

Supplier Performance Evaluation in a Pharmaceutical Company

Ana Teresa Nolan Ruas Rego Canha ^a

^aInstituto Superior Técnico, Av. Prof. Dr. Cavaco Silva, 2744-016 Porto Salvo, Portugal

Abstract

Ensuring quality throughout supply chains is challenging, especially due to the lack of cooperation among involved parties. Coordination and quality are critical in pharmaceutical supply chains, as quality issues can result in costly testing and validation processes. This study addresses a pharmaceutical company producing generic drugs, facing challenges due to dependence on external suppliers for raw materials, potentially leading to production delays from quality issues. To prevent disruptions and ensure quality in the supply chain, it is crucial that units within the Quality Management System evaluate and monitor the performance of raw material suppliers. A supplier evaluation model focusing on quality was created and applied to suppliers of the active substance Paracetamol to assess their performance. The construction of the model employed the multicriteria decision analysis approach MACBETH. The developed model also aims to be included in the future decision-making process for purchasing raw materials from suppliers.

Keywords: Pharmaceutical Industry, Quality Management System, Supplier Evaluation, Multicriteria Evaluation Model, MACBETH.

1. Introduction

Maintaining high quality in supply chains is challenging due to the lack of cooperation between entities. In pharmaceutical supply chains, high levels of coordination and quality are crucial, as quality issues lead to expensive testing and validation processes ^[1]. The quality, safety, and availability of medicines are essential for public health, and regulatory bodies ensure standards through guidelines such as Good Manufacturing Practices (GMP). Quality Control (QC) is vital at all stages of production, from the analysis of raw materials to the release of the final product. A challenge for QC laboratories is to conduct rapid and effective analysis of raw materials ^[2].

The generic drugs industry focuses on producing off-patent medicines, facing primarily supply chain challenges ^[1]. This study examines a pharmaceutical company (referred to as Company X for confidentiality reasons) that produces generic drugs and faces significant risks due to dependence on external suppliers for raw materials. Some suppliers

require deeper analysis or present quality non-conformities, potentially delaying or disrupting production. Therefore, it is crucial for QC to monitor supplier performance to ensure company X's internal quality standards.

This study aims to create a supplier evaluation model focused on quality, to monitor their performance. Additionally, the developed model is intended to be included in the future decision-making process for purchasing raw materials from suppliers.

The remainder of this paper is organized as follows. Section 2 presents a literature review. Section 3 describes the methodology adopted to develop the suppliers' performance evaluation model and its implementation. Section 4 provides the results of the model. Section 5 concludes the paper with some final remarks.

2. Literature Review

Performance management is a continuous process of identifying, measuring, and developing the performance of individuals and teams, and aligning

performance with the organization's strategic objectives. The key benefits of a performance management model include more effective administrative actions, clearer organizational goals, easier organizational change, and greater employee engagement and involvement [3].

Specifically, regarding supplier performance in an organization, performance evaluation and management systems enable the organization to gain a broader understanding of suppliers, and suppliers to understand the performance aspects valued by the organization. Consequently, the evaluation process becomes more effective, supply chain relationships are strengthened, and both supplier and company performance improve [4].

Ho et al. (2010) [5] conducted a literature review on supplier selection and evaluation methods described in international journal articles from 2000 to 2008, categorizing the methods into two main groups: individual methods and integrated methods. Individual methods, found in 46 articles (58.97%), include data envelopment analysis (DEA), mathematical programming, analytic hierarchy process (AHP), case-based reasoning (CBR), analytic network process (ANP), fuzzy set theory, simple multi-attribute rating technique (SMART), and genetic algorithm (GA). Integrated methods, found in 32 articles (41.03%), often incorporate AHP.

