Article

# A New Effective ABC Multicriteria Classification with AHP: How to Force Consistency of Paiwise Comparisons Matrix.

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**Abstract:** Multicriteria classification is usually a crucial step in the decision-making in manufacturing and purchasing management processes. But in such classification, both the attribution of weights to the criteria and the attribution of weights to the products according to each criterion strongly influence the coherence of the categorization. Saaty's Analytic Hierarchy Process (AHP) is an eminent method for assigning weights to multiple criteria. Yet, since criteria's pairwise comparison matrices are usually generated manually and based only on some employee know-how, there is high complexity in elaborating a consistent pairwise matrix, especially when comparing several criteria. The attribution of weights to the products according to each criterion is also a difficult task cause there is a need to balance all the quantitative values and the empirical values defined for the qualitative criteria. This article presents an efficient algorithm that can adjust inconsistent pairwise comparison matrices, a balancing procedure for attributing weights to the products according to qualitative criteria, and a new equation for ABC multicriteria classification. We tested the proposed solutions to companies in three sectors, demonstrating that this approach provided consistent results, according to the analysis of the company managers, being an essential resource for decision-making.

**Keywords:** ABC multicriteria classification; Analytic Hierarchy Process; consistency rate; multicriteria equation; COPSolver library.

## 1. Introduction

According to [1], the manufacturing decisions can be classified into three categories: strategic, tactical and operational. As explained by the authors, the operational decisions pertaining to issues such as order processing, detailed production scheduling, follow up, maintenance routines, and inventory control rules, drive the day to day activities. Manufacturing decisions are closely related to sales decisions. [2] warn that in today's competitive market the diversity in customer's need have resulted in a high level of variability in the products which have to be manufactured and this statement is also valid for the products acquired from other companies. Such complication brings to light the need for the use of complex techniques for purchasing / production management, especially at the operational decision level [3]. In such a scenario, prior optimized operational planning becomes impressible for better use of the productive capacity and to avoid investment losses in unnecessary or unprofitable material. And, given the wide variety of products, it is crucial to start any planning by understanding the importance of all products marked by the company.

One of the approaches that is widely applied to clustering products according to their importance is the multicriteria ABC classification. The scientific literature broadly emphasizes the value of multicriteria ABC classification for inventory management and

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presents several multicriteria methods. The Analytic Hierarchy Process is one of the most common techniques applied for this purpose [**? ? ? ?** ]. Some recent studies also emphasize the importance of applying multicriteria analysis to strategic planning [*e.g.,* **? ? ?** ]. **?** ] emphasizes that, when applying some multicriteria methods, it is crucial to pay particular attention to the objectivity factors of criteria weights. The author provides a detailed overview of different weighting methods applicable to multicriteria techniques.

In this work, we present a study with three companies from three different sectors, which market a wide variety of products, in some cases, highly personalized products. The interest of this study is to identify the principal products, that is, the products that each company must prioritize so that this information can guide the optimized operational planning. We opted for the method ABC for multicriteria classification and adopted the Analytic Hierarchy Process (AHP) [**?** ] to assign the weights to the different criteria. It is important to note that the AHP derives the weights of each criterion based on the eigenvector of a pairwise comparisons matrix, which is constructed manually according to an empirical evaluation. According to [**?** ], this matrix must be positive reciprocal and have a consistency rate of less than 0.1. The author reports that a software package supporting the AHP, called Expert Choice, for the IBM PC, was used in his work for making eigenvector calculations and guiding the decision maker to improve matrix inconsistency if needed. During the execution of the work we present in this paper, we found that there is a substantial difficulty in the calculation of the eigenvector, as well as in the construction of consistent pairwise comparisons matrices. Since we had no access to the Expert Choice software package, we developed an open-source COPSolver's library for solving the multicriteria classification problem, which applies a simple algorithm for forcing the consistency of such matrices when applying the AHP. We present this algorithm in this paper. We coupled the Eigen library from eigen.tuxfamily.org to COPSolver for the eigenvectors calculation of the matrices. Also, we identified that it is possible to use different criteria types (cumulative sum, qualitative, and binary) when assigning weights to ABC classification, depending on each specific criterion chosen, and we observed that such an assignment generates a bias in the multicriteria ABC classification. Therefore, we also developed a new methodology for assigning weights in a balanced way for ABC classification, and we proposed a new multicriteria weighting equation for the multicriteria classification COPSolver's library. We also present both propositions in this paper, as well as an in-depth analysis of the results found by the new library developed for COPSolver.

