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RESEARCH PAPER

Integrating fuzzy-MCDM methods to select project portfolios under uncertainty: the case of a pharmaceutical company

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ABSTRACT

Goal: The present work aims to improve the project portfolio selection processes under uncertainty of pharmaceutical companies by integrating two Multicriteria Decision Making (MCDM) methods in a fuzzy environment: the AHP and the VIKOR methods.

Design / Methodology / Approach: We employed normative axiomatic modeling as the methodology for our work. The MCDM are subjective methods representing decision-makers preferences and assisting the project portfolio selection process. Thus, the model is founded on integrating the fuzzy-AHP and fuzzy-VIKOR methods; the first one determines the importance of the company's strategy and the second for elaborating the project ranking. We validated this methodology in a Brazilian subsidiary of one of the biggest pharmaceutical enterprises worldwide.

Results: The developed model considers the evaluators' scores' indecision, enhancing the project portfolio selection process and optimizing its decision-making.

Limitations of the investigation: The proposed method does not verify the correlation, interdependence, or cannibalization between the criteria and the projects, which are common limitations to MCDM subjective approaches. In addition, resource constraints are not considered and scheduling routines.

Practical implications: The pharmaceutical market is heated by the increase in life expectancy, greater access to medications, and the most recurrent disease outbreaks, resulting in greater competitiveness, increasing the need for companies to seek greater strategic projects selection efficiency.

Originality / Value: A well-structured and assertive project portfolio selection becomes extremely important for the pharmaceutical market to keep the company competitive in the market, which explains the importance of this work.

Keywords: AHP; VIKOR; Fuzzy; MCDM; Pharmaceutical Industry; PPS.

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1 INTRODUCTION

The intense investment in Research and Development (R&D), high turnover rates, and indisputable social importance are factors that distinguish the pharmaceutical market (Shinzato et al., 2015). Project-driven companies that rely on this market must implement and develop new processes and products to ensure competitiveness and a stable share of sales (Souza et al., 2020). The number of new medicines and vaccines has grown over the years due to technology accelerations and the intense investments in R&D that aim to generate innovative treatments for well-known diseases and conditions. However, new pathogens may also emerge, resulting in an unexpected pharmaceutical race. For example, the worldwide public health crisis as the pandemic of COVID-19. The pandemic increased worldwide medical demand and a social outcry for vaccines (Romano et al., 2021).

Notwithstanding the increased and intensified investments in R&D by global pharmaceutical companies (Machado, 2013), and the reduced development cycles significantly (DePaula, 2007), comparing the number of drugs launched to the ones under development, the numbers become insignificant. Also, the number of drugs launched becomes insignificant compared to the number of drugs still under development, and the number of well-successful COVID-19 vaccines may not give us an accurate picture of the pharmaceutical segment. For example, although the number of drugs launched increased 74% from 2010 to 2018, in 2018, only 61 drugs were launched compared to 15,627 products under development, which is less than 0.4% of the drugs under development reached the market (Lloyd and Shimmings, 2018).

The leading causes for such a discrepancy between drugs understudy and approved are stricter legal and technical regulations concerning product quality and pricing, making the approval and launch processes slower. The approval of a drug may take over 15 years, being 3 to 6 years of R&D and Pre-clinic, 6 to 7 years of Clinical tests, 0.5 to 2 years of Analyze and Record, and many years of post-marketing studies. Compared to the other markets, the pharmaceutical market is noticeably longer. It explains this sector's high pricing and billing due to a prolonged period without positive cash flow (Shinzato et al., 2015).

Pharmaceutical companies spend large amounts of money that will not recover, given the low approval rate. However, despite the high investments exposed, the pharmaceutical market expands due to increased life expectancy worldwide and new players' entrance. The entry of nations like China, Brazil, and India in the pharmaceutical market and the growth in access to medicines estimate that, by 2023, the pharmaceutical market will exceed US$ 1.5 trillion. Linked to this factor, the incentive for developing this market in “pharmerging countries” (emerging countries in the pharmaceutical market) occurs by strengthening government programs, which finance the purchase and distribute high value-added drugs, facilitating the population's access to such drugs. Brazil fits into the group of pharmerging countries and has a high incentive for government programs, such as the Generic Medicines Law and the Patent Law (Aitken et al., 2019).

The pharmaceutical market follows the Blockbuster model, although heated and expanding. This market structure, continuously exploring the most profitable product and mainly aimed at diseases of considerable severity and high incidence makes the R&D process highly strategic. Furthermore, the competition between these companies occurs due to the efficiency in introducing new products (Shinzato et al., 2015). Therefore, a well-structured and assertive project portfolio selection (PPS) becomes extremely important for the pharmaceutical market to keep competitive. In this context, in times of resource contingency, prioritizing the enterprise's strategically critical projects, analyzing the previously established strategic goals, and the accomplishment of ongoing projects are the project portfolio management (PPM) purposes (Agápito et al., 2019).

Through a literature investigation, the research gap of this study is how to make the PPS in an uncertain pharmaceutical market environment, using an MCDM hybrid approach. This approach comprises fuzzy-AHP and fuzzy-VIKOR methods. For illustration, Agápito et al. (2019) examined the context of PPS using the fuzzy-AHP Method but in the public management sector. However, as we present in the subsection "Related works," we did not identify any research that used this hybrid MCDM approach in the pharmaceutical market.

As aforementioned, the present work aims to improve pharmaceutical companies' PPS process by incorporating AHP and VIKOR methods making the decision-making process sturdy. The fuzzy-AHP Method is relevant for fixing each criterion's influence on the company's strategy company, and the VIKOR method for determining the ranking of decision making. Further, together with the decision-makers of one pharmaceutical company through normative axiomatic modeling, we propose determining the relevance of each criterion for the company's strategy and gathering all the qualitative information from all the company's projects. Then, we aim to generate the criteria weights with the data collected and list the best projects using a spreadsheet developed in Excel software. We implemented the fuzzy-AHP Method, associated with the fuzzy-VIKOR Method, to make even comparisons between the criteria, which allows the determination of each criterion's influence on each situation's need. Also, we developed a more reliable ranking of priorities by comparing three different scores to determine the closest alternative to the ideal.

