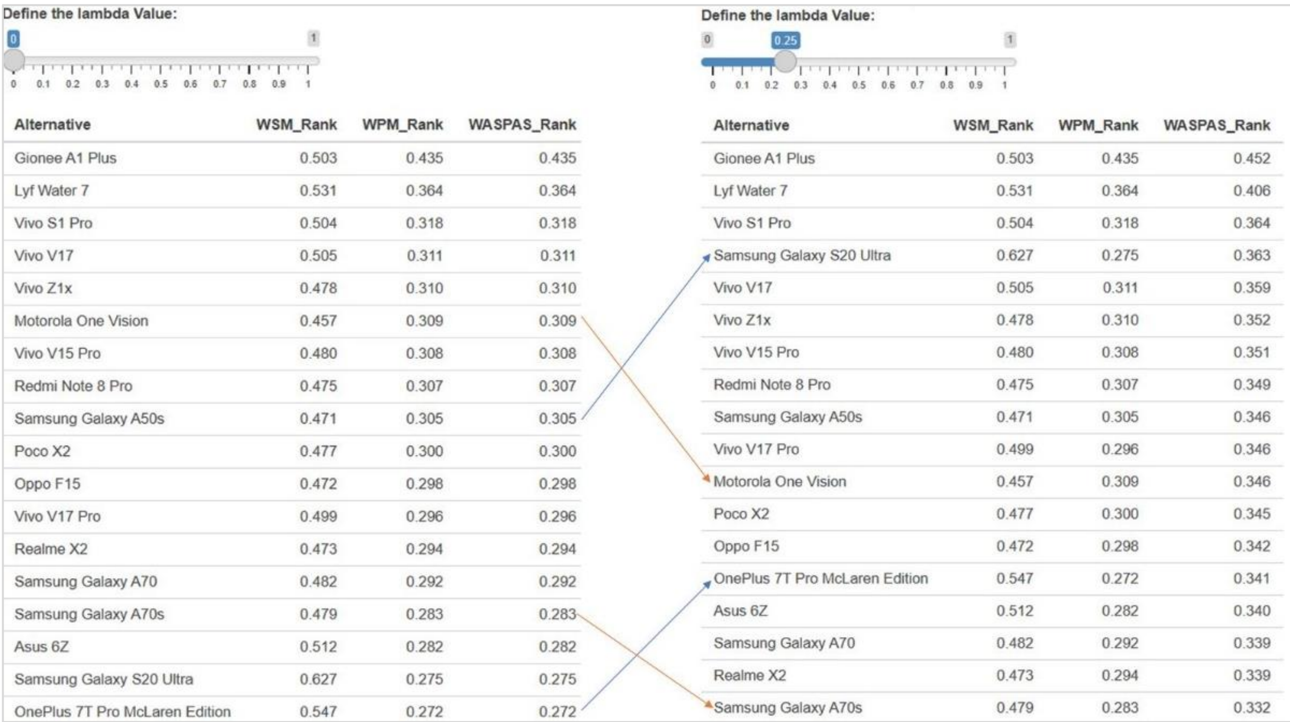
Figure 13. A dataset with 1359 cell phones with 11 criteria was successfully uploaded.

Dynamically different lambda ratings to observe the ranking change. The slider object allows the dynamic application of the lambda rating and the immediate visualization of the sensitivity of each of the underlying methods (WSM and WPM) to the dataset under study. It is very interesting to observe that a small push of lambda from zero to 2.5 already produces drastic changes, indicating how the database under study is sensitive to the weighting between the WSM and WPM methods, as can be observed in Figure 15.



Alternative	WSM_Rank	WPM_Rank	WASPAS_Rank
Gionee A1 Plus	0.503	0.435	0.469
Samsung Galaxy S20 Ultra	0.627	0.275	0.451
Lyf Water 7	0.531	0.364	0.448
Vivo S1 Pro	0.504	0.318	0.411
OnePlus 7T Pro McLaren Edition	0.547	0.272	0.410
Vivo V17	0.505	0.311	0.408
Asus 6Z	0.512	0.282	0.397
Vivo V17 Pro	0.499	0.296	0.397
OnePlus 7T Pro	0.521	0.269	0.395
Vivo V15 Pro	0.480	0.308	0.394
Vivo Z1x	0.478	0.310	0.394
Redmi Note 8 Pro	0.475	0.307	0.391
Poco X2	0.477	0.300	0.389
Huawei P30 Pro	0.511	0.266	0.389
Samsung Galaxy A50s	0.471	0.305	0.388
Samsung Galaxy A70	0.482	0.292	0.387
Oppo F15	0.472	0.298	0.385
Realme X2	0.473	0.294	0.383
Motorola One Vision	0.457	0.309	0.383
Samsung Galaxy A70s	0.479	0.283	0.381

Figure 14. Ranking of alternatives in a standard analysis.

