INSID

RECIFE-PE, 2026

INnovation for Systems Information and Decision meeting

LOCAL PROCEEDINGS

17 A 19 NOVEMBRO 2026 RECIFE PE

Edited by:

Lúcia Reis Peixoto Roselli

Danielle Costa Morais

Adiel Teixeira de Almeida

PPGEP UFPE Programa de Pós-Graduação em Engenharia de Produção

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ABOUT INSID

The **INSID Meeting 2026 (INnovation for Systems Information and Decision)** was held in Recife, Pernambuco, Brazil, from November 17 to 19, 2026.

The INSID Meeting brings together researchers and practitioners engaged in the development and application of advanced approaches to decision-making and decision aiding, with particular emphasis on Multicriteria Decision Making and Analysis (MCDM/A), Group Decision and Negotiation (GDN), and related areas.

The event aims to foster the exchange of knowledge and experiences, presenting recent advances in theories, methodologies, and practical applications. It also provides an opportunity to explore the use of these approaches in addressing complex decision problems across different fields. Through presentations and discussions, participants are encouraged to share perspectives, challenge existing ideas, and identify opportunities for future research and collaboration.

We would like to express our sincere appreciation to all reviewers who contributed their expertise and time to the evaluation process. Their thoughtful assessments and valuable suggestions played an important role in strengthening the scientific quality of the papers included in this volume.

This edition was made possible through the financial and institutional contributions of INCT-INSID (CNPq), CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior), and FACEPE (Fundação de Amparo à Ciência e Tecnologia do Estado de Pernambuco). We gratefully recognize their support, which has contributed to both the organization of the INSID Meeting 2026 and the publication of this volume.

We trust that the research presented in these proceedings will provide valuable insights to the scientific community, encourage new perspectives on decision-making and innovation, and foster lasting partnerships among researchers and institutions. May these contributions serve as a foundation for further advances in the field of Innovation for Systems Information and Decision.

November 2026

Lucia Peixoto Reis Roselli
Danielle Costa Morais
Adiel Teixeira de Almeida

SCOPE

Themes and areas of interest include but are not limited to the following:

Methodological advances in decision making and aid

- Methodological advances in MCDM/MCDA
- Methodological advances in GDN
- Neuroscience and Decision

Decision models in the environmental context

- Building Decision models in mitigation of climate changing and risk reduction of disturb due to flood in Brazilian cities
- Building Decision models in for environmental policies, including water management

Decision models in the energy context

- Decision models for renewable energy policies and alternative energy sources
- Decision models in for planning and maintenance of energy systems
- Decision models for technological risk, reliability and maintenance, in various systems, including nuclear energy, and renewable energy system
- Integration of DEA and MCDM models

Decision models in the service systems

- Decision models for public security
- Decision models for planning and management of national defense and security
- Decision models for business strategic planning for using information technology
- Decision models for planning and management of health systems

Potential Applications of Decision and Negotiation Models

- Strategy
- Quality
- Logistics
- Maintenance and Reliability
- Risk management and risk analysis
- Business
- Public Policy
- Project Management
- Diplomacy and international relationships
- Education
- Water and natural resources
- Sustainability
- Software engineering
- Interaction of human and software agents
- Artificial intelligence
- Auction theory
- Collaboration engineering
- Industry 4.0

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SCHEDULE

17 November 2026		
Time	**Room 1**	**Room 2**
14h00 – 14h20	Opening Session INSID	
14h20 – 16h20	Parallel Technical Session	Parallel Technical Session
16h20 – 16h40	Coffee Break	
16h40 – 18h	**Plenary Session** Thinking Slow Is Not Thinking Well: Decision Science for Reasoning Machines. Prof. Sajid Siraj (Leeds University Business School)	

18 November 2026		
Time	**Room 1**	**Room 2**
8h30 – 10h00	**Plenary Session** Self-Regulated Intelligence: Navigating Incompleteness and Ignored Unknowns. Prof. Prof. Marcos Estellita (Universidade Federal do Rio de Janeiro – UFRJ).	
10h00 – 10h20	Coffee Break	
10h20 – 12h20	Parallel Technical Session	Parallel Technical Session
12h20 – 14h00	Lunch	
14h00 – 15h30	**Round Table** Methodological Innovations and AI in Information and Decision Support Systems Profs. Adiel de Almeida (UFPE), Marcos Estellita (UFRJ), Leonardo Duarte (UNICAMP), and Sajid Siraj (Leeds University Business School)	
15h30 – 16h00	Coffee Break	
16h00 – 18h00	Parallel Technical Session	Parallel Technical Session

19 November 2026	
8h40 – 10h00	Technical Session with the Productive Sector
10h00 – 10h30	Coffee Break
10h30 – 11h30	**Plenary Session** Game Theory in Food Supply Chain Sustainability Prof.Sinndy Dayana Rico Lugo (Ritsumeikan Asia Pacific University)
11h30 – 12h00	Closing Section

LIST OF PAPERS

26 - Military Intelligence in the Analysis of Military Equipment Tenders: Modeling Using a Multicriteria Ranking Problem Structure - *Leonardo Pessoa, Rodrigo Ferreira, Marcelo. Alencar and Helder Gomes Cost* 11

27 - Hierarchical Sorting under Parameter Uncertainty: An Experimental Study Using MCHP, ELECTRE TRI-B, and SMAA-TRI for Freedom and Prosperity Indicators - *Diogo Lima, Brunno Rodrigues and Helder Gomes Costa* 24

5 - Prioritization of Service Orders in a Small Carpentry Workshop: An Integrated Application of Soft Systems Methodology and the PROMETHEE II Method - *Lucas Guilherme Pereira de Moura, Luís Henrique Melo Mendes, Maria Clara Silva Carvalho, Paola Kamily Araujo Rodriguez, Jaini Barbosa and Ricardo Pires de Souza* 25

54 - Assessing wind power sites: past decisions and preference learning - *Duan Ferreira, Ciro Figueiredo and Caroline Mota* 33

39 - Brazilian Oil and Gas Company CBM Project: Multicriteria Selection of BOP Component Failures - *Dalessandro Vianna, Marcilene Dianin, Edwin Mitacc Meza, Jamile Delesposte, Harvey Cosenza, Carlos Bazilio, Eduardo Marques, Rodolfo Cardoso and Iara Tammela* 37

29 - Decision Support System for Multi-Criteria Decision Making Based on Subjective Benefit-of-the-Doubt' - *Sandro Laudares, Petr Ekel, Iara Sibele Silva, Aline De Lurdes Zuliani Lunkes, André Gomes Coimbra, Marcos Flávio Silveira Vasconcelos D Angelo and Matheus Pereira Libório* 54

3 - From Ad Hoc Choices to Value-Driven Decisions: a Multi-Attribute Value Model for Project Prioritization in a State Department of Finance - *Adrian Daniel da Silva, Alexandre Farias Maia, Jaini Barbosa and Ricardo Pires de Souza*..... 69

41 - Organizational Productivity as an Emergent Property: The Integrated Autopoietic–Eudaimonic Management Framework (MIGAE) - *Victor Ramírez-Amaya, Silvia M. Pierotti, José F. Zanazzi, Daniel Pontelli and José L. Zanazzi* 76

35 - Resolving Weight Indeterminacy in the Simos Method - *Luis Dias and Rudolf Vetschera*..... 91

44 - Mathematical Formalization of the Integrated Autopoietic–Eudaimonic Theory of Organizational Productivity - *Silvia Pierotti, Víctor Ramírez-Amaya, Jose Francisco Zanazzi, Jose Luis Zanazzi and Daniel Pontelli* 93

50 - SIDTeleAsma: Telemedicine Information and Decision System for Asthma - Nilton *Rodrigo da Silva Araujo, Lucia Reis Peixoto Roselli, Eduarda Asfora Frej, Rodrigo José Pires Ferreira, Murilo Carlos Amorim de Britto, Ana Paula Cabral Seixas Costa and Adiel Teixeira de Almeida* 111

30 - Caracterização de pacotes de compromissos estratégicos para a expansão latino-americana de uma plataforma SaaS de tecnologia logística: uma aplicação do Strategic Choice Approach - *Amanda Meira da Silva, João Henrique Ferreira Barbosa da Si, Douglas Junior Ferreira de Queiróz, Evelyn Torres Siqueira, Rafael Sanaiotte Pinheiro, João Batista Sarmento dos Santos Neto, Carolina Lino Martins and Kassia Tonheiro Rodrigues*.....112

51 - ANÁLISE DINÂMICA DE CONFLITOS BILATERAIS COM HORIZONTE DE PREVISÃO LIMITADO E VARIÁVEL - *Paula Cristina de Amorim Andrade, Leandro Chaves Rêgo and Maísa Mendonça Silva*..... 127

31 - Literature Mapping of Operational Decision-Making in the Judiciary - *Altair Junior Ancelmo Soares and Carolina Lino Martins*..... 128

55 - APPLICATION OF THE MULTICRITERIA APPROACH TO CONSTRUCTION MANAGEMENT IN THE JUDICIARY - *Pedro Rodrigo de Menezes Almeida and Ana Paula Henriques Gusmão de Araújo Lima*..... 144

7 - Aplicação do Método FITradeoff à Ordenação de Ordens de Produção em uma Fábrica de Embalagens Plásticas Personalizadas - *Beatriz Cipolla Moreira, Fabiana Hernandes Detogni, Maria Luiza de Lima Souza, Shannian Nan, Ruan Renato Oliveira, Jaini Barbosa and Ricardo Pires de Souza*..... 148

48 - Machine Learning applied to eco-innovation assessment - *Isadora Vieira da Motta, Edilvando Pereira Eufrazio and Helder Gomes Costa*..... 155

1 - Toward Intelligent Decision-Making: A systematic review of hybrid frameworks combining multi-criteria analysis and generative AI - *Brunno Rodrigues, Carla Floriano, Diogo Ferreira de Lima Silva and Helder Gomes Costa* 156

34 - MAC-PNet: A Milestone-Based Adaptive Control System for Probabilistic Project Performance Monitoring - Ikenna Ravel Okonkwo and Caroline Maria de Miranda Mota……..172

47 - Ranked-Clustering of Countries on SDG9 Indicators with a No-Code Visual Clustering Web Application - *Helder Gomes Costa, Leonardo Fernandes Costa and Fábio Aquino da Silva* 180

4 - Integração de Value-Focused Thinking (VFT), Análise Multicritério AHP e Sistema de Informação Geográfica (GIS) para o Mapeamento de Áreas Suscetíveis a Inundações na Bacia do Rio Ceará-Mirim/RN - *Monalisa Simonelly Rebouças de Oliveira, Stéfani Arend Barichello Costa, Andrea Solange Alves Alves, Maria Eduarda Correia Pedrosa, Jaini Barbosa Dionizio da Silva and Ricardo Pires de Souza*..... 181

56 - A Preference-Constrained Hierarchical Benefit-of-the-Doubt Framework for Electricity Distribution Quality Assessment - *Adriana Marques and Lívia Torres*..... 189

52 - Plant-Based Packaging and Visual Attention: An Eye-Tracking Study of Vegetarian and Non-Vegetarian Consumers - *Aline Amaral Leal Barbosa, Gabrielly Caroline Mendes Da Cunha, Weslley Thiago Martins Fernandes and Denise Dumke de Medeiros* ……..……..193

58 - Complex Intelligence and the Systemic Investigation Network: A Complementary Approach to CHAP² - *Marcos Antonio Rodrigues de Souza Junior and Marcos Pereira Estellita Lins*..... 194

6 - Alocação de Viaturas Policiais por Meio da Integração entre Value Focused Thinking e FITradeoff: Um Estudo de Caso na Polícia Civil do Rio Grande do Norte - *Pedro Henrique Estevo, Abel Lameque Silva Damasceno, Jamille Pessoa Cavalcanti, Antônio Sérgio de Araújo Pereira, Jaini Barbosa and Ricardo Pires de Souza* 213

53 - A Multicriteria Decision Model to Support State Government Planning for Expanding Professional and Technological Education - *Maria Teresa Araújo de Lima, Daniel da Silva Oliveira and Luciana Hazin Alencar* 221

57 - Early Warning Indicators of Project Failure in PBOs - *Maria Helena Lasserre Ferreira and Caroline Maria de Miranda Mota* 222

40 - Sectoral Credit Risk Analysis: A Hybrid CRITIC-TOPSIS Approach Using Brazilian Central Bank Data - *Paulo Roberto da Silva Reis, Marcilene de Fátima Dianin Vianna, Edwin Benito Meza Mitacc and Dalessandro Soares Vianna*..... 226

49 - A DECISION SUPPORT MODEL FOR RANKING HIGH-VOLTAGE EQUIPMENTS FOR TRANSMISSION SUBSTATIONS - *Heitor Vilela and Luciana Hazin Alencar*..... 235

61 - Production Engineering and the New Industry Brazil (NIB): a systemic diagnosis through the CHAP² method and the 8 Intelligences Model - *Rafael Jahara and Marcos Estellita Lins*..... 236

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Military Intelligence in the Analysis of Military Equipment Tenders: Modeling Using a Multicriteria Ranking Problem Structure

Leonardo Antonio Monteiro Pessôa[1], Rodrigo José Pires Ferreira [2], Marcelo Hazin Alencar[3] and Helder Gomes Costa[4]

[1]Departamento de Ciências Atuariais e Finanças, Universidade Federal Fluminense, Rua Mário Santos Braga, 30, 7º andar – Centro, Niterói, RJ CEP 24020-140, Brazil
[2]Reason Research Group, Universidade Federal de Pernambuco, Av. Acadêmico Hélio Ramos, s/n – Cidade Universitária, Recife, PE, CEP 50.740-530, Brazil
[3]Reason Research Group, Universidade Federal de Pernambuco, Av. Acadêmico Hélio Ramos, s/n – Cidade Universitária, Recife, PE, CEP 50.740-530, Brazil
[4]Engenharia de Produção, Universidade Federal Fluminense, Rua Passo da Pátria, 156, São Domingos, Niterói, RJ, CEP 24.210-240, Brazil

lampessoa@id.uff.br, rodrigo@insid.org.br, marceloalencar@insid.org.br, heldergc@id.uff.br

Abstract. This paper proposes an original framework for Military Intelligence that utilizes Open Source Intelligence (OSINT), specifically the results of public military equipment tenders, to infer the preference structure and operational doctrine of potential adversaries. This research focuses on the strategic reverse analysis of an opponent's rationale. The methodology is grounded in the philosophy of preference disaggregation and the psychological concept of inverse decision-making. The model employs the FITradeoff ranking method integrated with Linear Programming (LP) to calculate scale-constant intervals that are mathematically consistent with the observed tender ranking. A case study applied to anti-tank missile systems demonstrates that the method can identify the decision-maker's technical priorities, which directly supports doctrinal anticipation. The model quantifies preference ambiguity through intervals, effectively reducing strategic uncertainty and allowing for the prioritization of future intelligence collection toward criteria with higher variance. The originality of this work lies in the reverse application of MCDA methods for strategic intelligence. Its value stems from the ability to transform publicly available data into high-value strategic knowledge at a low operational cost, reducing reliance on classified sources while providing robust, cross-validatable intelligence products.

Keywords: Military Intelligence, FITradeoff, MCDA.

1 Introduction/Purpose

Intelligence, as a military term, has one of its possible definitions set out by the Department of Defense (DoD, 2017) as:

> 1. The product resulting from the collection, processing, integration, evaluation, analysis, and interpretation of available information concerning foreign nations, hostile or potentially hostile forces or elements, or areas of actual or potential operations. 2. The activities that result in the product. 3. The organizations engaged in such activities.

From this definition, we can argue that intelligence is not only relevant to the military sphere but also to organizational contexts, by replacing the notion of foreign nations with external organizations, competitors, and operational spaces.

Thus, it is an area of interest that extends beyond the military, although this article focuses specifically on that domain. In practice, the required intelligence information is not always directly available, and it is often necessary to deal with incomplete and partial information. From its analysis, we can derive the knowledge that completes it.

Contemporary military intelligence has progressively shifted toward open sources because of the large volume and quality of available data. Public tenders for military equipment are among the richest and still underexplored sources, as they reveal not only acquisition intent but, above all, the value structure assigned

to technical characteristics, that is, the decision maker's preference function and, by extension, elements of operational doctrine.

In addition, the performance and characteristics of military systems, even when not publicly disclosed, can be consulted in specialized publications such as Jane's Information Group (2022, 2023, 2024). Multicriteria decision aid, in turn, has been widely used in the military and defense fields for many different purposes, with procurement being a common application.

Although multicriteria decision aid methods are widely applied in defense acquisition processes (Pessôa & Costa, 2020), their reverse use to infer an adversary's preference function from the observed tender ranking is rarely explored in the literature.

The present article addresses that gap by proposing an adapted use of the FITradeoff (de Almeida et al., 2016) in the ranking version (Frej et al., 2019) combined with linear programming to estimate weight intervals from a known ranking, transforming public tenders into high-value intelligence products.

The proposed method not only recovers an approximation of the adversary decision maker's preference function but also generates actionable intelligence from fully open sources. The value for intelligence can be grouped into five operational dimensions:

- Reduction of uncertainty: quantifies ambiguity in preferences by providing bounds for criterion scale constants.
- Doctrinal anticipation (related to the process of forecasting future scenarios to update the preparation, before conflicts occur): the ordering of criteria by normalized average weight reveals the expected mode of use.
- Collection prioritization: criteria with extreme weights or higher variance guide OSINT (Open Source Intelligence) collection toward confirming or refuting inferences.
- Cross-validation: the results can be triangulated with other sources.
- Resource savings: no classified access is required, reducing dependence on intelligence resources and lowering costs.

The research question can be posed in the following form: Assuming that the decision has already been made, how can one find the rational basis through which it was made?

In order to present a reasonable methodological structure, the next section details the theoretical foundations and the proposed method of use. This is followed by a case study based on an acquisition example from Pamučar & Dimitrijević (2021). Finally, the Conclusion section closes the paper.

2 Methodology

2.1 Literature Review

The fundamental objective of this work rests on preference disaggregation, since the philosophy of preference disaggregation in multicriteria analysis is to evaluate or infer global preference models from given preference structures and to address decision-aid activities through operational models within that framework (Jacquet-Lagrèze & Siskos, 2001).

Preference disaggregation methods such as UTA (UTilités Additives), Robust Ordinal Regression, and FITradeoff have been used to infer decision maker preferences from judgments, deriving a value function from a given ranking (Jacquet-Lagrèze & Siskos, 2001; Ghaderi et al., 2017; Oliveira et al., 2024).

The FITradeoff method uses a holistic approach and combines it with decomposition (Almeida et al., 2025; Pessôa et al., 2026). However, the traditional FITradeoff uses such judgments iteratively to support a decision maker's problem. Broadly speaking, the basic problem in this study is the opposite: finding the rational basis through which the decision was made

It uses a preference disaggregation structure and linear programming, inspired by the UTA method (Jacquet-Lagrèze & Siskos, 1982). The approach differs because it does not interact with the decision maker. In other words, the results of the public tenders are considered a "supreme holistic judgment" from the opponents' perspective, and the FITradeoff structure helps to decode an approximated preference function without interaction with the decision-maker. In this sense, it is closer to the concept of an inverse decision problem.

The idea of inferring preferences from observed choices is a well-established field of study known as inverse decision-making (Jern et al., 2017). In the specific context of MCDA (MultiCriteria Decision Analysis), one may cite the Inverse Multiple Criteria Sorting Problem (IMCSP).

However, a distinction must be made between the objective of this work, which is to infer the parameters that explain the observed ranking, and IMCSP, whose goals are different: to determine the set of actions to be implemented at minimum cost or within a limited budget in order to alter the ranking of objects into a desired class In other words, while the present work focuses on inferring the parameters of the preference model, IMCSP concentrates on prescribing actions to change performance (Mousseau et al., 2018; Özpeynirci et al., 2021).

MCDA applications in military problems are numerous (Pessôa & Costa, 2020), but almost all focus on supporting the buyer. No applications were identified that use public tenders as a source of observed rankings to infer the preferences of adversary decision makers, which constitutes the main gap addressed by this article Although preference disaggregation methods are consolidated in the MCDA literature for inferring parameters from observed decisions, their application in military intelligence contexts remains incipient. The only work explicitly connecting disaggregation and intelligence analysis is Frini (2017), which proposes the MCIA framework, “Multicriteria Intelligence Aid”. The MCIA method has four fundamental steps:

1. structuring the competitor/threat decision problem;
2. handling imperfect data;
3. modeling the analyst’s risk attitude; and
4. aggregating the performance of the generated potential actions.

The structure is very rich and uses triangular fuzzy sets to model the enemy’s possible actions with respect to several evaluation consequences. The present work differs by using exclusively public tender data and by adopting the structured FITradeoff procedure for ranking problems.

FITradeoff was chosen as an inspiration because of its additive structure, based on linear programming, which allows inferences to be built over the space of scale constants using only the final ranking and the consequence matrix.

2.2 Multicriteria Ranking Problem

Roy and Bouyssou (1993) present a classification of multicriteria problematics into four categories: choice, sorting, ranking, and description. The present work uses the ranking problematic to build an approximation of the decision makers' preference function, with narrower bounds between the admissible maximum and minimum values for the scale constants.

An interesting discussion on constructing the preference function of decision makers in the military context can be found in Santos et al. (2023), which also uses a ranking problem based on an additive compensatory model, as intended here, referring to the FITradeoff ranking model (Frej et al., 2019). However, whereas that work aims to build the preference function for evaluating the force's own investment projects, the present work seeks to obtain an approximation of the opponent's preference function in order to support inferences about their intentions from military equipment tender results.

Using an additive structure, alternatives are assumed to be ordered according to their global value, which is obtained by summing their normalized performances across criteria, weighted by the corresponding scale constants.

2.3 FITradeoff Ranking Method

The FITradeoff method (Frej et al. 2019) operates with partial information on weights, reducing cognitive effort. It has also been used in several problems related to the military or police domain (Silva et al. 2019; Lacerda and Cardoso 2023; Pessôa et al. 2020).

It would be difficult to obtain an exact preference function while dealing in the Intelligence domain, but the public information regarding the ranking in a public tender is easier to obtain. As FITradeoff allows flexibility regarding the scaling constants and encourages the use of ranges for them that are ranking consistent, it became an adequate method for our proposal.

Such range intervals also indicate doctrinal priority or guide future intelligence questions. The additive value function is:

$$V(a) = \sum_{i=1}^{n} k_i \; v_i(g_i(a)) \quad (1)$$

For each pair $a \succ b$, the following constraint holds:

$$\sum_{i=1}^{n} k_i \left[v_i(g_i(a)) - v_i(g_i(b))\right] \geq \delta \quad (2)$$

.

with $\sum k_i = 1, k_i \geq 0.05$, to filter out irrelevant criteria, and δ>0.
The proposed approach utilizes LPPs to define intervals for each ki that reflect the tender's results:

$$Fobji_{maxi} = \max(k_i) \quad (3)$$

$$Fobji_{mini} = \min(k_i) \quad (4)$$

Subject to the pre-defined rank and $\sum_i k_i = 1$, yielding intervals $[k_j^{\min}, k_j^{\max}]$.

By solving the LPPs, we narrow down the viable solution space that defines the adversary's rational basis, thereby uncovering additional insights into their intended strategy

2.4 Proposed Model Assumptions

It is important to highlight some assumptions and methodological choices. Philosophically, it mimics a natural cognitive process but within a mathematical structure, relying on the observation of choice as a powerful mechanism for social inference.

However, the approach is intended to be easily interfaced with a military intelligence domain. The approach is therefore meant to be direct and as simple as possible. Such a requirement demands simplification and a higher degree of approximation.

For instance, using a MAVT structure considers a linear criteria structure. Moreover, it also relies on a monotonic structure. Nevertheless, it allows non-linear criteria to be used in piecewise linear regions, which expands the application possibilities. The criteria are also assumed to be independent and compensatory. Thus, synergy and redundancy are aspects not considered in the model but must be dealt with beforehand in the criteria selection. Given the difference in the problem objectives, and since the choice of equipment has already been made, we adapt the general structure of multicriteria intelligence aid methodology (Frini 2017), in which the aggregation of alternative performance is carried out jointly with the handling of imperfect data.

1. Decision structuring:
   a. select the procurement object;
   b. describe the procurement criteria;
   c. obtain the alternatives included in the tender;
   d. obtain the performance of each alternative with respect to each criterion;
   e. obtain the tender result and its ranking.
2. Handling imperfect data:
   a. normalize the raw data, using different procedures for maximization and minimization criteria.
3. Linear programming:
   a. obtain scale-constant bounds in order to preserve the established ranking.
4. Risk modeling:
   a. approximate the preference function.
5. Inferences:
   a. derive inferences based on the available information;

b. produce intelligence elements (source and data used to gain knowledge about an adversary) for decision support.

Figure 1 details the proposed methodological arrangement:

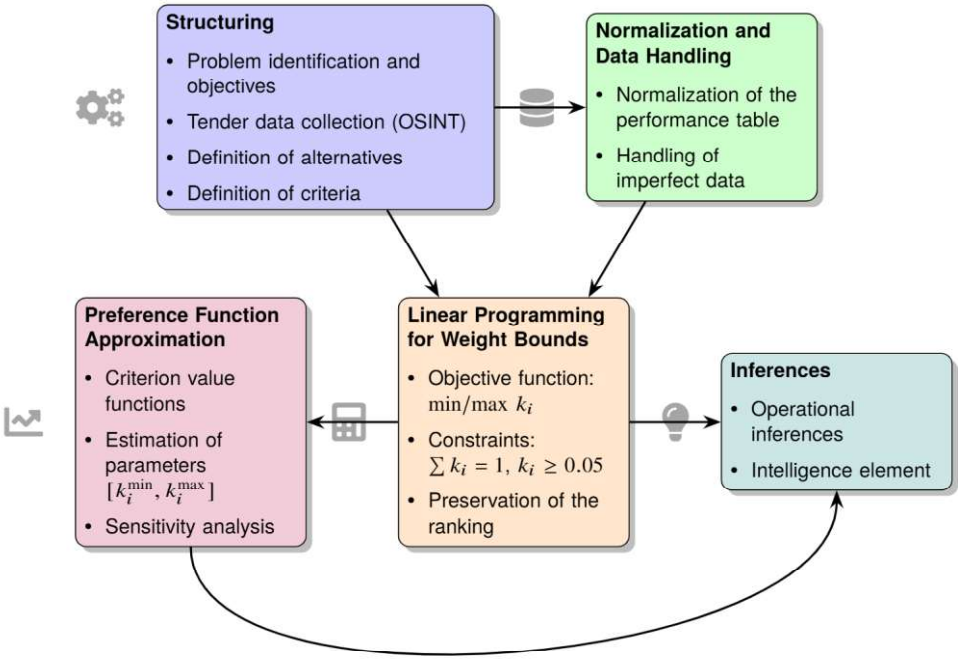

Fig. 1. Flowchart of the proposed MCDA method.

3 Application - Equipment Tenders Case Study

A case study applied to anti-tank missile systems demonstrates that the method can help identify the decision-maker's technical priorities and directly support doctrinal anticipation.

For illustration purposes, we adopt an example from (Pamučar and Dimitrijević 2021), which uses multicriteria analysis for procurement related to an anti-tank missile system, considered by the authors to be one of the most effective weapons against armored vehicles and mechanized units.

3.1 Decision Structure

3.1.1 Procurement Object

The problem is a procurement decision related to the acquisition of the Anti-Tank Ground Missile Weapon System.

3.1.2 Procurement Criteria

The criteria are as follows:

- Engagement range - meters (maximize);
- Hit probability (maximize);
- Weight - kgs (minimize);
- Cost - USD (minimize);
- Training simplicity (maximize);
- Reliability (maximize);
- Jamming resistance (maximize);
- Missile speed (maximize).

3.1.3 Alternatives Included in the Tender

The alternatives are not named in the reference (Pamučar and Dimitrijević 2021), but are designated as A1, A2, A3, and A4. Therefore, we follow the same designation.

3.1.4 Performance of Each Alternative Under Each Criterion

Table 1 presents the performance of each alternative under each criterion, according to (Pamučar and Dimitrijević 2021).

Table 1. Consequence Matrix.

	c1	c2	c3	c4	c5	c6	c7	c8
A1	3000	350	28	1000	2	3	5	115
A2	8000	950	30	5000	5	5	5	300
A3	2500	880	22	3000	4	3	4	186
A4	3500	890	25	4500	4	3	4	200

3.1.4 Tender Results and Ranking

In the work by (Pamučar and Dimitrijević 2021), two models are used. In this paper we adopt their final reported result, in which the ranking is:

$$A2 \succ A3 \succ A4 \succ A1$$

3.2 Handling Imperfect Data

3.2.1 Normalization of Raw Data

From the raw data, we normalize the consequence matrix for maximization criteria using:

$$\frac{x_i - x_{\min}}{x_{\max} - x_{\min}} \quad (5)$$

For minimization criteria:

$$\frac{x_i - x_{\max}}{x_{\min} - x_{\max}} \quad (6)$$

This yields the data shown in Table 2.

Table 2. Normalized Data.

	c1	c2	c3	c4	c5	c6	c7	c8
A1	0.091	0	0.25	1	0	0	1	0
A2	1	1	0	0	1	1	1	1
A3	0	0.883	1	0.5	0.667	0	0	0.384
A4	0.182	0.9	0.625	0.125	0.667	0	0	0.459

3.3 Linear Programming Problems for Scale Constants

From the obtained ranking, we formulate linear programming problems to obtain the maximum and minimum weights of each scale constant, with the goal of obtaining global values for the alternatives that preserve the established ranking. For each scale constant, a maximization and a minimization LP are built:

$$Fobji_{maxi} = \max(k_i) \quad (7)$$

$$Fobji_{mini} = \min(k_i) \quad (8)$$

subject to:

$$\sum_i k_i = 1 \quad (9)$$

Assuming that all criteria are relevant to the decision, it is reasonable to set a minimum scale-constant value, which we fix at 5% for this problem, with 8 criteria:

$$k_i \geq 0.05 \quad (10)$$

In order to preserve the ranking $A2 \succ A3 \succ A4 \succ A1$, the following constraints are also imposed:

$$\sum_i (k_i v_{a2i}) \geq \sum_i (k_i v_{a3i}) \geq \sum_i (k_i v_{a4i}) \geq \sum_i (k_i v_{a1i}) \quad (11)$$

Even with the artificial minimum of 5%, it remains possible to use equal weights for all scale constants. However, the maximum scale constant in this arrangement is 0.65, as each $k_i \geq 0.05$.

Thus, before solving the LPs, the feasible space of scale constants is already substantially reduced. Table 3 presents the values obtained from the linear programming runs for each objective, while Figure 2 presents the radar plot of the maximization problems shown in table 3.

Table 3. Representative extreme weights obtained from the LPs.