Thus, we organized this paper into five sections. The second section presents the context of project portfolio management (PPM), project portfolio selection (PPS), and multi-criterion support methods for decision making (MCDM). The third section exposes the practice of fuzzy-AHP and fuzzy-VIKOR. The fourth section observes the results, and the fifth this paper is presumed with the final considerations.

2 LITERATURE REVIEW

Project portfolio management and selection

A project portfolio is a collection of projects, programs, and sub-portfolios controlled by a group to accomplish the organization's strategic objectives (Agápito et al., 2019; Graves and Ringuest, 1992; Liberatore, 1993; Project Management Institute, 2017; Souza et al., 2020).

A project portfolio $p \subseteq X$ comprises the division of the m project propositions $X = \{x^1, x^2, \ldots, x^m\}$, through all potential portfolios symbolized by the energy set $P = 2^X$. The decision-makers assess the m submissions according to n criteria $i = 1, 2, \ldots n$ and the accomplishment of one-to-one project x_j on criterion i, say v_i, is represented by v_i^j. Equation 1 states the general weight of the project x^j (Liesiö et al., 2008; Souza et al., 2020; Tervonen et al., 2017).

$$V\left(x^j\right) = \sum_{i=1}^{n} w_i v_i^j \tag{1}$$

Choosing of one project over others is straight linked to its entire value, with w_i quantifying the i^{th} criterion's comparative standing. The decision-makers should estimate all weights $w = \{w_1, w_2, \ldots, w_n\}$ T in a way that $w \in W = \left\{ w \in \mathbb{R}^n \mid w_i \geq 0, \sum_{i=1}^{n} w_i = 1 \right\}$. With consistent and accurate w criteria importance, the most suitable portfolio is the one that maximizes the portfolio's broad assessment. For example, as shown in Equation 2, the following additive-linear function can capture all the general significances of its projects.

$$max_{p \in P} V\left(p, w, v\right) = max_{z(p)} \left\{ \sum_{x^j \in p} \sum_{i=1}^{n} w_i v_i^j = z\left(p\right)^T vw \right\} \tag{2}$$

Where $z(\bullet)$ is a bijection $z: P \rightarrow \{0,1\}^m$, we forsake the project submission when $z_j(p) = 0 \, if \, x^j \notin p$ and took when $z_j(p) = 1 \, if \, x^j \notin p$.

Nevertheless, the simplistic term of additive weighting may not describe variations between criteria or connections and interactions. Its components, or projects, can be independent or dependent on each other, having, or not, shared goals. However, the portfolio shares resource components, both monetary and human, which need to be carefully analyzed to achieve a balanced portfolio. PPM is a sub-area of project management that has tools capable of centralizing the management of a set of projects (Project Management Institute, 2017).

PPM visualizes a company's project portfolio to prioritize the projects that comprise it and facilitate the insertion and removal of projects, one of the most critical tasks in portfolio management (De Reyck et al., 2005). One of PPM's central elements is the Project Portfolio Selection (PPS) process.

PPS is a complex process strictly related to comparing a range of projects, considering mainly the relationship of each project with the company's objective (Archer and Ghasemzadeh, 1999; Tavana et al., 2015a). The complexity of PPS results from multiple and conflicting objectives, the uncertainty of data, market, and technology and global dynamics, risks, many viable portfolios, and the correlation between projects (Bhattacharyya et al., 2011; Oliveira and Rabechini Junior, 2017).

In order to minimize these conflicting objectives in the selection, a process encompassing projects to selection techniques is used and holds three stages: strategic events, specific evaluation of projects, and portfolio selection. The first activity aims to establish a strategic focus and a budget for the portfolio to reduce uncertainties and risks. The second analyzes the projects independently, while in the third stage, each project's parameters, together with the correlation between them, are considered to select the best portfolio. The last is the several methods and techniques developed to select portfolios and prioritize projects (Archer and Ghasemzadeh, 1999).

Within the wide range of methods studied and developed, some types stand out, including scoring methods, economical methods (e.g., payback method, net present value, internal rate return), mathematical programming, accurate options analysis, simulation modeling, heuristics methods, multi-criteria decision support methods, and hybrid methods (Iamratanakul et al., 2008; Silva et al., 2007). This article chose multi-criteria decision support methods for selecting a project portfolio.

Related works

In this subsection, based on the literature review made in Scopus® and Web of Science®, we present the researches regarding the decision-making process in the pharmaceutical enterprise. In this context, the most common studies in the pharmaceutical market were supplier selection. Ganguly et al. (2019) made a framework to analyzed and evaluated supplier selection in the pharmaceutical sector using fuzzy-AHP. Badi and Ballem (2018) selected the best medical suppliers through an MCDM analysis applying modified BWM (Best-Worst method) and MAIRCA (Multi-Attribute Ideal-Real Comparative Analysis) methods. In addition, the model was tested and verified through a case study in pharmaceutical supply in Libya. Subse, Gao et al. (2020) combined the conventional VIKOR model with q-RIVOFS to develop the q-rung interval-valued orthopair fuzzy-VIKOR model. After that, they verified the model's effectiveness using supplier selection of medical consumer products and demonstrated the Method's superiority through comparative analysis.

Santos et al. (2017) presented a segmentation model competent of aggregating quantitative and qualitative criteria. They applied the AHP approach to set the comparative importance of each criterion. Fuzzy 2-tuple, prominent computing with word (CWW) method, was utilized to assess suppliers with a composite of recorded quantitative and qualitative data. Finally, they illustratively applied the proposed model in a teaching hospital's pharmaceutical supply base. Yousefi et al. (2017) identified the vital success factors of new product development in the pharmaceutical companies later prioritized them using the AHP traditional approach. Kumar et al. (2019) identified the potential risks in adopting green supply chain (GSC) initiatives in the pharmaceutical sector. They used a literature review and fuzzy-Delphi approach (expert input) to finalize the risks and a fuzzy-AHP to prioritize them.