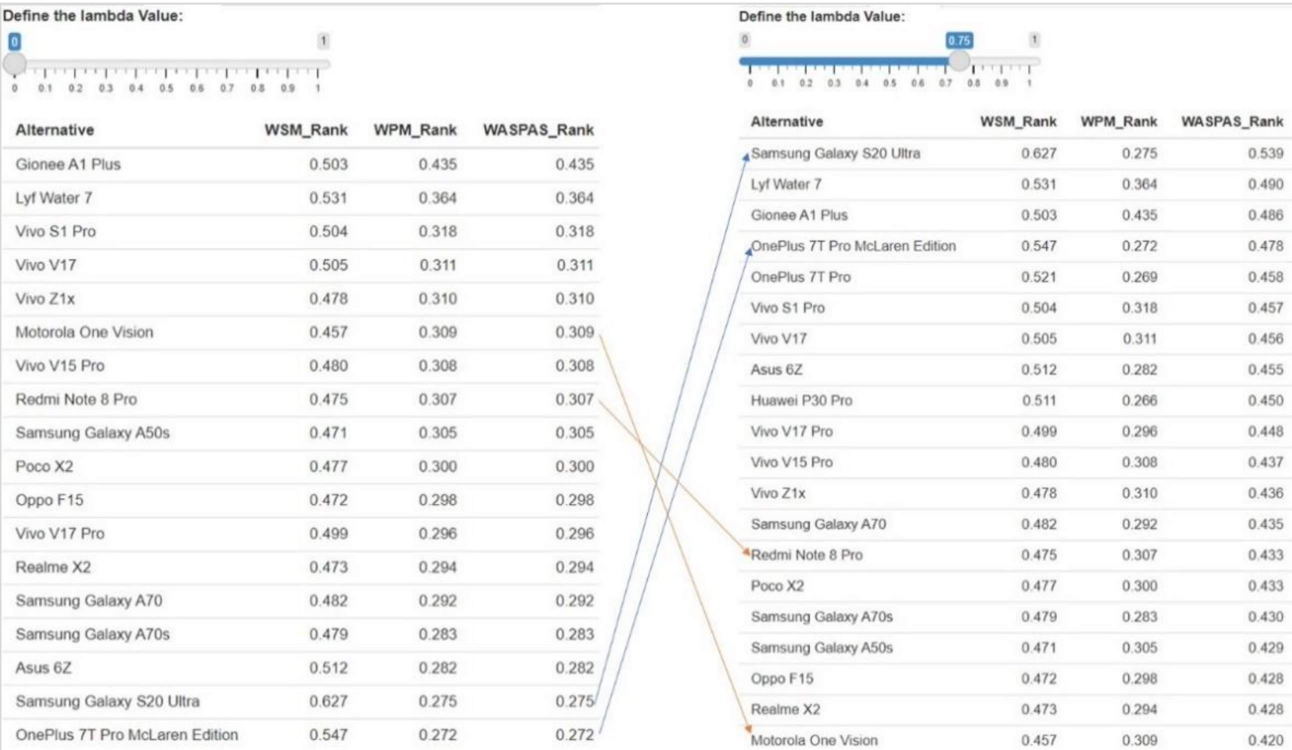


Alternative	WSM_Rank	WPM_Rank	WASPAS_Rank
Gionee A1 Plus	0.503	0.435	0.435
Lyf Water 7	0.531	0.364	0.364
Vivo S1 Pro	0.504	0.318	0.318
Vivo V17	0.505	0.311	0.311
Vivo Z1x	0.478	0.310	0.310
Motorola One Vision	0.457	0.309	0.309
Vivo V15 Pro	0.480	0.308	0.308
Redmi Note 8 Pro	0.475	0.307	0.307
Samsung Galaxy A50s	0.471	0.305	0.305
Poco X2	0.477	0.300	0.300
Oppo F15	0.472	0.298	0.298
Vivo V17 Pro	0.499	0.296	0.296
Realme X2	0.473	0.294	0.294
Samsung Galaxy A70	0.482	0.292	0.292
Samsung Galaxy A70s	0.479	0.283	0.283
Asus 6Z	0.512	0.282	0.282
Samsung Galaxy S20 Ultra	0.627	0.275	0.275
OnePlus 7T Pro McLaren Edition	0.547	0.272	0.272

Alternative	WSM_Rank	WPM_Rank	WASPAS_Rank
Gionee A1 Plus	0.503	0.435	0.452
Lyf Water 7	0.531	0.364	0.406
Vivo S1 Pro	0.504	0.318	0.364
Samsung Galaxy S20 Ultra	0.627	0.275	0.363
Vivo V17	0.505	0.311	0.359
Vivo Z1x	0.478	0.310	0.352
Vivo V15 Pro	0.480	0.308	0.351
Redmi Note 8 Pro	0.475	0.307	0.349
Samsung Galaxy A50s	0.471	0.305	0.346
Vivo V17 Pro	0.499	0.296	0.346
Motorola One Vision	0.457	0.309	0.346
Poco X2	0.477	0.300	0.345
Oppo F15	0.472	0.298	0.342
OnePlus 7T Pro McLaren Edition	0.547	0.272	0.341
Asus 6Z	0.512	0.282	0.340
Samsung Galaxy A70	0.482	0.292	0.339
Realme X2	0.473	0.294	0.339
Samsung Galaxy A70s	0.479	0.283	0.332

Figure 15. Major changes in the ranking, changing lambda from 0 to 0.25.

Again, changing it to 0.75, since we started with 0.5 and did not need to repeat, we can observe some radical changes. Notice how the direction arrows of the changes become more aggressive; observe Figure 16. By pushing lambda further towards making WASPAS exactly like a WPM, signifying making lambda equal to 1.0, we can observe a few more changes, as depicted in Figure 17. Note that the dashed arrows indicate alternatives that did not undergo any changes, while the solid arrows indicate new changes.