Obj	k1	k2	k3	k4	k5	k6	k7	k8	Obs
Max k1	0.497	0.050	0.203	0.050	0.050	0.050	0.050	0.050	A3=A4
Min k1	0.050	0.050	0.414	0.050	0.050	0.286	0.050	0.050	A2=A3
Max k2	0.050	0.650	0.050	0.050	0.050	0.050	0.050	0.050	dominance A2
Min k2	0.497	0.05	0.203	0.05	0.05	0.05	0.05	0.05	
Max k3	0.289	0.050	0.414	0.050	0.050	0.050	0.050	0.050	A2=A3
Min k3	0.457	0.107	0.050	0.186	0.05	0.05	0.05	0.05	
Max k4	0.050	0.328	0.050	0.371	0.050	0.050	0.050	0.050	A2=A3
Min k4	0.497	0.05	0.203	0.05	0.05	0.05	0.05	0.05	
Max k5	0.05	0.05	0.05	0.05	0.65	0.05	0.05	0.05	
Min k5	0.497	0.05	0.203	0.05	0.05	0.05	0.05	0.05	weights = min k4
Max k6	0.05	0.05	0.05	0.05	0.05	0.65	0.05	0.05	
Min k6	0.497	0.05	0.203	0.05	0.05	0.05	0.05	0.05	weights = min k4
Max k7	0.05	0.349	0.05	0.05	0.05	0.05	0.35	0.05	
Min k7	0.497	0.05	0.203	0.05	0.05	0.05	0.05	0.05	weights = min k4
Max k8	0.050	0.050	0.098	0.050	0.050	0.050	0.050	0.602	A3=A4
Min k8	0.497	0.05	0.203	0.05	0.05	0.05	0.05	0.05	weights = min k4

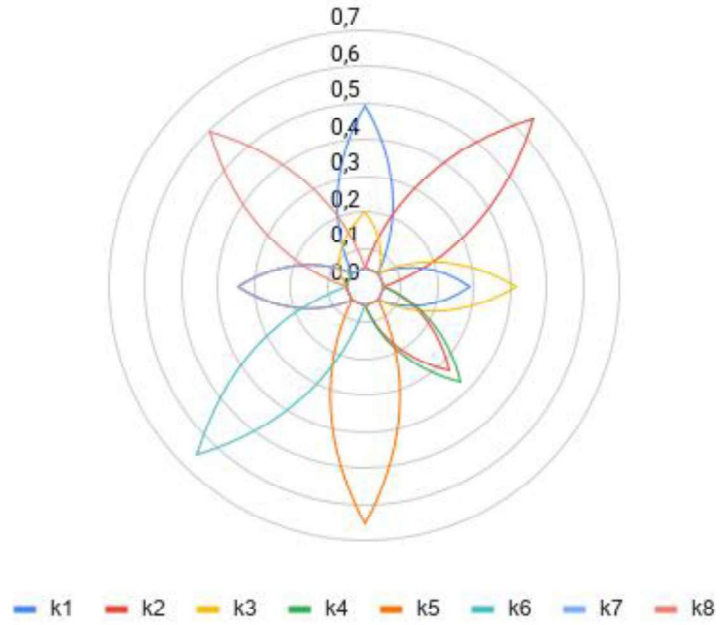

Fig. 2. Radar Plot maximization problem.

The global values of the alternatives are presented in Table 4, and Figure 3 depicts a representation of the global values of the alternatives obtained across all LPs.

Table 4. Global Value of Alternatives.

Obj	A1	A2	A3	A4	Obs
Max k1	0.196	0.747	0.325	0.325	tie between A3 and A4
Min k1	0.208	0.536	0.536	0.375	tie between A2 and A3
Max k2	0.117	0.900	0.702	0.688	
Min k2	0.196	0.747	0.325	0.325	tie between A3 and A4
Max k3	0.229	0.536	0.536	0.418	tie between A2 and A3
Min k3	0.290	0.764	0.290	0.290	tie between A1, A2, and A3
Max k4	0.439	0.578	0.578	0.439	tie between A2 and A3
Min k4	0.196	0.747	0.325	0.325	tie between A3 and A4
Max k5	0.117	0.900	0.571	0.548	
Min k5	0.196	0.747	0.325	0.325	tie between A3 and A4
Max k6	0.117	0.900	0.172	0.148	
Min k6	0.196	0.747	0.325	0.325	tie between A3 and A4
Max k7	0.417	0.900	0.436	0.417	
Min k7	0.196	0.747	0.325	0.325	tie between A3 and A4
Max k8	0.129	0.852	0.432	0.432	
Min k8	0.196	0.747	0.325	0.325	tie between A3 and A4

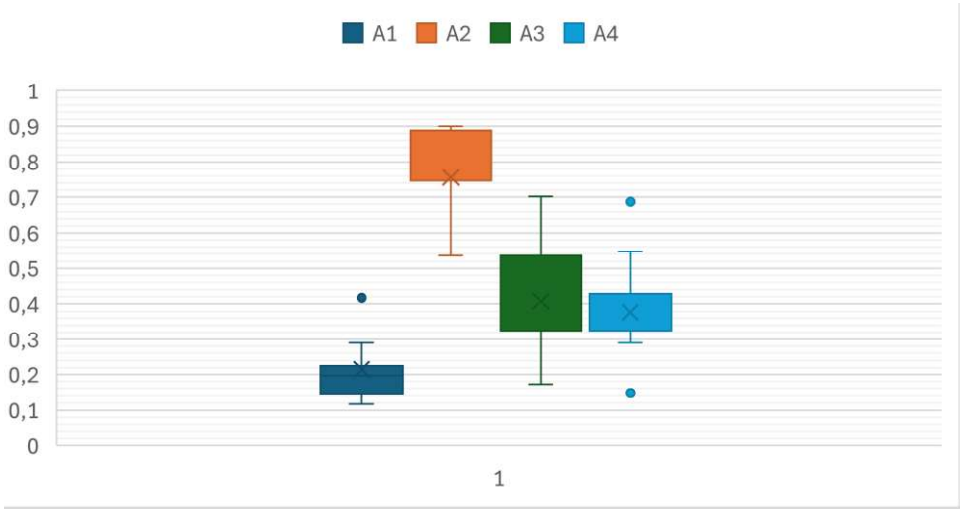

Fig. 3. Global Values obtained from the LPs.

3.4 Preference Function Approximation

After solving the LPs, the boundary values of the scale constants are obtained. With 8 criteria, there are 8! possible orderings, corresponding to 40,320 combinations. The initial space of scale constants corresponds to a rectangular area since each criterion may, before the analysis, account for the entire evaluation.

After the analysis, it is verified that three criteria (k{2},k{5},k{6}) can reach the maximum value of 0.65 in their scale constants, followed by k{8},k{1},k{3},k{4}, and k{7}, as shown in Figure 4.

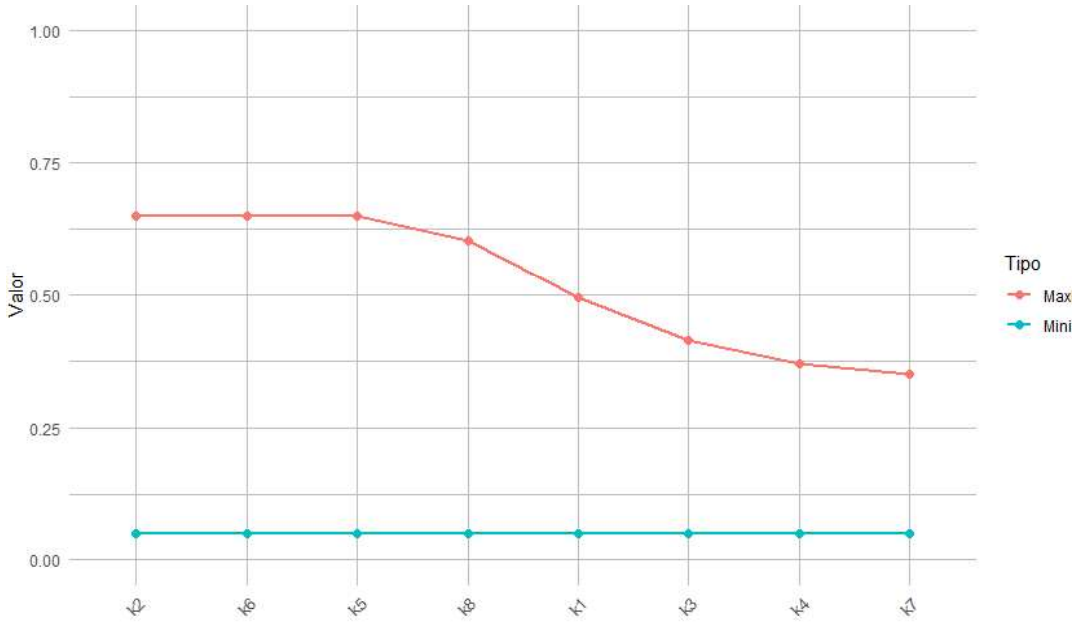

Fig. 4. Minimum and Maximum Bounds.

However, it is desirable to obtain an approximation of the adversary decision maker's preference function. We compute the approximate midpoint values of the sets. Nevertheless, normalization is required to preserve unit sum across the scale components. The approximate normalized values are shown in Table 5

Table 5. Means and normalization of the scale constants.

Criterion	Minimum	Maximum	Normalized average weight
k_1 – Maximum range	0.050	0.497	0.119
k_2 – Hit probability	0.050	0.650	0.152
k_3 – System weight	0.050	0.414	0.101
k_4 – Unit cost	0.050	0.372	0.092
k_5 – Training simplicity	0.050	0.650	0.152
k_6 – Reliability	0.050	0.650	0.152
k_7 – Jamming resistance	0.050	0.350	0.087
k_8 – Initial speed	0.050	0.602	0.142

These correspond to the following global values, using this normalized weight set:

$$A1 = 0.215, \quad A2 = 0.807, \quad A3 = 0.438, \quad A4 = 0.401.$$

The ranking $A2 \succ A3 \succ A4 \succ A1$ is preserved.

4 Discussion

An interpretation of the scale constants (k_i) represents the adversary's relative trade-off rates across criteria rather than simple importance percentages. The proposed framework transforms descriptive OSINT—such as public procurement documents—into an approximated model of the adversary's decision rationale.

The model outputs a polyhedron of feasible weight vectors rather than a single point estimate, allowing analysts to distinguish robust mathematical evidence from working hypotheses

While utilizing a secondary benchmark case study was essential for validating the underlying FITradeoff-LP formulation under controlled conditions, applying this model to primary, uncurated OSINT data introduces real-world challenges.

Public military tenders often involve incomplete disclosures, non-technical geopolitical or offset drivers, and potential strategic obfuscation. To transition to live OSINT, the framework can be expanded to handle noisy or qualitative evaluations by incorporating interval-valued matrices, non-technical criteria, and LP error or slack variables.

5 Conclusion

The problem that motivated this work lies in the absence of systematic methods for exploiting public tenders for military equipment as a source of strategic intelligence about the preferences and operational priorities of potential adversaries.

Although multicriteria decision aid methods are widely used in defense acquisition processes, the literature has not yet considered their reverse use to infer the decision maker's preference function from the observed tender ranking. The central objective was to develop an approach that would make it possible to generate actionable intelligence products using exclusively open-source data, reducing dependence on classified sources and enabling the anticipation of the opponent's doctrinal elements.

We therefore propose an original model based on the MCIA structure and the FITradeoff method for ranking problems, combined with linear programming, capable of recovering intervals of scale constants (criterion weights) that are compatible with the final tender ranking.

The methodology is organized into five stages: problem structuring from the public tender, construction of the performance table using OSINT data, normalization, application of linear programs to determine the minimum and maximum bounds of each weight, and the generation of operational and strategic inferences. This approach stands out because it does not require interaction with the decision maker, a condition that is unfeasible in hostile intelligence contexts, and because it provides robustness measures through the weight intervals.

The results obtained in the case study demonstrate the viability of the approach: it was possible to identify clear priorities: hit probability, training simplicity, and maximum range. That suggests a doctrine oriented toward engagement in light or mechanized units, with a limited perception of electronic threats.

It can, therefore, be concluded that the proposed method is a high-return and low-cost tool for open-source intelligence, with the potential for systematic application in Armed Forces intelligence centers.

The ability to transform public data into strategic knowledge about an opponent's operational priorities represents a relevant contribution to defense operations research. Future work includes longitudinal analysis of multiple tenders from the same country, the incorporation of non-compensatory methods, and integration with other OSINT sources such as satellite images of equipped units and exercise reports. Although intended for military applications, the process is also applicable to business contexts, including competition in governmental and non-governmental procurement settings.

As a limitation, the assumption of compensatory, additive, and linear rationality conditions the responses within this framework. However, since tender processes are conducted under a logic that is relatively easy to interpret and audit, such an approximation should fit a significant portion of cases. However, depending on the selected criteria, using the scales' constants, limits, and averages may not accurately represent the real preferences. Therefore, future connections to simulation can enhance the model power.

As an approximation of the decision maker's preference function, the model output must be connected to other intelligence information and remains subject to the ambiguities and imprecisions inherent in this field of activity. The model assumes consistency of the decision under a MAVT approach, which may not be true. Considering error variables in the linear programming problem can be explored in future developments for robustness purposes.

Furthermore, the case study presented here relies on data from an existing multicriteria study (Pamučar and Dimitrijević 2021) rather than on primary real-world tender. This choice was deliberate: the purpose is to demonstrate the methodological feasibility of the proposed approach using a well-documented and verifiable dataset. Applying the method to actual public military tenders, with primary data collected through OSINT, constitutes a natural next step and is identified as a priority for future research.

As future work, extending the model to non-compensatory and nonlinear multicriteria methods presents a challenge to be addressed. Another promising direction is to integrate textual OSINT sources, such as exercise reports, official statements, and specialized news alongside the numerical data from tenders.

Studies applying preference disaggregation to textual evaluations and comments suggest that multicriteria models can be calibrated from semi-structured information, opening the door to a broader Multicriteria Intelligence Aid framework that combines FITradeoff, linear programming, and natural language processing techniques. The model outputs a polyhedron of feasible weight vectors rather than a single point estimate, allowing analysts to distinguish robust mathematical evidence from working hypotheses.

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References

de Almeida, A. T., de Almeida, J. A., Costa, A. P. C. S., and de Almeida-Filho, A. T. (2016). A new method for elicitation of criteria weights in additive models: Flexible and interactive tradeoff. European Journal of Operational Research, 250(1):179–191.

de Almeida, J. A., Frej, E. A., Roselli, L. R. P., & de Almeida, A. T. (2025). Analytical aspects of combining holistic evaluation and decomposition elicitation for preference modeling in the FITradeoff method. International Transactions in Operational Research, 32(6), 3896-3937.

de Lacerda, M. M., & Cardoso, M. M. (2023). Improvement of Personnel Support to the Armed Forces Military Using FITradeoff Method. Proceedings of ICPR-Americas 2022, 314-320.

DoD. (2017). Dictionary of Military and Associated Terms. Department of Defense, Washington, DC.

Frej, E. A., de Almeida, A. T., & Costa, A. P. C. S. (2019). Using data visualization for ranking alternatives with partial information and interactive tradeoff elicitation. Operational Research, 19(4), 909-931.

Frini, A. (2017). A Multicriteria Intelligence Aid Methodology Using MCDA, Artificial Intelligence, and Fuzzy Sets Theory. Mathematical Problems in Engineering, 2017, 9281321.

Ghaderi, M., Ruiz, F., & Agell, N. (2017). A linear programming approach for learning non-monotonic additive value functions in multiple criteria decision aiding. European Journal of Operational Research, 259(3), 1073-1084.

Jacquet-Lagrèze, E., & Siskos, Y. (1982). Assessing a set of additive utility functions for multicriteria decision making: The UTA method. European Journal of Operational Research, 10(2), 151-164.

Jacquet-Lagrèze, E., & Siskos, Y. (2001). Preference disaggregation: 20 years of MCDA experience. European Journal of Operational Research, 130(2), 233-245.

Jane's Information Group. (2022). Janes Fighting Ships (2022-2023). JANES Information Group.

Jane's Information Group. (2023). Janes all the world's aircraft: in service: 2023-2024. Jane's Group UK Limited.

Jane's Information Group. (2024). Janes Weapons: Infantry 24/25. JANES Information Group.

Jern, A., Lucas, C. G., & Kemp, C. (2017). People learn other people's preferences through inverse decision-making. Cognition, 168, 46-64.

Mousseau, V., Özpeynirci, Ö., & Özpeynirci, S. (2018). Inverse multiple criteria sorting problem. Annals of Operations Research, 267(1-2), 379-412.

Oliveira, T. E. S., Pessôa, L. A. M., Frej, E. A., & Souza, A. C. (2024). A combination of FITradeoff and cognitive maps for object definition in public procurement. Pesquisa Operacional, 44, e273855.

Özpeynirci, Ö., Özpeynirci, S., & Mousseau, V. (2021). An interactive approach for inverse multiple criteria sorting problem. Journal of Multi-Criteria Decision Analysis, 28(3-4), 160-169.

Pamučar, D., & Dimitrijević, S. (2021). Multiple-criteria model for optimal Anti Tank Ground missile weapon system procurement. Vojnotehnicki glasnik, 69(4), 792-827.

Pessôa, L. A. M., & Costa, H. G. (2020). Multicriteria applied to Defence: a panorama of the scientific literature. IJCIEOM 2020.

Pessôa, L. A. M., Silva, R. C., Ferreira, R. J. P., & Costa, H. G. (2020). Proposta de aprimoramento do modelo CPC, baseado em FITradeoff durante um jogo de guerra. SBPO 2020.

Pessôa, M. E. B. T., Frej, E. A., & de Almeida, A. T. (2026). A novel information-driven approach for selecting a project portfolio: A benefit-to-cost based method combining decomposition and holistic elicitation paradigms. Omega, 139, 103456.

Roy, B., & Bouyssou, D. (1993). Aide multicritère à la décision: méthodes et cas. Economica, Paris.

Santos, A. G., Pessôa, L. A. M., Mota, C. M. M., & Frej, E. A. (2023). A FITradeoff-based approach for strategic decisions on military budget. Pesquisa Operacional, 43, e262789.

Silva, L. C., Daher, S. F. D., Santiago, K. T. M., & Costa, A. P. C. S. (2019). Selection of an Integrated Security Area for locating a State Military Police Station based on MCDM/A method. IEEE SMC 2019, 1530-1534.

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Hierarchical Sorting under Parameter Uncertainty: An Experimental Study Using MCHP, ELECTRE TRI-B, and SMAA-TRI for Freedom and Prosperity Indicators

Diogo Lima[1], Brunno Rodrigues[1], and Helder Gomes Costa[1]

[1]Universidade Federal Fluminense, Niterói RJ, Brazil

diogofls@id.uff.br, brunnoesr@id.uff.br, heldergc@id.uff.br

Abstract. Composite indicators are widely used to compare countries, yet a single point classification can conceal heterogeneous national profiles and convey a precision that the underlying model parameters do not support. This study integrates the Multiple Criteria Hierarchy Process (MCHP), ELECTRE TRI-B, and Stochastic Multi-criteria Acceptability Analysis (SMAA) to assess how robust the assignment of countries to ordered classes is when the parameters of the sorting model are uncertain. Drawing on the Atlantic Council's 2024 Freedom and Prosperity Indexes, the framework evaluates 151 countries described by 19 elementary indicators organized hierarchically under "Freedom" and "Prosperity", and reports category acceptability not only at the global level but also at each intermediate node of the hierarchy. Two experiments are conducted: the first varies the indifference, preference, and veto thresholds together with the boundary profiles while holding the weights fixed; the second additionally lets the criteria weights vary. The results show the impact of parameter uncertainty on class instability and how this impact is unevenly distributed across the levels of the hierarchy. Class acceptability is shown to be a central interpretive device for hierarchical sorting under parameter uncertainty, exposing differences in stability among countries that nonetheless share the same class.

Keywords: MCHP, ELECTRE TRI, SMAA, Composite indicator

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Prioritization of Service Orders in a Small Carpentry Workshop: An Integrated Application of Soft Systems Methodology and the PROMETHEE II Method

Lucas Guilherme Pereira de Moura[1], Luís Henrique Melo Mendes[1], Maria Clara Silva Carvalho[1], Paola Kamily Araujo Rodriguez[1], Jaini Barbosa[1] e Ricardo Pires de Souza[1]

[1]Department of Production Engineering, Federal University of Rio Grande do Norte (UFRN), Campus Universitário Lagoa Nova, Natal-RN, Brazil, 59078-970.
guilherme.pereira.163@ufrn.edu.br, luishenrique.melomendes@gmail.com, mclaracarva05@gmail.com, paola.araujo.114@ufrn.edu.br, jaini.barbosa@ufrn.edu.br

Abstract. Purpose: small make-to-order businesses face recurring and strategically sensitive decisions about the sequence in which to execute their orders. This paper addresses the prioritization of open service orders in a small carpentry workshop, where the decision was previously made in a subjective and individual manner. **Methodology:** the study integrates Soft Systems Methodology (SSM), used to structure the problem and to identify the criteria actually relevant to the decision-maker, with the PROMETHEE II multi-criteria method, which processes this information and produces a complete ranking of the alternatives; a sensitivity analysis with three alternative weight scenarios was then carried out. **Findings:** six decision criteria were structured from interviews with the manager — delay, project value, production time, input availability, service type and customer recurrence — and weighted by consensus. Applying PROMETHEE II to the twelve open orders produced a complete priority ranking in which the most valuable order, associated with the most recurrent customer, did not occupy the top positions. The sensitivity analysis confirmed the robustness of the extreme positions and revealed a pendulum alternative whose priority depends on the trade-off between revenue and production-capacity relief. **Originality/value:** the work shows, in a real micro-enterprise setting, that coupling a problem-structuring method with a compensatory outranking method turns a previously diffuse managerial doubt into a conscious, quantified strategic choice, at a very low adoption cost.

Keywords: Multi-criteria decision analysis; PROMETHEE II; Soft Systems Methodology; Service order prioritization; Production scheduling.

1 Introduction/Purpose

A.S. Móveis Planejados is a micro-enterprise specialized in the manufacture of MDF fitted furniture for residential and commercial use, established in June 2017 and located in the municipality of Macaíba, in the state of Rio Grande do Norte, Brazil. Classified as a carpentry workshop, it manufactures kitchen counters and cabinets, wardrobes and closets, desks, shelves, niches and panels, among others, and also provides furniture assembly and moving services.

Operating in a competitive market and characterized by make-to-order production, the company deals with variable demand and individualized deadlines for each order, a condition that makes the definition of the execution sequence a recurring and strategically sensitive decision. In such environments, adequate production sequencing is decisive for meeting deadlines and for operational efficiency, since inadequate decisions tend to compromise the fluidity of the entire work queue (Tubino, 2017). The complexity of these decisions is amplified by the fact that they simultaneously involve quantitative and qualitative criteria that are frequently in conflict (Almeida, 2013).

In the specific case of the studied company, the prioritization of open service orders was found to be conducted in a subjective and individual manner, based on the manager's momentary perception and without the support of a structured procedure. This practice exposes the organization to a problem reported by the manager himself: the longer a job is delayed, the higher its production cost tends to become, without the possibility of passing this increase on to the customer, since the delay is the workshop's own responsibility. Added to this is the difficulty of consistently assessing whether it is preferable to prioritize the already delayed orders, at the risk of delaying others still within their deadline, or whether factors such as project

value, production time, raw-material availability and customer relationship should weigh on the choice. The following research question is therefore posed: how can the prioritization of the workshop's service orders be structured so as to make the decision more rational and transparent?

The relevance of addressing this problem is both operational and financial. The literature shows that multi-criteria approaches provide more robust results than traditional approaches based exclusively on cost (Ho et al., 2010), and that the rational structuring of the decision process allows the trade-offs among the variables involved to be handled appropriately (Gomes et al., 2004). For ill-structured problems, in which understanding the situation precedes modelling, Soft Systems Methodology offers suitable instruments for comprehending the context and identifying the criteria that are actually relevant (Checkland, 1981), which can then be treated with the mathematical rigor of a multi-criteria method such as PROMETHEE II (Brans and De Smet, 2016).

Accordingly, the purpose of this work is to structure and apply a decision-support model, based on the integration of Soft Systems Methodology and the PROMETHEE II method, for the prioritization of the open service orders of A.S. Móveis Planejados. The specific objectives are: (i) to collect and process the company's service-order records; (ii) to structure the problem and identify, together with the manager, the criteria and preferences that guide the decision; (iii) to build the multi-criteria model, defining weights and preference functions; and (iv) to generate the priority ranking of the orders and assess its robustness through sensitivity analysis.

1.1 Theoretical Background

Multi-Criteria Decision Analysis operates within the field of Operations Research devoted to building models that structure the problem and organize the decision-maker's preferences, rather than imposing a supposedly optimal solution (Almeida, 2013). Applying this analysis in organizations makes it possible to view variables of different natures, frequently in conflict with one another, integrating them into a single evaluation model and providing greater rationality and transparency to the decision process; efficient demand management, in turn, requires information systems that transform raw data into strategic, easily accessible information (Claro, 2013). Applications range from supplier selection (Pereira et al., 2019) to the prioritization of productivity-improvement projects (Sousa et al., 2018).

Among these methods, PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) stands out in problems of ranking and prioritizing alternatives. Developed by Brans et al. (1986), it is based on pairwise comparisons, reducing the need for absolute scores. Each criterion receives a weight and a preference function that translates the performance difference between two alternatives into a preference degree between zero and one (Brans and De Smet, 2016). Brans and Mareschal (2002) propose six generalized preference functions — usual, quasi-criterion, V-shape, level, linear and Gaussian — each requiring specific parameters, such as the indifference (q) and preference (p) thresholds. From them, the positive outranking flow $\Phi^{+}(a)$, which measures the strength of each alternative, and the negative flow $\Phi^{-}(a)$, which measures its weakness, are computed; their difference yields the net flow, which defines the global performance of the alternative:

$$\Phi(a) = \Phi^{+}(a) - \Phi^{-}(a) . \quad (1)$$

While PROMETHEE I provides a partial pre-order and admits incomparability, PROMETHEE II provides a complete ordering of the alternatives from the net flow, being indicated when the decision-maker wants a total and direct prioritization (Brans and De Smet, 2016). According to Sousa et al. (2018), this characteristic makes the method particularly suitable for prioritizing demands, since it reduces ambiguities and provides consistent support to decision-making.

Defining the order in which tasks will be executed is one of the classical problems of Production Planning and Control, especially in make-to-order systems (Tubino, 2017). Sequencing rules such as the shortest processing time rule are recognized for reducing the mean flow time and the mean tardiness of orders (Pinedo, 2016), but they are based mostly on temporal criteria, neglecting qualitative dimensions that are essential for alignment with organizational strategy. Before mathematical modelling itself, therefore, complex organizational problems require a structuring stage. Soft Systems Methodology (SSM), developed by Checkland (1981), is aimed precisely at ill-structured problematic situations in which multiple perceptions and interests of the actors involved coexist, translating the perceived reality into conceptual models that guide improvement action (Checkland and Scholes, 1990). The articulation between SSM and multi-criteria methods is fruitful: the former reveals the criteria that are actually relevant, the latter provides the mathematical rigor required to process this information (Almeida, 2013).

2 Methodology

As to its nature, this research is classified as applied, since it aims to generate practical knowledge oriented to the solution of specific problems (Prodanov and Freitas, 2013). Regarding its approach, it is qualitative, since data collection and analysis seek to apprehend reality in the natural environment of the workshop, positioning the researcher as the central instrument (Gil, 2010). As for the technical procedures, the adopted design is the case study, that is, the in-depth empirical investigation of a contemporary phenomenon — the decision process of prioritizing service orders — within its real context (Yin, 2015).

The work was structured into four stages: (i) collection and processing of service-order data; (ii) structuring of the problem through SSM; (iii) construction and operationalization of the multi-criteria model through PROMETHEE II; and (iv) generation of the priority ranking and sensitivity analysis.

In the first stage, the workshop's service-order records were collected and processed, configuring documentary research based on operational records that had not yet received structured analytical treatment (Yin, 2015). Processing comprised the standardization of monetary values, the correction of status inconsistencies — reclassifying as delayed the orders whose promised date had already elapsed — and the estimation of two parameters missing from the database. Production times, not recorded by the company, were estimated from the principle stated by the manager, according to which larger and more valuable pieces require more days of production: each type of furniture was classified into duration ranges, and one day was added to items with a colored finish, owing to the need to purchase specific raw material not held in stock. The values of orders not yet commercially agreed were imputed as the median value of comparable orders of the same type and material. Both estimated parameters were subsequently validated by the manager.

In the second stage, exploratory conversations were held with the manager in order to understand the operational dynamics and the real needs of the decision-maker. In the third stage, the multi-criteria model was built and operationalized through PROMETHEE II, chosen for providing a complete ordering of the alternatives: the preference functions and the respective indifference and preference thresholds of each criterion were defined, the weights were assigned by consensus between the researchers and the manager, and the positive, negative and net outranking flows were computed through a computational routine developed by the researchers. Finally, in the fourth stage, the complete ordering was generated from the net flows and a sensitivity analysis was carried out, in which the weights of the most influential criteria were varied while keeping the relative proportion of the others.

2.1 Problem Structuring Through Soft Systems Methodology

The application of SSM followed the logic of the stages proposed by Checkland (1981), moving from the unstructured problematic situation towards its expression and the definition of the relevant systems for improving the situation. The problematic situation was expressed through a rich picture (Fig. 1), which synthesizes the actors involved, the work flow and the main tensions perceived in the workshop.

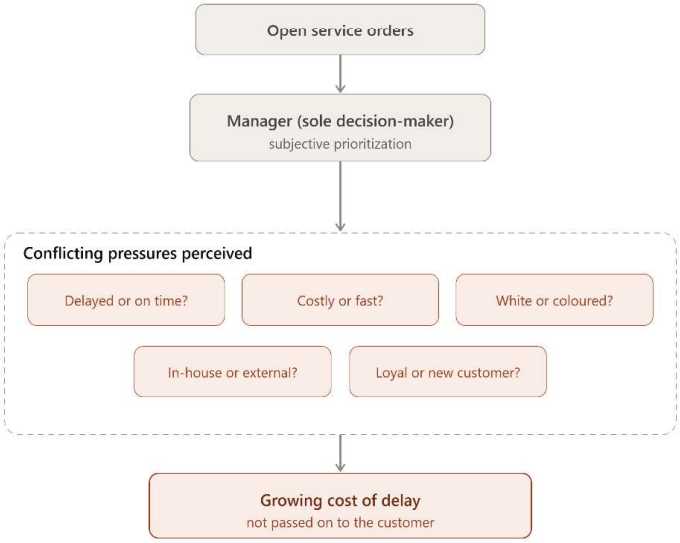

Fig. 1. Rich picture of the problematic situation. Source: prepared by the authors.

The rich picture showed that the manager, the sole person responsible for the decision, must reconcile conflicting pressures when prioritizing the production queue: the accumulation of delayed jobs, whose cost grows without the possibility of passing it on to the customer; the temptation to prioritize higher-value projects, generally larger and more time-consuming; the greater ease of producing white furniture, whose input is held in stock, compared with colored furniture, which requires specific purchasing; the distinction between in-house manufacturing services and external services, which take the manager away from the workshop; and the relationship with recurrent and new customers.

From this expression, the root definition of the relevant system was formulated: a system, operated by the manager of A.S. Móveis Planejados with the support of the researchers, intended to prioritize the open service orders through a multi-criteria model that weighs delay, value, production time, input availability, service type and customer recurrence, so as to make the decision rational and transparent and to reduce the cost of delays, respecting the capacity and raw-material constraints of the business. The elements of this definition are systematized by the CATWOE analysis presented in Table 1.

Table 1. CATWOE analysis of the problematic situation. Source: prepared by the authors.

Element	Description
C – Customers	The workshop's customers, who await delivery of their furniture, and the manager himself, who benefits from an organized production queue.
A – Actors	The manager (decision-maker) and the production team, with support from the researchers in structuring the model.
T – Transformation	Conversion of a queue prioritized subjectively and individually into a queue prioritized in a structured, rational and transparent way.
W – Worldview	The belief that a prioritization weighing delay, value, time, input, service type and relationship reduce the cost of delays and is superior to intuitive judgement.
O – Owner	The owner-manager of A.S. Móveis Planejados, with the power to adopt or discontinue the prioritization system.
E – Environment	Limited production capacity, raw-material availability (white in stock vs. colored to be purchased), promised deadlines, input-price fluctuations, and the impossibility of passing the cost of delays on to the customer.

From the conceptual model derived from the root definition — which foresees the activities of collecting the open orders, identifying and measuring the relevant criteria, weighting them, processing them and generating the prioritization — emerged the six decision criteria that structure the multi-criteria model: delay, project value, production time, input availability, service type and customer recurrence. The comparison between the

conceptual model and the practice in place at the company revealed the absence of a structured prioritization procedure, justifying the adoption of PROMETHEE II as the desirable and culturally feasible change for the problematic situation.