Tavana et al. (2015b) presented a hybrid fuzzy MDCM to measure the pharmaceutical industry's performance according to the balanced scorecard (BSC) perspectives. First, they determined the interdependencies among the BSC perspectives using the DEMATEL method and the criteria's relative importance using a fuzzy-ANP. Then, they calculated the efficiency scores of the decision-making units (DMUs) using fuzzy-DEA, and finally, they ranked the DMUs using Spearman Test and Shannon's Entropy.

Tabrizi et al. (2016) applied a combined MCDM framework to deal with the PPS uncertainty, composed of fuzzy-DEMATEL and a tailored multi-choice goal programming model. In addition, they conducted a case study in a large pharmaceutical enterprise in Iran to test the model's applicability.

These are the studies related to this research. However, we did not find any research of PPS and MCDM using a hybrid approach of the fuzzy-AHP and fuzzy-VIKOR Method, confirming this research's originality.

The following section shows the methodology of this research and the steps for solving the proposed hybrid MCDM approach.

3 METHODOLOGY

Conceptual framework

We developed the model proposed in conjunction with the studied company's PPM team. The team formed is composed of three principal head managers specialized in the company. In Figure 1, there is a flowchart that represents the structure of the model designed. The Method starts with the company team defining the business opportunities. After that, the next step is to identify a range of appropriate project alternatives.

Further, through meetings with the company's PPM team, we defined the criteria based on the strategy and objectives of the organization. Forthwith starts the fuzzy-AHP Method, described in the following subsection. Then, we created the structure of the decision hierarchy and submitted it to the company's PPM team. After the approval, we establish the fuzzy-AHP pairwise comparison matrix with the company's PPM team. With this synthesis of judgments of multiple decision-makers, it was possible to compute the fuzzy-AHP criteria weights. Finally, we analyzed the consistency using the traditional AHP method in the next step.

With the consisted fuzzy weight decision criteria, we started the fuzzy-VIKOR method as follow, and the decision-makers make only the first step the researchers make the other:

- Define the matrix of variables for each project.
- Define the best and worst values for each variable and project.
- Calculate the parameters of the difference of qualitative variables for each project.
- Calculate the maximum utility group and the minimum individual weight (Sj and Rj).
- Transform the parameter used to calculate Qi's score or the fuzzy-VIKOR method's last score.

The next step, for the construction of the ranking and the analysis of data reliability, the scores need to be in a crisp format by a defuzzification process. So, we did a defuzzification of scores calculated using the CFCS method (Converting Fuzzy Data into Crisp Score). Finally, we verified and validated the fuzzy-VIKOR Method with the condition test presented in the subsection defuzzification and conditions to verify the method VIKOR. If the conditions are not satisfied, we need to go back and reanalyze the matrix of variables of each project together with the decision-makers. Then, restarting the VIKOR method as shown in Figure 1.

Fuzzy-AHP Method

The fuzzy set theory negotiates with real-world issues underneath doubtful and ambiguous situations. The fuzzy set hypothesis's implications deal with inaccurate information and address the ambiguities of multi-criterion decision-making situations founded on personnel judgments. (Goswami et al., 2020; Liu et al., 2020; Saaty, 1987).

A fuzzy number is a particular fuzzy set of discourse universe U characterized by a membership function, which takes the unit interval values [0,1], as shown in Equation 3.

It is an extension of classical set theory, and the operations themselves are extensions of the complementary operations of the fundamental set theory.

$$\mu_A : U \rightarrow [0,1] \tag{3}$$

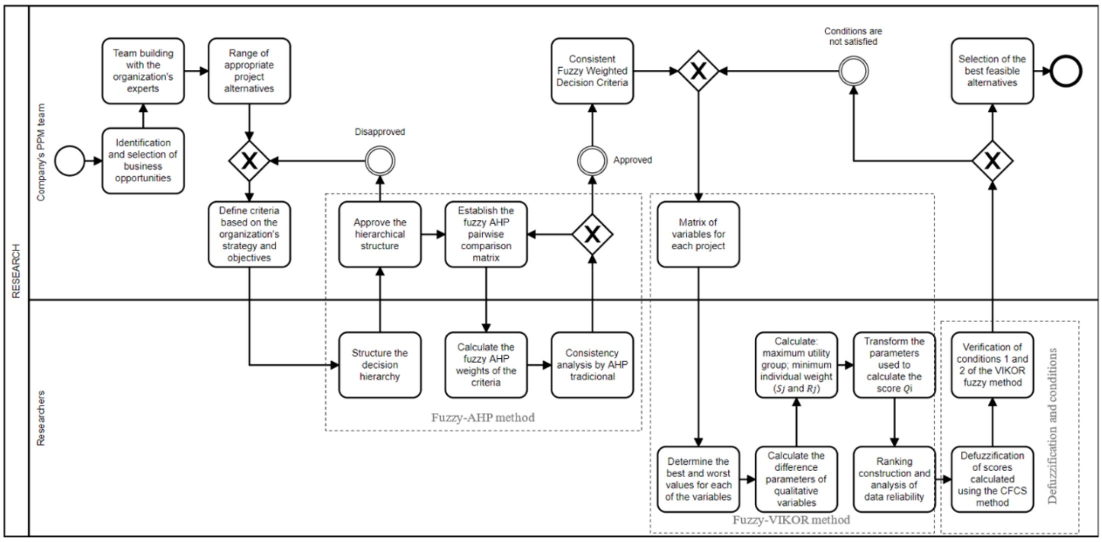

Figure 1 – The structure of the model designed.

Triangular fuzzy number (TFN) is the most popular means of judgment representation (Liu et al., 2020) and the most common in MCDM-based R&D PPS applications (Mohammady and Amid, 2011; Souza et al., 2020). Figure 2 illustrates the TFN membership function.