Define the lambda Value: 0

Alternative	WSM_Rank	WPM_Rank	WASPAS_Rank
Gionee A1 Plus	0.503	0.435	0.435
Lyf Water 7	0.531	0.364	0.364
Vivo S1 Pro	0.504	0.318	0.318
Vivo V17	0.505	0.311	0.311
Vivo Z1x	0.478	0.310	0.310
Motorola One Vision	0.457	0.309	0.309
Vivo V15 Pro	0.480	0.308	0.308
Redmi Note 8 Pro	0.475	0.307	0.307
Samsung Galaxy A50s	0.471	0.305	0.305
Poco X2	0.477	0.300	0.300
Oppo F15	0.472	0.298	0.298
Vivo V17 Pro	0.499	0.296	0.296
Realme X2	0.473	0.294	0.294
Samsung Galaxy A70	0.482	0.292	0.292
Samsung Galaxy A70s	0.479	0.283	0.283
Asus 6Z	0.512	0.282	0.282
Samsung Galaxy S20 Ultra	0.627	0.275	0.275
OnePlus 7T Pro McLaren Edition	0.547	0.272	0.272

Define the lambda Value: 0.75

Alternative	WSM_Rank	WPM_Rank	WASPAS_Rank
Samsung Galaxy S20 Ultra	0.627	0.275	0.539
Lyf Water 7	0.531	0.364	0.490
Gionee A1 Plus	0.503	0.435	0.486
OnePlus 7T Pro McLaren Edition	0.547	0.272	0.478
OnePlus 7T Pro	0.521	0.269	0.458
Vivo S1 Pro	0.504	0.318	0.457
Vivo V17	0.505	0.311	0.456
Asus 6Z	0.512	0.282	0.455
Huawei P30 Pro	0.511	0.266	0.450
Vivo V17 Pro	0.499	0.296	0.448
Vivo V15 Pro	0.480	0.308	0.437
Vivo Z1x	0.478	0.310	0.436
Samsung Galaxy A70	0.482	0.292	0.435
Redmi Note 8 Pro	0.475	0.307	0.433
Poco X2	0.477	0.300	0.433
Samsung Galaxy A70s	0.479	0.283	0.430
Samsung Galaxy A50s	0.471	0.305	0.429
Oppo F15	0.472	0.298	0.428
Realme X2	0.473	0.294	0.428
Motorola One Vision	0.457	0.309	0.420

Figure 16. Extreme changes were observed in the ranking, changing lambda from 0 to 0.75.


Define the lambda Value: 0

Alternative	WSM_Rank	WPM_Rank	WASPAS_Rank
Gionee A1 Plus	0.503	0.435	0.435
Lyf Water 7	0.531	0.364	0.364
Vivo S1 Pro	0.504	0.318	0.318
Vivo V17	0.505	0.311	0.311
Vivo Z1x	0.478	0.310	0.310
Motorola One Vision	0.457	0.309	0.309
Vivo V15 Pro	0.480	0.308	0.308
Redmi Note 8 Pro	0.475	0.307	0.307
Samsung Galaxy A50s	0.471	0.305	0.305
Poco X2	0.477	0.300	0.300
Oppo F15	0.472	0.298	0.298
Vivo V17 Pro	0.499	0.296	0.296
Realme X2	0.473	0.294	0.294
Samsung Galaxy A70	0.482	0.292	0.292
Samsung Galaxy A70s	0.479	0.283	0.283
Asus 6Z	0.512	0.282	0.282
Samsung Galaxy S20 Ultra	0.627	0.275	0.275
OnePlus 7T Pro McLaren Edition	0.547	0.272	0.272

Define the lambda Value: 1

Alternative	WSM_Rank	WPM_Rank	WASPAS_Rank
Samsung Galaxy S20 Ultra	0.627	0.275	0.627
OnePlus 7T Pro McLaren Edition	0.547	0.272	0.547
Lyf Water 7	0.531	0.364	0.531
OnePlus 7T Pro	0.521	0.269	0.521
Asus 6Z	0.512	0.282	0.512
Huawei P30 Pro	0.511	0.266	0.511
Vivo V17	0.505	0.311	0.505
Vivo S1 Pro	0.504	0.318	0.504
Gionee A1 Plus	0.503	0.435	0.503
Vivo V17 Pro	0.499	0.296	0.499
Samsung Galaxy A70	0.482	0.292	0.482
Vivo V15 Pro	0.480	0.308	0.480
Samsung Galaxy A70s	0.479	0.283	0.479
Vivo Z1x	0.478	0.310	0.478
Poco X2	0.477	0.300	0.477
Redmi Note 8 Pro	0.475	0.307	0.475
Realme X2	0.473	0.294	0.473
Oppo F15	0.472	0.298	0.472
Samsung Galaxy A50s	0.471	0.305	0.471
Motorola One Vision	0.457	0.309	0.457

Figure 17. Extreme changes were observed in the ranking, changing lambda from 0 to 1.

Now, let us change the criteria weight rating in the original dataset and see what happens. These first exercises demonstrate the ease of use of the waspasWEB tool (WASPAS for Dummies website). Now let us apply a more "human" weighting to the criteria since the technical specifications generally have different relative importance among themselves, and the weight of the price criterion may, in fact, not have the oversized importance that we used previously (in many cases, the price is less important than other performance criteria). The weighted set of criteria is shown in Table 2.

Table 2. Weighting criteria that would likely make more sense to a decision-maker.