3 Findings

3.1 Model Application and Priority Ranking

The multi-criteria model was operationalized over the set of twelve open service orders of the workshop, evaluated according to the six criteria structured from the manager's account: delay (C1), project value (C2), production time (C3), input availability (C4), service type (C5) and customer recurrence (C6). The weights were defined by consensus between the researchers and the manager, who was asked to distribute the relative importance across the six criteria in the light of the tensions previously expressed in the rich picture; greater importance was assigned to delay and value, which correspond to the two pressures the manager had described as dominant. Table 2 summarizes the resulting structure, with the measurement scale, the direction of optimization, the weight and the preference function of each criterion.

Table 2. Criteria, weights and preference functions of the multi-criteria model. Source: research data.

Criterion	Measurement scale	Direction	Weight	Preference function
C1 – Delay	Days elapsed beyond the promised date	Maximize	28%	Linear
C2 – Project value	Agreed or imputed value of the order (R$)	Maximize	22%	Linear
C3 – Production time	Estimated days of production	Minimize	18%	Linear
C4 – Input availability	Ordinal: white (in stock) / pine / coloured (to be purchased)	Maximize	14%	Level
C5 – Service type	Binary: in-house manufacturing / external service	Maximize	8%	Usual
C6 – Customer recurrence	Ordinal: new / occasional / recurrent customer	Maximize	10%	Level

The direction assigned to C1 deserves a note: the criterion is maximized because a larger delay indicates a more urgent order, and it is the delay itself, not its desirability, that is being measured. The quantitative criteria received linear preference functions because their scales are continuous and the manager was able to describe differences in performance as gradual rather than abrupt; the ordinal criteria received level functions, which allow a plateau of indifference within the same category and a discrete jump between categories; and the binary criterion received the usual function, in which any difference in performance translates immediately into full preference. From the computation of the positive, negative and net outranking flows over this structure, the complete ordering presented in Table 3 was obtained.

Table 3. Priority ranking of the service orders (base scenario). Source: research data.

Rank	Service order	Material	Φ^+	Φ^-	Φ (net)
1	Gean – Counter	White	0.2596	0.0676	0.1919
2	Barriga – Panel + rack	White	0.2339	0.0851	0.1488
3	Poliana – Counter	White	0.2131	0.0736	0.1395
4	Mayre – Closet	White	0.2443	0.1536	0.0907
5	Mizael – Kitchen	Coloured	0.3531	0.2763	0.0768
6	Patrykson – Kitchen	White	0.1962	0.1509	0.0453
7	Natalicio – Slatted panel	Coloured	0.1656	0.2079	−0.0424
8	Wendell – Dressing table	White	0.1103	0.1849	−0.0745
9	Jean – Bedroom	White	0.1517	0.2489	−0.0972

10	Assiz – Table base	Pine	0.1315	0.2416	−0.1101
11	Herika – Desk	White	0.0983	0.2550	−0.1567
12	Redjane – 2 counters	White	0.0639	0.2760	−0.2121

The most relevant result lies not only in the ordering obtained but in what it reveals about the decision logic. The service order of highest monetary value in the set (the R$ 2,400.00 kitchen of customer Mizael), also associated with the most recurrent customer, did not occupy the first positions, but rather the fifth. Although it presented the highest positive flow ($\Phi^+ = 0.3531$), indicating that it outranks the others on several criteria, it also accumulated the highest negative flow among the well-positioned alternatives ($\Phi^- = 0.2763$), since it is a colored piece requiring the purchase of specific raw material not held in stock, and demands the longest production time in the queue (eleven days). This behavior is consistent with what the literature points out: alternatives that appear superior under a single aspect are not necessarily the most effective when all criteria are considered in a compensated manner.

Conversely, the first three positions were occupied by orders combining high delay, low production time and white material available in stock — the counters of Gean and Poliana and the panel of Barriga. In practical terms, the model recommends prioritizing fast, ready-to-execute jobs, capable of relieving the production queue and containing the cascade effect of delays, to the detriment of large and time-consuming jobs, which tend to tie up the workshop's production capacity for prolonged periods. This directly addresses the central concern expressed by the decision-maker regarding the growing cost of delayed jobs.

3.2 Sensitivity Analysis

To verify the robustness of the recommendation against variations in weight assignment, a sensitivity analysis was conducted with three alternative scenarios, keeping the relative proportion of the remaining criteria in each change. In Scenario A the weight of customer recurrence was reduced from 10% to 5%; in Scenario B the weight of production time was raised from 18% to 28%; and in Scenario C the weight of value was raised from 22% to 32%. The variations in the positions of the alternatives are illustrated in Fig. 2.

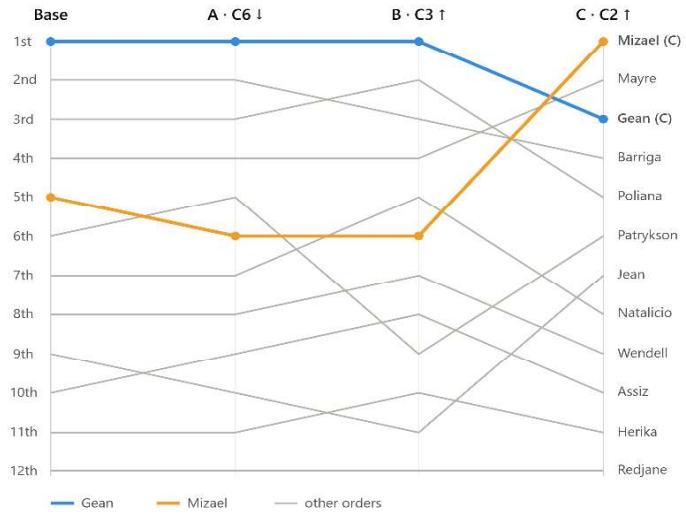

Fig. 2. Ranking shifts of the service orders across the weight scenarios. Source: research data.

Reducing the weight of recurrence (Scenario A) hardly altered the ordering, moving Mizael only from fifth to sixth position and leaving the group of the top four intact; this demonstrates that the intermediate position of the highest-value order did not stem from a bias favoring the recurrent customer. Raising the weight of production time (Scenario B) sharply penalized large and time-consuming jobs: the two kitchens in the queue moved down the ranking — Patrykson's, for example, from sixth to ninth position — while fast-executing jobs gained priority. Raising the weight of value (Scenario C), in turn, produced the opposite effect, taking Mizael's kitchen directly from fifth to first position and lowering Gean's counter to third.

From the joint analysis of the scenarios, three findings emerge. The first is the robustness of the extreme positions: Gean's counter remains the top priority in three of the four scenarios, being surpassed only when value dominates the decision, while Redjane's order invariably remains in last place. The second is the identification of a pendulum alternative: Mizael's kitchen oscillates from first to sixth position depending on the weight configuration, its priority being entirely governed by the balance between revenue (C2) and production-capacity relief (C3). The third is that this oscillation does not represent a weakness of the model, but rather the quantitative translation of a genuine strategic choice: it is up to the manager to decide, consciously, whether to prioritize immediate revenue maximization or the fluidity of the production process, a doubt that, before the modelling, remained diffuse and was resolved subjectively.

Finally, a limitation of the analyzed scope should be noted. The service-type criterion (C5) did not exert discriminating power in this application, since all open orders corresponded to in-house manufacturing services, with no assembly, moving or renovation demands in the current queue. The criterion was kept in the model structure for its conceptual pertinence and its usefulness in future rounds that include such services, but its effect on the ordering obtained was null.

4 Originality/value

The contribution of this work lies in demonstrating, in a real micro-enterprise setting rarely covered by the multi-criteria literature, that the combination of a problem-structuring method with a compensatory outranking method delivers more than a ranking. The replacement of a subjective and individual judgement by a structured recommendation made it possible to show that the alternative apparently most advantageous under a single aspect — the highest-value order, placed with the most recurrent customer — is not necessarily the most adequate when all the criteria pertinent to the business are jointly considered.

Three practical points sustain the value of the proposal. First, low adoption cost: the model runs on a spreadsheet with six criteria and previously agreed weights and preference functions, dispensing with dedicated software. Second, transparency: documenting criteria, weights and flows creates an auditable trail, so that any divergence between the model result and the manager's final choice is justified rather than hidden. Third, traceable robustness: the sensitivity analysis converted a previously diffuse doubt — immediate revenue or fluidity of the queue — into a conscious and quantified strategic choice, identifying exactly which judgement the recommendation depends on.

As for the limitations, the model was developed specifically for the reality of the studied company and cannot be fully transposed to other organizations without due adjustments. Part of the input parameters, in particular the production times and some values not yet agreed, was estimated from comparability criteria, which recommends their continuous validation with the manager. The model also presupposes an existing set of orders and represents a static snapshot of the production queue, requiring re-execution whenever this set changes. As future developments, it is suggested to structure a complementary model for evaluating the performance of customers and of the production processes themselves, to incorporate capacity constraints so as to evolve from prioritization to effective production sequencing, and to apply the approach to rounds that include external services, expanding the discriminating power of the criteria set.

References

Almeida, A.T. (2013), *Processo de decisão nas organizações: construindo modelos de decisão multicritério*. Atlas, São Paulo.

Brans, J.P., De Smet, Y. (2016), PROMETHEE methods. In: Greco, S., Ehrgott, M., Figueira, J.R. (eds.), *Multiple Criteria Decision Analysis: State of the Art Surveys*, International Series in Operations Research & Management Science, vol. 233, pp. 187-219. Springer, New York.

Brans, J.P., Mareschal, B. (2002), *PROMÉTHÉE-GAIA: une méthodologie d'aide à la décision en présence de critères multiples*. Éditions de l'Université de Bruxelles, Brussels.

Brans, J.P., Vincke, P., Mareschal, B. (1986), How to select and how to rank projects: the PROMETHEE method. *European Journal of Operational Research*, 24(2), 228-238.

Checkland, P. (1981), *Systems Thinking, Systems Practice*. John Wiley & Sons, Chichester.

Checkland, P., Scholes, J. (1990), *Soft Systems Methodology in Action*. John Wiley & Sons, Chichester.

Claro, A. (2013), *Sistemas de informações gerenciais*. 1st edn. Know How, São Paulo.

Gil, A.C. (2010), *Como elaborar projetos de pesquisa*. 5th edn. Atlas, São Paulo.

Gomes, L.F.A.M., Araya, M.C.G., Carignano, C. (2004), *Tomada de decisão em cenários complexos*. Thomson, São Paulo.

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.

Pereira, M.C.F.C., Lima, S.M.S., Mota, C.M.M., Silva, J.V. (2019), Modelo de apoio à decisão multicritério na seleção de fornecedores: um estudo de caso em uma empresa do ramo alimentício. In: *Anais do XXXIX Encontro Nacional de Engenharia de Produção (ENEGEP)*. ABEPRO, Santos.

Pinedo, M.L. (2016), *Scheduling: Theory, Algorithms, and Systems*. 5th edn. Springer, New York.

Prodanov, C.C., Freitas, E.C. (2013), *Metodologia do trabalho científico: métodos e técnicas da pesquisa e do trabalho acadêmico*. 2nd edn. Feevale, Novo Hamburgo.

Sousa, A.S., et al. (2018), Priorização de projetos de melhoria de produtividade através do método multicritério PROMÉTHÉE II. *Revista Produção Online*, 18(1), 1-25.

Tubino, D.F. (2017), *Planejamento e controle da produção: teoria e prática*. 3rd edn. Atlas, São Paulo.

Yin, R.K. (2015), *Estudo de caso: planejamento e métodos*. 5th edn. Bookman, Porto Alegre.

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Assessing wind power sites: past decisions and preference learning

Duan Vilela Ferreira[1], Ciro José Jardim de Figueiredo[2] and Caroline Mota[3]

[1]Universidade Federal de Pernambuco - Graduate Program in Management Engineering
Av. da Arquitetura, s/n - Cidade Universitária, Recife – PE, Brazil, 50740-550

[2]Universidade Federal Rural do Semi-Árido – Department of Management Engineering
Av. Transnordestina, s/n – Conjunto Universitário, Mossoró – RN, 59625-900

[3]Universidade Federal de Pernambuco - Graduate Program in Management Engineering
Av. da Arquitetura, s/n - Cidade Universitária, Recife – PE, Brazil, 50740-550

duanvilela@gmail.com, ciro.figueiredo@ufersa.edu.br, caroline.mota@ufpe.br

Abstract. Wind power has been one of the leading renewable energy sources for integration into modern power systems, especially for its cost-effectiveness and efficiency. However, current decision-support approaches for evaluating wind power sites often face limitations, including reliance on subjective parameters and high cognitive effort, which can lead to inconsistencies. Thus, this study proposes a framework based on the Dominance-Based Rough Set Approach – Preference Learning to overcome some of these limitations. The tool learns from past decisions through dominance principles and yields decision rules for sorting new sites. A case study in Rio Grande do Norte, Brazil, is presented and demonstrates reliable, explainable results obtained through an interactive process involving multiple decision-makers. The framework is flexible and can be applied to other regions and specific situations.

Keywords: wind power; rough set; preference learning; decision rules.

1 Introduction

The development of renewable energy sources (RES) has been a primary goal for countries and institutions to reduce carbon emissions and mitigate their impacts (UNFCCC 2016; Xu 2024). In this scenario, wind power is one of the best alternatives, given recent technological developments and benefits such as reduced land use and increased generation during both day and night (Spyridonidou and Vagiona 2020).

Given the relevance of this type of RES to investments and results, selecting potential sites requires considering several aspects, primarily spatial features that vary across regions, to ensure optimal operational performance of the selected sites (Rediske et al. 2021). Thus, decision models have been proposed to address this situation, often combining geographic information systems with other approaches, such as machine learning and multicriteria decision analysis (MCDA), to model climatic, technical, economic, social, and environmental attributes (Cook and Pétursson 2025). However, current solutions have limitations, including reliance on preferential parameters and centralized decision-making by a single person (Cinelli et al. 2020).

Correspondingly, this study presents a framework for addressing the previously mentioned drawbacks by applying the Dominance-Based Rough Set Approach – Preference Learning (DRSA-PL) (Greco et al. 2002; de Figueiredo and Mota 2019), which learns decision-makers' (DMs) preferences from an assessment of past decisions and applies the knowledge to new potential wind power sites (Ferreira et al. 2026).

2 Methodology

The proposed framework has three main steps. It starts with the problem formulation step, which includes setting the context and variables, defining DMs and other stakeholders, identifying and detailing the problem's objectives, and defining the set of criteria, sorting classes, and decision alternatives. Based on this previous information, spatial data on the criteria can be collected.

Next, the second step involves the creation of criteria maps and a decision matrix by the analysts, which contain the performance of the assessed alternatives on each attribute. Then each DM chooses a subset of alternatives at will and assigns each alternative to predefined classes. Based on this information, individual decision rules (if-then) are induced through DRSA-PL, and their capacity to sort the remaining areas is analyzed, namely, the quality of approximation.

The third step involves developing collective decision rules and examining each DM's level of participation in this process. Additionally, redundant decision rules are excluded, and collective sorting maps are created based on the new rules. Finally, each DM can update their individual subset and sorting, and new information is added to the collective knowledge.

3 Findings

To demonstrate the framework's effectiveness, the application was conducted in Rio Grande do Norte, Brazil, which comprised 3 DMs. In this sense, 216 project and operational sites (polygons) were defined as the set of decision alternatives. The sites' locations are defined by prior decisions that recognized them as suitable. Although this is the case, DMs are expected to differ in their suitability assessments when comparing one with another. Moreover, the DMs defined three decision classes, providing a basis for a more objective assessment. Thus, the classes have a preference order: $Cl_1 < Cl_2 < Cl_3$ where the third class represents the most suitable areas and the first the least.

Following the procedure, the set of evaluation criteria was defined as: wind speed, slope, elevation, distance from transmission lines, distance from roads, and distance from urban areas. For details on the meaning and purpose of the criteria, please see (Ferreira et al. 2026). Hence, spatial data on the criteria were collected, as exemplified in Figure 1.

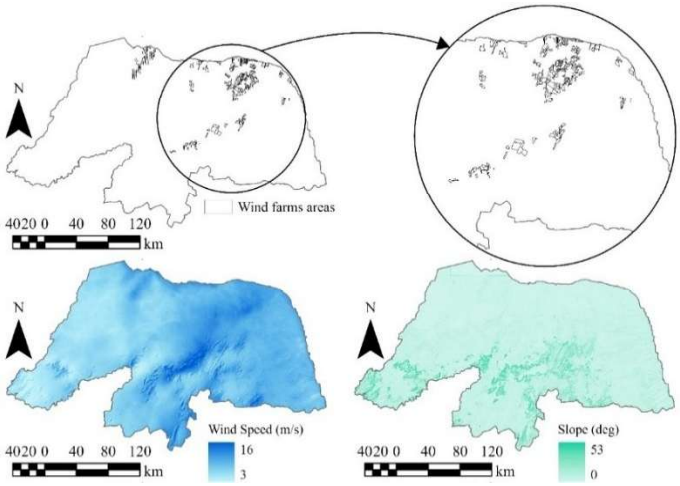

Figure 1. Assessed areas in RN and criteria maps. Source: Adapted from Ferreira et al. (2026)

At the end of the problem formulation, the performance of each polygon on the criteria was measured, forming the problem's decision matrix, as shown in the excerpt in Table 1.

Table 1. Excerpt of the decision matrix. Source: Adapted from Ferreira et al. (2026)

FID	Wind Speed (m/s)	Slope (degrees)	Elevation (m)	Dist. Trans. Lines (m)	Dist. Roads (m)	Dist. Urban Areas (m)
0	8.86	1.23	124.00	1013.16	3744.47	6838.59
1	8.22	0.45	8.00	5118.26	386.26	288.01
2	9.07	0.55	177.00	0.00	0.00	105.28
3	7.59	1.77	19.00	227.59	0.00	3288.22

By analyzing the maps (Figure 1) and the alternatives' performance on criteria (Table 1), each DM selected their individual reference examples ($a_{i,j}$) and assigned them to classes ($Cl_{t,j}$) in a holistic way. As a result of the first interaction, 39 individual decision rules were generated and analyzed for redundancy and inconsistency, as well as for the quality of approximation, as detailed in Figure 2 for the 5 interactions conducted.

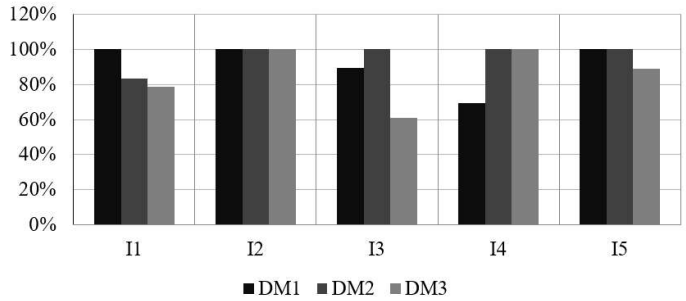

Figure 2. Individual rules' quality of approximation. Source: Adapted from Ferreira et al. (2026)

In step 3, the individual decision rules were aggregated while accounting for inconsistencies, forming collective decision rules. The 'at least' collective rules obtained from interaction one:

- If elevation ≥ 173.00 & dist_urban ≥ 6238.65 Then Class 3
- If elevation ≥ 165.00 & wind_speed ≥ 9.12 Then Class 2
- If wind_speed ≥ 8.16 & dist_roads ≤ 9.95 Then Class 3
- If slope ≤ 0.97 & wind_speed ≥ 7.87 Then Class 3
- If dist_urban ≥ 4708.91 & dist_translines ≤ 4094.89 Then Class 2
- If elevation ≥ 208.00 & slope ≤ 0.97 Then Class 3
- If elevation ≥ 199.00 & dist_urban ≥ 4708.91 Then Class 2

The collective decision rules were obtained after eliminating redundancies and aggregating the whole set. It is also important to note that the framework's results are highly interpretable, as the decision rules are fully readable by DMs and analysts, thereby easing the decision-making process. As previously mentioned, at the end of each iteration, performance indicators are measured, allowing DMs to review and discuss the results as needed. Following the procedure, the level of DMs' participation in building collective knowledge across iterations was also measured.

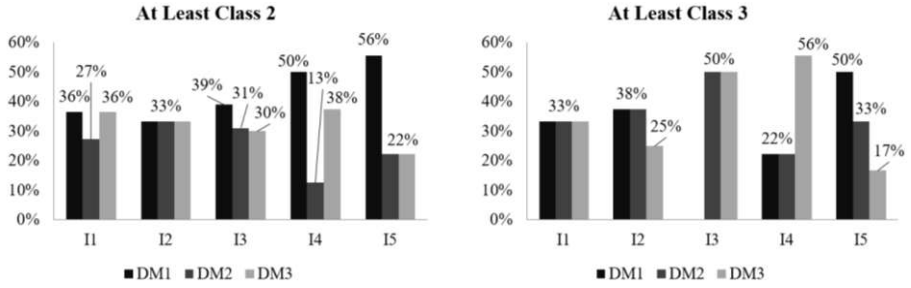

Figure 3. DMs' level of participation in collective rules. Source: Adapted from Ferreira et al. (2026)

The results demonstrate the diversity in the compositions of collective 'at least' decision rules. For instance, regarding 'at least 3', during the first iteration, all DMs had the same level (33%). On the other hand, interestingly, during the five iterations, DM1 increased the level 'at least 2'.

When comparing the collective results from interactions 1 to 5, differences emerge and highlight the construction of collective knowledge. For example, considering 'at least' rules, in the first interaction, 80% of the areas were assigned to class 3, 12% to class 2, and 8% were not sorted, meaning that the rules could not sort all the areas. On the other hand, after the fifth interaction, 71% were in class 3, 25% in class 2, and 4% were not sorted.

These variations demonstrate two facts regarding preference learning: first, the decrease in the percentage of areas not assigned to classes indicates an increase in the collective rules' coverage capacity. Second, the migration of alternatives from class 3 to class 2 reflects an increase in the discriminative power across interactions, indicating improved rule composition and more effective sorting.

4 Conclusions

This abstract presented a framework for assessing wind power sites based on past decisions and preference learning from multiple DMs, overcoming drawbacks from existing approaches.

In the Rio Grande do Norte case study (216 areas; 3 DMs; 5 iterations), the framework yielded robust results, with great individual quality-of-approximation levels (60%-100%) and a progressive increase in collective discriminative power of the rules. The share of unsorted areas decreased (from 8% to 4%), and the distribution across classes shifted, indicating this improvement.

The framework has some limitations, such as data availability and quality (spatial datasets, weather variables), and the computational structure is segmented across software (GIS, Python).

Future studies could focus on a sensitivity analysis of the results, the inclusion of environmental and social attributes, the development of a decision support system that can be integrated into GIS, and methodological advances to examine how the selection and composition of DM-labeled reference examples influence induced rules.

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References

Cinelli, M., Kadziński, M., Gonzalez, M. and Słowiński, R. 2020. How to support the application of multiple criteria decision analysis? Let us start with a comprehensive taxonomy. *Omega* 96, p. 102261. doi: 10.1016/J.OMEGA.2020.102261.

Cook, D. and Pétursson, J.G. 2025. The role of GIS mapping in multi-criteria decision analysis in informing the location and design of renewable energy projects - A systematic review. *Energy Strategy Reviews* 59. doi: 10.1016/J.ESR.2025.101765.

Ferreira, D.V., de Figueiredo, C.J.J. and Mota, C. 2026. Learning from past decisions: A framework for evaluating wind power locations. *Environmental and Sustainability Indicators* 30, p. 101260. doi: 10.1016/J.INDIC.2026.101260.

de Figueiredo, C.J.J. and Mota, C.M. de M. 2019. Learning Preferences in a Spatial Multiple Criteria Decision Approach: An Application in Public Security Planning. *International Journal of Information Technology and Decision Making* 18(4), pp. 1403–1432. doi: 10.1142/S0219622019500251.

Greco, S., Matarazzo, B. and Slowinski, R. 2002. Rough sets methodology for sorting problems in presence of multiple attributes and criteria. *European Journal of Operational Research* 138(2), pp. 247–259. doi: 10.1016/S0377-2217(01)00244-2.

Rediske, G., Burin, H.P., Rigo, P.D., Rosa, C.B., Michels, L. and Siluk, J.C.M. 2021. Wind power plant site selection: A systematic review. *Renewable and Sustainable Energy Reviews* 148. doi: 10.1016/j.rser.2021.111293.

Spyridonidou, S. and Vagiona, D.G. 2020. Systematic review of site-selection processes in onshore and offshore wind energy research. *Energies* 13(22). doi: 10.3390/en13225906.

UNFCCC. 2016. FCCC/CP/2015/10/Add.1: Paris Agreement. *United Nations (UN)* 01194(January), p. 36. Available at: http://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/FCCC_CP_2015_10_Add.1.pdf.

Xu, Z. 2024. Towards carbon neutrality in China: A systematic identification of China's sustainable land-use pathways across multiple scales. *Sustainable Production and Consumption* 44, pp. 167–178. doi: 10.1016/J.SPC.2023.12.008.

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Brazilian Oil and Gas Company CBM Project: Multicriteria Selection of BOP Component Failures

Dalessandro Soares Vianna[1], Marcilene de Fátima Dianin Vianna[1], Edwin Benito Mitacc Mezza[1], Jamile Eleutério Delesposte[2], Harvey José Santos Ribeiro Cosenza[1], Carlos Bazilio Martins[1], Eduardo Marques[1], Rodolfo Cardoso[1], Iara Tammela[1]

[1]Instituto de Ciência e Tecnologia, UFF, Rua Recife, s/n, Jardim Bela Vista, Rio das Ostras – RJ.
[2]Escola de Engenharia de Petrópolis, UFF, Rua Dom Silvério, 135, Quitandinha, Petrópolis – RJ.

dalessandrovianna@id.uff.br, marcilenedianin@id.uff.br, emitacc@id.uff.br, jamile_delesposte@id.uff.br, harveycosenza@id.uff.br, carlosbazilio@id.uff.br, emarques@id.uff.br, rodolfo_cardoso@id.uff.br, iaratammela@id.uff.br

Abstract. Blowout preventer (BOP) is a crucial tool to avoid environmental disasters and financial losses for oil and gas companies. To prevent unnecessary pulling out of BOPs and interruption of the drilling process, CBM projects are promising alternatives, which require identification and selection of appropriate data and mapping of what we aim to achieve through their monitoring, based on component failure analyses. We propose an MCDM approach, combining AHP, AHP Ratings and PROMETHEE II methods, for selecting a set of component failures to be analyzed in a BOP CBM project at Petrobras. Unlike traditional MCDM problems, the total number of failures to be selected is not predetermined; the proposed method is designed to offer strategic options to support a decision-making team in this selection process. AHP method is applied to hierarchize the problem and define the weights of criteria. AHP Ratings and PROMETHEE II methods are used to rank the alternatives. After two rounds of decisions, 293 of the 1378 available alternatives were selected by specialist team from the oil and gas industry. In addition to the MCDM method presented, an original contribution of this study is the proposition of an MCDM methodology to support decision makers in ranking alternatives, considering multiple criteria, when the number of alternatives to be selected is not known or fixed.

Keywords: Blowout preventer, AHP Ratings, AHP-PROMETHEE II.

1 Introduction

Blowout preventers (BOPs) are critical safety mechanisms installed at wellheads for deepwater drilling operations. Controlled remotely from the rig, these devices are designed to close, seal, and monitor oil and gas wells, effectively preventing blowouts – the uncontrolled and dangerous flow of oil and gas from the formation to the surface (Liu et al., 2015; Lukin et al., 2020; Martins et al., 2018). Blowouts are common in the exploration and production of oil and gas and pose severe risks to safety and the environment (Ismail et al., 2014).

The Macondo accident on April 20, 2010, starkly illustrates the potential impact of BOP failures. Triggered by a gas leak and the subsequent inability of the BOP to seal the well, this incident led to one of the largest offshore oil spills in US history, resulting in significant environmental damage and loss of life (Jaculli et al., 2022; Martins et al., 2018; Skogdalen et al., 2011). Similar incidents have occurred in the Gulf of Mexico, 1982 (Martin et al., 1983), in Brazil, 1984 (Qi and Ershaghi, 2013) and 1988 (Ismail et al., 2014), and in Australia, 2009 (Hayes, 2012), further underscoring the global challenge of managing BOP safety effectively.

In response to these significant challenges, the oil and gas industry has prioritized the development of advanced maintenance techniques. Preventive maintenance of BOPs, essential for ensuring operational continuity and safety, is carried out periodically, though it is costly and requires temporary interruption of drilling operations (Beim et al., 2023). Techniques such as Condition-Based Maintenance (CBM) and Prognostic Health Management (PHM) have been adopted to refine maintenance strategies (Jardine et al., 2006). These methods leverage real-time data and predictive analytics to optimize maintenance tasks, thereby minimizing downtime and preventing the recurrence of catastrophic failures (Beim et al., 2023; Jardine et al.,

2006). A review of literature integrating CBM and PHM with reliability concepts is presented in (Martins et al., 2018).

When developing a CBM project, it is crucial to identify and select the appropriate data to be monitored based on various operational parameters (Jardine et al., 2006). Before initiating data collection, mapping out the specific outcomes expected from monitoring this data, based on component failure analyses, is essential. This planning ensures that the most relevant and impactful data are collected.

The failure history of a company's BOPs is generally extensive, necessitating, due to financial and time constraints, the selection of only a subset of these failures for detailed analysis. To develop the most effective CBM project, it is essential that this selection process evaluates various criteria, such as technical and environmental factors. Multicriteria Decision-Making (MCDM) techniques, a specialized branch of operational research, are particularly suited for this task (Salari et al., 2018). These techniques systematically assess multiple conflicting criteria in decision-making, offering a robust framework for handling complex issues. MCDM is increasingly favored not only because it addresses both tangible and intangible aspects, which are often overlooked by traditional methods, but also because it facilitates the inclusion of diverse stakeholder perspectives in the decision-making process (Turcksin et al., 2011).

Despite the widespread potential of these decision-making techniques, few studies have focused on their application in offshore oil and gas production and exploration. For instance, the Multiattribute Utility Theory (MAUT) method has been employed to enhance investment decisions quality in oil exploration by allowing decision-makers to explicitly consider financial, environmental, and technological gains (Suslick and Furtado, 2001). Similarly, synthetic-based fluids were identified as the best drilling fluid compared to oil-based and water-based fluids, with a risk-based AHP being employed for their selection and evaluation, considering the impacts on operations, resources, economics, and liabilities (Sadiq et al., 2003).

Extending the application of MCDM methods, Carpio and Margueron (2007) concluded that prioritizing investments in oil exploration and production (E&P) requires the involvement of a multidisciplinary group to fully assess factors that could influence the generation of cash flow in international exploration projects. This insight was drawn from an analysis of ten investment opportunities in offshore exploration around the world, offered to a Brazilian oil multinational, using the MAUT method. In addition, the Multicriteria Approval (MA) method was chosen by Fowler et al. (2014) to evaluate and compare alternative decommissioning options based on environmental, financial, socioeconomic, and health and safety criteria. This method was particularly effective during the decommissioning scenario for the Grace Platform in southern California, indicating that the “leave intact” option would provide better environmental outcomes.

In (Zolotuhin and Stepin, 2019), an AHP approach was proposed to assess the risks and effectiveness of strategies for developing and ranking of potential offshore production assets in the Arctic, considering geological, economic, technological, climatic, social, and environmental criteria. AHP method was employed to evaluate different methane emission mitigation technologies for offshore oil and gas rigs, focusing on environmental, financial, and operational criteria (Barbosa et al., 2019). The proposed AHP method selected the alternative “vapor recovery from cargo tanks associated with methane reuse” as the most effective option due to its significant mitigation potential.

Moreover, in (Ardjmand and Daneshfar, 2020), an AHP model was developed for collecting, transferring and recycling drilling waste produced in the operational areas of the Iranian offshore oil company. The “collecting waste in a cutting container” was identified as a suitable option in the waste collection sector. Additionally, “waste transfers from the western Persian Gulf to Kharg Island” and “waste transfers from the eastern areas to Lavan Island” were chosen as the best options for waste transfer. “Thermal method” was selected as the most suitable waste recycling option.