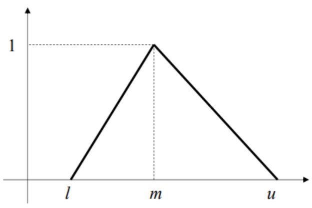

Figure 2 – Triangular membership function

Equation 4 defines TFN by a lower limit (), a median value (), and an upper limit (), where:

$$\mu_A(X) = \begin{cases} 0, & x \leq l \\ \dfrac{x-l}{m-l}, & l < x \leq m \\ \dfrac{x-u}{m-u}, & m < x \leq u \\ 1, & x \geq u \end{cases} \tag{4}$$

According to the Method, it is necessary to decompose the problem in a hierarchy, including goal, criteria, sub-criteria, and alternatives. However, a hierarchical structure of the AHP will not necessarily have all levels present, varying according to the project or problem that requires it (Liu et al., 2020; Saaty, 1987). The company's PPM team must approve this hierarchical structure. Following the approval, we develop a square matrix composed of pairwise comparisons from the Saaty scale, the first stage for applying the AHP method. In this matrix, we investigated one term's dominance over another (Al-Harbi, 1999). To establish the pairwise comparison judgments for criteria for l decision-makers. Let n be the number of criteria considered in the problem. The comparison matrix for each decision-maker, $C^k(nxn)$ contains the comparison values between every pair of criteria. We use the Fundamental Scale of Saaty (Saaty, 1987) for the best accuracy of comparing the criteria. Figure 3 shows the fundamental scale of AHP used.

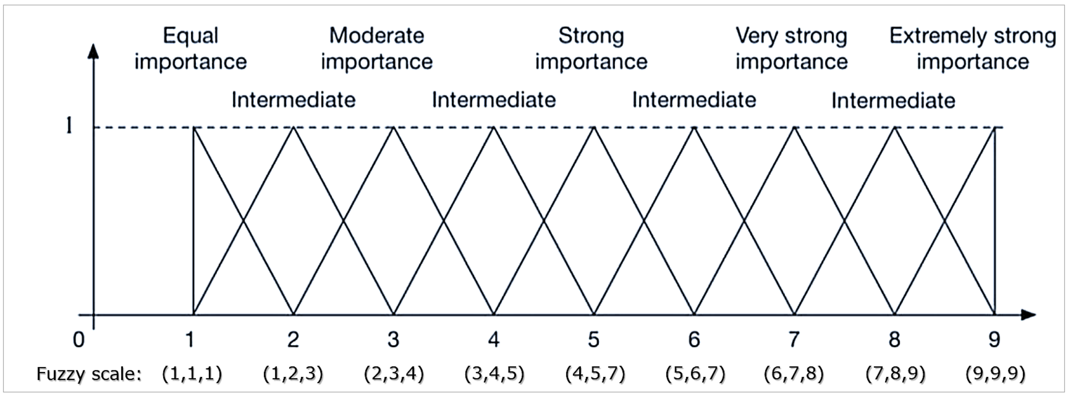

Figure 3. Fuzzy-AHP ranking significance

In a generic notation, for every matrix where c_{ij} = weight of criterion i related to criterion j, as shown in Equation 5.

$$C = \left[c_{ij}^k\right] = \begin{bmatrix} c_{11}^k & c_{11}^k & \cdots & c_{1j}^k \\ c_{21}^k & c_{22}^k & \cdots & c_{2j}^k \\ \vdots & \vdots & \ddots & \vdots \\ c_{i1}^k & c_{i2}^k & \cdots & c_{ij}^k \end{bmatrix}_{nxn} \tag{5}$$

Now we need to synthesize the judgments of multiple decision-makers. The primary objective of this assemblage is to deliver consistent outcomes from the pairwise comparison matrix. To make that, we need to convert the pairwise comparison matrices C^k into fuzzified pairwise comparison matrices $\tilde{C}^k$, following the power of fuzzy ranking significance given by Figure 2. We use a TFN, where $\tilde{c}_{ij}^k = \left(c_{ij1}^k, c_{ij2}^k, c_{ij3}^k\right)$, and $\tilde{c}_{ji}^k = \left(\frac{1}{c_{ij3}^k}, \frac{1}{c_{ij2}^k}, \frac{1}{c_{ij1}^k}\right)$ if $i \neq j$.

We require to several multiple fuzzy sets in the matrix into a single fuzzy set and calculate the criteria' fuzzy weights. We use the geometric mean Method by assembling the l fuzzified pairwise comparison matrices $\tilde{C}^k$ into an assembled fuzzified pairwise comparison matrix $\tilde{C}$, as shown in Equation 6.

$$\tilde{c}_{ij}^k = \left(\prod_{k=1}^{n} A_k\right) = \left(c_{ij}^1 \otimes c_{ij}^2 \otimes \ldots \otimes c_{ij}^k\right)^{\frac{1}{k}} \tag{6}$$

To calculate the fuzzy weights $\tilde{w}_i$ concerning i^{th} criterion, we use Equation 7 below.

$$\tilde{w}_i = \tilde{c}_{ij} \otimes \left(\tilde{r}_1 \oplus \tilde{r}_2 \oplus \ldots \oplus \tilde{r}_i\right)^{-1} \quad (7)$$

Consistency measurement ensures slight inconsistencies among the pairwise comparisons in the matrix. The matrix is uniform if the contrarieties between paired comparisons are within a predefined brink: consistency ratio. For this, we use Crisp consistency. The Crisp consistency principle is to defuzzify the fuzzy matrix first and then employ the Saaty consistency ratio (CR). A defuzzified matrix with CR smaller than 0.1 is considered to be suitably consistent (Liu et al., 2020). Equations 8 and 9 show how we calculated as follows:

$$CR = \frac{CI}{RI} \quad (8)$$

$$CI = \frac{\left(\lambda \text{max} - \text{n}\right)}{\left(n-1\right)} \quad (9)$$

CI is a consistency index. λ_{max} is the comparison matrix's max eigenvalue, calculated by multiplying the matrix columns' sum by the normalized eigenvector. RI is the randomized consistency index. The weight of RI relies on the matrix's size, as shown in Table 1.

Table 1. Random consistency index RI for n compared

Randomized Consistency Indexes								
n	2	3	4	5	6	7	8	9
RI value	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

After completing the fuzzy-AHP Method, the company team places the PPS for the next step. For this, we use each criteria weight to implement the fuzzy-VIKOR Method.