Later, Azhar et al. (2021) [6] reviewed more recent literature from 2008 to 2021, identifying three main categories of multicriteria decision-making methods: distance-based, outranking, and pairwise comparison. The most popular methods in these categories are the technique for order of preference by similarity to ideal solution (TOPSIS) and visekriterijumska optimizacija i kompromisno resenje (VIKOR), elimination et choix traduisant la réalité (ELECTRE) and preference ranking organization method for enrichment of evaluations (PROMETHEE), and AHP and ANP, respectively.

On the other hand, Bana e Costa et al. (2012) [7] presented the application of Measuring Attractiveness by a Categorical-Based Evaluation Technique (MACBETH) method in supplier evaluation problems. MACBETH is a multi-criteria

decision analysis method that builds a quantitative value model based on qualitative judgments [8]. Thus, it considers the preferences of the decision-makers and performs both the weighting of criteria and the evaluation on each one individually, overcoming the disadvantages of the TOPSIS and VIKOR methods [9]. Furthermore, it is a simple method capable of solving complex decision-making problems and obtains a quantitative scale representing the overall attractiveness of alternatives, addressing the drawbacks of the ELECTRE and PROMETHEE methods [8]. Finally, it is noteworthy that this method, unlike AHP and ANP, does not require the number of criteria to be limited and takes into account that the weights of the criteria stem from the relative importance of the swings between two reference levels in each criterion (e.g., worst-best or neutral-good).

The MACBETH approach is transparent for the evaluators and allows for obtaining a score of the overall value of the suppliers according to the preferences expressed by the decision-makers. For these reasons, the MACBETH approach is chosen to construct the supplier evaluation model of this study.

3. Methodology

This section presents a methodology to evaluate the performance of suppliers in terms of their quality management system. The phases of the model development include structuring the multicriteria model, constructing the evaluation model, and defining the value categories.

3.1. Structuring the multicriteria model

3.1.1. Identification of the criteria

The present study considers value-focused thinking (VFT) to identify criteria. This approach identifies the objectives that should serve as criteria for evaluating alternatives, allowing for an expanded number of criteria that meet the objectives because these are the guide for analyzing decisions [10].

According to the VFT approach, objectives are defined first. For this, a method is necessary to establish the objectives and only then define the criteria. The Strategic Options Development and

Analysis (SODA) method allows for the graphical representation of a complex system with multiple objectives, helping a group of decision-makers to reach the final objectives [11].

One of the tools used in this method is group causal mapping, which begins by defining actions/means-objectives, located at the bottom of the map, and subsequently, the end-objectives, located at the top of the map, which correspond to the criteria. To draw the group causal map, a “post-it session” is conducted, where each participant writes ideas they find relevant for evaluating the performance of the alternatives, one idea per post-it. After, each participant has written her ideas, the post-its are placed on a wall to enhance visualization, and those with similar ideas are grouped together, allowing for the elimination of repetitions [12]. Subsequently, values and concepts are separated into fundamental objectives and means-objectives using classic VFT method questions. Towards the fundamental objectives, the classic question used is “Why is it important?”. In the opposite direction, the question used is “How can it be achieved?”.

Thirteen criteria were identified for this study, as observed in red in Figure 1, with seven from the Risk family, two from the Consistency family, and three from the Productivity family. Each of these is described below.



Figure 1. Value tree of the case under study

Compliance of the Last Audit (CUA): The extent to which the last audit conducted on the supplier complied with the established standards.

Date of the Last Audit (DUA): The extent to which the last audit was conducted within a time frame that

verified the current relevance of information regarding the supplier's performance.

Date of the Last Inspection by Regulatory Entities (DUI): The extent to which the last inspection was conducted within a time frame that verified the current relevance of information regarding the supplier's performance.

Complaint Outcome (R): The extent to which the supplier demonstrated the capability to meet expectations without detected issues.

Recurrence of Complaints (RR): The extent to which the supplier showed operational efficiency, particularly in implementing preventive and/or corrective actions.

Complaint Response Capability (CR): The extent to which complaints presented to the supplier were appropriately addressed.

Adequacy of Response Time for Implementing Corrective and/or Preventive Actions (ARC): The extent to which the supplier's response to complaints was provided within a time frame that demonstrates the supplier's ability to identify the cause of the problem quickly and provide a solution and response promptly.