AHP method was used by (Novgorodcev Jr. and Jarquín-Laguna, 2021) to rank offshore renewable technologies to support deepwater oil and gas production, considering different criteria representing technical, economic and environmental aspects of energy supply. Results showed floating offshore wind energy is the best option for the case of the Mero oil field in Brazil. Gaudencio et al. (2021) developed a MCDM system of sustainability indicators based on identified economic, environmental, social and operational impacts associated with the activities of production units. The proposed system was applied to compare the sustainability of three oil and gas production units operating in Brazilian marine environment against a benchmark considered ideal. For this comparative analysis, a hybrid MCDM approach was employed, integrating the PROMETHEE II and COPELAND methods.

Discussions in (Khalidov et al., 2023; Lima et al., 2023; Moraes et al., 2022) also focused on the topic of decommissioning. The former proposed an approach that uses continuous-time Markov chains and regret functions to find an appropriate compromise in the context of Multicriteria decision analysis, in which the decision process is modeled as a stochastic process. The authors mentioned that the proposed model avoids the shortcomings of deterministic MCDM approaches, which can result in endogenous uncertainty and

potentially compromise reliability and reproducibility. This MCDM method was applied to an oil and gas decommissioning problem that sought a responsible way to dismantle and decommission production facilities. In (Khalidov et al., 2023), AHP method was used to optimize the decommissioning process in the California offshore zone. Results suggested full removal of the steel jacket from the Hermosa platform was the best option for its decommissioning. Lima et al. (2023) proposed a MCDM method, which combines the Stochastic Multicriteria Acceptability Analysis (SMAA) technique and the Exponential TODIM (ExpTODIM) method, as an approach capable of incorporating the uncertainties of the decision makers' zones of ignorance and the approximations of alternative assessments of a complex decommissioning problem, which involves institutional decision makers with different incentive instruments.

The AHP method, consulted by a specialist team in (Peecock et al., 2022), identified ideal fields for coupling with offshore wind energy, which could facilitate large-scale renewable hydrogen production and storage. The results obtained will be used as inputs for modeling future energy systems, optimizing potential synergies between the offshore oil and gas and renewable energy sectors. Lastly, in (Oliveira et al., 2024), a hybrid MCDM method using the Preference Selection Index (PSI) method and the Combined Compromise Solution (CoCoSo) method was applied to support the selection of aircraft for aero-medical rescue operations in an offshore company, resulting in the choice of the S-92 (OMNI) and the AW139 (BRISTOW) as preferred options.

The objective of this study is to propose a MCDM approach for selecting a set of component failures to be analyzed in a BOP CBM project at Petrobras, the Brazilian oil and gas company. Unlike traditional MCDM problems, the total number of failures to be selected is not predetermined; the proposed method is designed to offer strategic options to support a decision-making team in this selection process.

Three different MCDM methods, Analytic Hierarchy Process (AHP), AHP Ratings and Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) II, compose the proposed method. Those methods were chosen due to their easy applicability to large-scale and complex decision problems involving multiple criteria and subjective evaluations (Sennaroglu and Celebia, 2018) and their simplicity compared to other MCDM methods (such as TOPSIS, VIKOR and ELECTRE) (Sari et al., 2020). AHP is used to structure the decision problem and assign weights to the criteria, while AHP Ratings, a multi-attribute utility method, and PROMETHEE II, an outranking method, are used to generate a final ranking of alternatives. The aim of using methods with distinct features is to obtain different rankings of alternatives, which will be analyzed to detect commonalities, ultimately supporting the definition of the set of component failures to be selected.

The original contributions stemming from this study are as follows:

- The development of an AHP Ratings method and a hybrid AHP-PROMETHEE II method for selecting a set of component failures to be analyzed in a BOP CBM project.
- The creation of a MCDM methodology to support decision makers in ranking alternatives, considering multiple criteria, even when the number of alternatives to be selected is unknown or not fixed.

The remainder of this article is structured as follows. Section 2 discusses the theoretical background, detailing the used MCDM methods: AHP, AHP Ratings and PROMETHEE II. The proposed method is described in Section 3. Section 4 clarifies the purpose of the study, how the problem is solved and discusses the results. Section 5 contains concluding remarks.

2 Theoretical Framework

2.1 AHP Ratings

The Analytical Hierarchy Process (AHP) method was developed by Saaty (1980; 2008) and is one of the most widely applied MCDM methods for calculating weights based on pairwise comparison judgments (Mohammadi et al., 2023). AHP method is based on three principles: (i) construction of a hierarchical structure, (ii) definition of priorities and (iii) logical consistency (Zhang et al., 2023). The hierarchical structure is established with at least three levels: the objective at the top, the criteria (and sub-criteria) at the intermediate levels and the alternatives considered at the bottom.

The traditional AHP method has the disadvantage that the number of pairwise comparisons to be made can become large (more specifically: $n(n-1)/2$) depending on the number n of alternatives (Wang and Yang, 2007). For this case, Saaty (2008) presented a method of prioritizing alternatives, known as AHP ratings, which establishes a rating scale for each criterion and prioritizes each level of the scale through pairwise comparison. Afterwards, the alternatives are evaluated using these scales independently (Andrade et al.,

2019). The global priority of an alternative i (g_i) is defined by Equation 1, where w_j represents the weight of criterion j and r_{ij} represents the rating score of alternative i with respect to criterion j.

$$g_i = \sum_{j=1}^{n} w_j r_{ij} \quad (1)$$

The structuring of the decision hierarchy and the assignment of weights to the criteria (and sub-criteria, if any) are carried out in the same way as in AHP method (Saaty, 2008).

2.2 PROMETHEE II

The PROMETHEE II method, like any other method in the PROMETHEE family, requires two components for each criterion, a weight value, and a preference function. The weight value defines the contribution rate of each criterion to the total suitability and can be determined according to various methods (Sari et al., 2020). Preference functions were used to scale decisions into a preference ranging from 0 to 1. Six basic types of preference function are proposed to the decision maker to ease selection of the preference function (Dağdeviren, 2008): usual function, U-shaped function, V-shaped function, level function, linear function, and Gaussian function. In each case, a maximum of two parameters is required to be set.

In the PROMETHEE II method, a preference index $\pi(a,b)$ of a over b is defined (Equation 2), using the weight (w_i) and the preference function – $P_i(a,b)$ – of each criterion i, which considers all k criteria.

$$\pi(a,b) = \frac{\sum_{i=1}^{k} w_i P_i(a,b)}{\sum_{i=1}^{k} w_i} \quad (2)$$

The leaving flow $\phi^+(a)$, Equation 3, is the measure of the outranking character of a (how a dominates all the other alternatives of A – A is the set of all alternatives under analysis). Symmetrically, the entering flow $\phi^-(a)$, Equation 4, gives the outranked character of a (how a is dominated by all the other alternatives of A). $\phi(a)$, Equation 5, represents a value function, whereby a higher value reflects a higher attractiveness of alternative and is called net flow (Dağdeviren, 2008).

$$\phi^+(a) = \sum_{x \in A} \pi(a,x) \quad (3)$$
$$\phi^-(a) = \sum_{x \in A} \pi(x,a) \quad (4)$$
$$\phi(a) = \phi^+(a) - \phi^-(a) \quad (5)$$

In PROMETHEE II method, the alternative a outranks the alternative b whether $\phi(a) > \phi(b)$. If $\phi(a) = \phi(b)$, we say that a is indifferent to b.

3 Method

The proposed MCDM approach received as input a set of 1378 groups of BOP component failures, representing the set of possible alternatives for the problem. A group of component failures consists of failures that occurred in the same component and share the same:

- Failure Mode – represents the ways in which a failure occurs. It can be categorized into three types (ISO 14224, 2016): (i) required function is not obtained; (ii) deviation from the required function (performance specifications); and (iii) failure indication is observed, but there is no immediate or critical impact on the required function. An example is “internal packing element leak”.
- Failure Mechanism – represents physical, chemical, electrical, thermal or other processes that result in failure. An example is “mechanical failure (deformation)”.
- Failure cause – refers to the circumstances relating to design, manufacture or use that lead to a failure. An example is “maintenance error”.

The set of 1378 alternatives was defined and validated with specialists from Petrobras and two Drilling Contractors. It represents failures of the components “Blind Shear Ram” (BSR), “Annular Preventer”, “Manual Koomey Regulator” (MKR), “Hydraulic Koomey Regulator” (HKR), “Compensated Chamber Solenoid Valve” (CCSV), “Tubing” and “Hoses”.

The proposed MCDM approach is depicted in Fig. 1 and its steps will be described in Sections 3.1– 3.6. AHP method is used to assign weights to criteria and sub-criteria. Given the high number of 1378 alternatives, traditional AHP method is not recommended for ranking them (Wang and Yang, 2007). Therefore, two other methods, AHP Ratings and PROMETHEE II, were used for this purpose. Their results were graphically overlaid and, with the support of specialists from academia and the oil and gas industry, a subset of alternatives was returned as output of the proposed method.

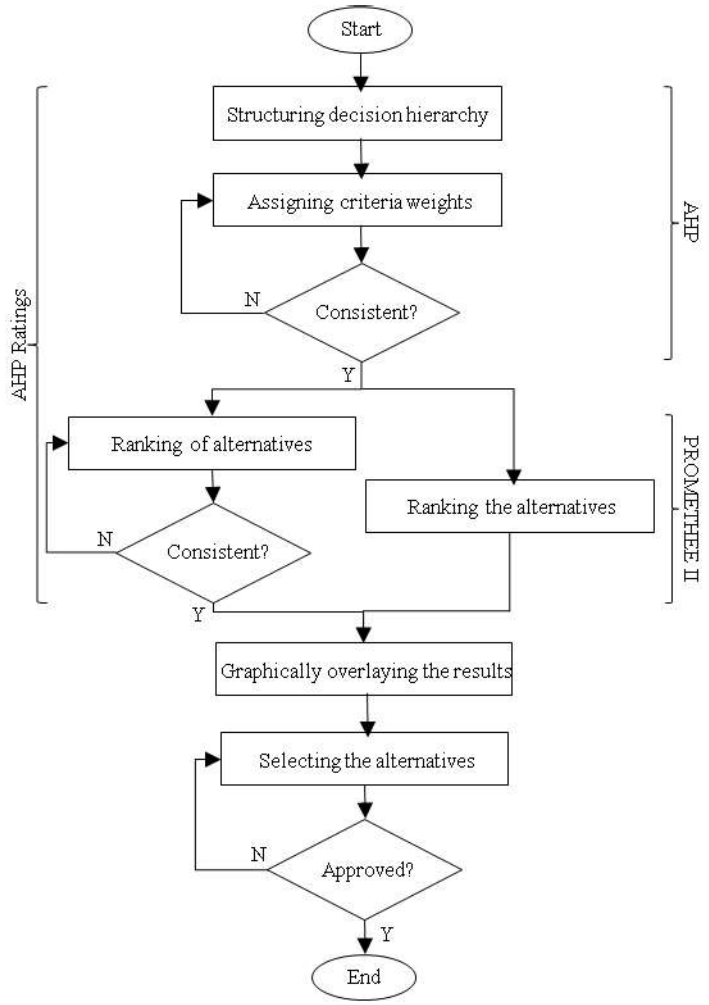

Fig. 1. Proposed MCDM method.

3.1 Structuring decision hierarchy

A team of scholars and oil and gas industry specialists was assembled to define criteria to be used in the proposed MCDM method. Initially, each specialist, based on their area of expertise, proposed criteria. A total of 41 possible criteria were initially proposed. These criteria were then collectively analyzed by all specialists and some aspects were observed to consolidate the proposals: (i) the analysis and selection would be based on an extensive set of alternatives, making an individualized and qualitative assessment of each alternative prohibitive; (ii) the criteria should be suitable for "automated" analysis, meaning the decision matrix should be derived from quantitative or qualitative data identifiable through automatic programming routines; and (iii) the 41 criteria should be grouped into five main perspectives defined as important for analyzing alternatives, which are: (a) sensing and monitoring of the group of component failures, (b) predictive capacity of the group of component failures, (c) criticality, (d) propagation following failures, and (e) probabilities and occurrences. This criteria grouping was based on the Failure Modes, Mechanisms and Effects Analysis (FMMEA) methodology, aligning the dimensions with the Risk Priority Number (RPN) (Pecht and Gu, 2009).

Ten evaluation criteria were consolidated and structured in the decision hierarchy presented in Fig. 2, where C1, C2, and C3 are criteria and represent, respectively, “Detectability”, “Criticality/severity” and “Accountability/ occurrence”. The sub-criteria of the “Detectability” criterion are “Sensing/monitoring capacity” (C1.1), “Possibility of prognosis of the failure mode” (C1.2), and “Ability to manage the failure of the base event of the group of component failures” (C1.3). “Impact of the mechanism on functional failures” (C2.1), “Propagation capacity” (C2.2), “Number of associated base events” (C2.3), and “Association of failure mode with BOP pull” (C2.4) are the sub-criteria of criterion “Criticality/severity”. The “Accountability/occurrence” criterion has “Evaluation of average times to failure” (C3.1), “Evaluation of failure frequencies” (C3.2) and “Evaluation of average repair times” (C3. 3) as sub-criteria. A1 – A1378 are the alternatives.

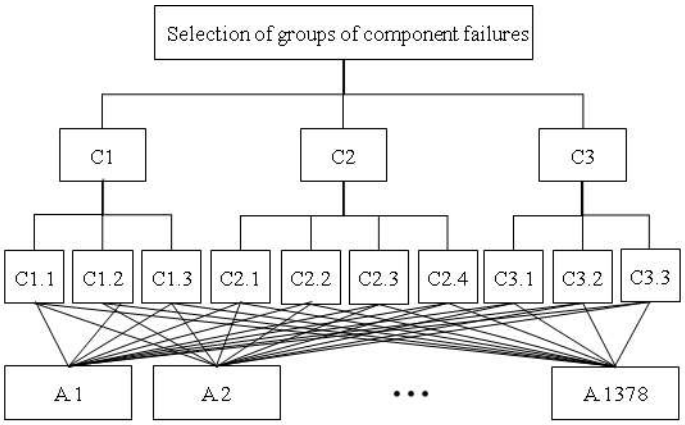

Fig. 2. Hierarchical decision tree.

3.2 Assigning criteria weights

At this stage, the same team of scholars and oil and gas industry specialists that defined the structure of the decision hierarchy (Section 3.1) was utilized. This team also participated in alternative ranking steps (Sections 0 and 0). For all these instances, the team met in person to make decisions.

Criteria and sub-criteria weights were calculated according to AHP procedure using the main criteria pairwise comparison matrix, Table 1(a), and three pairwise comparison matrices, Table 1(b), Table 1(c) and Table 1(d), for sub-criteria defined by consensus of the specialist team. The consistency ratio of each comparison matrix used was less than 10%, which is considered acceptable (Saaty, 1980).

Table 1. AHP pairwise comparison matrices for criteria and sub-criteria.

	C1	C2	C3
C1	1	3	4
C2	1/3	1	3
C3	1/4	1/3	1

(a)

	C1.1	C1.2	C1.3
C1.1	1	4	4
C1.2	1/4	1	2
C1.3	1/4	½	1

(b)

	C2.1	2.2	C2.3	C2.4
C2.1	1	2	1/2	1/7
C2.2	1/2	1	1	1/5
C2.3	2	1	1	1/4
C2.4	7	5	4	1

(c)

	C3.1	3.2	C3.3
C3.1	1	1	3
C3.2	1	1	3
C3.3	1/3	1/3	1

(d)

After applying the AHP method to the matrices in Table 1, the “Detectability” criterion was the most preferred (61.40%), followed by the “Criticality/severity” (26.80%) and “Accountability/occurrence” (11.80%). Global priorities for each sub-criterion were calculated as follows: C1.1 – 40.60%; C1.2 – 12.79%; C1.3 – 8.06%; C2.1 – 3.02%; C2.2 – 2.77%; C2.3 – 4.13%; C2.4 – 16.91%; C3.1 – 5.02%; C3.2 – 5.02%; and C3.3 – 1.67%.

Expert Choice decision-making software was used to execute the AHP method and to perform pairwise comparisons of the AHP Ratings method, which will be detailed in Section 0.

3.3 AHP Rantings for ranking the alternatives

AHP Ratings method is an AHP mode designed for problems with many alternatives (Saaty, 1980). Its use in this study is feasible because each sub-criteria to be analyzed has a scale of possible assigning values. However, it is necessary to apply the AHP Ratings method separately for each component of the problem – BSR, Annular, MKR, HKR, CCSV, Tubing, and Hoses – since the same criterion may have different rating scales for distinct components. For example, considering sub-criterion C3.2 (Evaluation of failure frequencies), rating scales 1, 2, 3, and 4 were defined for the Annular, BSR, and CCSV components, whereas rating scales 1 and 2 were defined for the HKR, Hoses, MKR and Tubing components.

To demonstrate the application of the AHP Ratings method in the present study, the ranking of the 162 groups of component failures (alternatives) of the Annular component will be detailed. Table 2 presents the first 10 alternatives, for the Annular component, showing the rating scale values associated with each criterion.

Table 2. Details of the first 10 alternatives of the Annular component – rating scale values.

ID	C1.1	C1.2	C1.3	C2.1	C2.2	C2.3	C2.4	C3.1	C3.2	C3.3
1	0	0	0	3	1	1	1	3	2	2
2	0	0	0	1	1	1	1	3	2	2
3	1	1	1	1	1	1	1	3	2	2
4	0	1	0	1	1	1	1	3	2	2
5	0	0	0	1	1	1	1	3	2	2
6	1	1	0	4	0	0	1	4	2	1
7	1	1	0	3	0	0	1	4	2	1
8	1	1	1	4	1	1	3	3	2	4
9	1	1	1	4	1	1	3	3	2	4
10	1	1	1	4	0	1	3	3	2	4

Table 3 presents, for the Annular Component, ten pairwise comparison matrices of the rating scale values associated with each sub-criterion, which were defined by consensus of the specialist team. After this step, the rating scores were established. **Erro! Fonte de referência não encontrada.** presents, for each sub-criterion, its orientation (maximization or minimization), the rating scale values of each component, and the rating score associated with each rating scale value (in parentheses).
Table 5 displays the first 10 alternatives of the Annular component, as presented in Table 2, after calculating the rating scores. The global priority of each alternative is defined by Equation 1.

3.4 PROMETHEE II for ranking the alternatives

To implement the PROMETHEE II method, the Visual PROMETHEE software was used, which has already been cited in almost 2500 articles (Sikalo et al., 2023).

As mentioned in Section 2.2, the application of the PROMETHEE II method requires two components for each criterion: a weight value and a preference function. The weights of the criteria and sub-criteria of the addressed problem were calculated using the AHP method (Saaty, 1980).

Preference functions were then defined based on the nature of each criterion and the viewpoint of the specialist team. The V-shaped preference function was chosen because the problem's sub-criteria were defined by rating scale values and, according to (Turcksin et al., 2011), the PROMETHEE guidelines recommend using a linear preference function for quantitative assessments. The preference functions and thresholds for each evaluation sub-criterion are presented in

To further compare the methods, we plotted the alternative ranked sets on line graphs. We observed regions in the graph where the difference between consecutive alternatives was small, making the line curve smoother – we called these flat regions. Conversely, there were regions where this difference was more prominent – we called these slope regions.

Fig. 3 presents the ranked sets of 133 alternatives of the CCSV component obtained by AHP Ratings and PROMETHEE II methods. Arrows in

Fig. 3 and gray lines in **Erro! Fonte de referência não encontrada.** highlight the slope regions. When considering flat and slope regions, both methods showed similar behavior. The same pattern was observed when the other components were analyzed (Fig. 4).

When we analyzed the flat regions, we perceived inversions in the alternative ranked sets obtained by AHP Ratings and PROMETHEE II methods. This fact not surprising because the alternatives in these regions had similar evaluations, making it normal for methods with very different characteristics to classify them distinctly. However, when we analyzed the slope regions, we realized the alternatives preceding these regions were the same (with changes in ranking position) in both methods. This was understandable because, in slope regions, the difference between consecutive alternatives was prominent. Even different methods, configured by the same specialist team, tended not to invert these alternatives. In **Erro! Fonte de referência não encontrada.** it is possible to verify that the 12 alternatives preceding Alternative 13 (first slope region) are the same; the same occurs with the 20 alternatives preceding Alternative 21 (second slope region) and with the 24 alternatives preceding Alternative 25 (third slope region).

Table 6.

After calculating the weights and defining the preference functions of the sub-criteria, the method described in Section 2.2 was applied to generate a ranking of the alternatives. Like the application of the AHP Ratings method (Section 0), the six components had to be treated separately due to preference functions that could vary from component to component.

Table 3. **Pairwise comparison matrices of sub-criteria rating scale values.**

C1.1	0	1
0	1	1/9
1	9	1

(a)

C1.2	0	1
0	1	1/9
1	9	1

(b)

C1.3	0	1
0	1	1/9
1	9	1

(c)

C2.1	1	2	3	4
1	1	1/2	1/3	1/4
2	2	1	1/2	1/3
3	3	2	1	1/2
4	4	3	2	1

(d)

C2.2	0	1	2	3
0	1	2	3	4
1	1/2	1	2	3
2	1/3	1/2	1	2
3	1/4	1/3	1/2	1

(e)

C2.3	0	1
0	1	1/9
1	9	1

(f)

C2.4	1	2	3	4
1	1	1/2	1/3	1/4
2	2	1	1/2	1/3
3	3	2	1	1/2
4	4	3	2	1

(g)

C3.1	1	2	3	4
1	1	2	3	4
2	1/2	1	2	3
3	1/3	1/2	1	2
4	1/4	1/3	1/2	1

(h)

C3.2	1	2	3	4
1	1	1/2	1/3	1/4
2	2	1	1/2	1/3
3	3	2	1	1/2
4	4	3	2	1

(i)

C3.3	1	2	3	4
1	1	1/2	1/3	1/4
2	2	1	1/2	1/3
3	3	2	1	1/2

4	4	3	2	1
		(j)		

3.5 Graphically overlaying the results

AHP Ratings and PROMETHEE II methods, presented respectively in Sections 0 and 0, resulted in the ranking of the 1378 alternatives. Each method generated (i) a set of 162 alternatives for the Annular component, (ii) a set of 263 alternatives for the BSR, (iii) a set of 133 for the CCSV, (iv) a set of 311 for the HKR, (v) a set of 83 for Hoses, (vi) a set of 336 for MKR and (vii) a set of 90 alternatives for the Tubing component. AHP Ratings method returned the seven sets in decreasing order by the global priority value (Equation 1). The PROMETHEE II method returned the seven sets in decreasing order by the net flow value $\phi()$ – Equation 5.

To compare the results of AHP Ratings and PROMETHEE II methods, we initially analyzed whether there was similarity in the ranking sets generated. **Erro! Fonte de referência não encontrada.** presents the first 25 (out of 133) alternatives from the set obtained by the two methods for the CCSV component. It is possible to observe rankings are different and there are some coincidences – 11 out of 25. However, there are quite a few distinctions such as, for example, Alternative 1 which was ranked in the sixth position using the AHP Ratings method but occupied the eleventh position in the PROMETHEE II ranking. Similar behaviors were detected when the other six components were analyzed.

Table 4. Rating scores calculated for each sub-criterion/component.

Criteria	Rating scores
C1.1(max)	All components: 0 (0.11), 1 (1.00)
C1.2(max)	All components: 0 (0.11), 1 (1.00)
C1.3(max)	All components: 0 (0.11), 1 (1.00)
C2.1(max)	Annular: 1 (0.20), 2 (0.34), 3 (0.59), 4 (1.00)
	BSR, Hoses: 1 (0.11), 2 (0.17), 3 (0.27), 4 (0.42), 5 (0.66), 6 (1.00)
	CCSV: 1 (0.30), 2 (0.55), 3 (1.00)
	HKR, MKR: 1 (0.07), 2 (0.10), 3 (0.15), 4 (0.22), 5 (0.32), 6 (0.48), 7 (0.71), 8 (1.00)
	Tubing: 1 (0.09), 2 (0.13), 3 (0.19), 4 (0.30), 5 (0.45), 6 (0.69), 7 (1.00)
C2.2(min)	All components: 0 (1.00), 1 (0.59), 2 (0.34), 3 (0.20)
C2.3(max)	All components: 0 (0.11), 1 (1.00)
C2.4(max)	Annular, BSR, CCSV, HKR, MKR: 1 (0.20), 2 (0.34), 3 (0.59), 4 (1.00)
	Hoses, Tubing: 1 (0.11), 2 (1.00)
C3.1(min)	Annular: 1 (1.00), 2 (0.59), 3 (0.34), 4 (0.20)
	BSR, CCSV, HKR, MKR: 1 (1.00), 2 (0.55), 3 (0.30)
	Hoses, Tubing: 1 (1.00), 2 (0.11)
C3.2(max)	Annular, BSR, CCSV: 1 (0.20), 2 (0.34), 3 (0.59), 4 (1.00)
	HKR, Hoses, MKR, Tubing: 1 (0.11), 2 (1.00)
C3.3(max)	Annular, BSR: 1 (0.20), 2 (0.34), 3 (0.59), 4 (1.00)
	CCSV, HKR, MKR: 1 (0.30), 2 (0.55), 3 (1.00)
	Hoses, Tubing: 1 (0.11), 2 (1.00)

Table 5. Details of the first 10 alternatives of the Annular component – rating scores.

ID	C1.1	C1.2	C1.3	C2.1	C2.2	C2.3	C2.4	C3.1	C3.2	C3.3
1	0.11	0.11	0.11	0.59	0.59	1.00	0.20	0.34	0.34	0.34
2	0.11	0.11	0.11	0.20	0.59	1.00	0.20	0.34	0.34	0.34
3	1.00	1.00	1.00	0.20	0.59	1.00	0.20	0.34	0.34	0.34
4	0.11	1.00	0.11	0.20	0.59	1.00	0.20	0.34	0.34	0.34
5	0.11	0.11	0.11	0.20	0.59	1.00	0.20	0.34	0.34	0.34
6	1.00	1.00	0.11	1.00	1.00	0.11	0.20	0.20	0.34	0.20
7	1.00	1.00	0.11	0.59	1.00	0.11	0.20	0.20	0.34	0.20

8	1.00	1.00	1.00	1.00	0.59	1.00	0.59	0.34	0.34	1.00
9	1.00	1.00	1.00	1.00	0.59	1.00	0.59	0.34	0.34	1.00
10	0.11	0.11	0.11	0.59	0.59	1.00	0.20	0.34	0.34	0.34

To further compare the methods, we plotted the alternative ranked sets on line graphs. We observed regions in the graph where the difference between consecutive alternatives was small, making the line curve smoother – we called these flat regions. Conversely, there were regions where this difference was more prominent – we called these slope regions.

Fig. 3 presents the ranked sets of 133 alternatives of the CCSV component obtained by AHP Ratings and PROMETHEE II methods. Arrows in
Fig. 3 and gray lines in **Erro! Fonte de referência não encontrada.** highlight the slope regions. When considering flat and slope regions, both methods showed similar behavior. The same pattern was observed when the other components were analyzed (Fig. 4).

When we analyzed the flat regions, we perceived inversions in the alternative ranked sets obtained by AHP Ratings and PROMETHEE II methods. This fact not surprising because the alternatives in these regions had similar evaluations, making it normal for methods with very different characteristics to classify them distinctly. However, when we analyzed the slope regions, we realized the alternatives preceding these regions were the same (with changes in ranking position) in both methods. This was understandable because, in slope regions, the difference between consecutive alternatives was prominent. Even different methods, configured by the same specialist team, tended not to invert these alternatives. In **Erro! Fonte de referência não encontrada.** it is possible to verify that the 12 alternatives preceding Alternative 13 (first slope region) are the same; the same occurs with the 20 alternatives preceding Alternative 21 (second slope region) and with the 24 alternatives preceding Alternative 25 (third slope region).

Table 6. Preference functions.

Criteria	Preference functions
C1.1(max)	All components: V-shaped function (p = 0)
C1.2(max)	All components: V-shaped function (p = 0)
C1.3(max)	All components: V-shaped function (p = 0)
C2.1(max)	Annular: V-shaped function (p = 3)
	BSR, Hoses: V-shaped function (p = 5)
	CCSV: V-shaped function (p = 2)
	HKR, MKR: V-shaped function (p = 7)
	Tubing: V-shaped function (p = 6)
C2.2(min)	All components: V-shaped function (p = 3)
C2.3(max)	All components: V-shaped function (p = 0)
C2.4(max)	Annular, BSR, CCSV, HKR, MKR: V-shaped function (p = 3)
	Hoses, Tubing: V-shaped function (p = 0)
C3.1(min)	Annular: V-shaped function (p = 3)
	BSR, CCSV, HKR, MKR: V-shaped function (p = 2)
	Hoses, Tubing: V-shaped function (p = 0)
C3.2(max)	Annular, BSR, CCSV: V-shaped function (p = 3)
	HKR, Hoses, MKR, Tubing: V-shaped function (p = 0)
C3.3(max)	Annular, BSR: V-shaped function (p = 3)
	CCSV, HKR, MKR: V-shaped function (p = 2)
	Hoses, Tubing: V-shaped function (p = 0)

Table 7. 25 first alternatives from the ranked sets obtained by the AHP Ratings and PROMETHEE II methods for the CCSV component.

Ranking	AHP Ratings		PROMETHEE II	
	Alternative ID (i)	Global priority (g_i)	Alternative ID (i)	Net flow - $\phi(i)$
1	31	0,85	31	70,44
2	32	0,84	32	69,21
3	33	0,84	33	69,21
4	19	0,83	80	67,69
5	20	0,83	19	67,20

6	1	0,82	20	67,20
7	80	0,81	79	66,47
8	79	0,80	81	66,47
9	81	0,80	89	66,47
10	89	0,80	91	66,47
11	91	0,80	1	65,19
12	70	0,78	70	62,44
13	51	0,70	61	46,93
14	52	0,70	62	46,93
15	61	0,70	51	46,93
16	62	0,70	52	46,93
17	113	0,68	113	42,66
18	128	0,68	128	42,66
19	111	0,66	123	39,42
20	123	0,66	111	39,42
21	14	0,56	14	27,16
22	11	0,55	11	25,15
23	4	0,54	4	23,14
24	13	0,53	13	21,91
25	16	0,48	16	15,22

The slope regions were presented to decision makers as the most appropriate for defining the number of alternatives to be selected.

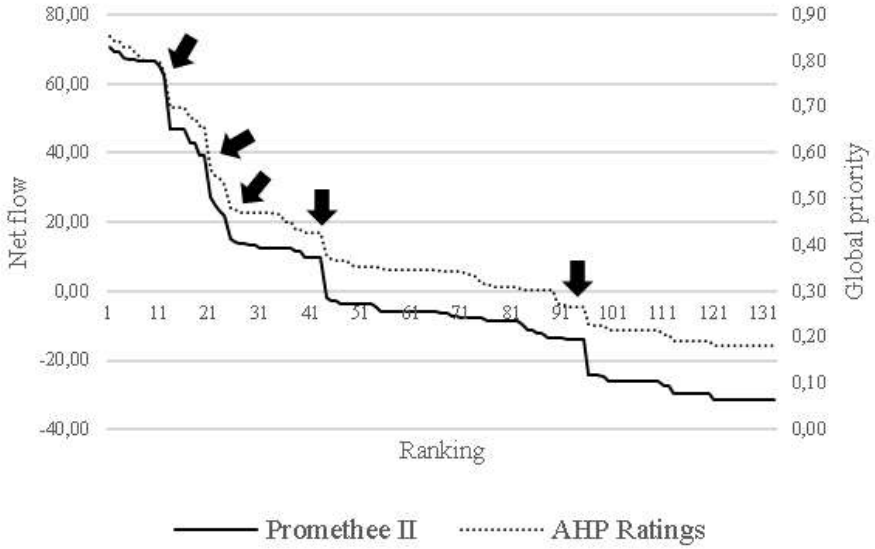

Fig. 3. Ranked sets obtained by the AHP Ratings and PROMETHEE II methods for the CCSV component.

3.6 Selecting the alternatives

BOP professionals from Petrobras and Drilling Contractors formed a new specialist team for this step. The sets of ranked alternatives and the indication of the slope regions in each were presented to the team. These slope regions were the choice options for the number of alternatives to be selected.