Fuzzy-VIKOR Method

The VIKOR method (VlseKriterijumska Optimizacija I Kompromisno Resenje), or “Multicriteria Optimization and Compromise Solution,” is a Serbian method designed in 1998 by Opricovic to optimize the classification of complex systems multi-criteria (Opricovic, 1998). According to Opricovic and Tzeng, complex systems usually have conflicting criteria that are unlikely to be solved by a method capable of satisfying them simultaneously (Opricovic and Tzeng, 2004). Therefore, the optimization of multi-criteria classification points to select the most suitable achievable compromise resolution to meet the established criteria, based on the importance of each of them, that is, an arrangement that aims to optimize decision making. Thus, the VIKOR method generates a ranking that seeks to find the ideal closest solution.

The VIKOR method's great advantage is using two weights to consider decision-making. One comes from the criterion, represented by w_i. Moreover, the other comes from the Method itself. This weight considers decision-making based on the group's maximum utility, expressed by the symbol υ, and can vary from 0 to 1, but usually, υ = 0.5 (Tong et al., 2007)

The fuzzy-VIKOR Method uses each criteria weight from fuzzy-AHP to calculate its scores. For this, we have inserted all the quantitative characteristics of the projects. The company experts provided the qualitative characteristics of fuzzy numbers and the quantitative characteristics expressed in crisp numbers founded on the fuzzy-AHP Method's criteria.

The method starts by determining the best and the worst values of every criteria functions represented by f. Then, it is necessary to interpret each variable individually, considering that a variable can have directly or inversely proportional characteristics. Therefore, we considered the variable's highest values in the first case, and the second, the lowest (Rodrigues Junior et al., 2016).

Equations 10 and 11 show how to select the best f_j^* and the worst f_j^- values of every criteria function.

$$f_j^* = \max f_{ij}, f_j^- = min\, f_{ij},\ i = 1,2,\ldots,m, j = 1,2,\ldots,n \tag{10}$$

whether function *jth* should be maximized (benefit) and

$$f_j^* = \min f_{ij}, f_j^- = max\, f_{ij},\ i = 1,2,\ldots,m, j = 1,2,\ldots,n \tag{11}$$

whether function *jth* function should be minimized (cost).

Like the AHP method, it is also possible to use the fuzzy approach in the VIKOR method with some adaptations (Chang, 2014; Zadeh, 1965). Essentially the replacement of the whole numbers used in the equations by fuzzy numbers. Thus, in the first stage, the denomination of each criterion's weight will be given by $w_j = \left(l_j, m_j, u_j\right)$.

Respectively, the best and the worst values we stated as follows $f_j^* = \left(l_j^*, m_j^*, u_j^*\right)$: and $f_j^- = \left(l_j^-, m_j^-, u_j^-\right)$.

The fuzzy-VIKOR Method will be necessary to calculate a new parameter, the difference parameter d_{ij}. Which represents the distance between x_{ij}, the variable value, and the best value of each variable, f_j^* as shown in Equation 12 (Opricovic, 2011).

$$d_{ij} = \frac{\left(f_i^* - x_{ij}\right)}{\left(u_i^* - l_i^-\right)} \tag{12}$$

After calculating this parameter, it is possible to calculate the S_j and R_j scores, represented by the fuzzy numbers $S_j = \left(s_j^l, s_j^m, s_j^u\right)$ and $R_j = \left(r_j^l, r_j^m, r_j^u\right)$, and calculated through the expressions represented by Equations 13 and 14 (Wang and Chang, 2005).

$$S_j = \sum_{i=1}^{n} \left(w_i \otimes d_{ij}\right) \tag{13}$$

$$R_j = max\left(w_i \otimes d_{ij}\right) \tag{14}$$

where S_j is maximum utility group, R_j is the minimum individual weight and w_i is the weight of the jth criterion.

The third step consists of calculating the score Q_j, called the VIKOR index. We will use the parameters $R^* = \left(r^{*l}, r^{*m}, r^{*u}\right)$, $R^- = \left(r^{-l}, r^{-m}, r^{-u}\right)$, $S^* = \left(s^{*l}, s^{*m}, s^{*u}\right)$, $S^- = \left(s^{-l}, s^{-m}, s^{-u}\right)$, to calculate $Q_j = \left(Q_j^l, Q_j^m, Q_j^u\right)$ as shown in Equation 15.

$$Q_j = \upsilon \frac{\left(S_j - S^*\right)}{\left(S^{-u} - S^{*l}\right)} \oplus \left(1-\upsilon\right) \frac{\left(R_j - R^*\right)}{\left(R^{-u} - R^{*l}\right)} \tag{15}$$

Where $S^* = min_i\, S_i$; $S^- = max_i\, S_i$; $R^* = min_i\, R_i$; $R^- = max_i\, R_i$; and υ is a weight for the "majority of criteria" (or "maximum group utility") strategy.

With all the scores calculated, we need to build a project prioritization ranking. For this, the scores need to be in a "crisp format," going through the process of defuzzification (Chang, 2014).

Defuzzification and conditions to verify the Method

With these data, the three scores (S, Q, and R) were defuzzified using the CFCS method, and then three rankings were generated, represented by crisp numbers, one for each score of the fuzzy-VIKOR Method (S, Q, and R). There are several methods used for defuzzification, such as the Maximum Method (MoM), Average Maximum Method (CoM), and Centroid Method (CoA), the latter being the most used to defuzzify (G. C. dos Santos et al., 2014). However, many authors considered the Centroid Method only an approximation because it is not simple to find the center of the area of complex functions; not able to differentiate between two different fuzzy numbers but with the same crisp number; and consequently, not being as accurate.