Out-of-Specification Results (RFE): The extent to which laboratory test results confirmed that the batch is out of the specifications or acceptance criteria established in official compendia or by the manufacturer. Company X evaluates out-of-specification test results according to the FDA's guidance for the industry, representing the current FDA thinking on this topic [13]. If there are out-of-specification results, the batches are rejected, and only when proof of the implemented solution by the supplier is received will batches be accepted again.

Out-of-Tolerance Results (RFT): The extent to which laboratory test results from Company X confirmed that the batch is out of the established tolerances.

Having out-of-tolerance results does not imply that the batches are rejected, but it does mean that the raw material analysis cannot be a reduced one because the results are not consistent over time, requiring more tests to be conducted on the raw materials, which consumes resources and time.

Adequacy of Batch Expiry Dates (ADV): The extent to which batches were received with appropriate expiry dates that did not disrupt the QC task planning.

Adequacy of Batch Numbers (AL): The extent to which the correct number of batches was received, without compromising the productivity of QC analysts. For example, receiving a large number of batches of the same raw material will require more sampling, increasing the time needed to analyze a raw material.

Complexity of Analysis (CA): The extent to which the sampling of raw materials presented the appropriate degree of complexity, such as the required number of High-Performance Liquid Chromatography (HPLC) analyses and the necessary number of workdays.

Dependence on External Analyses (DAE): The extent to which the analyses performed on the raw material samples depended on external laboratories to be executed. When external analyses are performed, Company X will depend on third parties and the date they can issue the sampling results.

For the same raw material, the number of external analyses can vary due to the source of the raw materials, resulting in different purity levels and secondary products, which requires different types of analyses. Some of these analyses need to be conducted externally because Company X does not have the necessary equipment to perform them.

3.1.2. Association of a performance descriptor with each evaluation criterion

After identifying the criteria, a performance descriptor is associated with each one. This descriptor refers to a set of performance levels of the alternatives concerning a particular criterion. Among the identified performance levels, two are reference levels, one superior and the other inferior, which can correspond respectively to the "good" level (indicating a significantly positive performance) and the "neutral" level (with neither attractive nor repulsive performance)^[14]. The descriptors of this study aggregate one or more qualitative and/or quantitative indicators.

3.2. Constructing the evaluation model

3.2.1. Construction of value functions

One of the requirements from the decision-making group at Company X is that this supplier evaluation model can be reusable, meaning that suppliers can be evaluated regularly using the same model. Thus, it was decided to construct an additive value function model instead of a utility model. The overall value of each supplier is given by the equation (1)^[15]:

$$V(x_1, \dots, x_n) = \sum_{i=1}^n w_i v_i(x_i),$$

$$\text{with } \sum_{i=1}^n w_i = 1, w_i > 0, \quad (1)$$

$$v_i(x_i^+) = 100, v_i(x_i^0) = 0, \text{ for } i = 1, \dots, n$$

where: V refers to the overall value of the supplier x that has the performance profile x_1, \dots, x_n ; w_i refers to the weight of criterion i ; $v_i(x_i)$ is the value on criterion i of performance x_i ; x_i^+ represents a good performance e x_i^0 represents a neutral performance.

To obtain the overall value of a supplier, it is necessary to construct a value function for each criterion. These value functions can be constructed using numerical techniques, with the most commonly used being "direct scoring," which involves numerical estimates by the evaluator, and "bisection," which is based on judgments of indifference^[15]. These two techniques require the evaluator to make relative

value judgments between each pair of actions, making the questioning process by the analyst complex and difficult to execute [15].

On the other hand, there are non-numerical techniques, namely the MACBETH technique, for constructing value functions. This technique also requires a dialogue between the analyst and the evaluator, but in this case, the evaluator does not make relative value judgments but rather absolute judgments of attractiveness differences between two actions. Thus, the MACBETH technique addresses the difficulties of the numerical techniques mentioned above and will be used in this model [16].