Initially, it was decided to select a number of alternatives (considering all components) that were suitable for the period and cost previously defined for the development of the CBM project. In this way, 228 of the

1378 groups of component failures were selected, representing 16.55% of the total of alternatives. Table 8 presents the selected quantity of alternatives per component.
For the set of 228 selected alternatives, graphs were created in an electronic spreadsheet to provide a more comprehensive view of the chosen groups of component failures. These graphs classified the alternatives by failure modes, mechanisms, sub-mechanism, cause, sub-cause and also indicated which parts of each component were most covered.

Upon analyzing the available graphs, the specialist team realized the Annular and BSR components needed to be reevaluated; some failure causes and sub-causes were not sufficiently addressed. Therefore, a new decision round was initiated, increasing the selected quantity of the Annular and BSR components to 66 and 54, respectively. This totaled 293 (21.26% of 1378) selected alternatives. Table 9 presents the number of groups of failures selected by component.

The supporting graphics were updated and, after analyzing them, the specialist team decided the set of alternatives selected in the second decision round was adequate. It was also decided to negotiate a possible adjustment in the period and cost of the CBM project due to the addition of groups of component failures.

4 Discussion

As already mentioned, Blowout preventer (BOP) is a crucial tool to avoid environmental disasters and financial losses for oil and gas companies. To prevent the unnecessary pulling out of the BOP and interruption of the drilling process, CBM and PHM projects are promising alternatives (Martins et al., 2018; Elusakin and Shafiee, 2020). Recently, computational intelligence techniques combined with CBM and PHM projects are being researched to make more assertive decisions about when maintenance should occur (Anderson and Barvik, 2020; Machado et al., 2021).

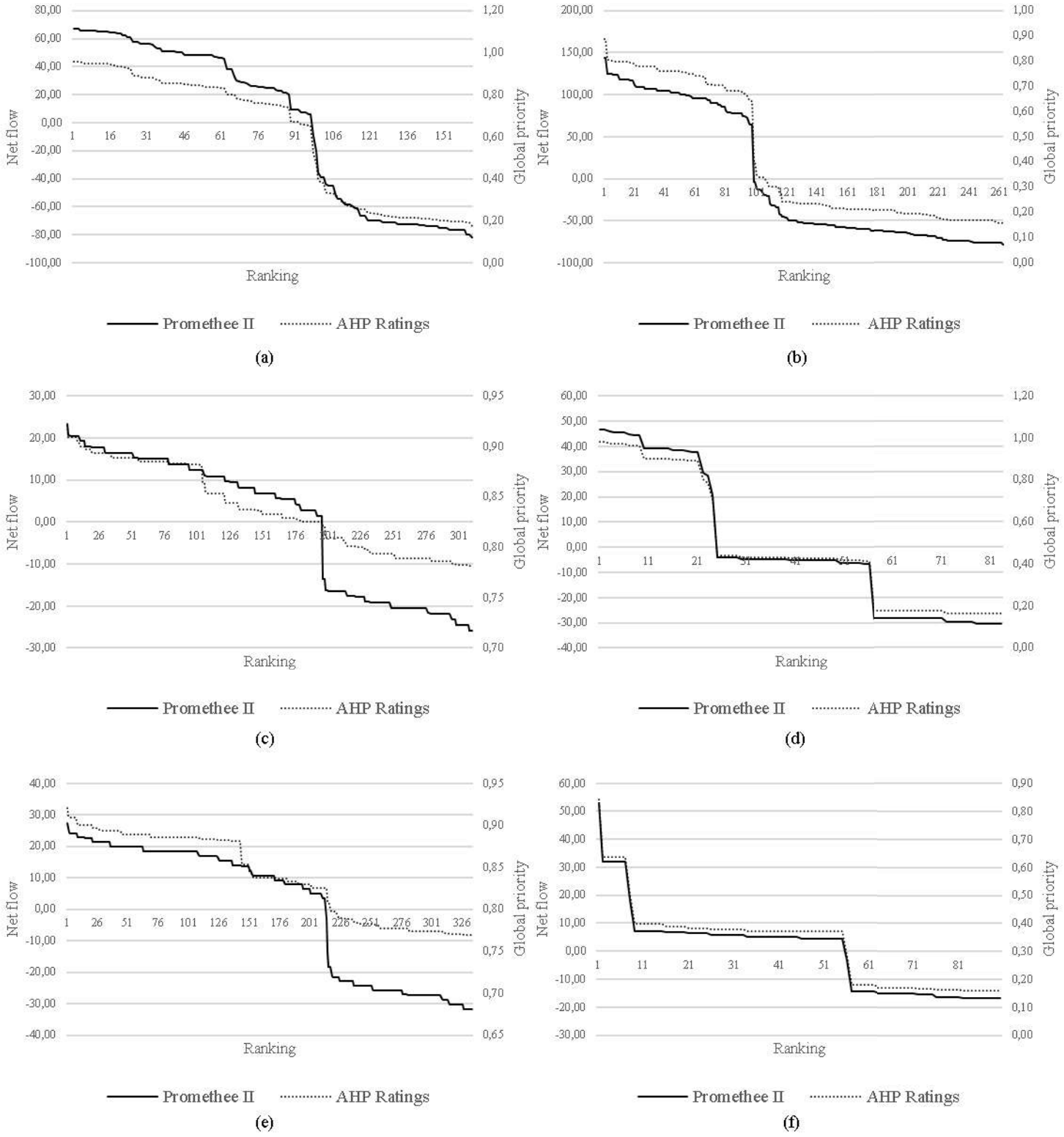

Fig. 4. Ranked sets obtained by the AHP Ratings and PROMETHEE II methods for (a) Annular, (b) BSR, (c) HKR, (d) Hoses, (e) MKR, and (f) Tubing components.

Table 8. Total selected by component in the first round of decision by the specialist team.

Component	Total	Selected	Percentage (%)
Annular	162	20	12,35
BSR	263	35	13,31
CCSV	133	18	13,53
HKR	311	55	17,68
Hoses	83	24	28,92
MKR	336	68	20,24
Tubing	90	8	8,89

Table 9. Total selected by component in the second round of decision by the specialist team.

Component	Total	Selected	Percentage (%)
Annular	162	66	40,74
BSR	263	54	20,53
CCSV	133	18	13,53
HKR	311	55	17,68
Hoses	83	24	28,92
MKR	336	68	20,24
Tubing	90	8	8,89

Identification and selection of appropriate data to be monitored in CBM projects are very important. However, for the success of such a step, it is essential to map out what we aim to achieve by monitoring this data, based on component failure analyses. Therefore, appropriate selection of the groups of BOP component failures to be analyzed is a key step for a successful CBM project of this tool.

AHP-PROMETHEE II method, which uses the AHP method to assign weights to criteria (and sub-criteria) and PROMETHEE II method to rank alternatives, has been successfully applied to solve MCDM problems in different areas such as sustainability (Turcksin et al., 2011; Majji et al., 2023; Hou et al., 2023), urban sanitation (Zhang et al., 2023), economy (Sikalo et al., 2023), energy (Abdel-Basset et al., 2021), food (Mohammadi et al., 2023), and the environment (Salari et al., 2018).

We believe that AHP-PROMETHEE II hybrid MCDM method would have been suitable for the problem addressed in this paper if the objective of this study was only to select a set of x groups of BOP component failures. However, defining the value of x is also part of the problem. Therefore, we chose to use a second method to rank the alternatives. The AHP Ratings method was chosen because it is a variant of the AHP method, one of the most used MCDM methods in the literature (Andrade et al., 2019), known for its simplicity (Sari et al., 2020) and effectiveness in dealing with multiple alternatives (Saaty, 2008). The AHP Ratings method was also chosen because it is a method based on the multi-attribute theory, meaning each alternative a is evaluated through a multi-attribute function that encompasses the evaluation given to a in each criterion (Logullo et al., 2022; Islam and Periaiah, 2023). This theory contrasts with outranking methods, such as the PROMETHEE II method, which considers that each criterion must be analyzed individually.

After integration of the sets of ranked alternatives, a specialist team from the oil and gas industry was provided with options (slope regions) to choose the number of groups of BOP component failures to select. After two rounds of decisions, the specialist group decided to select 293 (21.26%) alternatives, as shown in Table 9.

Sensitivity analysis is a step in the development of MCDM solutions that evaluates how much the result of the proposed method changes when the weights of the criteria are modified. Generally, we use sensitivity analysis to provide a range of weights per criterion that maintains the obtained solution (Sikalo et al., 2023; Turcksin et al., 2011). This allows us to identify which criteria have the greatest impact on the generated ranking (Mohammadi et al., 2023; Wang and Yang, 2007). However, in this study, due to the unusual characteristics and objectives of the problem addressed, we chose to perform a different sensitivity analysis. The weight of each sub-criterion was varied by 10% up and down, and the new rankings obtained by the AHP Ratings and PROMETHEE II methods were evaluated. It was observed that changes in the ranking of some alternatives always occurred in flat regions. When a slope region was analyzed, the set of alternatives that preceded it remained the same regardless of the variation in the weights of the sub-criteria. In other words, even with the suggested variation of the sub-criteria weight, the specialist team would always receive the same options regarding the number of alternatives to select.

5 Conclusion

The objective of this work is to select a set of *x* groups of component failures, which will serve as the basis for a BOP CBM project. However, unlike existing MCDM studies in the literature, the value of *x* is also to be defined by the proposed method.

The method proposed in this article combines the AHP method, applied to hierarchize the problem and define the weights of criteria and sub-criteria, with the AHP Ratings and PROMETHEE II methods, both used to rank the alternatives. These three methods were chosen due to their efficiency demonstrated in other studies in literature and their simplicity of use. Furthermore, the AHP Ratings and PROMETHEE II methods are based on different theoretical concepts, one on the multi-attribute utility theory and the other on the concept of outranking.

The two sets of ranked alternatives obtained by the proposed method, for each component, were analyzed and, as expected, there was a difference in the ranking of some alternatives. However, when separating these sets into flat regions (consecutive alternatives with a small difference between their evaluations) and slope regions (consecutive alternatives with a prominent difference between their evaluations), we realized that ranking inversions occurred only in the flat regions. When the slope regions were evaluated, we verified these regions were coincident in both sets and all alternatives that preceded a slope region were the same in the two rankings obtained (AHP Ratings and PROMETHEE II).

The slope regions were offered to a specialist team from the oil and gas industry as options for choosing the number of groups of BOP component failure (alternatives) to select. After two decision rounds, 293 of the 1378 available alternatives were selected: 66 from the Annular component, 35 from BSR, 18 from CCSV, 55 from HKR, 25 from Hoses, 68 from MKR and 8 from Tubing.

The credibility of the results obtained by the proposed method can be ensured by including specialists from the oil and gas industry – more specifically, BOP specialists – in all decision-making processes (Ikwan et al., 2020). Furthermore, a sensitivity analysis was carried out on the proposed method, demonstrating that adjustments in weights of up to 10% would not change the result of the proposed method.

In addition to the MCDM method proposed to select a set of groups of component failures that will form the basis of a Petrobras BOP CBM project, an original contribution of this study is the proposition of an MCDM methodology to support decision makers in ranking alternatives, considering multiple criteria, when the number of alternatives to be selected is not known or fixed.

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References

Abdel-Basset, M., Gamal, A., Chakrabortty, R.K., Ryan, M. (2021), A new hybrid multi-criteria decision-making approach for location selection of sustainable offshore wind energy stations: A case study. *Journal of Cleaner Production*, 280, 124462.

Anderson, S., Barvik, S. (2020), Advanced Offshore Digital Inspection Methods. In: *International Petroleum Technology Conference*, Dhahran, IPTC-20087-Abstract.

Andrade, W.E., Vianna, M.F.D., Meza, E.B.M., Vianna, D.S. (2019), Criticality evaluation and definition of pressure relief device inspection intervals using AHP ratings. *Brazilian Journal of Development*, 5(12), 32355-32373.

Ardjmand, M., Daneshfar, M.A. (2020), Selecting a suitable model for collecting, transferring, and recycling drilling wastes produced in the operational areas of the Iranian offshore oil company (IOOC) using analytical hierarchy process (AHP). *Journal of Environmental Management*, 259, 109791.

Barbosa, R., Guimarães, C., Serra, E., Bellon, D., Martínez-Amariz, A. (2019), Multicriteria analysis of methane mitigation options on offshore oil and gas production platforms. *Journal of Physics: Conference Series*, 1386, 012118.

Beim, S., Givens, M., Olson, M. (2023), *Electric Well Control: The Next Century Blowout Preventer*, ADIPEC, Abu Dhabi, SPE-216917-MS.

Carpio, L.G.T., Margueron, M.V. (2007), Decision-Making Process Under Uncertainty in International Investments in Petroleum Exploration and Production: Multicriteria Approach. *Energy Exploration & Explotation*, 25(5), 339-356).

Dağdeviren, M. (2008), Decision making in equipment selection: an integrated approach with AHP and PROMETHEE. *Journal of Intelligent Manufacturing*, 19, 397-406.

Elusakin, T., Shafiee, M. (2020), Quantifying the Added Value of Adopting Condition Monitoring to Subsea Blowout Preventer (BOP). In: *European Safety and Reliability Conference and the 15th Probabilistic Safety Assessment and Management Conference*. Research Publishing. Singapore, 781-788.

Fowler, A., Macreadie, P., Jones, D., Booth, D. (2014), A multi-criteria decision approach to decommissioning of offshore oil and gas infrastructure. *Ocean & Coastal Management*, 87, 20-29.

Gaudencio, L.M.A., Oliveira, R., Curi, W.F. (2021), Sustainability Indicators System Based on Multicriteria Analysis: A Tool for the Management of the Sustainability of Offshore Oil and Gas Production Units. *Integrated Environmental Assessment and Management*, 17(3), 614-625.

Hayes, J. (2012), Operator competence and capacity - Lessons from the Montara blowout. *Safety Science*, 50(3), 563-574.

Hou, X., Li, M., Xu, Y., Li, Z., Qin, S., You, X., Wang, F. (2023), Developing a Multidimensional Strategy for Water Eco-Environmental Protection in the Beijing−Tianjin−Hebei Urban Agglomeration: An Integrated SWOT-PROMETHEE-AHP Approach. *ACS ES&T Water*, 3(9), 3025-3034.

Ikwan, F., Sanders, D., Haddad, M. (2020), A Combined AHP-PROMETHEE Approach for Intelligent Risk Prediction of Leak in a Storage Tank. *International Journal of Reliability, Risk and Safety: Theory and Application*, 3, 55-61.

Islam, R., Periaiah, N. (2023), Overcoming the pitfalls in employee performance evaluation: An application of ratings mode of the Analytic Hierarchy Process. *Journal of Entrepreneurship, Management and Innovation*, 19(2), 127-157.

Ismail, Z., Kong, K.K., Othman, S.Z., Law, K.H., Khoo, S.Y., Ong, Z.C. (2014), Evaluating accidents in the offshore drilling of petroleum: Regional picture and reducing impact. *Measurement*, 55(1), 18–33.

Jaculli, M.A., Choueri Jr., N., Mata, C.R., Leite, A.G.A.S., Mendes, J.R.P., Colombo, D. (2022), Well safety and integrity evaluation of offshore wells: A review of past, present, and future. *Journal of Petroleum Science and Engineering*, 212, 110329.

Jardine, A.K., Lin, D., Banjevic, D. (2006), A review on machinery diagnostics and prognostics implementing condition-based maintenance. *Mechanical Systems and Signal Processing*, 20(7), 1483-1510.

Khalidov, I., Milovidov, K., Stepin, Y. (2023), Models for the Multicriteria Selection of Options for Decommissioning Projects for Offshore Oil and Gas Structures. *Energies*, 16, 2253.

Lima, Y.Q., Gomes, L.F.A.M., Leoneti, A.B. (2023), Decommissioning offshore oil and gas production systems with SMAA-ExpTODIM. *Pesquisa Operacional*, 43, 1-22.

Liu, Z., Liu, Y., Cai, B., Zhang, D., Zheng, C. (2015), Dynamic Bayesian network modeling of reliability of subsea blowout preventer stack in presence of common cause failures. *Journal of Loss Prevention in the Process Industries*, 38, 58-66.

Logullo, Y., Bigogno-Costa, V., Silva, A.C.S., Belderrain, M.C. (2022), A prioritization approach based on VFT and AHP for group decision making: a case study in the military operations. *Production*, 32, e20210059.

Lukin, N., Moura, R.T., Alves, M., Brünig, M., Driemeier, L. (2020), Analysis of API S-135 steel drill pipe cutting process by blowout preventer. *Journal of Petroleum Science and Engineering*, 195, 107819.

Machado, R.C., Leite, F., Xavier, C., Albuquerque, A., Lima, S., Carvalho, G. (2021), Development of Failure Prediction Models for Subsea Blowout Preventers Using Data Analytics and AI. In: *Offshore Technology Conference*, Houston, D041S053R004.

Majji, D., Abrar, I., Dutta, A. (2023), Multi-criteria decision-making framework for selection of surfactant-free microemulsion fuels as a sustainable diesel alternative. *Computers and Chemical Engineering*, 177, 108366.

Martin, W., Marsh, E., Hubble, E., Hrachovy, D. (1983), *Investigation of October 1982 blowout and fire, Eugene Island Block 361, Gulf of Mexico*. U.S. Geological Survey.

Martins, F.B., Cardoso, R., Tammela, I., Colombo, D., Acioli de Matos, B. (2018), Applying CBM and PHM concepts with reliability approach for Blowout Preventer (BOP): a literature review. *Brazilian Journal of Operations & Production Management*, 15(1), 78-95.

Mohammadi, M.H., Hejazi, Z., Saeedi, M.A., Giordani, E. (2023), Using AHP and PROMETHEE Multicriteria Decision-Making Approaches to Rank Available Fruit Crops for Orchard Expansion in Nangarhar, Afghanistan. *Erwerbs-Obstbau*, 65, 1837-1847.

Moraes, F.F.; Ferreira Filho, V.J.M., Infante, C.E.D.C., Santos, L., Arruda, E.F. (2022), A Markov Chain Approach to Multicriteria Decision Analysis with an Application to Offshore Decommissioning. *Sustainability*, 14, 12019.

Novgorodcev Jr., A.R., Jarquín-Laguna, A. (2021), *Multi-criteria analysis to rank offshore renewable technologies to support deep-water oil and gas production*. Balkema, CRC Press, pp. 771-778.

Oliveira, L.A., Pereira Jr., E.L., Gomes, C.F.S., Santos, M., Silva, M.P.R.L., Moratelli, A.C.A.B. (2024), Application of the PSI-CoCoSo Method for the Selection of an Aircraft for Aeromedical Rescue in an Offshore Company. In: *International Conference on Mobile Computing and Sustainable Informatics*, Lalitpur, 257-263.

Pecht, M., Gu, J. (2009), Physics-of-failure-based prognostics for electronic products. *Transactions of the Institute of Measurement and Control*, 31(3-4), 309-322.

Peecock, A., Edlmann, K., Mouli-Castillo, J., Martinez-Felipe, A. (2022), Mapping hydrogen storage capacities of UK offshore hydrocarbon fields and exploring potential synergies with offshore wind. *Geological Society*, 528, 171-187.

Qi, Q., Ershaghi, I. (2013), Aspects of Oilfield related Accidents. In: *SPE Annual Technical Conference and Exhibition*, SPE-166412-MS, Society of Petroleum Engineers.

Saaty, T.L. (1980), *The analytical hierarchy process*. Wiley, New York.

Saaty, T.L. (2008), Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, 1(1), 83-98.

Sadiq, R., Husain, T., Veitch, B., Bose, N. (2003), Evaluation of Generic Types of Drilling Fluid Using a Risk-Based Analytic Hierarchy Process. *Environmental Management*, 32, 778-787.

Salari, M., Rakhshandehroo, G.R., Nikoo, M.R. (2018), Degradation of ciprofloxacin antibiotic by Homogeneous Fenton oxidation: Hybrid AHP-PROMETHEE method, optimization, biodegradability improvement and identification of oxidized by products. *Chemosphere*, 206, 157-167.

Sari, F., Kandemir, İ., Ceylan, D.A., Gül, A. (2020), Using AHP and PROMETHEE multi-criteria decision making methods to define suitable apiary locations. *Journal of Apicultural Research*, 59(4), 546-557.

Sennaroglu, B., Celebia, G.V. (2018), A military airport location selection by AHP integrated PROMETHEE and VIKOR methods. *Transportation Research Part D*, 59, 160-173.

Sikalo, M., Arnaut-Berilo, A., Delalic, A. (2023), A Combined AHP-PROMETHEE Approach for Portfolio Performance Comparison. *International Journal of Financial Studies*, 11(1), 46.

Skogdalen, J.E., Utne, I.B., Vinnem, J.E. (2011), Developing safety indicators for preventing offshore oil and gas deepwater drilling blowouts. *Safety Science*, 49(8-9), 1187-1199.

Suslick, S.B., Furtado, R. (2001), Quantifying the value of technological, environmental and financial gain in decision models for offshore oil exploration. *Journal of Petroleum Science and Engineering*, 32, 115-125.

Turcksin, L., Bernardinia, A., Macharisa, C. (2011), A combined AHP-PROMETHEE approach for selecting the most appropriate policy scenario to stimulate a clean vehicle fleet. *Procedia Social and Behavioral Sciences*, 20, 954–965.

Wang, J.-J., Yang, D.-L. (2007), Using a hybrid multi-criteria decision aid method for information systems outsourcing. *Computers & Operations Research*, 34, 3691–3700.

Zhang, C., Kwon, S., Oh, J., Park, K. (2023), An integrated AHP-PROMETHEE II ranking method to evaluate the resilience of sewer networks considering urban flood and ground collapse risks. *Water Science & Technology*, 87, 1438.

Zolotuhin, A.B., Stepin, Y.P. (2019), Problem and models of multicriteria decision making and risk assessment of the arctic offshore oil and gas field development. *IOP Conference Series: Materials Science and Engineering*, 700, 012050.

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Decision Support System for Multi-Criteria Decision Making Based on Subjective Benefit-of-the-Doubt

Sandro Laudares[1[0000-0001-8873-695X]], Petr I. Ekel[1[0000-0001-6372-2316]], Iara S. Silva[2[0000-0001-7700-8842]], Aline de L. Z. Lunkes[2,3[0000-0002-1846-4853]], André G. Coimbra[2[0009-0005-3652-0010]], Marcos Flávio S. V. D'Angelo[2[0000-0001-5754-3397]], and Matheus P. Libório[3[0000-0003-1411-0553]]

[1]Pontifical Catholic University of Minas Gerais (PUC Minas) [2]State University of Montes Claros (UNIMONTES)
[3]Pontifical Catholic University of Paraná (PUCPR)

sandrolaudares@gmail.com, petr.ekel2709@gmail.com, iarasibelesilva@gmail.com, alinelunkesazl@gmail.com, andregcoimbra@gmail.com, marcos.dangelo@unimontes.br, m4th32s@gmail.com

Abstract: Multi-Criteria Decision Making (MCDM) problems frequently re-quire the integration of objective data and expert knowledge to support transpar-ent and evidence-based decisions. Although numerous weighting methods have been proposed, relatively little attention has been paid to computational environ-ments that can operationalize hybrid weighting approaches in practical decision-support processes. To address this gap, this study proposes a computational De-cision Support System (DSS) based on the Subjective Benefit-of-the-Doubt (S-BoD), a consensus-dependent weighting method that combines empirical evi-dence and expert judgments through admissible weight intervals. The proposed framework integrates data management, expert opinion, adaptive weighting, and ranking generation within a unified computational environment. The system was implemented in Python and Streamlit and applied to assess sports facility availa-bility across Urban Planning Units in Belo Horizonte, Brazil. Six sports infra-structure categories were evaluated using geospatial data and expert judgments regarding their contributions to public health and well-being. Results revealed substantial territorial disparities in sports facility availability, with most planning units concentrated in the lowest availability classes. The S-BoD weighting mech-anism successfully incorporated expert disagreement while preserving the adap-tive nature of endogenous weighting. Furthermore, criteria that were given greater weight in the optimization process tended to exhibit stronger spatial dif-ferentiation, highlighting the framework's ability to identify territorially relevant factors. The proposed DSS contributes to the MCDM and decision-support liter-ature by providing a transparent mechanism for integrating subjective and objec-tive information within a single evaluation framework. The results demonstrate its potential to support public planning and resource allocation decisions in mul-tidimensional contexts.

Keywords: decision support system; benefit-of-the-doubt; sports facilities; composite indicators.

1 Introduction

Multi-Criteria Decision Making (MCDM) has become one of the most important re-search fields for supporting complex decision processes involving multiple, often con-flicting criteria. Applications of MCDM can be found in public policy, environmental management, sustainability assessment, healthcare, education, transportation planning, regional development, and social assistance, where decision-makers must simultane-ously consider multiple performance dimensions [1]. As decision problems become in-

creasingly multidimensional, the demand for computational tools that support transpar-ent, systematic, and evidence-based decision-making has grown substantially.

In this regard, the development of Decision Support Systems (DSS) has played a central role in addressing these challenges by providing computational environments that support data management, alternative evaluation, and recommendation generation. At the same time, composite indicators have emerged as practical instruments for syn-thesizing multidimensional phenomena into interpretable measures that facilitate benchmarking, monitoring, and policy evaluation [2]. Recent advances in composite indicator construction have further highlighted the importance of computational ap-proaches that integrate heterogeneous information sources into coherent decision-sup-port frameworks [3].

A fundamental component of virtually every multicriteria evaluation process is de-termining criteria weights. Criteria weights reflect the relative importance of evaluation dimensions and directly influence rankings, prioritization procedures, and final recom-mendations. Consequently, the credibility and practical usefulness of decision out-comes depend strongly on the weighting strategy adopted. As demonstrated in sustain-ability assessment and composite indicator construction, different weighting assump-tions may substantially alter evaluation results and policy conclusions [4; 5].

Weighting approaches are classified as subjective, objective, and hybrid. Subjective methods rely on expert judgments, stakeholder opinions, or decision-maker opinions, whereas objective methods derive weights directly from observed data. While subjec-tive approaches can incorporate contextual knowledge and strategic priorities, they may introduce bias and inconsistency. Conversely, objective approaches reduce the influ-ence of personal judgments but may overlook theoretical considerations and domain-specific expertise. This trade-off has motivated growing interest in methodologies that combine empirical evidence and expert knowledge within a unified evaluation frame-work. Among objective weighting approaches, the Benefit-of-the-Doubt (BoD) method has become one of the most influential techniques for composite indicator construction and multicriteria evaluation. Originally proposed by Cherchye et al. [6], the method derives endogenous weights that maximize the performance of each evaluated alterna-tive while preserving comparability across observations. The flexibility of this ap-proach allows the weighting structure to adapt to the data's characteristics, reducing the need for arbitrary assumptions about the importance of criteria.

Despite its flexibility and widespread adoption, the classical BoD relies exclusively on information extracted from observed data, preventing the explicit incorporation of expert knowledge, policy priorities, and theoretical expectations regarding the relative importance of criteria [7]. This limitation is particularly relevant in decision-making environments where experts possess valuable knowledge that cannot be directly in-ferred from empirical observations. To address this limitation, recent studies have in-troduced qualitative information, weight restrictions, and alternative constraint struc-tures into BoD-based methods. Examples include the incorporation of decision-maker preferences into DEA-based composite indicators [8], the use of unsupervised con-straints to improve weight stability and interpretability [9], the introduction of weight restrictions reflecting expert knowledge and policy priorities [7], and the incorporation of preference structures inspired by Prospect Theory [10].

Although these contributions have significantly advanced the methodological litera-ture, most studies remain focused on weighting procedures and composite indicator construction. Comparatively less attention has been devoted to the development of DSS capable of operationalizing these methodological advances within practical multicrite-ria decision-making environments. In particular, there remains a lack of integrated frameworks that combine expert knowledge, objective information, adaptive weighting mechanisms, and ranking generation within a unified computational platform.

To address this research gap, this study proposes a DSS for multicriteria decision-making based on the Subjective BoD (S-BoD) [11]. The proposed DSS integrates ob-jective information extracted from data and subjective information provided by experts through a consensus-dependent weighting mechanism. By combining empirical evi-dence and expert knowledge within a unified computational environment, the DSS seeks to provide transparent, interpretable, and context-aware support for multicriteria decision-making processes.

The main contributions of this study are threefold. First, it proposes a computational framework specifically designed for multicriteria decision support. Second, it opera-tionalizes the S-BoD method within a practical DSS environment. Third, it provides a mechanism to integrate expert knowledge and objective information through a weighting strategy, ensuring conceptual compatibility for objectively defined weights.

2 Background

2.1 Multi-Criteria Decision Making

Multi-Criteria Decision Making encompasses a family of methodologies designed to support decisions involving multiple evaluation criteria. The primary objective of MCDM is to assist decision-makers in selecting, ranking, prioritizing, or classifying alternatives based on multiple performance dimensions. In particular, a typical MCDM problem involves a set of alternatives evaluated according to economic, social, envi-ronmental, institutional, technical, or strategic criteria. Since these criteria are fre-quently measured in different units and often exhibit conflicting behavior, aggregation procedures are required to transform multidimensional information into a format that facilitates comparison among alternatives [1].

The MCDM literature contains a wide variety of methodological approaches. Util-ity-based methods, such as Multi-Attribute Utility Theory (MAUT), represent prefer-ences through utility functions [12]. Outranking approaches, including ELECTRE and PROMETHEE, establish dominance relationships among alternatives [13]. Distance-based methods, such as TOPSIS and VIKOR, evaluate alternatives based on their prox-imity to the ideal and anti-ideal solutions [14]. Other approaches focus on determining weights and constructing composite indicators, providing mechanisms for synthesizing multidimensional information into a single performance measure.

Among the various components of MCDM methodologies, weight determination is one of the most influential stages, as different weighting schemes can substantially alter rankings and decision outcomes. For this reason, considerable research effort has been devoted to developing weighting methods that balance objectivity, interpretability, and decision-maker involvement. In this context, objective weighting methods have at-tracted particular attention because they reduce the need to make arbitrary assumptions about the importance of criteria. One of the most influential approaches belonging to this class is the BoD.

2.2 Benefit-of-the-Doubt (BoD)

The BoD was originally introduced by Cherchye et al. [6] as a method for constructing composite indicators based on the principles of Data Envelopment Analysis (DEA). The central idea of the method is to assign each evaluated alternative the set of weights that maximizes its own performance while preserving comparability across all alterna-tives. As a result, each alternative is evaluated under its most favorable weighting struc-ture and therefore receives the “benefit of the doubt” regarding the relative importance of evaluation criteria.

Several characteristics contribute to BoD's popularity in multidimensional evalua-tion problems. The method eliminates the need for arbitrary weight assignment, accom-modates indicators measured in different units, and provides a transparent interpretation of performance relative to observed best practices. These properties have motivated numerous applications across different domains. For example, BoD has been employed in waste management assessment [15], well-being measurement [16], sustainability evaluation [4; 5], public service assessment [2], higher education analysis [17], and urban sustainability measurement [18].

The widespread adoption of BoD has stimulated the development of several meth-odological extensions. Van Puyenbroeck and Rogge [19] proposed a multiplicative ver-sion of the framework based on geometric aggregation mechanisms, while Rogge [20] generalized the BoD formulation through generalized weighted averages. These devel-opments expanded the flexibility of the original methodology and broadened its ap-plicability to different evaluation contexts. Additional extensions have focused on im-proving the robustness and interpretability of BoD-based evaluations. Rogge et al. [15] proposed a conditional directional-distance BoD that accounts for contextual factors affecting performance. Sayed et al. [21] introduced goal-programming formulations designed to reduce ranking inconsistencies and improve comparability among

alternatives. Together, these contributions demonstrated the potential of extending the original framework beyond its classical formulation.