Flags	Weights	Criteria
Benefit	0.10	Battery capacity (mAh)
Cost	0.07	Screen size
Benefit	0.09	Resolution X
Benefit	0.09	Resolution Y
Benefit	0.06	Processors
Benefit	0.10	RAM (MB)
Benefit	0.12	Internal storage (GB)
Benefit	0.09	Rear camera
Benefit	0.09	Front camera
Benefit	0.05	Number of SIMs
Cost	0.14	Price

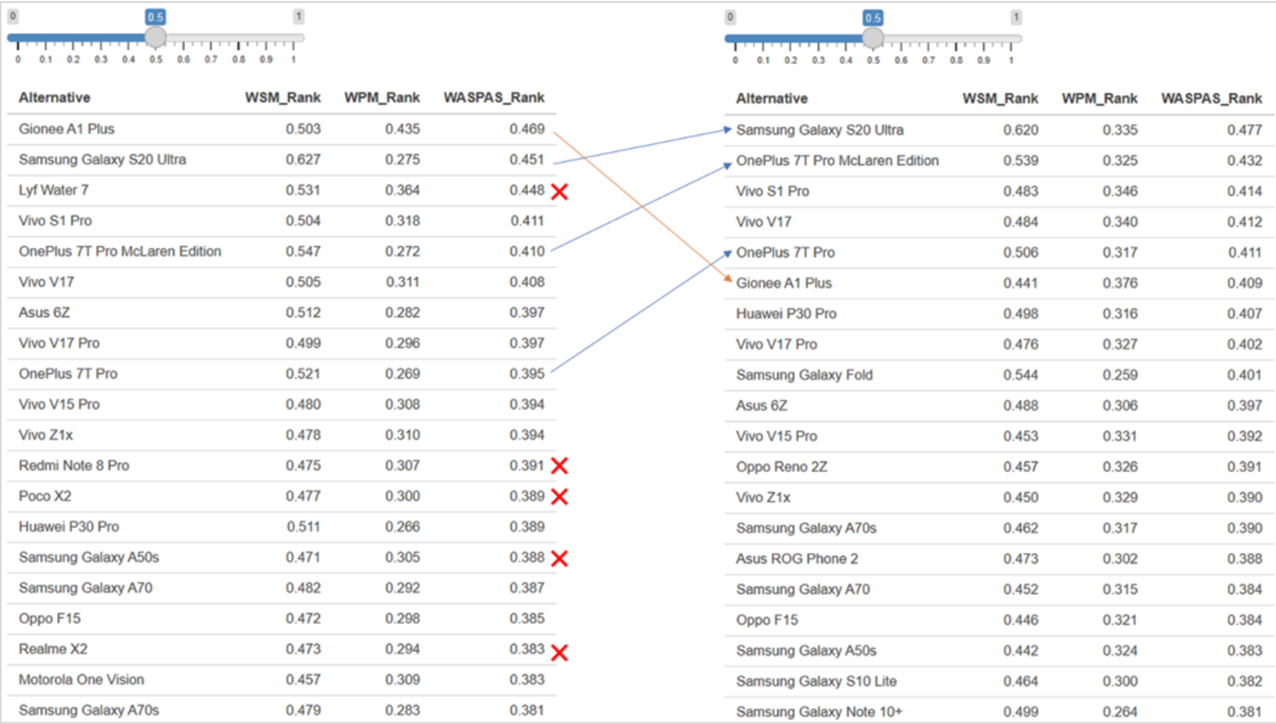
One could say that the set of criteria now assigned in the case study scope is not only more rigorous but also has a more human aspect. For instance, even though cost remains the most important criterion in the selection process of the best option, it no longer presents such a significant difference compared to other criteria. As a result, those devices whose only advantage is a low price but have poor technical characteristics will not be artificially overrated.

Another significant change made for the upcoming exercises was the inversion of the “Screen size” criterion from a monotonically increasing benefit criterion to a monotonically increasing cost criterion. This change makes sense within the context that a subjective criterion related to the desires, tastes, and personal preferences of the decision-maker is the most important aspect of the entire process. Thus, what is negative for some may be positive for others. Mathematical methods, algorithms, formulas, and all the technical, scientific tools serve as support so that, from a human perspective, whether individual or as a group, the best decision can be made. The tool used should apply computational effort to support decisions without ever neglecting human interests. The mechanism that ensures that human desire overrides the coldness of calculations is the subjective imposition of the relative importance weighting of the criteria associated with the direction of maximizing or minimizing the performance rating of each option under analysis determined based on the evaluated criteria.

In this new set of weights, in addition to the decrease in the relative importance of the price of the mobile device, the decision-maker also considers the battery performance, memory, and data storage capacity as important. The quantity of processors and SIM cards, on the other hand, is considered less important. A reasonable explanation for these decisions could be, for example, the lack of intention to use the smartphone for gaming, making higher processing power less relevant. As for SIM cards, there may not be an immediate intention to use two (or more) phone numbers, but since it could become a future necessity, the criterion, although considered of low relative importance, should not be excluded from the set of criteria.

Now, simply execute some steps again using the new metadata configuration. The first observation, as evidenced by Figure 18, is the elimination of some options from the shortlist and changes in the ranking, which is now much less sensitive to price compared to other technical criteria.

Now, just as it was performed previously, we will alter the rating of lambda to observe the changes in the ranking derived from the sensitivity of the set of options in relation to the percentage weight assigned to the underlying WSM and WPM methods, as proposed by the WASPAS method.