Besides that, Opricovic and Tzeng developed, in 2003, the CFCS Method (Converting Fuzzy Data into Crisp Score), a method that, through a weighted average that considers the maximum and minimum fuzzy values of each group of numbers, results in a defuzzification more accurately (Karaman and Dagdeviren, 2015). We need to calculate some parameters. First, we consider a set of fuzzy numbers of the format $d_i = \left(d_{i1}, d_{i2}, d_{i3}\right)$, it is required to calculate the lowest value of the left end and the highest value of the right end of the set of fuzzy numbers di, represented by L_D and U_D, denoted by Equations 16 and 17.

$$L_D = \min d_{i1} \tag{16}$$

$$U_D = \max d_{i3} \tag{17}$$

Subsequently, it is necessary to calculate the difference between the highest value on the right end and the lowest value on the left end, represented by Δ_D and calculated by Equation 18.

$$\Delta_D = U_D - L_D \tag{18}$$

With the calculated parameters, the crisp number, represented by D_i can be determined through the expression presented in Equation 19, thus marking the CFCS defuzzification method's end.

$$D_i = L_D + \Delta_D \times \frac{\left(d_{i2} - L_D\right)\left(\Delta_D + d_{i3} - d_{i2}\right)^2 \left(U_D - d_{i1}\right) + \left(d_{i3} - L_D\right)^2 \left(\Delta_D + d_{i2} - d_{i1}\right)^2}{\left(\Delta_D + d_{i2} - d_{i1}\right)\left(\Delta_D + d_{i3} - d_{i2}\right)^2 \left(U_D - d_{i1}\right)\left(d_{i3} - L_D\right)\left(\Delta_D + d_{i2} - d_{i1}\right)^2 \left(\Delta_D + d_{i3} - d_{i2}\right)} \tag{19}$$

The last step of the proposed method consists of analyzing the problem alternatives. Finally, they need to satisfy the two conditions of fuzzy-VIKOR methods, which generated the project's ranking, allowing the portfolio choice aligned with the company's strategy.

The first condition, known as "Acceptable Advantage," consists of evaluating the score Qj of each of the alternatives, and the alternative is only to be accepted if the expression, presented by Equations 20 and 21, is true. In the expression, a' represents the preferable alternative, a'' the alternative immediately afterward, and n, used for calculating DQ, the number of system alternatives (Opricovic and Tzeng, 2004).

$$Q(a'') - Q(a') \geq DQ \tag{20}$$

$$DQ = \frac{1}{(n-1)} \tag{21}$$

According to Opricovic (1998), the second condition, or condition of "Acceptable Stability in Decision Making," is more common when υ = 0.5 and consists of evaluating the two remaining scores, Sj and Rj of each alternative.

Thus, a' will satisfy this condition if the values of Sj and, or Rj are lower than the other alternatives. Furthermore, if one of the conditions is not satisfied, the decision-making must be based on the compromise's solutions set, which will consist of:

- If Condition 2 is not satisfied, A1 and A2 are the preferable alternatives.
- If Condition 1 is not satisfied, a', a'', ..., $a^{(M)}$ can be chosen, and (M) will be calculated by the relationship $Q\left(a^{(M)}\right) - Q(a') < DQ$ for the highest value of (M), in order that the alternatives are as close as possible to each other.

4 RESULTS AND DISCUSSION

For better comprehension, we followed the steps shown in Figure 1, to present the results and discussion in this section.

The proposal's project consists of implementing a new PPS methodology developed within the Business Excellence area, a branch of the company's Supply Chain sector responsible for monitoring and optimizing business performance. The company studied is a multinational pharmaceutical company belonging to an American group. The group is present in more than 150 countries, has more than 35,000 employees worldwide, and started its Brazil activities in 1964. It has a team responsible for PPM and PPS consisted of three members. The Business Excellence Manager with nine years experience, Project Supervisor with six years experience, and New Products Introduction Supervisor with three years experience comprises the Company's PPM team. This team is the evaluators described in Figure 1.

The hierarchical matrix was built with the most relevant criteria for its strategy, using the fuzzy-AHP Method, as shown in Figure 4. The criteria proposed by the company's PPM team experts were:

- Impact on Strategy: for project selection to be effective, it is essential to determine whether the proposed project aligns with its current strategy.
- Investment: this criterion evaluated each project's cost and the impact on the company's available cash. This value represents the cost in that particular year.
- Net Present Value (NPV): this parameter aims to verify the initial value invested versus the present value of the project's projected cash flows.
- Risk: it is crucial to determine the project's risk if not executed to have an effective project selection.

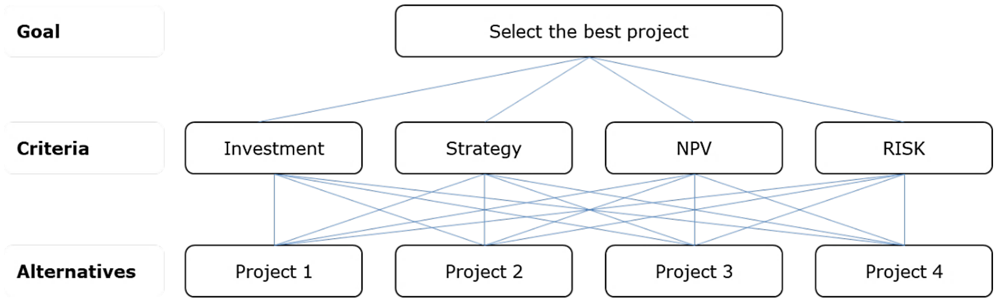

Figure 4 – The hierarchical structure approved.

Modeling

Fuzzy-AHP Method

We organized a conference with the evaluators to select the main criteria of the model. This discussion was structured to define the main decision variables for creating a strategic portfolio for the company. We reviewed the GUT matrix criteria already used to see if they were the most appropriate for the company's current moment during the meetings and discuss the inclusion of unknown variables in the model. After a series of meetings, we defined the criteria as Impact on Strategy, Investment, Present Net Value (NPV), and Risk.

With the defined criteria, we initiated the fuzzy-AHP Method, by which it was possible to select the comparable weights of each criterion. We carried the following steps out for the assignment of weights:

1. The first step is an equal comparison between the four criteria selected using Saaty's (1987) fundamental scale, which ranks relevance on a scale of 1 to 9. Then, using a fuzzy approach method, we describe the specialists' scores by each vector's central value and the ends of the scores considering the degree of fuzzification used ($\delta = 1$), which considers the uncertainty of the evaluations. Thus, it was possible to generate Table 2, which contains the results of each peer comparison.