To construct the value functions for each criterion in this study, several meetings were held with the same group of decision-makers from the model structuring phase. The fact that more than one decision conference was held was due to changes in the initially developed model, specifically altering the performance descriptors for some criteria. In the decision conferences, the process facilitator guided the meeting, asking the decision-making group to qualitatively assess the attractiveness difference between each pair of performance levels using the MACBETH semantic scale: null, weak, very weak, moderate, strong, very strong, and extreme. These questions were asked considering that the suppliers' performance in the remaining criteria were equal. It is noteworthy that the attractiveness difference was classified into more than one category when there was hesitation about which scale level to choose.

3.2.2. Assessing the criteria weights

In multi-criteria decision analysis models, various methods can be used for weighting criteria. Among the most commonly used methods are the swing weighting and trade-off procedure methods [17]. In the swing weighting method, criteria are ranked according to the decision-makers' order of preference by asking the following question: "If it were possible to change the performance of only one criterion from a neutral level to a good level, which would you choose?" This question is repeated until all swings are ranked. Then, 100 is assigned to the most important swing, and the decision-maker is

asked to assign values to the remaining swings. The weights are obtained by normalizing the values assigned to the swings at the end of this process [18]. The trade-off method requires comparing two hypothetical alternatives that differ only in two criteria at a time, where the decision-maker must adjust one of these alternatives to achieve indifference between them. This procedure is repeated $n - 1$ times, where n is the number of criteria. Each indifference relationship is translated into an equation which, together with the normalization equation, allows for the determination of the criteria weights [18].

In addition to the methods mentioned above, there is another criteria weighting method, the MACBETH method, where weighting is performed through qualitative judgments regarding the attractiveness difference between criterion swings [17]. In the end, a quantitative value is generated for the weight of each criterion.

In the methodology to be implemented in this study, the weighting method to be used is MACBETH because it allows for the consideration of qualitative judgments, which reduces the difficulty of interaction with the decision-makers of company X and helps detect any inconsistencies in their judgments.

A decision conference was held to assess the weights of the criteria in each family using the MACBETH procedure. The first step in this procedure was to rank the swings from neutral to good levels of the criteria in each family according to their attractiveness. To achieve this ranking, the facilitator asked the decision-makers to consider a hypothetical supplier whose performance in all criteria was at the neutral level. Then, the facilitator asked the decision-makers the following question: "In the Risk family, if you could choose only one criterion in which the performance of a supplier could be changed from neutral to good, which would you choose?" This question helped identify the swing with the highest attractiveness. The question was repeated until all swings were ranked in descending order of attractiveness. The ranking of the Risk family criteria swings can be seen in Figure 2.

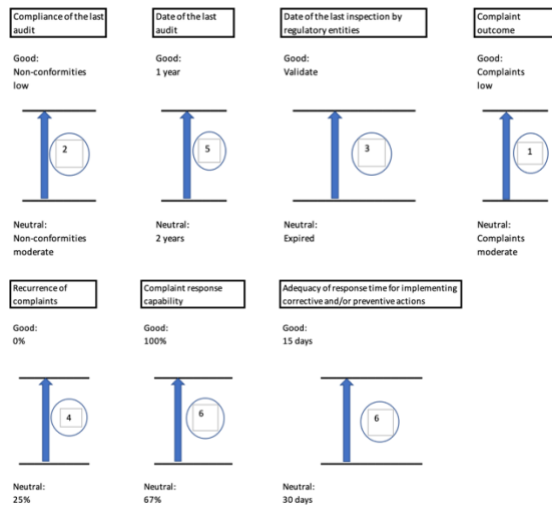


Figure 2. Ranking of the Risk family criteria swings

In the second step of this procedure, the decision-makers qualitatively judged the difference in attractiveness between the above-mentioned swings. The MACBETH judgment matrix, presented in Table 1, was filled in starting from the last column (Neutral in all), where the difference in attractiveness of moving from neutral to good in each criterion was questioned. Then, the first row of the matrix was filled in, where the difference in attractiveness between the most attractive neutral-good swing and the swings of each remaining criterion was questioned, followed by the difference in attractiveness between consecutive swings in the ranking, which filled in the diagonal above the main diagonal.