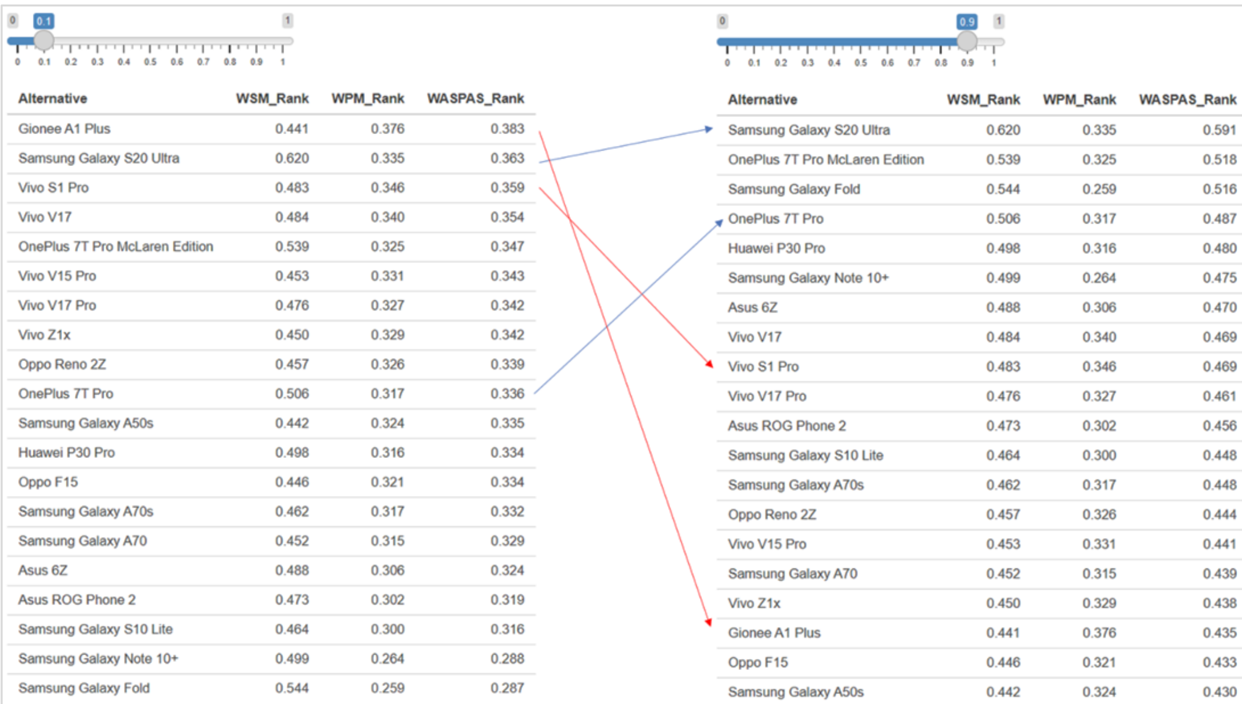


Alternative	WSM_Rank	WPM_Rank	WASPAS_Rank
Gionee A1 Plus	0.503	0.435	0.469
Samsung Galaxy S20 Ultra	0.627	0.275	0.451
Lyf Water 7	0.531	0.364	0.448
Vivo S1 Pro	0.504	0.318	0.411
OnePlus 7T Pro McLaren Edition	0.547	0.272	0.410
Vivo V17	0.505	0.311	0.408
Asus 6Z	0.512	0.282	0.397
Vivo V17 Pro	0.499	0.296	0.397
OnePlus 7T Pro	0.521	0.269	0.395
Vivo V15 Pro	0.480	0.308	0.394
Vivo Z1x	0.478	0.310	0.394
Redmi Note 8 Pro	0.475	0.307	0.391
Poco X2	0.477	0.300	0.389
Huawei P30 Pro	0.511	0.266	0.389
Samsung Galaxy A50s	0.471	0.305	0.388
Samsung Galaxy A70	0.482	0.292	0.387
Oppo F15	0.472	0.298	0.385
Realme X2	0.473	0.294	0.383
Motorola One Vision	0.457	0.309	0.383
Samsung Galaxy A70s	0.479	0.283	0.381

Alternative	WSM_Rank	WPM_Rank	WASPAS_Rank
Samsung Galaxy S20 Ultra	0.620	0.335	0.477
OnePlus 7T Pro McLaren Edition	0.539	0.325	0.432
Vivo S1 Pro	0.483	0.346	0.414
Vivo V17	0.484	0.340	0.412
OnePlus 7T Pro	0.506	0.317	0.411
Gionee A1 Plus	0.441	0.376	0.409
Huawei P30 Pro	0.498	0.316	0.407
Vivo V17 Pro	0.476	0.327	0.402
Samsung Galaxy Fold	0.544	0.259	0.401
Asus 6Z	0.488	0.306	0.397
Vivo V15 Pro	0.453	0.331	0.392
Oppo Reno 2Z	0.457	0.326	0.391
Vivo Z1x	0.450	0.329	0.390
Samsung Galaxy A70s	0.462	0.317	0.390
Asus ROG Phone 2	0.473	0.302	0.388
Samsung Galaxy A70	0.452	0.315	0.384
Oppo F15	0.446	0.321	0.384
Samsung Galaxy A50s	0.442	0.324	0.383
Samsung Galaxy S10 Lite	0.464	0.300	0.382
Samsung Galaxy Note 10+	0.499	0.264	0.381

Figure 18. Extreme changes were observed in the ranking, fixing the lambda in 0.5.

Once again, we observe a noticeable alteration due to the weighting of the underlying methods, as demonstrated in Figure 19. This leads us to believe that the prices of the products composing the set of alternatives exhibit a significant internal discrepancy, suggesting a parallel analysis of this criterion. We then conducted a parallel analysis and found the following results: The maximum price rating is 35,423% higher than the minimum, the average is 11,466, and the standard deviation is high at 13,852.