## 2. Materials and Methods

Materials and Methods should be described with sufficient details to allow others to replicate and build on published results. Please note that publication of your manuscript implicates that you must make all materials, data, computer code, and protocols associated with the publication available to readers. Please disclose at the submission stage any restrictions on the availability of materials or information. New methods and protocols should be described in detail while well-established methods can be briefly described and appropriately cited.

Research manuscripts reporting large datasets that are deposited in a publicly available database should specify where the data have been deposited and provide the relevant accession numbers. If the accession numbers have not yet been obtained at the time of submission, please state that they will be provided during review. They must be provided prior to publication.

Interventionary studies involving animals or humans, and other studies require ethical approval must list the authority that provided approval and the corresponding ethical approval code.

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## 3. Results

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation as well as the experimental conclusions that can be drawn.

### *3.1. Subsection*

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Bulleted lists look like this:

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All figures and tables should be cited in the main text as Figure 1, Table 1, etc.


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| Entry 2 | Data<br>Data<br>Data | Data<br>Data<br>Data | Data<br>Data<br>Data |
| Entry 3 | Data<br>Data<br>Data | Data<br>Data<br>Data | Data<br>Data<br>Data |
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* Tables may have a footer.

Text.

Text.

### *3.3. Formatting of Mathematical Components*

This is the example 1 of equation:

$$a = 1, \tag{1}$$

the text following an equation need not be a new paragraph. Please punctuate equations as regular text.

This is the example 2 of equation:

$$a = b + c + d + e + f + g + h + i + j + k + l + m + n + o + p + q + r + s + t + u + v + w + x + y + z \tag{2}$$

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## Abbreviations

The following abbreviations are used in this manuscript:

| | |
|---|---|
| MDPI | Multidisciplinary Digital Publishing Institute |
| DOAJ | Directory of open access journals |
| TLA | Three letter acronym |
| LD | Linear dichroism |

## Appendix A

### *Appendix A.1*

The appendix is an optional section that can contain details and data supplemental to the main text—for example, explanations of experimental details that would disrupt the flow of the main text but nonetheless remain crucial to understanding and reproducing the research shown; figures of replicates for experiments of which representative data are shown in the main text can be added here if brief, or as Supplementary Data. Mathematical proofs of results not central to the paper can be added as an appendix.

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## Appendix B

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## References

1. Singhal, J.; Bitran, G.R.; Dasu, S. Production Management. In *Encyclopedia of Operations Research and Management Science*; Gass, S.I., Fu, M.C., Eds.; Springer US: Boston, United States, 2013; pp. 1173–1182.
2. Ebrahimi, A.H.; Johansson, P.E.C.; Bengtsson, K.; Åkesson, K. Managing Product and Production Variety – A Language Workbench Approach. *Procedia CIRP* **2014**, *17*, 338–344.

3. Kiran, D.R. *Production Planning and Control: A Comprehensive Approach*, 1rd ed.; Butterworth-Heinemann: Cambridge, United States, 2019.
4. Author 1, T. The title of the cited article. *Journal Abbreviation* **2008**, *10*, 142–149.
5. Author 2, L. The title of the cited contribution. In *The Book Title*; Editor 1, F., Editor 2, A., Eds.; Publishing House: City, Country, 2007; pp. 32–58.
6. Author 1, A.; Author 2, B. *Book Title*, 3rd ed.; Publisher: Publisher Location, Country, 2008; pp. 154–196.
7. Author 1, A.B.; Author 2, C. Title of Unpublished Work. *Abbreviated Journal Name* year, *phrase indicating stage of publication (submitted; accepted; in press)*.
8. Author 1, A.B. (University, City, State, Country); Author 2, C. (Institute, City, State, Country). Personal communication, 2012.
9. Author 1, A.B.; Author 2, C.D.; Author 3, E.F. Title of presentation. In Proceedings of the Name of the Conference, Location of Conference, Country, Date of Conference (Day Month Year); Abstract Number (optional), Pagination (optional).
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