Table 1. MACBETH judgment matrix of the Risk family criteria swings

	R	CUA	DUI	RR	DUA	CR	ARC	Neutral in all
R		weak	moderate	moderate	strong	extreme	extreme	extreme
CUA			weak	positive	positive	positive	positive	very strong
DUI				moderate	positive	positive	positive	very strong
RR					moderate	positive	positive	strong
DUA						weak	weak	moderate
CR								weak
ARC								weak
Neutral in all								

After filling in the matrix, the M-MACBETH software identified some inconsistencies in the judgments made, providing suggestions for changes to make the judgments consistent. The decision-makers made modifications to resolve these issues. Subsequently, the software generated a proposed weighting for the criteria, where the weights of the criteria "Complaint response capability" and "Adequacy of response time for implementing

corrective and/or preventive actions" received the same weight because the swings in these criteria were considered indifferent. The weights of the criteria in the Risk family are presented in Figure 3.

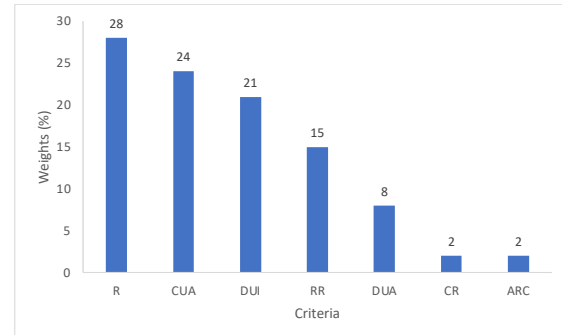


Figure 3. Risk family criteria weights

These two steps were repeated for the remaining Consistency and Productivity families, allowing for the determination of the internal criteria weights for each family.

3.2.3. Assessing the families' weights

One of the methods that allows for calculating the weights of families of criteria, or areas of interest, is the swing weighting method. Despite requiring the decision-makers to make quantitative judgments, this method is simple and does not take a long time to implement.

There are two options for applying the swing weighting method in the hierarchical additive model to determine the weights of the areas. In one option, the swings from the lower to the upper reference levels of all criteria in each area are compared. In the other possible option, the swings from the lower to the upper reference levels of one criterion in each area are compared [18].

The chosen option for the proposed model was the first one, as it is less complex to implement. Considering a hypothetical supplier whose performance in all criteria is at a neutral level, the first question posed to the group of decision-makers was: "If all the criteria in the Risk, Consistency, and Productivity families and the External Analysis Dependency criterion were at a neutral level, which of these four sets of criteria would you choose to move first to the good reference levels?" The

decision-makers initially selected only the sets of criteria in the Risk family but later also considered those in the Consistency family when they had to quantify the swings. This question was repeated until all the swings of the sets of criteria were ordered.

The next question posed to the group of decision-makers was: "How would you quantify the swing from neutral to good levels in the Productivity criteria, knowing that equivalent swings in the Risk and Consistency criteria were assigned 100 points?" They responded that this swing was equivalent to 50% of the swings in the Risk (or Consistency) criteria. When quantifying the swing for Dependence on external analysis, it was evaluated as equivalent to 25% of the swings in the Risk (or Consistency) criteria.

Once the swings were quantified, they were normalized. The weighting coefficients for the Risk, Consistency, and Productivity families and Dependence on external analysis are 0.365, 0.365, 0.18, and 0.09, respectively. These weighting coefficients were calculated by dividing the swing score of the respective family by the sum of the swing scores of all families (including the Dependence on external analysis criterion, which is unique in its "family").

Figure 4 presents the weights of the families obtained by the swing weighting procedure.