Alternative	WSM_Rank	WPM_Rank	WASPAS_Rank
Gionee A1 Plus	0.441	0.376	0.383
Samsung Galaxy S20 Ultra	0.620	0.335	0.363
Vivo S1 Pro	0.483	0.346	0.359
Vivo V17	0.484	0.340	0.354
OnePlus 7T Pro McLaren Edition	0.539	0.325	0.347
Vivo V15 Pro	0.453	0.331	0.343
Vivo V17 Pro	0.476	0.327	0.342
Vivo Z1x	0.450	0.329	0.342
Oppo Reno 2Z	0.457	0.326	0.339
OnePlus 7T Pro	0.506	0.317	0.336
Samsung Galaxy A50s	0.442	0.324	0.335
Huawei P30 Pro	0.498	0.316	0.334
Oppo F15	0.446	0.321	0.334
Samsung Galaxy A70s	0.462	0.317	0.332
Samsung Galaxy A70	0.452	0.315	0.329
Asus 6Z	0.488	0.306	0.324
Asus ROG Phone 2	0.473	0.302	0.319
Samsung Galaxy S10 Lite	0.464	0.300	0.316
Samsung Galaxy Note 10+	0.499	0.264	0.288
Samsung Galaxy Fold	0.544	0.259	0.287

Alternative	WSM_Rank	WPM_Rank	WASPAS_Rank
Samsung Galaxy S20 Ultra	0.620	0.335	0.591
OnePlus 7T Pro McLaren Edition	0.539	0.325	0.518
Samsung Galaxy Fold	0.544	0.259	0.516
OnePlus 7T Pro	0.506	0.317	0.487
Huawei P30 Pro	0.498	0.316	0.480
Samsung Galaxy Note 10+	0.499	0.264	0.475
Asus 6Z	0.488	0.306	0.470
Vivo V17	0.484	0.340	0.469
Vivo S1 Pro	0.483	0.346	0.469
Vivo V17 Pro	0.476	0.327	0.461
Asus ROG Phone 2	0.473	0.302	0.456
Samsung Galaxy S10 Lite	0.464	0.300	0.448
Samsung Galaxy A70s	0.462	0.317	0.448
Oppo Reno 2Z	0.457	0.326	0.444
Vivo V15 Pro	0.453	0.331	0.441
Samsung Galaxy A70	0.452	0.315	0.439
Vivo Z1x	0.450	0.329	0.438
Gionee A1 Plus	0.441	0.376	0.435
Oppo F15	0.446	0.321	0.433
Samsung Galaxy A50s	0.442	0.324	0.430

Figure 19. Extreme changes were observed in the ranking, fixing the lambda in 0.5.

We also observed that the options with extreme ratings are the ones that appear most frequently on the shortlist. This certainly occurs because these options with very high prices have extremely high technical criteria, resulting in a set of options that are radically opposite. There is no technical issue in this aspect, and it is still very important that the purpose of the presented case study is to demonstrate the power of the tool offered to the public, which has already been demonstrated at this point.

Therefore, the subsequent operations serve only a more didactic purpose in relation to the discipline of OR. Then, we performed a summary cut of the devices with prices above 10,000 and below 5000 monetary units. As a result, the original set of 1359 alternatives (see Figure 19) was reduced to a subset of 524 alternatives, representing a volume reduction of over 60%.

So, a flat cut-off of devices with prices above 10,000 and below 5000 monetary units was made. As a result, the original set of 1359 alternatives was reduced to a subset of 524 alternatives, representing a volume reduction of over 60%.

This seems like a fair and more meticulous contention. It is important to remember that the imposition of constraints is often one of the steps in OR processes. To enhance the ongoing decision-making process, we have implemented a revision in the weighting of criteria, and the new setup can be seen in Table 3.

Table 3. Weighting criteria that drastically reduce the importance of the price criterion.

Flags	Weights	Criteria
Benefit	0.10	Battery capacity (mAh)
Cost	0.05	Screen size
Benefit	0.10	Resolution X
Benefit	0.10	Resolution Y
Benefit	0.07	Processors
Benefit	0.14	RAM (MB)
Benefit	0.14	Internal storage (GB)
Benefit	0.10	Rear camera
Benefit	0.10	Front camera
Benefit	0.05	Number of SIMs
Cost	0.05	Price

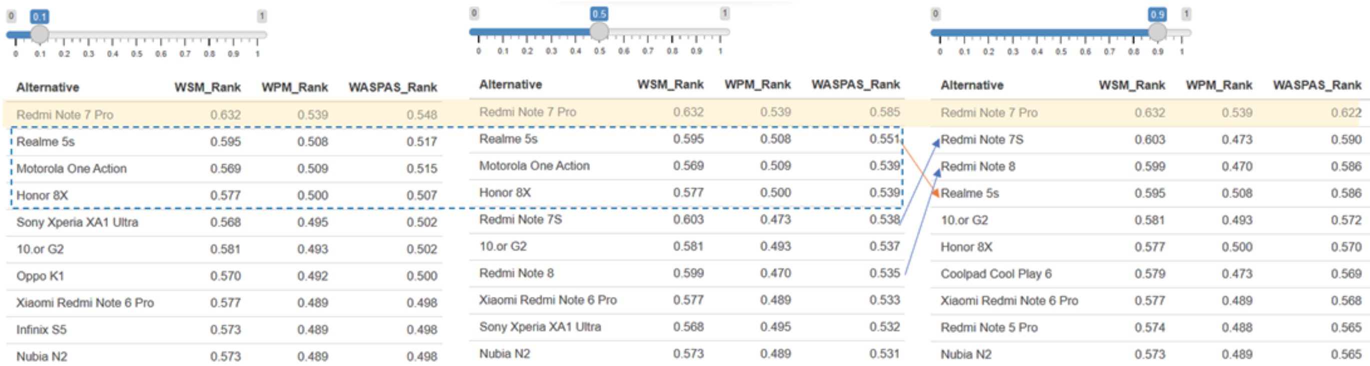
In this configuration, the weight of the price criterion has been reduced, and it has been redistributed to other criteria.