2.3 Subjective Benefit-of-the-Doubt (S-BoD)

More recently, researchers have investigated mechanisms for incorporating qualitative information and expert opinion into the weighting process. Pereira et al. [8] integrated decision-maker preferences into DEA-based composite indicators. Maricic and Jeremic

[9] proposed unsupervised constraints to improve weight stability and interpretability. Camanho et al. [7] investigated the use of weight restrictions to reflect policy priorities and expert knowledge, whereas Zhang and Liao [10] incorporated preference structures inspired by Prospect Theory into DEA-based efficiency assessment models.

Although these contributions have significantly improved the interpretability and policy relevance of BoD-based evaluations, most of them rely on fixed restrictions or aggregated expert judgments. Consequently, expert disagreement is typically reduced to a single collective representation, limiting the weighting process's ability to explicitly account for uncertainty and heterogeneity in expert opinions. This limitation is partic-ularly relevant in complex decision-making contexts, where multiple stakeholders may hold different yet equally valid perspectives regarding the relative importance of eval-uation criteria.

To address this issue, Silva et al. [11] proposed the Subjective BoD (S-BoD). Unlike previous extensions, S-BoD introduces a consensus-dependent mechanism that adjusts the influence of expert knowledge according to the degree of agreement among experts. Consequently, the methodology preserves the adaptive nature of the classical BoD while incorporating contextual and theoretical knowledge into the weighting process. The ability of S-BoD to combine empirical evidence and expert judgments makes it particularly suitable for multicriteria decision-making environments where both infor-mation sources are relevant. For this reason, the S-BoD method serves as the weighting engine for the computational decision-support framework proposed in this study.

The selection of S-BoD is particularly appropriate for the decision problem ad-dressed in this study because the availability of sports facilities involves both objective and subjective dimensions. While geospatial data provide measurable information on the availability of sports infrastructure, experts contribute contextual knowledge about the relative contributions of different facility types to public health, physical activity, and social inclusion. Unlike conventional weighting approaches that rely exclusively on expert judgments or observed data, S-BoD integrates both sources through admissi-ble weight intervals defined by experts. This preserves the adaptive weighting structure of classical BoD while incorporating expert knowledge.

Importantly, S-BoD treats disagreement among experts as information that deter-mines the flexibility of the optimization process. High consensus results in narrower weight intervals, keeping the optimization close to the common expert assessment, whereas greater disagreement produces wider intervals and allows greater flexibility. Thus, the method does not seek to eliminate disagreement or optimize consensus; ra-ther, disagreement defines the admissible space within which the BoD optimization operates.

A discrepant assessment from a single expert may therefore widen the feasible in-terval if it substantially increases the observed disagreement. However, this prevents any individual expert from unilaterally determining the final weights, as the resulting weights reflect the collective assessment of the expert panel. Instead, the assessment is retained as a feasible expert judgment, while the BoD optimization determines the weights within the resulting bounds. Hence, a discrepant assessment is not automati-cally treated as an outlier to be discarded. This approach operationalizes the BoD prin-ciple by optimizing the weights to provide each evaluated unit with the most favorable feasible score, subject to the expert-derived constraints. S-BoD therefore accommo-dates heterogeneous expert opinions while maintaining a transparent and theoretically consistent optimization structure for multicriteria decision-making.

3 Subjective-Objective Decision Support System (DSS)

The proposed DSS integrates data management, expert opinion, Subjective BoD weighting, and ranking generation within a unified computational environment. The framework is organized into five modules: Problem Definition, Data Management, Ex-pert Opinion, S-BoD Weighting Engine, and Decision Support. The decision-making process begins with defining alternatives and criteria. Experts then provide assessments of the conceptual importance of each criterion. Then, the DSS applies S-BoD weighting to combine objective information extracted from the data with subjective information obtained from experts. In particular, the weights of the criteria defined by the experts were used as con-straints (lower and upper admissible weights) in the S-BoD algorithm as follows:

$$\text{SBoD} = max_{w_{ir}} \sum_{i=1}^{n} w_{ir} P_{ir} \quad (1)$$

subject to:

$$\sum_{i=1}^{n} w_{ir} P_{ir} \leq 1, \ \forall r \in \{1, \dots, m\} \quad (2)$$

$$w_i^- \leq w_{ir} \leq w_i^+, \ \forall i \in \{1, \dots, \text{n}\} \quad (3)$$

$$0 \leq w_{ir} \leq 1, \ \forall i \in \{1, \dots, n\} \quad (4)$$

$$\sum_{i=1}^{m} w_{ir} = 1 \quad (5)$$

where w_{ir} is the corresponding weight of criterion i of decision-making unit r, the sum of w_{ir} equals one, w_i^- and w^+ correspond, respectively, to the lower and upper admis-
sible weights for criterion i, obtained from the expert elicitation procedure.

Note that Equation (5) ensures compatibility between objective and subjective weights, as experts' assessments constrain the range within which the objective weights are determined. Then, the resulting weights are used to construct composite scores and generate rankings. The framework allows decision-makers to explore the impact of ex-pert consensus on final rankings and identify criteria that most strongly influence deci-sion outcomes. In that sense, the DSS works not only as a ranking tool but also as an environment for knowledge integration and decision support. The DSS based on the

BoD can be run via an online application through the website: https://bodindica-tor.streamlit.app/

The S-BoD DSS illustrated in Figure 1 was developed using Python 3.11. The user interface was built using Streamlit, a framework that allows interactive data visualiza-tion.

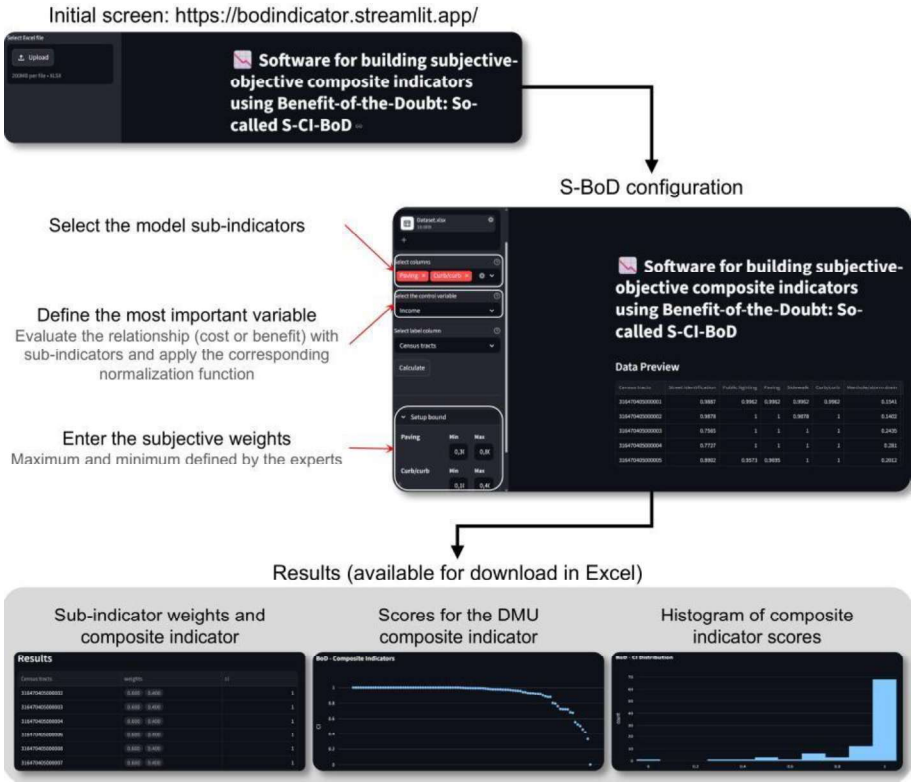

Fig. 1. Subjective-objective Decision Support System based on S-BoD method.

4 Application example: Sports Facilities Availability Index

Sport is an unparalleled driver of sustainable development, fully aligned with Sustain-able Development Goal 3 (SDG3): “ensure healthy lives and promote well-being for all at all ages” [22]. The contribution of sport to making cities and communities more inclusive (SDG11) is also widely recognized in the literature [23; 24]. However, the dissemination of sport still faces many challenges that limit its reach. Among these challenges is the adequate measurement of the availability of existing sports facilities from a multi-criteria perspective. This study seeks to address this gap by integrating qualitative and quantitative data into the novel Sports Facilities Availability Index.

The criteria Open-Air Academy, Soccer Field, Sports Equipment, Gymnasium, Skate Park, and Sports Court were selected because they represent the main types of

sports and recreational infrastructure available in the urban environment, covering dif-ferent sports modalities, age groups, and user profiles. In addition to their relevance for promoting physical activity, health, and social inclusion, the selection process also con-sidered data availability, completeness, and quality, prioritizing variables with adequate spatial coverage and reliable information across all Urban Planning Units (UPUs).

4.1 Collection of qualitative and quantitative data

The qualitative data were obtained from six experts selected through purposive sam-pling based on their academic qualifications and professional experience. The selection criteria included an undergraduate degree in Physical Education or a related field, post-graduate training, at least five years of professional experience, and backgrounds in sports management, public administration, recreation, and public sports planning and management. The panel comprised professionals serving as General Coordinator, Sports Coach, Technical Agent, Public Service Specialist, and Project Manager. This combination of academic and professional profiles provided complementary perspec-tives and ensured that the elicited judgments were grounded in both technical knowledge and practical experience in the management, planning, and promotion of sports and leisure infrastructure.

The quantitative data were obtained on May 5, 2026, from the Spatial Data Infra-structure of Belo Horizonte (IDE-BHGeo: https://bhmap.pbh.gov.br/v2/mapa/idebh-geo). IDE-BHGeo is the official geospatial platform maintained by the Belo Horizonte municipal government and widely used for urban planning and territorial management. The use of this authoritative source enhances the reliability, transparency, and repro-ducibility of the composite indicator by providing standardized, consistently updated, and institutionally validated geospatial information. Moreover, the data are based on official administrative records, ensuring data completeness and eliminating the need for missing-data imputation. Consequently, the selected criteria combine conceptual rele-vance with the robustness and credibility of the underlying data source.

4.2 Criteria weights

The criteria were weighted in two stages. First, experts were asked to assign scores ranging from 0 (not important) to 10 (extremely important) to each type of sports facil-ity, based on the following question: “Public sports facilities contribute to population health by providing spaces for physical activity.” The assigned scores were subse-quently used to derive the criterion weights incorporated into the composite indicator. Table 1 presents the importance assigned to each criterion by the six experts.

Table 1. Importance of criteria according to experts.

Criteria	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6
Open-Air Academy	10	5	5	10	9	8
Soccer Field	7	6	10	8	9	5
Sports Equipment	6	9	5	6	9	10

Gymnasium	7	8	10	7	8	8
Skate Park	4	6	9	3	10	5
Sports Court	7	7	10	7	10	10

Next, the criterion scores were normalized into weights. Specifically, the importance assigned by the expert to each criterion was divided by the sum of the importance scores across all criteria. Thus, the elicited importance scores were converted into normalized weights ranging from 0 to 1 and summing to one. The weights for each expert, along with the maximum and minimum weights, are detailed in Table 2. Note that the weight range indicates the degree of flexibility of the S-BoD optimization.

Table 2. Criterion weights (maximum, minimum, and interval) according to experts.

Criteria	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Max	Min	Inter-val
Open-Air Academy	0.244	0.122	0.102	0.244	0.164	0.174	0.244	0.102	0.244
Soccer Field	0.171	0.146	0.204	0.195	0.164	0.109	0.204	0.109	0.171
Sports Equipment	0.146	0.220	0.102	0.146	0.164	0.217	0.220	0.102	0.146
Gymnasium	0.171	0.195	0.204	0.171	0.145	0.174	0.204	0.145	0.171
Skate Park	0.098	0.146	0.184	0.073	0.182	0.109	0.184	0.073	0.098
Sports Court	0.171	0.171	0.204	0.171	0.182	0.217	0.217	0.171	0.171

Secondly, the highest and lowest weights for each criterion, according to the experts' opinions, are used as constraints on function (3).

4.3 Sports Facilities Availability in Belo Horizonte

The expert elicitation process revealed differences in the perceived importance of the six sports infrastructure categories considered in the analysis. After normalization and incorporation into the S-BoD optimization model, Open-Air Academy obtained the highest average weight (0.23), followed by Sports Court (0.20) and Soccer Field (0.17). Gymnasium (0.15), Skate Park (0.13), and Sports Equipment (0.12) received compar-atively lower weights. These results indicate that experts generally considered facilities associated with regular and widespread physical activity to be more relevant for pro-moting population health and well-being.

Table 3 shows substantial differences in the availability of the six categories of sports facilities across the planning units of Belo Horizonte. The mean values range from 0.03 for Sports Equipment to 5.46 for Open-Air Academy, while the standard deviations indicate different levels of dispersion across the planning units. In addition, the maxi-mum values vary considerably across the criteria, reaching 19 facilities for Sports Court, whereas some categories have much lower maximum values.

Table 3. Descriptive statistics of sports facilities across the planning units of Belo Horizonte.

Criteria	Open-Air Academy	Soccer Field	Sports Equip.	Gymna-sium	Skate Park	Sports Court

Mean	5.46	1.58	0.03	0.10	0.35	2.74
Standard deviation	4.02	1.78	0.16	0.34	0.62	3.44
Sample variance	16.18	3.16	0.02	0.12	0.38	11.82
Minimum	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	16.00	9.00	1.00	2.00	2.00	19.00
Sum	437.00	126.00	2.00	8.00	28.00	219.00

The presence of zero values for all criteria indicates that at least one planning unit has no facility of a given type, while the substantially different maximum values reveal pronounced differences in the scales and distributions of the criteria. This heterogeneity is particularly relevant for normalization because the criteria cannot be interpreted on a common raw scale: applying a normalization function must account for criterion-spe-cific minimum and maximum values to preserve the relative differences among plan-ning units. Consequently, the observed distributional characteristics provide an im-portant basis for selecting a normalization procedure that is appropriate for count data with zero values and markedly different ranges.

One of the main advantages of the proposed DSS is its ability to incorporate expert disagreement without imposing a single fixed weighting structure. The admissible weight intervals shown in Figure 2 represent the range of importance that the specialists attribute to each criterion and constitute the subjective constraints of the S-BoD model. Consequently, the resulting weights reflect a balance between empirical information extracted from the data and expert knowledge regarding the relative importance of sports facilities.

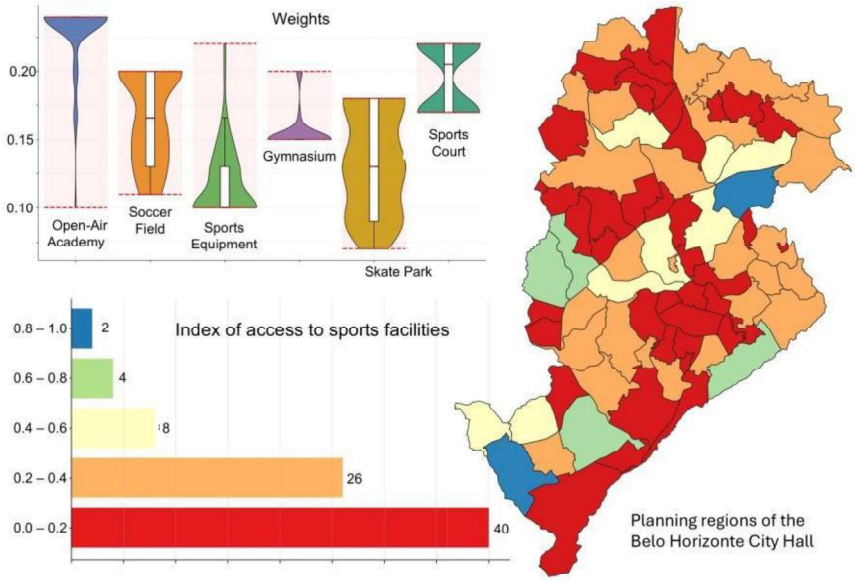

Fig. 2. S-BoD weights by criterion and Sports Facilities Availability Index. **Note:** Five equal-interval classes ranging from 0 to 1 were defined to facilitate differentiation.

The S-BoD composite indicator generated by the DSS reveals substantial territorial disparities in the availability of sports infrastructure across Belo Horizonte. Most UPUs were concentrated in the lower-availability classes, particularly the 0.00–0.20 and 0.20–

0.40 ranges. Specifically, 40 UPUs were classified in the lowest category and 26 in the second-lowest, whereas only six UPUs achieved scores above 0.60.

The highest composite indicator score was obtained by UPU 5, with a score of 1.00. This unit reported 15 Open-Air Academies, 9 Soccer Fields, 1 Sports Equipment facil-ity, 1 Gymnasium, 2 Skate Parks, and 8 Sports Courts, with optimized weights of 0.10, 0.20, 0.20, 0.15, 0.18, and 0.17, respectively. At the opposite end of the distribution, three planning units (UPUs 8, 9, and 70) obtained the minimum composite score of 0.00, as none of them reported facilities in any of the six criteria. Given their identical criterion values, the optimization procedure assigned the same weight to all criteria (approximately 0.17), resulting in identical composite scores. Together, these results illustrate the ability of the proposed approach to differentiate territorial units according to their levels of sports infrastructure while also identifying units with uniformly absent facilities.

Overall, the results demonstrate that sports facility availability is unevenly distrib-uted across the municipality, revealing substantial territorial disparities and identifying areas with comparatively limited infrastructure.

Beyond ranking territorial units, the DSS provides additional insights into the be-havior of the evaluation criteria by incorporating their spatial structure into the analysis. Table 4 compares the average criterion weights with the spatial autocorrelation of each criterion. The results suggest an association between criterion importance and spatial structure. Open-Air Academy, which received the highest average weight, also exhib-ited the highest average Moran's I value (0.89). Similarly, Sports Court presented a relatively high average weight (0.20) and strong spatial autocorrelation (0.79). In con-trast, Sports Equipment received the lowest average weight (0.12) and exhibited the weakest spatial dependence (0.29). These results indicate that the criteria differ not only in their contribution to the composite indicator but also in the extent to which their spatial distributions are geographically structured.

Beyond ranking territorial units, the DSS provides additional analytical insights re-garding the behavior of evaluation criteria. Table 4 compares the average criterion weights with the spatial autocorrelation of each criterion. The results indicate that cri-teria receiving higher weights tend to exhibit stronger spatial structure. Open-Air Acad-emy, the most influential criterion in the composite indicator, had the highest average Moran's I value (0.89), while Sports Court also had both a high weight (0.20) and a high spatial autocorrelation (0.79). In contrast, Sports Equipment displayed the lowest weight (0.12) and the weakest spatial dependence pattern (0.29).

Table 4. Spatial autocorrelation of the S-BoD-CI with the criteria and their average weights.

	Open-Air Academy	Soccer Field	Sports Equipment	Gymna-sium	Skate Park	Sports Court
Minimum	0.82	0.55	0.26	0.44	0.59	0.72
Maximum	0.92	0.80	0.34	0.52	0.60	0.85
Mean rho	0.89	0.66	0.29	0.48	0.59	0.79

Weight	0.23	0.17	0.12	0.15	0.13	0.20

These findings suggest that the S-BoD framework naturally favors criteria that more effectively distinguish territorial patterns among alternatives. Variables exhibiting stronger spatial differentiation provide greater discriminatory power and therefore exert greater influence on the final ranking. Importantly, the width of the admissible weight intervals does not appear to be associated with spatial autocorrelation levels, indicating that expert disagreement affects the flexibility of the optimization process without nec-essarily influencing the spatial behavior of the indicators.

Overall, the application demonstrates the practical capabilities of the proposed DSS for multicriteria decision support. By integrating expert opinion, objective data, adap-tive weighting, and ranking generation into a single computational environment, the system provides transparent and interpretable support for decision-making. The case study illustrates how the framework can assist policymakers and planners in identifying priority areas, understanding the contribution of individual criteria, and exploring the implications of expert knowledge for multicriteria evaluations.

5 Conclusions

This study proposed a computational DSS for Multi-Criteria Decision Making based on the S-BoD. The framework was developed to address the lack of integrated decision-support environments that combine objective information extracted from data with ex-pert knowledge while preserving the adaptive weighting characteristics of BoD. The proposed DSS integrates data management, expert opinion, S-BoD optimization, and ranking generation within a unified computational environment. Its main novelty lies in operationalizing the S-BoD as a practical decision-support tool that incorporates ex-pert knowledge through consensus-dependent admissible weight intervals. In this way, the framework bridges methodological advances in composite indicator construction and real-world decision-support applications.

The application to assess the availability of sports facilities in Belo Horizonte demonstrated the system’s practical utility. The results showed that the DSS success-fully integrates subjective and objective information to generate interpretable rankings and identify the criteria that most strongly influence decision outcomes. Beyond rank-ing alternatives, the framework provides additional insights into the relationship be-tween criterion importance and territorial differentiation.

Despite these contributions, several limitations should be acknowledged. First, the empirical validation was conducted using a single case study, which limits the assess-ment of the framework's generalizability across different decision-making contexts. Second, expert opinions were obtained from a relatively small group of experts, and different stakeholder groups may exhibit distinct opinion formats and levels of consen-sus. Third, the current framework assumes deterministic expert judgments and criterion values, without explicitly modeling uncertainty, vagueness, or incomplete information that frequently characterize real-world decision problems. Fourth, the proposed DSS is centered on the S-BoD methodology and therefore does not yet provide systematic

comparisons with other widely adopted MCDM approaches. Finally, the current imple-mentation focuses on static evaluations and does not address dynamic decision envi-ronments in which opinions, criteria, and data evolve over time.

These limitations open several promising avenues for future research. Additional applications in domains such as sustainability assessment, healthcare, transportation, education, and public policy could provide further evidence of the framework's robust-ness and transferability. Comparative studies involving methods such as AHP, TOPSIS, PROMETHEE, ELECTRE, and DEA-based models could help position S-BoD within the broader MCDM literature and identify the contexts in which its consensus-depend-ent weighting mechanism offers the greatest advantages. Future developments may also incorporate fuzzy sets, probabilistic approaches, rough sets, or other uncertainty-mod-eling techniques to better represent imprecise expert knowledge and incomplete infor-mation. Furthermore, extending the framework to group decision-making environments involving multiple stakeholder categories could provide new insights into consensus formation and conflict management in multicriteria evaluations. Finally, integrating sensitivity analysis, explainable artificial intelligence, machine learning techniques, and real-time data sources may transform the proposed DSS into a more adaptive and intelligent decision-support environment.

From a broader perspective, future developments along these directions have the potential to contribute not only to the practical evolution of the proposed DSS but also to the advancement of the MCDM field itself. In particular, they may help strengthen the integration between subjective and objective weighting paradigms, improve the treatment of uncertainty in multicriteria evaluations, and advance the development of transparent, adaptive, and knowledge-driven decision-support systems capable of ad-dressing increasingly complex decision problems. Overall, the proposed Subjective-Objective DSS represents a novel contribution to the DSS and MCDM literature by providing a transparent mechanism for integrating expert knowledge and objective ev-idence within a unified multicriteria decision-support framework.

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References

Pascoe, S., Cannard, T., Dowling, N. A., Dichmont, C. M., Asche, F., & Little, L. R. (2023). Use of Data Envelopment Analysis (DEA) to assess management alternatives in the pres-ence of multiple objectives. Marine Policy, 148, 105444.

Muhanguzi, H., Scioni, M., Bassi, F., Mwanga, Y., & Wokadala, J. (2025). Constructing a Composite Indicator of Service Delivery in Uganda: Methodological Insights and Regional Rankings. Statistical Journal of the IAOS, 41(4), 1265–1275.

Libório, M. P., Ekel, P., D'Angelo, M. F. S. V., Martínez, L., & Rabiei, H. (2025). Con-structing Composite Indicators Through Extreme Values Reductions-Ordered Weighted Averaging: Human Development Index. IEEE Access, 13, 48306–48317.

Zhou, L., Tokos, H., Krajnc, D., & Yang, Y. (2012). Sustainability performance evaluation in industry by composite sustainability index. Clean Technologies and Environmental Pol-icy, 14(5), 789–803.

Jia, X., Buyle, S., & Macário, R. (2023). Developing an airport sustainability evaluation index through composite indicator approach. Journal of Air Transport Management, 113, 102469.

Cherchye, L., Moesen, W., Rogge, N., & Van Puyenbroeck, T. (2007). An introduction to Benefit of the Doubt composite indicators. Social Indicators Research, 82(1), 111–145.

Camanho, A. S., Zanella, A., & Moutinho, V. (2023). *Benefit-of-the-Doubt Composite In-dicators and Use of Weight Restrictions*. In *Advanced Mathematical Methods for Economic Efficiency Analysis: Theory and Empirical Applications* (pp. 93–112).

Pereira, M. A., Camanho, A. S., Figueira, J. R., & Marques, R. C. (2021). Incorporating preference information in a range directional composite indicator: The case of Portuguese public hospitals. European Journal of Operational Research, 294(2), 633–650.

Maricic, M., & Jeremic, V. (2023). Imposing unsupervised constraints to the Benefit-of-the-Doubt (BoD) model. Metron, 81(3), 259–296.

Zhang, Z., & Liao, H. (2024). A stochastic cross-efficiency DEA approach based on the prospect theory and its application in winner determination in public procurement tenders. Annals of Operations Research, 341(1), 509–537.

Silva, I. S., Vidoli, F., Coimbra, A. G., D'Angelo, M. F. S. V., Mendes, J. B., Ekel, P., & Libório, M. P. (2026). Subjective Benefit-of-the-Doubt (S-BoD) for constructing composite indicators. IEEE Systems, Man, and Cybernetics Letters.

Figueira, J., Greco, S., & Ehrgott, M. (Eds.). (2005). Multiple Criteria Decision Analysis: State of the Art Surveys. Springer.

Belton, V., & Stewart, T. (2012). Multiple criteria decision analysis: an integrated approach. Springer Science & Business Media.

Ishizaka, A., & Nemery, P. (2013). Multi-Criteria Decision Analysis: Methods and Soft-ware. Chichester, UK: John Wiley & Sons.

Rogge, N., De Jaeger, S., & Lavigne, C. (2017). Waste performance of NUTS 2-regions in the EU: A conditional directional distance Benefit-of-the-Doubt model. Ecological Eco-nomics, 139, 19–32.

Peiró-Palomino, J., & Picazo-Tadeo, A. J. (2018). OECD: One or Many? Ranking Countries with a Composite Well-Being Indicator. Social Indicators Research, 139, 847–869.

Pereira, M. A., D'Inverno, G., & Camanho, A. S. (2025). Learning Mobility in European Higher Education: How Has the Union's Flagship Initiative Progressed? Annals of Opera-tions Research, 351, 1589–1619.

Marjanović, I., Milanović Zbiljić, S., Stanković, J. J., & Marković, M. (2025). Towards Urban Sustainability: Composite Index of Smart City Performance. Sustainability, 18, 372.

Van Puyenbroeck, T., & Rogge, N. (2017). Geometric mean quantity index numbers with Benefit-of-the-Doubt weights. European Journal of Operational Research, 256(3), 1004–1014.

Rogge, N. (2018). Composite indicators as generalized Benefit-of-the-Doubt weighted av-erages. European Journal of Operational Research, 267(1), 381–392.

Sayed, H., Hamed, R., Hosny, S. H., & Abdelhamid, A. H. (2018). Avoiding ranking con-tradictions in Human Development Index using Goal Programming. Social Indicators Re-search, 138(1), 405–442.

Lemke, W. (2016). The role of sport in achieving the sustainable development goals. UN chronicle, 53(2), 6-9.

Liu, Y. D. (2009). Sport and social inclusion: Evidence from the performance of public leisure facilities. Social indicators research, 90(2), 325-337.

Som, C. V. (2023). Building a case for incorporating sport as an indicator in human devel-opment index. Sport Sciences for Health, 19(1), 177-184.

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From Ad Hoc Choices to Value-Driven Decisions: a Multi-Attribute Value Model for Project Prioritization in a State Department of Finance

Adrian Daniel da Silva[1], Alexandre Farias Maia[1],Jaini Barbosa[1] and Ricardo Pires de Souza[1]

[1]Department of Production Engineering, Federal University of Rio Grande do Norte (UFRN), Campus Universitário Lagoa Nova, Natal-RN, Brazil, 59078-970.
adrian.daniel.136@ufrn.edu.br, alexandre.maia.702@ufrn.edu.br, ricardo.pires@ufrn.br, jaini.barbosa@ufrn.edu.br

Abstract. Purpose: this paper reports on an internship experience in the project office of a State Department of Finance (Secretaria Estadual da Fazenda – SEFAZ), where the annual selection of projects to be executed has been made on a discretionary basis by the Secretary, without explicit criteria, ever since a computerized decision-support system considered impractical was abandoned. The purpose is to diagnose the causes of the previous system's failure and to develop and numerically test a value-driven multi-attribute decision model for project prioritization. **Methodology:** the study combines participant observation, informal interviews with staff of the project office and the Value-Focused Thinking (VFT) framework to identify and qualitatively structure a hierarchy of fundamental objectives; on this structure a Multi-Attribute Value model was developed following the SMART/SMARTS tradition, with single-dimensional value functions, weights elicited through swing weighting and additive aggregation, followed by a one-way sensitivity analysis. **Findings:** the previous system failed mainly because it moved directly to quantification without a prior qualitative stage of identifying and validating objectives, and because it required an excessive number of redundant technical parameters. A leaner hierarchy of six fundamental objectives was identified and translated into an additive model; applied to three hypothetical projects it produced a narrow ranking, and the sensitivity analysis showed that this ranking is highly sensitive to the weight assigned to the fiscal/legal risk objective, with a breakeven point only slightly below the elicited value. **Originality/value:** the contribution lies in showing, through a real public-sector case, that overcoming a previously failed prioritization initiative requires not only a qualitative stage of value structuring but also an explicit, auditable multi-attribute value model together with a documented sensitivity analysis, which increases the technical defensibility and the legitimacy of the resulting ranking.

Keywords: Value-Focused Thinking; Multi-Attribute Utility Theory; project prioritization; sensitivity analysis; public sector decision-making.

1 Introduction/Purpose

The State Department of Finance (SEFAZ) studied here has a project office responsible for planning, every year, the set of initiatives in which the institution will invest its financial resources and its execution capacity — initiatives that generally materialize as public tenders, competitive examinations, consultancy contracts and internal system development. The different sub-secretariats (Revenue, Information Technology, Administration and Enforcement) submit, annually, between 18 and 25 project proposals, competing for an estimated annual budget of R$ 45 to 60 million, as well as for a limited capacity to conduct simultaneous tender processes.

The final decision on which projects will be executed in each cycle rests with the Secretary of Finance. Around 2021, the project office implemented a computerized decision-support system (here referred to as PPS – Project Prioritization System), which required managers to fill in numerous quantitative parameters and weights for each evaluation criterion. The system was perceived by users as cumbersome — difficult to operate, with many technical fields and little clarity about the practical meaning of the requested parameters — and, after a few cycles of use, it fell out of use. Over the last three years, project selection has been made in an essentially discretionary manner, without documented criteria, which creates difficulties in justifying decisions before oversight bodies such as the State Audit Court (Tribunal de Contas do Estado, TCE), inconsistency from one year to the next, and low transparency for the proposing areas themselves.

Two features of this setting deserve emphasis, because they shape what an adequate decision model must look like. The first is that the competition is not only budgetary. Even a project fully funded within the annual ceiling may be infeasible if the department cannot conduct one more tender process in parallel, so

execution capacity operates as a second, non-monetary constraint that a purely financial ranking would miss. The second is that the proposals are heterogeneous in kind: a data cross-matching initiative to combat tax evasion, a new digital channel for issuing tax certificates and the automation of an internal refund routine are not commensurable on any single natural scale, and each is defended by a different sub-secretariat with its own understanding of what the Department should be pursuing. Any prioritization instrument that fails to make those competing understandings explicit will be perceived, sooner or later, as arbitrating between areas rather than between projects.

The department's advisor pointed out, in reviewing an earlier version of this study, that structuring objectives with Value-Focused Thinking (VFT) is not, by itself, a decision model: it produces a qualitative map of what matters, but it does not generate a ranking of projects, nor does it indicate how confident one should be in that ranking. The present paper addresses this gap directly. Its purpose is threefold: first, to diagnose why the decision process evolved as it did, in light of the VFT framework proposed by Keeney (1992); second, to develop — not merely to structure — a multi-attribute decision model, built on the VFT-derived objectives and capable of producing an auditable, weighted ranking of candidate projects; and third, to subject that model to a sensitivity analysis, so that the robustness of its recommendations, and not only their existence, becomes part of what is delivered back to the organization.