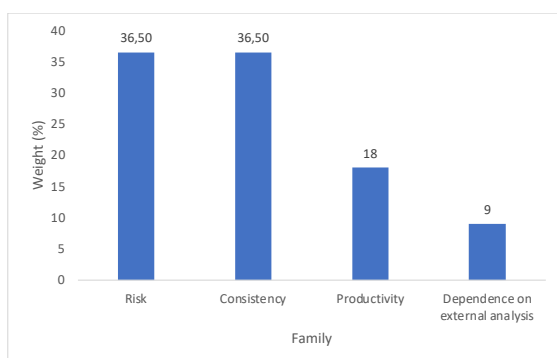


Figure 4. Family weights

3.3. Defining the value categories

The method used by Bana e Costa and Oliveira (2002) [19] to identify urgency thresholds for interventions in buildings in the city of Lisbon was employed in this study, as described below.

Lisbon has an extensive housing stock that requires maintenance, repair, and renovation. Therefore, a model was developed to assist the Lisbon City Council in prioritizing these activities. In this model, a method was used to identify multidimensional reference profiles that establish urgency categories, allowing each possible action to be allocated to one of these categories [19].

Four predefined ordered categories of action priority ("urgency categories") were considered: C \uparrow - absolutely urgent; C $++$ - urgent; C $+$ - medium priority; and C $-$ - low priority. To distinguish these categories and establish the assignment rules, specific limits were created, expressed in terms of a priority index, as shown in Figure 5 [19]. In this model, the procedures used to construct the value categories were both bottom-up and top-down.

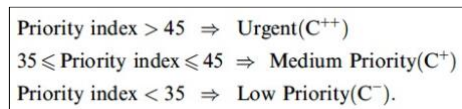


Figure 5. Category boundaries in terms of priority index (Source: Bana e Costa & Oliveira, 2002)

To determine the categories, the process facilitator met with the group of decision-makers from the structuring and evaluation phases of the model and used the bottom-up procedure to identify the respective threshold values.

First, it was suggested that performance be classified into five categories: Excellent, Satisfactory, Acceptable, Negative, and Very Negative. Considering all the criteria, the facilitator began by asking the group of decision-makers to consider a hypothetical supplier whose performance is characterized by having the most negative level of performance in all criteria of this family. Next, they were asked to consider a hypothetical supplier who differs from the previous one by having a more attractive level of performance in a given criterion. The group of decision-makers was then asked the following question: "Does the new supplier, with a more attractive level of performance, belong to the same category as the previously considered supplier?" When the answer to this question was

negative, the threshold for the next more attractive category was found. This procedure allowed the determination of the following category thresholds in terms of performance value:

- Score $\geq 106 \Rightarrow$ Excellent
- $100 \leq$ Score $< 106 \Rightarrow$ Satisfactory
- $0 \leq$ Score $< 100 \Rightarrow$ Acceptable
- $-144 \leq$ Score $< 0 \Rightarrow$ Negative
- Score $< -144 \Rightarrow$ Very negative

4. Results

As previously mentioned, the suppliers evaluated are those of paracetamol A and B, and the period analyzed refers to the timeframe from April 1, 2021, to April 1, 2023. By applying the proposed model, the suppliers' scores were obtained for each family of criteria and at the overall level, as shown in Table 2.

Table 2. Partial and overall supplier scores

Supplier	Family				Global score
	Risk	Consistency	Productivity	Dependence on external analysis	
	36.5%	36.5%	18%	9%	
A	-4.36	75	37.17	100	41.47
B	-32.42	50	-50.50	100	6.33

The most attractive option is supplier A, with an overall score of 41.47 points, followed by supplier B, with an overall score of 6.33 points. Since the overall scores of suppliers A and B fall within the 0 to 100 value range, both are classified in the Acceptable value category, as seen in Figure 6. The group of decision-makers was not surprised by the results, as supplier B imposes more constraints on the work in the QC department.