Table 2. Fuzzy-AHP pairwise comparison matrix

	Investment	Strategy	NPV	Risk
Investment	(1,1,1)	(1/7,1/6,1/5)	(1/9,1/9,1/9)	(1/8,1/7,1/6)
Strategy	(5,6,7)	(1,1,1)	(1/4,1/3,1/2)	(1/3,1/2,1)
NPV	(9,9,9)	(2,3,4)	(1,1,1)	(2,3,4)
Risk	(6,7,8)	(1,2,3)	(1/4,1/3,1/2)	(1,1,1)

2. With the punctuated comparisons, we determined the eigenvector (geometric mean) of each line. Then, with the aid of spreadsheet software, it was possible to calculate the vectors, as shown in Table 3.

Table 3. Model eigenvectors

Criteria	Eigenvector
Investment	(0.211, 0.227, 0.247)
Strategy	(0.803, 1, 1.368)
NPV	(2.449, 3, 3.464)
Risk	(1.107, 1.470, 1.861)

3. In the fuzzy-AHP Method, it is necessary to calculate the sum vector, described by the sum of the eigenvectors represented in Table 3. After that, we must calculate the reciprocal vector, represented by the sum vector's inverse, to establish the defined

criteria' weight. Finally, the ratio between the reciprocal vector and the eigenvectors defines the criteria weight. Table 4 shows the weights.

Table 4. Fuzzy-AHP weight of the criteria

Criteria	Fuzzy Criteria Weight
Investment	(0.030, 0.040, 0.054)
Strategy	(0.116, 0.176, 0.299)
NPV	(0.353, 0.527, 0.758)
Risk	(0.159, 0.258, 0.407)

4. With each criterion's weights already defined, the fuzzy-AHP Method requires consistency analysis to verify that the matrix is consistent. The crisp matrix can perform this analysis using the traditional AHP method. Tables 5 and 6 show the crisp matrix used and the eigenvectors and normalized eigenvectors calculated. Table 7 provides the data for the consistency analysis, showing the results of the λmax, CI, and RC calculations, calculated with the help of the Saaty random index table (Table 1), already presented in section 3. If the consistency ratio (RC) is less than 10%, the comparisons are validated, resulting in the model under study.

Table 5. Crisp Matrix of Model Parity Comparisons

	Investment	Strategy	NPV	Risk
Investment	1	1/6	1/9	1/7
Strategy	6	1	1/3	1/2
NPV	9	3	1	3
Risk	7	2	1/3	1

Table 6. Eigenvectors

Criteria	Eigenvectors	Normalized eigenvectors
Investment	0.227	3.98%
Strategy	1.000	17.55%
NPV	3.000	52.66%
Risk	1.470	25.80%

Table 7 shows the consistency ratio (RC) of 4.90%, validating the AHP traditional consistency analysis comparisons. Finally, we have consistent fuzzy weighted decision criteria, as shown in Table 7.

Table 7. Model Consistency Analysis

Índices	Valores
λmax	4.132
IC	0.044
RC	4.90%

Fuzzy-VIKOR Method

The project management model proposed in this work will use the criteria weights, already defined and validated by the fuzzy-AHP Method, to develop a prioritization ranking using the fuzzy-VIKOR Method. To enable this model's construction, we agreed that the projects to be evaluated would be the company's proposed projects for 2020. However, we do not use the projects' names for confidentiality reasons, only numbered 1 to 24. To conclude the ranking of the studied model, the fuzzy-VIKOR Method will follow the following steps:

1. In the first stage, we elaborated the matrix of variables for each project, which was scored adequately by the company's PPM team, as shown in Table 8. We considered the quantitative variables crisp numbers (fixed real value), while the qualitative variables were studied as fuzzy numbers because they relate to the decision-maker's opinions.

Table 8. Matrix of variables for each project

Projects	Investment	Strategy	NPV	Risk
Project 01	$200,000.00	(9,9,9)	$120,055.10	(1,1,1)
Project 02	$147,000.00	(9,9,9)	$87,869.90	(1,1,1)
Project 03	$147,000.00	(5,6,7)	$98,823.50	(3,4,5)
...				
Project 24	$300,000.00	(9,9,9)	$233,517.10	(1,1,1)

2. With the matrix already built, it is possible to calculate each variable's maximum and minimum values presented in Table 9. We considered the highest value the best for the beneficial criteria while the lowest (worst) for the non-beneficial type criteria. Thus, we will have the Strategy and Risk criteria as beneficial for this model and the NPV and Investment as non-beneficial. Table 9 shows the best and worst values in the matrix, represented by $fi*$ and $fi-$, respectively.

Table 9. Best and Worst Variables

	Investment	Strategy	NPV	Risk
$fi*$	$40,000.00	(9,9,9)	$35,650.60	(9,9,9)
$fi-$	$2,000,000.00	(1,1,1)	$1,112,682.60	(1,1,1)

3. With all the projects evaluated and each criterion's best and worst values defined, we calculated the various parameters, represented by dij, for each Method's qualitative variables: the Strategy and Risk variables. With these parameters determined, we calculated the S score of the criteria used to determine the Sj and Rj scores of the fuzzy-VIKOR Method. These will be calculated by adding each criterion's S parameters and identifying the S scores' maximum value, respectively. The results are in Tables 10 to 13.

Table 10. Calculation of the Difference Parameters

Projects	$d_{STRATEGY}$	d_{RISK}
Project 01	(0,0,0)	(1,1,1)
Project 02	(0,0,0)	(1,1,1)
Project 03	(0.25, 0.375, 0.5)	(0.75, 0.625, 0.5)
...		
Project 24	(0,0,0)	(1,1,1)

Table 11. Calculation of Scores S of Investment Criteria and Strategy

Projects	$S_{INVESTMENT}$	$S_{STRATEGY}$
Project 01	(0.002, 0.003, 0.004)	(0,0,0)
Project 02	(0.002, 0.002, 0.003)	(0,0,0)
Project 03	(0.002, 0.002, 0.003)	(0.029, 0.066, 0.15)
...		
Project 24	(0.004, 0.005, 0.007)	(0,0,0)

Table 12. Calculation of Scores S of the NPV and Risk Criteria

Projects	S_{NPV}	S_{RISK}
Project 01	(0.028, 0.041, 0.059)	(0.159, 0.258, 0.407)
Project 02	(0.017, 0.026, 0.037)	(0.159, 0.258, 0.407)
Project 03	(0.021, 0.031, 0.044)	(0.12, 0.161, 0.204)
...		
Project 24	(0.065, 0.097, 0.139)	(0.159, 0.258, 0.407)

Table 13. Calculation of Scores S_i and R_i

Projects	Score S_i	Score R_i
Project 01	(0.159, 0.258, 0.407)	(0.159, 0.258, 0.407)
Project 02	(0.159, 0.258, 0.407)	(0.159, 0.258, 0.407)
Project 03	(0.12, 0.161, 0.204)	(0.12, 0.161, 0.204)
...		
Project 24	(0.065, 0.097, 0.139)	(0.159, 0.258, 0.407)

4. The calculated S and R scores make it possible to determine both scores' maximum and minimum values, shown in Table 14. This table, $R*$, and $S*$ represent the minimum values and $R-$ and $S-$ each score's maximum values.