1.1 Theoretical Background

Value-Focused Thinking, introduced by Keeney (1992), holds that decision quality depends primarily on the prior identification and structuring of objectives, rather than on the evaluation of already available alternatives (Keeney, 1996). VFT supplies qualitative tools — objective networks and means-ends distinctions — that precede any quantitative modelling effort, and Keeney (1993) argues that this qualitative stage is where most of the creativity, and most of the decision quality, of a decision-analytic intervention is generated.

Once a set of fundamental objectives has been identified, Multi-Attribute Utility Theory (MAUT) offers a formal apparatus for aggregating performance across multiple, often conflicting, objectives into a single value or utility score (Keeney and Raiffa, 1976). Under conditions of preferential and additive independence — or as a defensible approximation when these conditions hold only loosely — an additive value function, i.e. the weighted sum of single-dimensional value scores, is an adequate and transparent aggregation rule (von Winterfeldt and Edwards, 1986).

The Simple Multi-Attribute Rating Technique (SMART) and its refinements, SMARTS and SMARTER (Edwards, 1977; Edwards and Barron, 1994), operationalize the additive model with two simplifications well suited to low-resource public-sector settings: (i) single-dimensional value functions are elicited through direct-rating procedures, often approximated as piecewise-linear functions anchored at the worst and best levels observed among the alternatives under consideration; and (ii) weights are elicited through swing weighting, in which decision-makers rank and rate the swing from the worst to the best level of each attribute, rather than assigning importance in the abstract — a procedure reported to reduce elicitation bias relative to naive point-allocation schemes (von Winterfeldt and Edwards, 1986; Belton and Stewart, 2002).

In public administration this apparatus carries an additional burden that it does not carry in private settings. A private decision-maker may legitimately keep the reasoning behind a portfolio choice internal; a public one is expected to be able to reconstruct it before oversight bodies, sometimes years later and before officials who did not take part in the original discussion. This is why the attribute of an additive value model that matters most here is not its optimality but its decomposability: because the overall score is a weighted sum of independent single-dimensional values, any figure in the final ranking can be traced back to a specific measured performance and a specific elicited judgement. A model that cannot be taken apart in this way offers no defence when questioned, however sophisticated its internal machinery.

A recurring criticism of applied multi-attribute models, including in the public sector, is that weights and scores tend to be presented as if they were exact figures, when they in fact encode subjective judgements made under uncertainty. Sensitivity analysis — systematically varying weights or scores to check whether the ranking of alternatives changes — is therefore regarded as an integral part of the modelling process rather than an optional addendum (Belton and Stewart, 2002); it identifies which parameters most deserve further elicitation effort and gives decision-makers an explicit account of how robust a recommendation is before it is acted upon. Such limitations can be alleviated not only through continuous monitoring of key factors during the decision process, but also by using different decision-making methods throughout it (Taherdoost and Mohebi, 2024). The present work situates itself at the intersection of these two traditions.

2 Methodology

This account results from participant observation during an internship in SEFAZ's project office, complemented by informal conversations with staff responsible for conducting the project-selection process, and by consultation of internal records (meeting minutes and project-monitoring spreadsheets from the last three cycles). The analysis was conducted in four stages.

Diagnosis of the current process.
In the first stage, the actual decision process was mapped and contrasted with the two modes of thinking described by Keeney (1992): alternative-focused thinking, in which the decision starts from the options already on the table and only then, informally, evaluates criteria; and value-focused thinking, in which objectives are made explicit before alternatives are generated and evaluated. Both the current discretionary process and the former computerized system were found to suffer from the same structural problem: in neither case was there, in fact, a qualitative stage of identifying and structuring the organization's fundamental objectives.

The internal records consulted at this stage were used to reconstruct, for the last three cycles, which proposals had been submitted, which had been approved and what justification, if any, had been recorded for the choice. The comparison revealed that approval decisions were documented as outcomes rather than as reasoned selections: the minutes register what was decided, not the grounds on which one proposal prevailed over another. This absence is itself a finding, since it means that the department currently has no way of demonstrating internal consistency across cycles, nor of explaining to a proposing area why its project was postponed.

Qualitative structuring of objectives.
In the second stage, following the objective-identification procedures described by Keeney (1992, ch. 3) and Keeney (1996), the objectives that effectively guide — even if only implicitly — project selection at SEFAZ were elicited from staff across different areas. Questions such as “why would this project matter?” and “what kind of project would the Department never approve, even if it were cheap?” were used to separate means objectives from fundamental objectives.

Development of the multi-attribute value model.
For each fundamental objective, an attribute was defined — natural where possible, and a constructed 0–4 scale otherwise — and a single-dimensional value function $v_i(x)$ was specified, normalizing performance onto a common 0–100 scale. For constructed scales the value function was assumed linear, $v_i(x) = 25x$; for natural attributes, a linear value function was anchored at the worst and best levels observed among the candidate projects, following the direct-rating procedure recommended for SMART models (Edwards, 1977). Weights were elicited using swing weighting (von Winterfeldt and Edwards, 1986): objectives were ranked by the importance of a swing from their worst to their best level, points were assigned to each swing (100 points for the most important one), and the resulting numbers were normalized to sum to 1, yielding weights w_i. The overall value of a project j was then computed as an additive function:

$$V(j) = \Sigma_i \, w_i \cdot v_i(x_{ij}) \, . \qquad (1)$$

Deliberately, only six objectives and simple linear value functions were used, and the model was kept to an additive form rather than a full multiplicative multi-attribute utility function, so as to avoid the excess of parameterization that, per the diagnosis above, was the main cause of the previous system's abandonment (Keeney, 1992, ch. 5).

Two design decisions in this stage deserve justification. First, the value functions were kept linear even where a decision-maker might plausibly exhibit diminishing returns — for instance, in the reduction of average service time, where the first days saved may be worth more than the last. A linear approximation was preferred because the elicitation effort required to estimate curvature is substantial and, in a model whose main purpose is to make reasoning explicit, that effort is better invested in the weights, which drive the ranking far more strongly. Second, attribute ranges were anchored at the worst and best levels observed among the candidate projects rather than at absolute maxima. This choice makes the swing weighting meaningful — a decision-maker can only rate a swing that corresponds to a range actually on the table — but it also implies that weights must be re-elicited whenever the pool of candidate projects changes substantially, a point that has to be made clear to the users of the spreadsheet.

Sensitivity analysis.
Following standard practice in applied MAUT/SMART models (Belton and Stewart, 2002), a one-way sensitivity analysis was performed on the weight of the objective identified as most influential for the ranking of the top-scoring projects. The remaining weights were re-scaled proportionally to their original ratios as the weight under study, w_1, was varied, and a breakeven weight w_1^* was computed — the value of w_1 at which the ranking of the two leading projects reverses. This procedure was chosen over a full Monte Carlo analysis because it is easy to explain and to reproduce in a spreadsheet by non-specialist staff, consistently with the low-complexity requirement that motivated the whole redesign.

3 Findings

3.1 Why the Previous System Was Abandoned

The analysis pointed to three main causes, consistent with pitfalls already described in the VFT literature:

- **Inverted logical order:** the system quantified criteria (weights, 0–100 scores, weighted formulas) before those criteria had been discussed and validated qualitatively with the main stakeholders, including the Secretary; users did not recognize the resulting numbers as a faithful translation of what actually mattered (Keeney, 1992, ch. 2).
- **Excessive number of parameters:** the system requested between 12 and 15 technical criteria per project, many of them redundant with one another (double counting) or difficult to fill in for staff without technical expertise, raising the cost of use without a proportional gain in information quality.
- **Low institutional ownership:** because there had been no process of collective construction of the Department's strategic objectives, the system's output was perceived as a "black box" rather than a decision-support tool; faced with this, the Secretary preferred to return to discretionary judgement, which was faster and more familiar, even if less transparent.

This diagnosis is consistent with Keeney's (1993, 1996) warning that the creativity and quality of a decision depend, above all, on the effort invested in understanding and structuring values before any attempt at quantification. Skipping the qualitative stage, however, is only half of the problem: skipping the quantitative model and its sensitivity analysis, as the original version of this study did, leaves the organization without a defensible, auditable ranking.

These three causes are not independent, and the order in which they operate matters for the remedy. The inverted logical order is the primary one; the proliferation of parameters is largely its consequence, since a team that has not agreed on what matters has no principled basis for leaving anything out and will tend to include every measurable variable it can think of. The loss of institutional ownership then follows from both: a long form whose fields nobody can connect to a declared purpose is experienced as bureaucratic overhead, and the score it produces is not recognized as the group's own judgement. This ordering is what justifies beginning the redesign with value structuring rather than with a leaner interface, which is the response the failure would most naturally suggest.

3.2 Hierarchy of Objectives, Value Functions and Weights

From conversations with staff across different sub-secretariats, a lean hierarchy of six fundamental objectives was reached, shown in Table 1, each accompanied by a measurement attribute and by the single-dimensional value function defined for it.

Table 1. Fundamental objectives, measurement attributes and single-dimensional value functions. Source: research data.

Fundamental objective	Attribute (range: worst–best)	Value function $v_i(x)$
1. Minimize fiscal and legal risk	Constructed scale, 0 to 4 (none to high risk of TCE audit finding)	$v_1(x) = 25x$
2. Maximize net tax collection	Estimated increase in tax collection over 24 months: R$ 0 to R$ 5.0 million	$v_2(x) = (x/5) \times 100$
3. Maximize administrative	Hours of manual work eliminated per year: 0 to	$v_3(x) = (x/2000) \times 100$

efficiency	2,000 h	
4. Improve taxpayer service	Expected reduction in average service time: 0 to 10 days	$v_4(x) = (x/10) \times 100$
5. Ensure budgetary and technical feasibility	Compliance with the annual budget ceiling and execution capacity (0 to 4)	$v_5(x) = 25x$
6. Strengthen governance and transparency	Degree of documentation and traceability of the decision process (0 to 4)	$v_6(x) = 25x$

Table 2 shows the swing-weighting exercise conducted in a simulated workshop with the project office team. Objectives were ranked by the importance of the swing from their worst to their best level, points were assigned relative to the top-ranked swing (100 points), and the results were normalized to sum to 1.

Table 2. Weights elicited by swing weighting. Source: research data.

Objective	Swing rank	Swing points	Normalized weight w_i
1. Risk	1st	100	0.25
2. Net tax collection	2nd (tie)	80	0.20
3. Efficiency	2nd (tie)	80	0.20
4. Taxpayer service	4th	60	0.15
5. Feasibility	5th (tie)	40	0.10
6. Governance/transparency	5th (tie)	40	0.10
Total		400	1.00

3.3 Illustrative Application and Sensitivity Analysis

Table 3 illustrates, with fictitious data, how three hypothetical projects (A, B and C) would be scored on each of the six attributes (raw performance, with the single-dimensional value in parentheses), and how these values combine, through the weights of Table 2, into an overall additive value V(j). This replaces the ad hoc weighted sum of the original diagnosis with a fully specified, reproducible model, in line with Keeney's (1992, ch. 5) recommendation that the value-model form should be the simplest one compatible with the quality of the available information.

Table 3. Illustrative scoring of three hypothetical projects (fictitious data). Values in parentheses are the single-dimensional value scores $v_i(x_{ij})$, 0–100. Source: research data.

Project	Risk (w=.25)	Tax collect. (w=.20)	Efficiency (w=.20)	Service (w=.15)	Feasib. (w=.10)	Governance (w=.10)	V(j)
A	4 (100)	R$ 3.0M (60)	800 h (40)	6 d (60)	4 (100)	3 (75)	71.5
B	2 (50)	R$ 5.0M (100)	2000 h (100)	4 d (40)	3 (75)	2 (50)	71.0
C	3 (75)	R$ 2.0M (40)	1200 h (60)	8 d (80)	2 (50)	4 (100)	65.8

The resulting ranking is A (71.5) > B (71.0) > C (65.8). The overall score does not replace the Secretary's decision: it works as a decision-support input, making explicit the reasons a project ranks ahead of another, and allowing any divergence between the spreadsheet result and the final choice to be justified and documented rather than hidden. In this example, however, the margin between the top two projects is only 0.5 points on a 0–100 scale, which motivates the sensitivity analysis.

It is instructive that the narrowness of this margin is itself informative. Under the previous system a difference of half a point would have been reported as a decision, since the output was a single ordered list with no indication of how much separated its entries. Here it is visible that projects A and B are, for practical purposes, tied on the group's current judgement, and that they are tied because they are strong on different things: A is dominant on risk, feasibility and governance, while B is dominant on the two objectives most directly tied to revenue and internal productivity. That is a substantive finding about the portfolio, not an

artefact of the arithmetic, and it is the kind of finding a decision-maker can act on — for instance by asking whether the two projects are genuinely mutually exclusive within the cycle.

Because the weight assigned to the fiscal and legal risk objective ($w_1 = 0.25$) is both the largest weight in Table 2 and the attribute on which projects A and B differ the most ($v_1 = 100$ for A versus $v_1 = 50$ for B), it was chosen as the focus of the one-way sensitivity analysis. Holding the ratios among the other five weights fixed and re-scaling them as w_1 varies, the value scores of A and B become linear functions of w_1:

$$V_A(w_1) = 62.0 + 38.0\, w_1 \qquad V_B(w_1) = 78.0 - 28.0\, w_1 \,. \tag{2}$$

Setting $V_A(w_1) = V_B(w_1)$ gives a breakeven weight $w_1^* \approx 0.242$: for any risk weight above this value Project A is recommended; below it, Project B overtakes A. The weight elicited in the simulated workshop, $w_1 = 0.25$, is only 0.008 above this breakeven point — that is, the current recommendation of Project A over Project B is not robust to small changes in how the group evaluates the relative importance of fiscal and legal risk. A shift in the State Audit Court's enforcement posture, or a change in workshop participants, could plausibly move the elicited weight below 0.242.

This result illustrates the practical value of sensitivity analysis for the model: rather than presenting Project A's first place as a settled fact, the analysis flags the risk weight as the single parameter most worth revisiting — through a follow-up elicitation session, ideally with the Secretary present — before the ranking is used to support a real budget decision. It also shows that, unlike the previous system's single opaque score, the additive model developed here can be interrogated to show exactly which judgement a recommendation depends on.

3.4 Implications for the Decision Record

Beyond the ranking itself, the model changes what the project office is able to put on record at the end of a cycle. Under the current discretionary practice, the documentary output of the process is a list of approved projects. Under the proposed model, the output is a set of four linked artefacts: the objective hierarchy, with the rationale for each objective; the attribute definitions and value functions, which fix how performance is measured; the elicited weights, with the swing-weighting record that produced them; and the resulting scores, with the sensitivity analysis that qualifies them. Each of these can be questioned separately, which is precisely what makes the whole defensible.

This also reframes the relationship between the model and the Secretary's authority. Because the additive score is not binding, a decision that departs from the ranking is not a failure of the instrument: it is an occasion to record which consideration, absent from the six objectives, justified the departure. Over successive cycles such records are informative in themselves, since a recurring departure in the same direction is evidence that the objective hierarchy is incomplete and should be revised — a feedback loop that a discretionary process, producing no comparable trace, cannot generate.

4 Originality/value

The contribution of this work is not to propose yet another decision-support software, but to show, with a real case of state public management, that the failure of a project-prioritization initiative can lie less in the technology employed and more in skipping two steps that decision analysis treats as essential: a prior stage of qualitative value structuring, as prescribed by VFT (Keeney, 1992, 1993, 1996), and an explicit, quantified value model together with its sensitivity analysis, as prescribed by MAUT/SMART practice (Keeney and Raiffa, 1976; Edwards, 1977; von Winterfeldt and Edwards, 1986; Belton and Stewart, 2002). In this sense, the practical value of the proposal rests on four points.

- **Low adoption cost:** the proposed tool is a simple spreadsheet, with six objectives and previously agreed value functions and weights, dispensing with the development of a dedicated computerized system — which reduces the barrier to use that made the previous solution impractical.
- **Legitimacy:** because it results from a collective and explicit process of identifying objectives together with the areas involved and senior management, the objective hierarchy tends to be recognized as more legitimate than criteria defined unilaterally by a technical team.
- **Transparency and auditability:** documenting the objective hierarchy, the value functions, the elicited weights and the resulting scores creates a defensible trail before oversight bodies, responding to a concrete weakness pointed out by the staff interviewed.

- **Traceable robustness:** unlike the previous system, whose black-box scores could not be interrogated, the additive value model can be decomposed and re-run under alternative weights, so that a sensitivity analysis, rather than a single point estimate, is delivered to decision-makers together with the ranking.

It is worth being explicit about what is and what is not transferable from this case. The six objectives and the weights reported here are specific to a state revenue administration and would not survive transposition to another public body without re-elicitation. What does transfer is the diagnosis and its remedy: wherever a prioritization system has been abandoned as impractical, it is worth asking whether the failure lay in the tool or in the two omitted steps, since the instinctive response — commissioning a better system — addresses the symptom and reproduces the cause. In this sense the modest technical form of the proposal, a spreadsheet with six objectives, is not a limitation of the study but part of its argument.

This account remains qualitative and exploratory in its origin, based on a single internship and a reduced sample of staff; the value functions, weights and scores presented in Tables 1 to 3 are illustrative and need to be recalibrated in a formal workshop with SEFAZ's senior management, ideally including the Secretary directly in the swing-weighting exercise, since the sensitivity analysis shows the ranking is sensitive to exactly the kind of judgement only the Secretary can validate. The additive aggregation rule also assumes approximate preferential and additive independence among the six objectives; this assumption was not formally tested and should be checked — for instance through simple trade-off questions — before the model is used to support a real budget cycle. As future work, a pilot implementation of the proposed model is suggested for one real budget cycle, followed by a comparative evaluation between the ranking produced by the spreadsheet and the decisions actually made, together with a fuller, multi-parameter sensitivity analysis (e.g. a tornado diagram across all six weights), so as to verify the model's acceptance and its contribution to the quality and transparency of the decision process.

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References

Belton, V., Stewart, T. (2002), *Multiple Criteria Decision Analysis: An Integrated Approach*. Kluwer Academic Publishers, Boston.

Edwards, W. (1977), How to Use Multiattribute Utility Measurement for Social Decisionmaking. *IEEE Transactions on Systems, Man, and Cybernetics*, 7(5), 326-340.

Edwards, W., Barron, F.H. (1994), SMARTS and SMARTER: Improved Simple Methods for Multiattribute Utility Measurement. *Organizational Behavior and Human Decision Processes*, 60(3), 306-325.

Keeney, R.L. (1992), *Value-Focused Thinking: A Path to Creative Decisionmaking*. Harvard University Press, Cambridge.

Keeney, R.L. (1993), Creativity in MS/OR: Value-Focused Thinking — Creativity Directed toward Decision Making. *Interfaces*, 23(3), 62-67.

Keeney, R.L. (1996), Value-focused thinking: Identifying decision opportunities and creating alternatives. *European Journal of Operational Research*, 92, 537-549.

Keeney, R.L., Raiffa, H. (1976), *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*. Wiley, New York.

Taherdoost, H., Mohebi, A. (2024), Using SMART method for multi-criteria decision making: Applications, advantages, and limitations. *Archives of Advanced Engineering Science*, 2(4), 190-197.

von Winterfeldt, D., Edwards, W. (1986), *Decision Analysis and Behavioral Research*. Cambridge University Press, Cambridge.

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Organizational Productivity as an Emergent Property: The Integrated Autopoietic–Eudaimonic Management Framework (MIGAE)

Víctor Ramírez-Amaya[1], Silvia M. Pierotti[1], José F. Zanazzi[1], Daniel Pontelli[1] and José L. Zanazzi[1]

[1] Laboratorio de Ingeniería y Mantenimiento Industrial. Facultad de Ciencias Exactas, Físicas y Naturales. Universidad Nacional de Córdoba

victor.ramirez.amaya@unc.edu.ar , silvia.pierotti@unc.edu.ar , jfzanazzi@unc.edu.ar , dpontelli@unc.edu.ar, jose.luis.zanazzi@unc.edu.ar ,

Abstract. Productivity remains one of the central objectives of organizational management and industrial engineering. However, most existing approaches explain organizational performance primarily through structural, technological, or economic factors, providing limited understanding of the adaptive mechanisms that enable sustainable productivity in complex socio-technical systems. This paper proposes the Integrated Autopoietic–Eudaimonic Management Framework (MIGAE), a theoretical framework that explains organizational productivity as an emergent property arising from eudaimonic organizational states generated by autopoietic, negentropic-entropic pulsation, and sensemaking dynamics. The framework was developed through an integrative conceptual research approach grounded in systems thinking, autopoiesis, dissipative structures, organizational sensemaking, organizational learning, socio-technical systems, and action research. The proposed framework is methodologically articulated with the MInFRO intervention model, which provides the organizational intervention architecture supporting the construction of the theoretical model. Unlike conventional management models that seek to optimize productivity directly, MIGAE postulates that organizations enhance long-term performance by cultivating systemic conditions that promote adaptive self-organization, collective meaning construction, organizational learning, resilience, and continuous regeneration. Under this perspective, productivity is interpreted not as an independent managerial objective but as an emergent consequence of organizational dynamics that maintain systemic coherence while continuously adapting to environmental disturbances. The proposed framework contributes to organizational engineering and management theory by integrating biological, cognitive, and systemic perspectives into a unified explanation of organizational adaptation and productivity. Furthermore, it establishes the conceptual foundations for future mathematical formalization, computational simulation, and empirical validation of the proposed theory across production and service organizations.

Keywords: Organizational Productivity; Autopoiesis; Eudaimonia; Complexity Theory; Organizational Sensemaking; Organizational Learning; Socio-Technical Systems; Systems Thinking; Organizational Resilience; Action Research.

1 Introduction

Productivity in industrial organizations is traditionally regarded as the primary indicator of its performance and competitiveness. Although substantial advances have been achieved through quality management, operations management, organizational learning, and systems engineering, existing approaches predominantly explain productivity through structural, technological, economic, or process-oriented variables (Deming, 1986; Coelli et al., 2005; Oakland, 2014). However, contemporary organizations increasingly operate as complex socio-technical systems characterized by continuous adaptation, distributed decision-making, nonlinear interactions, and emergent behaviors. Under these conditions, productivity cannot be fully understood as the direct consequence of isolated managerial practices but rather as the outcome of systemic organizational dynamics that continuously regenerate the conditions required for coordinated action and long-term adaptation (Holland, 1992; Stacey, 2021; Duchek, 2020).

During the last four decades, several theoretical traditions have independently contributed to understanding organizational adaptation. Autopoiesis explains how living systems preserve their identity through continuous self-production despite environmental perturbations (Maturana & Varela, 1980; Luhmann, 1995). Complexity theory and dissipative structures describe how order may emerge spontaneously in open systems operating far from equilibrium (Nicolis & Prigogine, 1977; Prigogine & Stengers, 1984). Organizational sensemaking emphasizes the collective construction of meaning that enables coordinated action under uncertainty (Weick, 1995; Maitlis & Christianson, 2014), whereas organizational learning explains how organizations progressively modify routines, capabilities, and shared knowledge through experience and reflection (Deming, 1986; Coelli et al., 2005; Oakland, 2014). More recently, research on resilience, dynamic capabilities, and organizational adaptability has further demonstrated that sustainable organizational performance depends more on the continuous regeneration of adaptive capabilities (Lengnick-Hall et al., 2011; Teece, 2007; Uhl-Bien & Arena, 2018).

Despite these advances, the literature still lacks an integrative theoretical framework capable of explaining how these processes jointly contribute to organizational productivity. Existing models generally adopt partial perspectives, emphasizing either organizational structures, human behavior, operational excellence, or knowledge management, without providing a unified framework through which adaptive organizational states emerge and translate into sustained productive performance, and productivity is treated as an objective rather than as the emergent consequence of deeper systemic processes.

This article addresses this theoretical gap by proposing the Integrated Autopoietic–Eudaimonic Management Framework (MIGAE), a conceptual framework that explains organizational productivity as an emergent property of eudaimonic organizational states generated through the interaction of autopoietic and socio-technical dynamics. Although currently there is no previous validation of a similar organizational model in the literature, the convergence of autopoietic dynamics with the eudaimonic purpose in industrial management suggests that organizational viability depends on structuring systems where functional autonomy acts as a catalyst for human flourishing. From a systems theory perspective, autopoiesis defines organizations as self-referential networks that maintain their identity through closed loops of production and communication (Luhmann, 1995; Maturana & Varela, 1980). When this capacity for self-regulation is applied to the industrial realm, organizational cybernetics demonstrates that granting operational autonomy to work units is essential for system adaptability (Beer, 1981); this aligns with Sociotechnical Systems theory, which calls for the joint optimization of technology and the social factor through self-managed teams (Trist & Bamforth, 1951). Finally, the Humanistic Management perspective complements this functional design by establishing that autonomy should not aim merely for quantitative efficiency but should be ethically oriented toward respecting the worker's dignity and fostering their holistic fulfillment within the workplace (Pirson, 2017). Within the MIGAE perspective, organizations are understood as adaptive systems that continuously regenerate their internal coherence through organizational learning, collective sensemaking, distributed coordination, and the preservation of their operational identity while interacting with changing environments. The theoretical development of MIGAE is methodologically supported by the MInFRO (Flexible and Reflective Organizational Intervention Model) (Zanazzi, 2025), which provides the intervention architecture through which organizational diagnosis, contextual understanding, stakeholder participation, and continuous learning are integrated into the construction of adaptive organizational interventions. In this way, MInFRO supplies the methodological foundation, whereas MIGAE extends this with a novel organizational theoretical framework.

The current contribution is threefold the integration of biological, cognitive, systemic, and organizational perspectives into a coherent theoretical explanation of productivity in complex socio-technical systems, and

to reinterpret productivity as an emergent organizational property rather than as a directly controllable managerial objective, shifting the focus from process optimization toward the continuous regeneration of adaptive organizational conditions. This is the first stage of a cumulative research program devoted to the theoretical development of the MIGAE framework across production and service organizations.

Following in Section 2 we develop the theoretical foundations of the proposed framework by integrating contributions from systems science, complexity theory, autopoiesis, negentropic-entropy pulsation, organizational cognition, organizational eudaimonia, and productivity research. In Section 3 we present the MIGAE framework and explain the dynamic organizational mechanism through which productivity emerges from adaptive organizational processes. In Section 4 we provide the conceptual formalization of the framework by identifying its principal organizational constructs, multilevel interactions, and recursive feedback mechanisms, thereby establishing the conceptual architecture for future mathematical development. In Section 5 we discuss the theoretical, methodological, and epistemological contributions of the proposed framework, highlighting its implications for Organizational Engineering, Management Science, Systems Thinking, and productivity research. And finally in Section 6 we summarize the principal contributions of the study, acknowledge its limitations, and outline the future research agenda, including the mathematical formalization, computational simulation, and empirical validation of the MIGAE framework.

Taken together, these sections develop the central argument of the article: sustainable organizational productivity is not generated directly through managerial optimization but emerges from the continuous interaction of autopoietic, negentropic, cognitive, and eudaimonic organizational dynamics.

2 Theoretical Foundations of the MIGAE Framework

The Integrated Autopoietic–Eudaimonic Management Framework (MIGAE) is grounded on the convergence of complementary theoretical traditions that have evolved independently within systems science, organizational theory, cognitive sciences, and industrial engineering. Rather than adopting a single disciplinary perspective, the framework integrates concepts that explain organizational adaptation from biological, systemic, cognitive, and socio-technical viewpoints. This integration addresses a persistent limitation of existing management theories, which frequently explain organizational performance through isolated structural, technological, or behavioral variables while providing only partial explanations of how sustainable productivity emerges in complex organizational systems.

Within the proposed framework, productivity is understood as the consequence of dynamic interactions occurring across multiple organizational dimensions rather than as the direct outcome of managerial optimization. Accordingly, the theoretical foundations of MIGAE are organized as an explanatory sequence that progressively connects complexity, self-organization, cognition, organizational flourishing, and productive performance. Complexity theory provides the systemic perspective required to understand organizations as adaptive socio-technical systems. Autopoiesis and dissipative structures explain how organizational identity is continuously regenerated through self-organization. Sensemaking and organizational learning describe the cognitive mechanisms that sustain collective adaptation. Eudaimonia characterizes the emergent organizational state resulting from these adaptive processes, while productivity is interpreted as the systemic property that emerges from maintaining organizational coherence under changing environmental conditions.

Instead of representing independent theoretical pillars, these perspectives constitute complementary explanatory constructs whose interaction forms the conceptual architecture of MIGAE. Their integration establishes the theoretical foundations for the framework presented in this article and provides the basis for its subsequent mathematical formalization, computational simulation, and empirical validation.

2.1 Complexity and Adaptive Socio-Technical Systems

Organizations increasingly operate under conditions characterized by uncertainty, interdependence, technological acceleration, and continuous environmental change. Under these circumstances, linear and reductionist approaches become progressively insufficient to explain organizational behavior because organizational performance no longer depends exclusively on the optimization of isolated processes but on the interactions among multiple organizational components. Complexity theory therefore proposes that organizations should be understood as complex adaptive systems composed of heterogeneous agents whose

collective behavior emerges from nonlinear interactions rather than centralized control (Boulding, 1956; Holland, 1992; Stacey, 2021).

Within this perspective, adaptation is interpreted as a continuous process through which organizations preserve their functional coherence while simultaneously modifying internal structures in response to environmental perturbations. Consequently, organizational phenomena such as resilience, innovation, coordination, and productivity cannot be fully explained through the analysis of individual organizational components but emerge from the dynamic interactions occurring throughout the entire organizational system (Allen, 2001; Uhl-Bien & Arena, 2018).

Industrial organizations constitute socio-technical systems in which technological infrastructures, human actors, organizational routines, institutional rules, and decision-making processes evolve simultaneously. Their effectiveness therefore depends not only on technical efficiency but also on the capability to coordinate adaptive responses under conditions of uncertainty. This systemic perspective establishes the conceptual context within which the remaining theoretical constructs of MIGAE are developed (Trist & Bamforth, 1951; Pasmore et al., 1982; Hollnagel et al., 2006).

2.2 Autopoiesis, Negentropy-Emtropy Pulsation and Organizational Self-Organization

The concept of autopoiesis, originally introduced by Maturana and Varela (1980), defines living systems as networks capable of continuously producing and regenerating the components that maintain their own organization. Rather than preserving stability through rigid equilibrium, autopoietic systems sustain their identity through continuous structural adaptation while interacting with changing environments. This perspective has significantly influenced organizational theory by suggesting that organizations likewise preserve their operational identity through ongoing processes of organizational self-production and structural renewal (Luhmann, 1995; Magalhães & Sanchez, 2009).

The theory of dissipative structures further complements this interpretation by explaining how open systems operating far from thermodynamic equilibrium generate increasing levels of organization through the continuous exchange of matter, energy, and information with their environments (Nicolis & Prigogine, 1977; Prigogine & Stengers, 1984). Under this perspective, disturbances do not necessarily threaten organizational stability but may instead become sources of innovation, adaptation, and organizational evolution.

Negentropy-entropy pulsation represents the organizational capacity to maintain internal coherence despite increasing environmental complexity. Rather than eliminating uncertainty, negentropic-entropy pulsation processes continuously regenerate organizational routines, informational structures, communication patterns, and shared knowledge that preserve the system's functional organization. Consequently, organizational self-organization is interpreted as the dynamic process through which adaptive structures emerge without requiring permanent centralized control.

Within MIGAE, autopoiesis and negentropy-entropy pulsation constitute the fundamental mechanisms through which organizations preserve their identity while continuously adapting to changing operational environments. These processes establish the systemic conditions necessary for the emergence of higher-order organizational capabilities.