So, we applied a price restriction based on a spending ceiling and a purchasing budget theory, and also considering that very cheap devices probably will not have technically advanced features with good performance and could compromise the shortlist due to their extremely low price. It would be more appropriate to apply restrictions to each of the criteria, but the most important within the scope of this work, as mentioned earlier, is to present the public decision support tool based on WASPAS, as well as the development process and the contributions to society derived from this research.

Now we have a winner. It can be observed in Figure 20 that even when moving lambda between its extreme rating, the top-ranked option remains unchanged.

It is also observed that for lambda ratings between a weight of 90% for the underlying WPM method (lambda = 0.1) and an equal weighting between the two methods (WSM and WPM), the top four rankings remain unchanged. The alteration of this “elite group” is only observed when we apply a lambda rating close to 1 (in the example of Figure 20, lambda = 0.9).

The waspasWEB public service also offers a radar graph view, in which the lambda rating is also dynamically applied, and immediate visualization of the WASPAS (green), WSM (black), and WPM (red) ranking lines is obtained. The radar charts, also known as spider web charts or Kiviat diagrams, are shown in Figure 21.



Alternative	WSM_Rank	WPM_Rank	WASPAS_Rank
Redmi Note 7 Pro	0.632	0.539	0.548
Realme 5s	0.595	0.508	0.517
Motorola One Action	0.569	0.509	0.515
Honor 8X	0.577	0.500	0.507
Sony Xperia XA1 Ultra	0.568	0.495	0.502
10.or G2	0.581	0.493	0.502
Oppo K1	0.570	0.492	0.500
Xiaomi Redmi Note 6 Pro	0.577	0.489	0.498
Infinix S5	0.573	0.489	0.498
Nubia N2	0.573	0.489	0.498

Alternative	WSM_Rank	WPM_Rank	WASPAS_Rank
Redmi Note 7 Pro	0.632	0.539	0.585
Realme 5s	0.595	0.508	0.551
Motorola One Action	0.569	0.509	0.539
Honor 8X	0.577	0.500	0.539
Redmi Note 7S	0.603	0.473	0.538
10.or G2	0.581	0.493	0.537
Redmi Note 8	0.599	0.470	0.535
Xiaomi Redmi Note 6 Pro	0.577	0.489	0.533
Sony Xperia XA1 Ultra	0.568	0.495	0.532
Nubia N2	0.573	0.489	0.531

Alternative	WSM_Rank	WPM_Rank	WASPAS_Rank
Redmi Note 7 Pro	0.632	0.539	0.622
Redmi Note 7S	0.603	0.473	0.590
Redmi Note 8	0.599	0.470	0.586
Realme 5s	0.595	0.508	0.586
10.or G2	0.581	0.493	0.572
Honor 8X	0.577	0.500	0.570
Coolpad Cool Play 6	0.579	0.473	0.569
Xiaomi Redmi Note 6 Pro	0.577	0.489	0.568
Redmi Note 5 Pro	0.574	0.488	0.565
Nubia N2	0.573	0.489	0.565

Figure 20. The winning option remains unchanged.

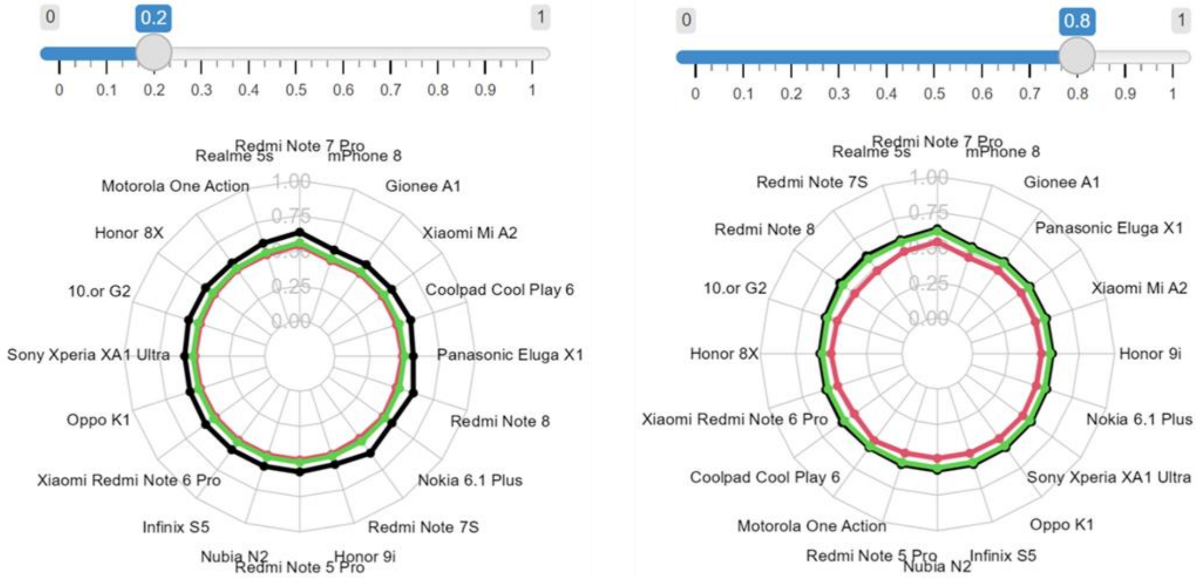


Figure 21. Spider chart is a functionality available in the waspasWEB service.