Table 14. Maximum and Minimum Values of Scores R and S

Scores	Value
R^*	(0.060, 0.066, 0.150)
$R-$	(0.353, 0.527, 0.758)
$S*$	(0.107, 0.157, 0.239)
$S-$	(0.533, 0.811, 1.201)

5. From this information and the scores calculated in the previous steps, it is possible to calculate the fuzzy-VIKOR Method's last Q score. For this, the group's maximum utility (υ) used for this calculation will be equal to 0.5. Table 15 displayed the Q values.

Table 15. Calculating the Q_i Score

Projects	Score Q_i
Project 01	(-0.016, 0.204, 0.415)
Project 02	(-0.021, 0.196, 0.404)
Project 03	(-0.053, 0.115, 0.237)
...	
Project 24	(0.002, 0.230, 0.453)

6. With all the scores calculated, the next step is to build a project prioritization ranking. For this, the scores need to be in a crisp format. Therefore, as shown in the subsection “Defuzzification and conditions to verify the method,” we performed the scores' defuzzification using the CFCS method, and for that, we calculated some parameters shown in Table 16.

Table 16. Calculation of the CFCS Method Parameters

Parameters	Values
Δ_D	(1.094, 0.698, 1.125)
U_D	(1.201, 0.758, 1)
L_D	(0.107, 0.060, -0.125)

7. Defuzzification can be performed through these parameters, calculating the crisp values for all scores using the CFCS method. Table 17 shows the results of this process. We highlight the lowest values of the three Q scores to analyze the consistency of the Method. According to the fuzzy-VIKOR Method, at least two of the three lowest values of the scores must come from the same project, ensuring its preference. In the present model, the three lowest values belong to the same project, Project 9, indicating the trend of the Method's consistency. In addition, however, the Method needs to satisfy the two conditions, C1 and C2, shown in the subsection “Defuzzification and conditions to verify the method.” Table 18 presents the analyzes of these two conditions.

Table 17. Calculation of Crisp Scores from the fuzzy-VIKOR Method

Projects	Score S_i Crisp	Score R_i Crisp	Score Q_i Crisp	Ranking
Projects 09	**0.163**	**0.073**	**0.008**	**1**
Projects 07	0.239	0.173	0.109	2
Projects 19	0.289	0.149	0.115	3

Table 18. Fuzzy-VIKOR Method Condition Test

CONDITION TESTS		RESULTS
Acceptable Advantage	Q (a”) - Q (a')	0.101
	DQ	0.043
	Q (a”) - Q (a') ≥ DQ	Validated
Acceptable stability in decision making	*SCORE* R (0,073)	Validated
	SCORE S (0,163)	Validated

Both conditions of the fuzzy-VIKOR Method are validated, as we can see in Table 18. Hence, it is possible to continue with the ranking's construction, which will classify the best projects by placing the values of the three scores in ascending order, as shown in Table 18 above.

After completing all the hybrid MCDM method steps proposed, we held some meetings with the company's PPM team to identify the advantages of the studied model compared to the one currently GUT (Gravity, Urgency, and Tendency) Matrix of Kepner and Tregoe (1976) currently used. This tool benefits the objectivity and simplicity of employment, making it simple to identify which problems must be solved first (Silva et al., 2017). In these interviews, we identified that the hybrid MCDM proposed presents a list of improvements compared to the GUT matrix:

- The model can rank the importance of the criteria used to evaluate the projects.
- The possibility of considering the uncertainties of the assessments, reducing imprecision, and making the model more reliable.
- The company's PPM team also highlighted that there are no ties in the scores in the ranking of projects, which guarantees that there will be no need to choose between two projects, which would bring inaccuracies to the company's decision-making process.

Consequently, based on decision-makers' opinions, we can accept that the model selects the company's project portfolio more appropriately.

5 CONCLUSIONS

To ensure that the company's resources are well allocated, project portfolio management is vital. Thus, we designed this project as an essential key to direct the discussions and decision-making during leadership meetings.

We carried out the Method's test using variables proposed and evaluated by specialists and real projects. The generated ranking was analyzed and presented a result consistent with reality, validated both by the model's consistency tests and by the company's PPM team (decision-makers), who claimed to have generated a consistent result with reality.

Many companies rely on weak tools to prioritize projects, as indicated by the GUT matrix presented in section 4. In the case of the studied company previous tool presented several projects with tied scores and did not work with the evaluators' scores' uncertainty, not effectively assisting decision-making.

As pointed by the studied company, the model is easy to handle, making it possible to fill in the information quickly and effectively and generate the ranking of projects instantly, facilitating the direction of its decision-making meetings. Furthermore, as a theoretical research implication, the model's strength, which combined two widely studied methods and a new approach, was also praised for bringing more security when defining the projects to be executed.

Consequently, as a practical research implication, we concluded that the model developed in this study, combining the AHP and VIKOR methods through the fuzzy approach, which considers the evaluators' scores' indecision, will bring greater robustness to the project portfolio selection process and will optimize the company decision.

The proposed method does not verify the correlation, interdependence, and cannibalization between the criteria and the projects, standard limitations to MCDM subjective approaches. In addition, resource constraints are not considered, as well as scheduling routines.

The main suggestion for future work is the model sensitivity analysis. It is possible to verify the importance and influence of the various criteria on the final result, which may increase the Method's robustness.

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