To understand in which criteria and areas supplier A performs better relative to supplier B, difference profiles between suppliers A and B were analyzed by criterion, as shown in Figure 7, and by family, as shown in Figure 8.

The difference in overall scores between suppliers A and B is 35.15 points, which is significant. Supplier A performs better in all families and on the criterion Dependence on external analysis.

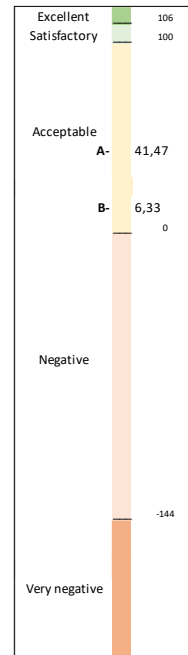


Figure 6. Supplier performance by category

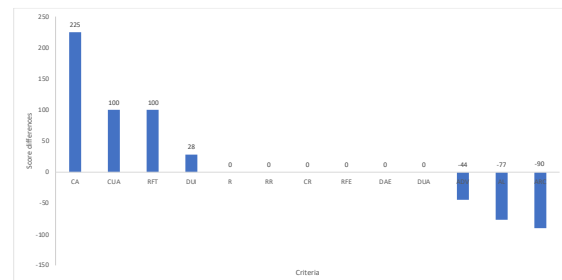


Figure 7. Profiles of differences between suppliers A and B by criterion

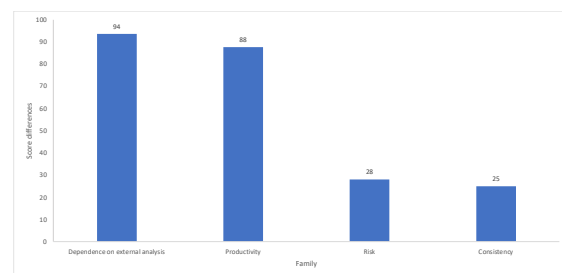


Figure 8. Profiles of differences between suppliers A and B by families

In the Productivity family, supplier A's higher score is due to significantly better performance in the Complexity of Analysis criterion compared to supplier B, which was expected due to the current productivity levels in the QC laboratory when the raw material to be sampled is provided by supplier B. In the Risk family, supplier A's higher score is due to superior

performance in the criteria of Compliance of the Last Audit and Date of the Last Inspection by Regulatory Entities. In the Consistency family, although the performance of both suppliers is equal in the Out-of-Specification Results criterion, supplier A performs better in the Out-of-Tolerance Results criterion.

5. Conclusion

The developed model is flexible because it can include different criteria, quantitative and qualitative. Additionally, it is transparent, allowing the decision-making group to understand how their judgments are considered in the evaluation process. By applying the MACBETH method in the model construction, the consistency of the decision-makers' judgments is verified, ensuring valid and sufficiently accurate results. Furthermore, it is a simple method capable of solving complex decision-making problems and performs a quantitative evaluation of alternatives. In summary, the new model is an effective management tool for analyzing supplier evaluation decisions with a focus on Quality.