The spider chart available in the WASPASWEB service presents a green line representing the ranking distribution by the WASPAS method, a black line shows the distribution by the WSM (sum) method, and a red line represents the ranking by the WPM (product) method. By moving the slider and dynamically applying a different rating for the lambda, the WASPAS result (green line) can be observed moving between complete overlap with the red line (WPM) when lambda is equal to zero and expanding until it completely overlaps with the black line (WSM) for lambda equal to 1.

In Figure 21, it is evident that the green line is very close to the red line for a lambda rating of 0.2, and it is very close to the black line for a lambda equal to 0.8. In Figure 22, the line derived from WASPAS for equal weighting between WSM and WPM (lambda = 0.5) is positioned in the middle of the two lines.

In Figure 22, it is evident that the green line is very close to the red line for a lambda rating of 0.2, and it is very close to the black line for a lambda equal to 0.8.

As presented, the proposed computational model works as an aid in the implementation of WASPAS methodology, performing the aggregation of numerical preferences through numerical and graphical resources, helping the clarity of results transparently. The numerical example used in this study works just as an aid in the understanding of the interactivity of the internet-based platform, and the implementation of different case studies with different levels of complexity in operational, tactical, and strategical environments is possible.

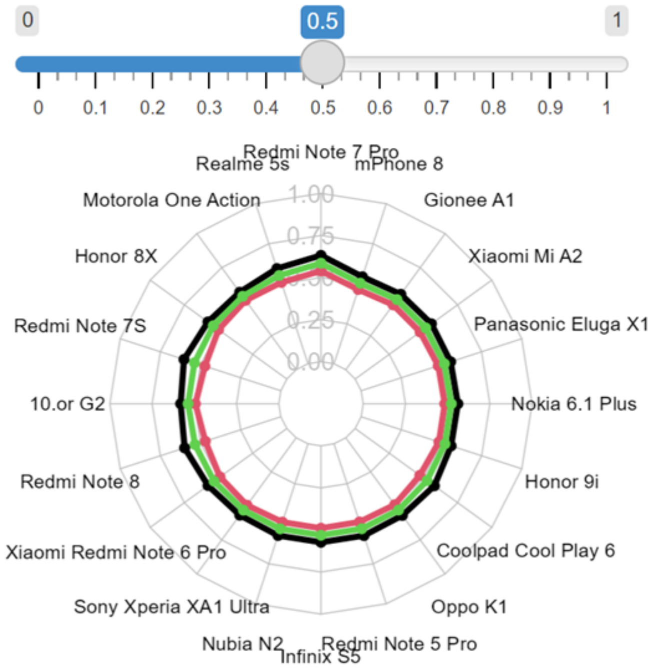


Figure 22. Spider chart is a functionality available in the waspasWEB service.

5. Discussion

The primary focus of this work was to obtain practical results and apply the authors' knowledge in the development of tangible products [46]. Although the contributions may be modest, they serve as a valuable resource for the community [47]. The website created during this work serves as a useful tool for professionals in the field of OR and individuals seeking to make informed decisions based on reliable mathematical models without the need for complex calculations or software implementations [48].

As questions of limitations to the proposed model, we identify the need for an axiomatic understanding of the mathematical model to enable its correct and satisfactory application. The software is limited to the implementation of the WASPAS multi-criteria method.

Regarding the source code complexity perspective, all the necessity of computational programming is transcribed into an internet-based platform, where there is no necessity for coding by the user, as is presented in some computational models [37,49], being just necessary for the alignment of the problematic situation to the WASPAS methodology and basic knowledge to interactive computational platforms, where on the website, is possible to understand all software functionalities through a manual guide to support the users.

A computational model needs to be constantly updated and technically adapted. For future research, we seek to increase the computational model and practical application in different case studies, clarifying the limitations of the mathematical model, thus continuing the research regarding the development of new axiomatic techniques that can incorporate the base method and thus provide improvements and new possibilities to the present computational model.

6. Conclusions

The present study was based on presenting a computational interactive web model as support in the decision-making process through the implementation of the WASPAS method, built under the multi-criteria decision support approach.

The WASPAS method is a flexible approach and can be adapted to different types of problems and scenarios. However, it is important to remember that it depends on the accuracy of the weights and ratings assigned to the criteria and alternatives, which can be difficult to obtain in some situations. Furthermore, the WASPAS methodology can be mathematically demanding for problems with many alternatives or criteria being necessary for the computation support.

The computation proposed framework presents an interactive approach concerning the user, enabling the implementation of the mathematical model along with the performance of sensitivity analysis in the changing of the weights and thresholds of the methodology. As a form of future studies, we search for the integration of a module for open format exportation of the provided calculations and their results, along with the chart exportation by vectorial graphics, with high-quality images. Also, we consider the implementation of the model in other case studies framed in the specifications of the method, providing not only the resolution of these but also the identification of improvement points for greater robustness in the method and computational model.

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