References

- [1] Abdallah A. (2013). Global Pharmaceutical Supply Chain: A Quality Perspective. *International Journal of Business and Management*, 8(17). <http://dx.doi.org/10.5539/ijbm.v8n17p62>
- [2] Dispas, A., Sacré, P., Ziemons, E., Hubert, P. (2022). Emerging analytical techniques for pharmaceutical quality control: Where are we in 2022?. *Journal of Pharmaceutical and Biomedical Analysis*, 221, 115071. <https://doi.org/10.1016/j.jpba.2022.115071>
- [3] Aguinis, H., Joo, H., Gottfredson, R. K. (2011). Why we hate performance management-And why we should love it. *Business Horizons*, 54(6). <https://doi.org/10.1016/j.bushor.2011.06.001>
- [4] Luzzini, D., Caniato, F., & Spina, G. (2014). Designing vendor evaluation systems: An empirical analysis. *Journal of Purchasing and Supply Management*, 20(2), 113–129. <https://doi.org/10.1016/j.pursup.2014.03.002>
- [5] Ho, W., Xu, X., & Dey, P. K. (2010). Multi-criteria decision making approaches for supplier evaluation and selection: A literature review. *European Journal of Operational Research*, 202(1), 16–24. <https://doi.org/10.1016/j.ejor.2009.05.009>
- [6] Azhar, N. A., Radzi, N. A. M., & Wan Ahmad, W. S. H. M. (2021). Multi-criteria Decision Making: A Systematic Review. *Recent Advances in Electrical & Electronic Engineering (Formerly Recent Patents on Electrical & Electronic Engineering)*, 14(8), 779–801. <https://doi.org/10.2174/2352096514666211029112443>
- [7] Bana e Costa, C., De Corte, J., Vansnick J. (2012b). MACBETH. *International Journal of Information Technology & Decision Making*, 11(2) 359-387. <https://doi.org/10.1142/S0219622012400068>
- [8] Karande, P., & Chakraborty, S. (2013). Using MACBETH method for supplier selection in manufacturing environment. *International Journal of Industrial Engineering Computations*, 4(2), 259–272. <https://doi.org/10.5267/j.ijiec.2013.01.002>
- [9] Akyüz, G., Tosun, Ö., Aka, S. (2018). Multi criteria decision-making approach for evaluation of supplier performance with MACBETH method. *Int. J. Information and Decision Sciences*, 10(3).
- [10] Keeney, R. (1992). *Value-Focused Thinking: A Path to Creative Decisionmaking*. Harvard University Press.
- [11] de Almeida, S., Morais, D. C., & de Almeida, A. T. (2014). Aggregation of stakeholder viewpoints using the value-focused thinking methodology in association with cognitive maps. *Produção*, 24(1), 144–159. <https://doi.org/10.1590/S0103-65132013005000037>
- [12] Bana e Costa, C. A., Lourenço, J. C., Oliveira, M. D., & Bana e Costa, J. C. (2014). A Socio-technical Approach for Group Decision Support in Public Strategic Planning: The Pernambuco PPA Case. *Group Decision and Negotiation*, 23(1), 5–29. <https://doi.org/10.1007/s10726-012-9326-2>
- [13] U.S. Department of Health and Human Services Food and Drug Administration Center for Drug Evaluation and Research (CDER). (2006). *Guidance for Industry Investigating Out-of-Specification (OOS) Test Results for Pharmaceutical Production*.

- [14] Karande, P., & Chakraborty, S. (2013). Using MACBETH method for supplier selection in manufacturing environment. *International Journal of Industrial Engineering Computations*, 4(2), 259–272. <https://doi.org/10.5267/j.ijiec.2013.01.002>
- [15] Bana e Costa, C., Vansnick, J. (2008). A critical analysis of the eigenvalue method used to derive priorities in AHP. *European Journal of Operational Research*, 187(3). <https://doi.org/10.1016/j.ejor.2006.09.022>
- [16] Bana e Costa, C., Beinat, E. (2005). Model-structuring in public decision-aiding. *Operational Research working papers (LSEOR 05.79)*.
- [17] Bana e Costa, C., Lourenço, J., Chagas, M., Bana e Costa, J. (2008). Development of Reusable Bid Evaluation Models for the Portuguese Electric Transmission Company. *Decision Analysis*, 5(1). <https://doi.org/10.1287/deca.1080.0104>
- [18] Lourenço, J. (2002). Modelo aditivo hierárquico: exemplos de métodos de ponderação e problemas associados. CEG-IST – Centre for Management Studies of IST.
- [19] Bana e Costa, C., Oliveira, R. (2002). Assigning priorities for maintenance, repair and refurbishment in managing a municipal housing stock. *European Journal of Operational Research*, 138(2), 380-391. [https://doi.org/10.1016/S0377-2217\(01\)00253-3](https://doi.org/10.1016/S0377-2217(01)00253-3)