2.3 Sensemaking and Organizational Learning as Cognitive Mechanisms of Adaptation

Structural adaptation alone is insufficient to explain organizational evolution. Organizations must also interpret environmental changes, construct shared meanings, and coordinate collective responses capable of preserving organizational coherence under uncertainty. Consequently, adaptive organizational systems require cognitive mechanisms that transform distributed information into coordinated organizational action.

Sensemaking provides one of the principal mechanisms through which organizations reduce ambiguity while confronting novel or unexpected situations. According to Weick (1995), organizational actors continuously construct plausible interpretations that enable coordinated action rather than seeking objective representations of reality. These interpretative processes facilitate collective coordination under conditions of incomplete information and allow organizations to maintain operational coherence despite environmental complexity (Weick et al., 2005; Maitlis & Christianson, 2014).

Organizational learning complements this perspective by explaining how organizations progressively modify routines, capabilities, and shared knowledge through experience, reflection, and feedback (Argyris, & Schön, 1978; Senge, 1990). Through learning processes, adaptive responses become institutionalized and

progressively incorporated into organizational memory, thereby strengthening long-term adaptive capacity. Similarly, knowledge creation processes enable organizations to regenerate capabilities continuously while supporting innovation and organizational renewal (Nonaka & Takeuchi, 1995).

Within the MIGAE framework, sensemaking and organizational learning are interpreted as the principal cognitive mechanisms supporting autopoietic adaptation. Rather than constituting independent managerial capabilities, both processes continuously regenerate the shared interpretations, collective knowledge, and organizational coordination required to sustain systemic coherence under changing environmental conditions.

2.4 Organizational Eudaimonia as an Emergent Adaptive State

While autopoiesis explains how organizations preserve their identity and sensemaking describes how they construct collective meaning, neither perspective fully explains the organizational conditions under which adaptive capabilities become sustainable over time. The concept of eudaimonia provides this missing explanatory dimension by shifting attention from short-term satisfaction or isolated performance indicators toward the sustained realization of individual and collective potential within organizational systems (Ryan & Deci, 2001; Ryan et al., 2008; Seligman, 2011).

Within organizational contexts, eudaimonia should not be interpreted merely as employee well-being or psychological satisfaction. Rather, it represents an emergent systemic state characterized by shared purpose, organizational commitment, collective learning, trust, adaptive resilience, and the continuous development of organizational capabilities. These properties enable organizations to preserve coherence while simultaneously fostering innovation and long-term adaptability.

From this perspective, organizational flourishing emerges through the interaction of biological, cognitive, social, and organizational processes rather than through isolated managerial interventions. The continuous regeneration of organizational identity, collective meaning, learning, and adaptive coordination progressively creates organizational conditions that facilitate both human development and organizational effectiveness. Consequently, eudaimonia constitutes the systemic expression of successful organizational adaptation rather than an independent managerial objective.

Within MIGAE, organizational eudaimonia represents the emergent adaptive state generated by the interaction among autopoietic processes, negentropic regulation, collective sensemaking, and organizational learning. This emergent state provides the immediate antecedent of sustained organizational productivity.

2.5 Productivity as an Emergent Organizational Property

Productivity has traditionally been conceptualized as the relationship between organizational outputs and the resources required to generate them (Coelli et al., 2005; Tangen, 2005). Consequently, most management approaches have attempted to improve productivity through the optimization of processes, technologies, or organizational structures. Although these approaches have produced substantial practical advances, they generally treat productivity as a controllable organizational objective rather than as the consequence of broader systemic dynamics.

The theoretical perspective proposed in this article departs from this conventional interpretation. Organizations become productive because they successfully maintain autopoietic organization, preserve negentropic-entropy pulsation, construct shared meaning, institutionalize learning, and generate eudaimonic organizational states capable of sustaining coordinated collective action over time.

This interpretation does not deny the importance of operational efficiency, quality management, or process optimization. Instead, it situates these managerial practices within a broader explanatory framework in which sustainable productivity results from maintaining the organizational conditions that continuously regenerate adaptive capabilities. Consequently, interventions should focus less on maximizing productivity directly and more on cultivating the systemic processes that enable productivity to emerge naturally as a consequence of organizational adaptation.

The integration of these theoretical constructs constitutes the conceptual foundation of the MIGAE framework presented in the following section, where their relationships are synthesized into a unified organizational model explaining productivity as an emergent property of autopoietic and eudaimonic organizational dynamics.

Table 1. Theoretical foundations and explanatory contribution of the constructs integrated into the MIGAE framework.

Theoretical Perspective	Representative Contributions	Role within the MIGAE Framework
Complexity Theory	Organizations as complex adaptive socio-technical systems	Explains emergence, adaptation and nonlinear organizational dynamics.
Autopoiesis	Organizational self-production and identity preservation	Explains recursive self-organization and adaptive regeneration.
negentropic-entropy pulsation	Renewal of organizational order through information and energy Exchange	Maintains organizational coherence under environmental uncertainty.
Sensemaking	Collective interpretation of environmental perturbations	Supports coordinated organizational responses and adaptive decision-making.
Organizational Learning	Institutionalization of adaptive knowledge and capabilities	Reinforces long-term adaptive capacity.
Organizational Eudaimonia	Shared purpose, trust, resilience and collective flourishing	Represents the emergent adaptive organizational state.
Productivity Theory	Sustainable organizational performance	Conceptualized as the emergent consequence of adaptive organizational dynamics.

Table 1 synthesizes the theoretical integration supporting the MIGAE framework. Rather than representing independent theoretical perspectives, the seven constructs constitute complementary components of a unified explanatory architecture. Complexity provides the systemic context, autopoiesis and negentropic-entropy pulsation explain organizational self-organization, sensemaking and organizational learning describe adaptive cognition, organizational eudaimonia characterizes the emergent adaptive state, and productivity represents the systemic outcome of maintaining these adaptive organizational conditions over time.

3 The MIGAE Framework: A Theory of Emergent Organizational Productivity

The theoretical foundations presented in the previous section converge into the Integrated Autopoietic–Eudaimonic Management Framework (MIGAE), a conceptual theory that explains organizational productivity as an emergent property generated through adaptive organizational dynamics. Unlike conventional management models, which primarily seek to improve productivity by directly optimizing processes, technologies, or organizational structures, MIGAE proposes that sustainable productive performance emerges indirectly through the continuous regeneration of organizational conditions that enable coordinated adaptation, organizational learning, and collective flourishing.

The central premise of the framework is that organizations should be understood as living socio-technical systems continuously exchanging matter, energy, and information with their environments. These exchanges generate perturbations that stimulate adaptive responses. Through autopoietic and negentropic processes, organizations preserve their operational identity while simultaneously reorganizing internal structures. Sensemaking and organizational learning transform environmental information into shared interpretations and coordinated collective action, progressively generating organizational conditions characterized by trust, commitment, resilience, shared purpose, and continuous improvement. These adaptive conditions define an organizational eudaimonic state from which sustainable productivity naturally emerges.

Consequently, productivity is not interpreted as an independent managerial objective but as the observable manifestation of successful organizational adaptation. Organizations do not directly create productivity; instead, they continuously regenerate the organizational conditions from which productivity emerges. This perspective shifts organizational management from the optimization of isolated operational variables toward the cultivation of adaptive organizational capabilities capable of sustaining long-term organizational performance under changing environmental conditions.

The dynamic logic of the proposed theory is synthesized in Figure 1, which illustrates the causal mechanism linking environmental interaction, organizational self-organization, collective cognition, organizational eudaimonia, and emergent productivity.

3.1 Dynamic Architecture of the MIGAE Framework

The MIGAE framework is organized as a dynamic multilevel system in which operational, structural, cognitive, human, and systemic processes interact continuously through recursive feedback relationships. Rather than representing sequential management stages, these levels constitute mutually reinforcing organizational mechanisms whose interactions continuously regenerate organizational adaptability.

At the operational level, organizations function as open systems exchanging matter, energy, and information with their environments. These exchanges simultaneously provide resources for organizational functioning and introduce disturbances that challenge organizational stability. Instead of considering environmental variability as a source of instability alone, the framework assumes that perturbations constitute the primary drivers of adaptation, innovation, and organizational evolution.

Autopoietic and negentropic mechanisms regulate these exchanges by continuously preserving organizational identity while reorganizing internal structures. Autopoiesis explains the continuous regeneration of organizational capabilities, routines, and structural coherence, whereas negentropic regulation maintains organizational order through the renewal of communication patterns, informational structures, and collective coordination despite increasing environmental complexity.

Adaptive regulation alone, however, cannot fully explain organizational evolution. Organizations must also interpret environmental signals, construct shared meanings, and coordinate collective responses capable of preserving organizational effectiveness. Sensemaking and organizational learning therefore constitute the cognitive mechanisms through which environmental information is transformed into organizational knowledge, adaptive routines, and coordinated decision-making. Through repeated learning cycles, organizations progressively strengthen their adaptive capabilities while expanding organizational memory.

The interaction among structural regulation and cognitive adaptation progressively generates an emergent organizational state characterized by shared purpose, trust, commitment, resilience, collaboration, and continuous capability development. Within the proposed framework, this adaptive condition is conceptualized as organizational eudaimonia. Rather than representing employee satisfaction alone, organizational eudaimonia expresses the degree to which the organization has developed the internal conditions necessary for sustainable adaptation and collective flourishing.

Ultimately, organizational productivity emerges as the systemic consequence of maintaining these adaptive conditions over time. Productive organizations are therefore not merely efficient organizations but adaptive organizations capable of continuously regenerating the organizational processes that sustain coordinated collective action despite environmental uncertainty.

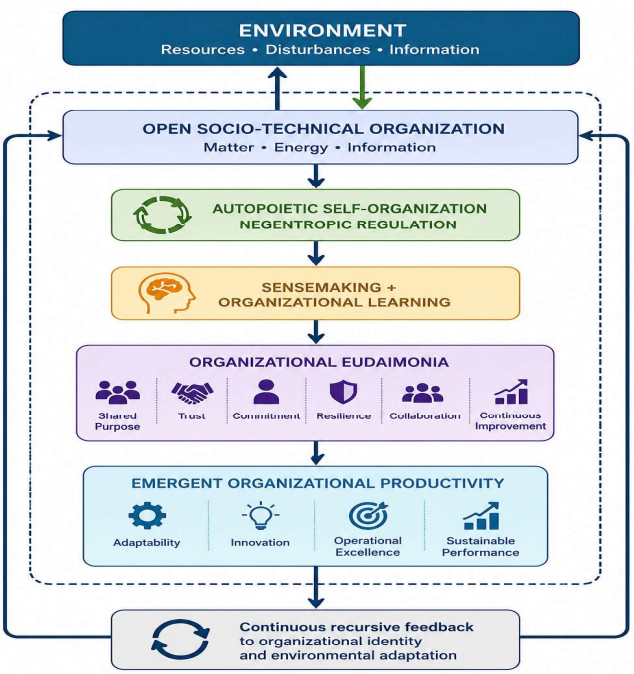

Figure 1. Conceptual mechanism of emergent organizational productivity proposed by the MIGAE framework.

Following the adaptive logic represented in Figure 1, the framework depicts organizations as open socio-technical systems that continuously interact with dynamic environments through the exchange of matter, energy, and information. Environmental disturbances stimulate autopoietic and negentropic regulatory mechanisms responsible for preserving organizational identity while simultaneously enabling structural adaptation. These adaptive processes support collective sensemaking and organizational learning, allowing distributed information to be transformed into coordinated organizational action. As adaptive capabilities accumulate, organizations progressively develop an eudaimonic state characterized by shared purpose, resilience, trust, collaboration, and commitment. Sustainable productivity subsequently emerges as the systemic consequence of maintaining these adaptive organizational conditions rather than as the direct outcome of managerial optimization. Finally, productive performance reinforces organizational learning and adaptive capacity through recursive feedback processes, completing the continuous cycle of organizational evolution.

3.2 Productivity as an Emergent Organizational Property

The principal theoretical contribution of MIGAE lies in redefining productivity from a systemic perspective. Conventional management theories generally assume that productivity can be improved through the direct optimization of operational processes, technological resources, or organizational structures. Although these interventions frequently generate important efficiency gains, they provide only partial explanations regarding the adaptive mechanisms that enable organizations to sustain productive performance over time.

The proposed framework adopts a fundamentally different explanatory logic. Within the MIGAE framework, productivity is not understood as an isolated performance indicator but as an emergent organizational property arising from the continuous interaction of adaptive organizational processes.

Emergence implies that productive performance cannot be fully explained by analyzing individual organizational variables in isolation because it results from the coordinated interaction among operational, structural, cognitive, and human processes occurring simultaneously across multiple organizational levels.

Under this interpretation, adaptive organizational capability becomes the principal explanatory construct. Organizations capable of continuously regenerating their operational identity, preserving informational coherence, constructing shared meanings, institutionalizing learning, and fostering organizational eudaimonia progressively create the conditions necessary for sustainable productive performance. Consequently,

managerial interventions should prioritize strengthening adaptive organizational processes rather than exclusively optimizing operational outputs.

This perspective substantially broadens conventional productivity theory by integrating concepts derived from biology, systems science, organizational cognition, and human flourishing into a unified explanation of organizational effectiveness. Rather than replacing established managerial approaches such as Lean Production, Total Quality Management, Operational Excellence, or Six Sigma, MIGAE provides a higher-order theoretical framework capable of explaining why these practices become effective when adaptive organizational conditions are successfully sustained.

3.3 Theoretical Propositions

Based on the theoretical integration developed throughout this article, the MIGAE framework advances the following propositions:

Proposition 1. Organizations preserve long-term adaptive capacity through continuous autopoietic regeneration and negentropic regulation that maintain organizational identity while enabling structural adaptation.

Proposition 2. Organizational sensemaking and organizational learning constitute the principal cognitive mechanisms through which environmental disturbances are transformed into coordinated adaptive organizational responses.

Proposition 3. Organizational eudaimonia emerges from the sustained interaction among autopoietic regulation, collective sensemaking, organizational learning, and adaptive socio-technical coordination.

Proposition 4. Sustainable organizational productivity emerges as a systemic property of eudaimonic organizational states rather than as the direct consequence of isolated managerial interventions.

Together, these propositions constitute the theoretical core of the MIGAE framework. They establish a coherent causal mechanism connecting organizational adaptation, collective cognition, human flourishing, and productive performance while simultaneously defining the conceptual basis for the mathematical formalization, computational simulation, and empirical validation that will be developed in the subsequent stages of the research program.

4 Conceptual Formalization of the MIGAE Framework

The previous section introduced the dynamic mechanism through which organizational productivity emerges from adaptive organizational processes. The purpose of the present section is to formalize this theoretical architecture by explicitly identifying the principal organizational constructs, their functional roles, and the multilevel relationships that collectively define the MIGAE framework. Rather than proposing a mathematical representation, this conceptual formalization establishes the organizational ontology upon which subsequent analytical developments will be constructed.

Within the proposed theory, organizations are understood as adaptive socio-technical systems composed of interacting organizational levels that cannot be analyzed independently. Each level performs a specific organizational function while simultaneously influencing the behavior of the remaining levels through recursive feedback mechanisms. Consequently, organizational productivity cannot be attributed to any isolated construct but emerges from the continuous interaction among operational exchanges, structural regulation, collective cognition, organizational eudaimonia, and adaptive organizational performance.

This multilevel architecture distinguishes the proposed framework from conventional productivity models. Traditional approaches generally identify productivity as the direct consequence of process efficiency or resource optimization. MIGAE instead conceptualizes productivity as a systemic organizational state generated through continuous adaptive interactions distributed across multiple organizational levels.

To clarify the conceptual organization of the framework, Table 2 summarizes the principal organizational levels together with their corresponding constructs and explanatory functions within the overall adaptive mechanism.

Table 2. Conceptual architecture of the MIGAE framework: organizational levels, adaptive mechanisms, and emergent outcomes

Organizational Level	Core Constructs	Adaptive Mechanism	Emergent Organizational Outcome
Operational	Matter, Energy, Information	Continuous exchange with the environment generating organizational perturbations.	Adaptive interaction with environmental conditions.
Structural	Autopoiesis; Negentropic-Entropy Pulsation	Recursive self-organization, preservation of organizational identity, and structural adaptation.	Organizational coherence and adaptive stability.
Cognitive	Sensemaking; Organizational Learning	Collective interpretation of environmental signals and continuous renewal of organizational knowledge.	Adaptive intelligence and coordinated organizational action.
Human	Organizational Eudaimonia	Development of shared purpose, trust, commitment, resilience, collaboration, and continuous improvement.	Collective flourishing and sustainable adaptive capability.
Systemic	Emergent Organizational Productivity	Integration of multilevel adaptive organizational dynamics.	Sustainable organizational performance, adaptability, innovation, and long-term viability.

Table 2 synthesizes the multilevel conceptual architecture of the MIGAE framework. Each organizational level performs a specific adaptive function while simultaneously interacting with the remaining levels through recursive feedback mechanisms. The operational level generates the environmental exchanges that stimulate organizational adaptation. Structural mechanisms preserve organizational identity through autopoietic regeneration and negentropic regulation. Cognitive processes transform environmental information into shared organizational knowledge, whereas organizational eudaimonia represents the emergent adaptive condition resulting from sustained organizational coordination. Productivity consequently emerges as the highest-order systemic property generated through the recursive interaction of all organizational levels rather than as the isolated consequence of process optimization

An important implication of this conceptual organization is that causal relationships within the framework are recursive rather than linear. Organizational learning continuously modifies structural regulation, structural adaptation influences organizational identity, eudaimonic organizational states reinforce collaborative learning, and productive performance generates additional organizational resources that stimulate further adaptive development. Consequently, organizational evolution should be interpreted as a continuous process of recursive self-organization instead of a sequence of independent managerial interventions.

The proposed conceptual architecture also provides the basis for future analytical formalization. Each organizational construct identified in the framework can subsequently be represented as a dynamic state variable interacting through nonlinear feedback relationships. Autopoietic regulation, negentropic balance, organizational learning, collective cognition, organizational eudaimonia, and productivity therefore become measurable components of an integrated dynamic system whose evolution can be analyzed mathematically and computationally. Although such formalization lies beyond the scope of the present article, the conceptual relationships established here define the organizational structure required for its development.

Accordingly, the MIGAE framework should be understood as an explanatory theory rather than a prescriptive management methodology. Its primary objective is not to prescribe managerial practices but to explain the adaptive organizational mechanisms through which sustainable productivity emerges. By explicitly identifying the organizational constructs, levels, and recursive interactions responsible for this emergence, the framework establishes a coherent theoretical foundation for subsequent mathematical modeling, computational simulation, and empirical validation within production and service organizations.

5 Discussion

The MIGAE framework contributes to management science, systems engineering, and organizational theory by offering an integrative perspective on how sustainable performance is generated in complex socio-technical systems. Rather than competing with traditional operational frameworks, MIGAE reinterprets organizational dynamics through a unified lens that bridges systems thinking, organizational cognition, positive organizational studies, and humanistic management.

5.1 Theoretical Integration and Conceptual Contributions

The framework addresses a persistent theoretical gap by articulating how biological, cognitive, and socio-technical processes jointly sustain organizational productivity. Classical approaches in operations management and industrial engineering have successfully demonstrated the importance of process improvement, total quality management, operational excellence, and efficient resource utilization (Deming, 1986; Oakland, 2014; Coelli, et al., 2005). However, these approaches primarily explain how organizations improve operational performance in the short term, without fully explaining why certain systems are capable of sustaining those gains under continuous environmental uncertainty and perturbation. MIGAE complements these traditional views by establishing that long-term organizational performance depends upon the continuous regeneration of adaptive capability rather than upon isolated operational adjustments.

A key theoretical advancement of the framework is the operationalization of organizational eudaimonia as an adaptive systemic state. While existing literature in positive organizational scholarship frequently treats employee well-being, engagement, or flourishing as desirable secondary outcomes of organizational success (Ryan & Deci, 2001; Seligman, 2011; Martela, 2025), MIGAE positions eudaimonia—manifested through shared purpose, trust, commitment, resilience, and psychological safety—as a fundamental structural antecedent of adaptive performance. Furthermore, by incorporating autopoiesis (Maturana & Varela, 1980; Luhmann, 1995) and negentropic-entropy pulsation (Nicolis & Prigogine, 1977), the framework moves beyond metaphorical descriptions of organizational self-maintenance, demonstrating that operational closure and self-regulation are necessary structural conditions for collective flourishing and continuous capability development.

5.2 Practical Application and Managerial Implementation

Although MIGAE is introduced primarily as a conceptual framework, its principles provide actionable guidelines for operations management, socio-technical system design, and plant-floor management. Rather than remaining a purely descriptive model, MIGAE can be operationalized in industrial environments through three primary practical avenues:

Design of Autonomous Industrial Work Cells (Autopoietic Engineering): Traditional industrial engineering often enforces rigid process standardization that limits operator autonomy (Trist & Bamforth, 1951). Under MIGAE, manufacturing assembly lines or maintenance teams are designed as self-governing units endowed with operational closure and decision-making authority (Beer, 1981; Pasmore et al., 1982). Operators are granted the autonomy to adjust line speeds, modify shift schedules, and reconfigure task assignments in response to real-time operational disturbances. This structural autonomy operationalizes autopoietic feedback loops, turning frontline workers into active regulators rather than passive task executors.

Implementation of Reflective Management Protocols (Sensemaking & Learning): In daily operations, collective sensemaking is operationalized by replacing top-down monitoring with structured reflective learning loops (Weick, 1995; Argyris & Schön, 1978). Short, decentralized Kaizen huddles or post-incident review protocols allow workers to collectively analyze process variances and interpret environmental signals in real time. This practice institutionalizes immediate operational adjustments into updated standard operating procedures (SOPs), directly supporting organizational learning and knowledge creation (Nonaka & Takeuchi, 1995).

Eudaimonic Performance Indicators (Measuring Leading System Metrics): To operationalize the eudaimonic state in industrial settings, operations managers can complement traditional Key Performance

Indicators (such as OEE, yield, or throughput) with Eudaimonic System Metrics (ESMs). These metrics evaluate team trust, decision-making autonomy, task variety, and psychological safety (Pirson, 2017; Ryan & Martela, 2016). By monitoring ESMs as leading indicators, plant managers can detect systemic exhaustion, rigidity, or operational friction before it manifests as a decline in physical productivity or an increase in defect rates.

Multi-Criteria Decision-Making (MCDM) for Systemic Prioritization: Operationalizing MIGAE requires managers to balance multiple, often competing, socio-technical conditions (e.g., operational autonomy, psychological safety, and technical throughput). Multi-Criteria Decision-Making (MCDM) methodologies—such as the Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), or PROMETHEE—provide a robust mathematical structure to assess, weight, and prioritize these emergent organizational conditions. By integrating MCDM frameworks into MIGAE, decision-makers can systematically evaluate trade-offs, align resource allocation with eudaimonic system metrics, and strategically sequence organizational interventions based on their relative impact on systemic resilience and long-term productivity.

5.3 Methodological Scope, Limitations, and Alignment with Management Practice

From a methodological perspective, this study represents the foundational stage of a cumulative research program supported by the MInFRO intervention model (Zanazzi, 2025). As a conceptual formulation, the relationships among constructs are theoretically derived and require further mathematical specification, computational simulation, and empirical testing. The framework does not attempt to quantify the exact mathematical thresholds governing the transition into an eudaimonic state, defining the explicit scope for subsequent dynamic modeling and organizational case studies.

Ultimately, MIGAE does not seek to replace established operational methodologies such as Lean Production (Womack & Jones, 2003), Total Quality Management (Oakland, 2014), or Six Sigma. Instead, it provides a higher-order explanatory framework that clarifies why these practices succeed or fail: they become effective over time only when the underlying adaptive, cognitive, and eudaimonic conditions are successfully sustained within the socio-technical system.

6 Conclusions and Future Research

This article introduced the Integrated Autopoietic–Eudaimonic Management Framework (MIGAE) as a novel organizational theory integrating contributions from systems science, complexity theory, autopoiesis, negentropic-entropy pulsation, organizational cognition, organizational learning, and eudaimonic perspectives, the framework provides a coherent theoretical explanation of how organizations continuously regenerate the adaptive conditions that sustain long-term productive performance. Rather than assembling concepts from different disciplines, MIGAE organizes them into a unified explanatory mechanism that connects organizational adaptation with sustainable productivity.

The principal contribution of the proposed framework lies in redefining productivity from a systemic perspective. Instead of treating productivity as an organizational objective to be directly optimized through managerial interventions, MIGAE conceptualizes it as the emergent consequence of maintaining adaptive organizational conditions characterized by autopoietic self-organization, negentropic regulation, collective sensemaking, organizational learning, and organizational eudaimonia. This theoretical reinterpretation extends conventional productivity theory by shifting the focus from the optimization of organizational outputs toward the continuous regeneration of the organizational capabilities from which productive performance naturally emerges.

Beyond its conceptual contribution, the framework establishes the foundations for a cumulative research program. The organizational constructs, multilevel architecture, recursive feedback mechanisms, and theoretical propositions presented in this article provide the conceptual basis for subsequent mathematical formalization, computational simulation, and empirical validation. Consequently, the present work should be understood as the first stage of a broader scientific agenda intended to progressively transform the conceptual theory into an analytically rigorous and empirically testable explanatory model.

Future research will therefore develop four complementary stages. The present article establishes the theoretical foundations and conceptual architecture of the MIGAE framework. The second stage will

formalize the adaptive organizational dynamics through nonlinear mathematical models representing the interaction among the principal organizational constructs. The third stage will evaluate the behavior of the proposed theory through computational simulation under multiple organizational scenarios, analyzing the emergence and stability of adaptive organizational states. Finally, the fourth stage will validate the explanatory capacity of the framework through empirical studies and action research interventions conducted within production and service organizations. Additionally, future methodological extensions will explore the integration of Multi-Criteria Decision-Making (MCDM) techniques to support real-time decision-making, enabling managers to prioritize and balance the multi-dimensional eudaimonic and operational criteria that drive emergent organizational productivity.

Ultimately, the contribution of MIGAE is not the proposal of another management methodology but the advancement of a new organizational theory capable of explaining why sustainable productivity emerges. By positioning productivity as the emergent consequence of autopoietic, negentropic, cognitive, and eudaimonic organizational dynamics, the framework offers a new theoretical perspective for Organizational Engineering, Industrial Engineering, Management Science, and Systems Thinking. In doing so, it provides a coherent foundation for future interdisciplinary research while opening new opportunities for the mathematical modeling, computational analysis, and empirical study of adaptive organizational systems.

Productive organizations are not those that simply optimize their processes, but those that continuously regenerate the adaptive organizational conditions from which productivity emerges.

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This article represents the first theoretical contribution of an ongoing interdisciplinary research program devoted to the development, mathematical formalization, computational simulation, and empirical validation of the **Integrated Autopoietic–Eudaimonic Management Framework (MIGAE)** for production and service organizations.

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Research Statement
This article presents a conceptual theoretical contribution. It does not report empirical findings but develops the theoretical foundations of the Integrated Autopoietic–Eudaimonic Management Framework (MIGAE). The mathematical formalization, computational simulation, and empirical validation of the proposed framework constitute subsequent stages of the ongoing research program.

References

1 .- Allen, P. M. (2001). What is complexity science? Knowledge of the limits to knowledge. *Emergence*, 3(1), 24–42. https://doi.org/10.1207/S15327000EM0301_03
2 .- Argyris, C., & Schön, D. A. (1978). Organizational learning: A theory of action perspective. Addison-Wesley.
3 .- Beer, S. (1981). *Brain of the firm* (2nd ed.). John Wiley & Sons.
4 .- Boulding, K. E. (1956). General systems theory—The skeleton of science. *Management Science*, 2(3), 197–208. https://doi.org/10.1287/mnsc.2.3.197
5 .- Coelli, T., Rao, D. S. P., O'Donnell, C., & Battese, G. (2005). An introduction to efficiency and productivity analysis (2nd ed.). Springer.
6.- Deming, W. E. (1986). *Out of the crisis*. Massachusetts Institute of Technology, Center for Advanced Engineering Study.
7.- Duchek, S. (2020). Organizational resilience: A capability-based conceptualization. Business Research, 13, 215–246. https://doi.org/10.1007/s40685-019-0085-7.
8.- Holland, J. H. (1992). Complex adaptive systems. Daedalus, 121(1), 17–30.
9.- Hollnagel, E., Woods, D. D., & Leveson, N. (Eds.). (2006). *Resilience engineering: Concepts and precepts*. Ashgate Publishing, Ltd.
10.- Lengnick-Hall, C. A., Beck, T. E., & Lengnick-Hall, M. L. (2011). Developing a capacity for organizational resilience through strategic human resource management. Human Resource Management Review, 21(3), 243–255. https://doi.org/10.1016/j.hrmr.2010.07.001.
11.- Luhmann, N. (1995). Social systems. Stanford University Press.
12.- Magalhães, R., & Sanchez, R. (2009). Autopoiesis in organization theory and practice. Journal of Organizational Change Management, 22(3), 276–289.
13.- Maitlis, S., & Christianson, M. (2014). Sensemaking in organizations: Taking stock and moving forward. Academy of Management Annals, 8(1), 57–125. https://doi.org/10.5465/19416520.2014.873177.
14.- Martela, F. (2025). Well-being as having, loving, doing, and being: An integrative framework for employee flourishing. *Journal of Organizational Behavior*, *46*(2), 112–129.
15.- Maturana, H. R., & Varela, F. J. (1980). *Autopoiesis and cognition: The realization of the living*. D. Reidel Publishing Company. https://doi.org/10.1007/978-94-009-8947-4
16.- Nicolis, G., & Prigogine, I. (1977). Self-organization in nonequilibrium systems. Wiley.
17.- Nonaka, I., & Takeuchi, H. (1995). *The Knowledge-Creating Company: How Japanese Companies Create the Dynamics of Innovation*. Oxford University Press.
18.- Oakland, J. S. (2014). Total quality management and operational excellence (4th ed.). Routledge.
19.- Pasmore, W. A., Francis, C., Haldeman, J., & Shani, A. B. (1982). Sociotechnical systems: A North American reflection on empirical studies of the seventies. Human Relations, 35(12), 1179–1204.
20.- Pirson, M. (2017). *Humanistic management: Protecting dignity and promoting well-being*. Cambridge University Press. https://doi.org/10.1017/9781316675946
21.- Prigogine, I., & Stengers, I. (1984). Order out of chaos: Man's new dialogue with nature. Bantam.
22.- Ryan, R. M., & Deci, E. L. (2001). On happiness and human potentials: A review of research on hedonic and eudaimonic well-being. *Annual Review of Psychology*, 52(1), 141-166.
23.- Ryan, R. M., Huta, V., & Deci, E. L. (2008). Living well: A self-determination theory perspective on eudaimonia. *Journal of Happiness Studies*, 9(1), 139–170. https://doi.org/10.1007/s10902-006-9023-4
24.- Ryan, R. M., & Martela, F. (2016). Eudaimonia as a way of living: Connecting Aristotle with self-determination theory. In Joar Vittersø (Ed.), *Handbook of eudaimonic well-being* (pp. 109–122). Springer.
25.- Seligman, M. E. P. (2011). Flourish: A visionary new understanding of happiness and well-being. Free Press.
26.- Senge, P. (1990). The fifth discipline: The art and practice of the learning organization. Doubleday.
27.- Stacey, R. D. (1996). *Complexity and Creativity in Organizations*. Berrett-Koehler Publishers.
28.- Tangen, S. (2005). Demystifying productivity and performance. International Journal of Productivity and Performance Management, 54(1), 34–46.
29.- Trist, E. L., & Bamforth, K. W. (1951). Some social and psychological consequences of the Longwall Method of coal-getting: An examination of the psychological situation and defences of a work group in relation to the social and technological structure of the work system. *Human Relations*, 4(1), 3–38. https://doi.org/10.1177/001872675100400101
30.- Uhl-Bien, M., & Arena, M. (2018). Leadership for organizational adaptability: A theoretical synthesis and integrative framework. The Leadership Quarterly, 29(1), 89–104.
31.- Weick, K. E. (1995). Sensemaking in organizations. Sage Publications.
32.- Weick, K. E., Sutcliffe, K. M., & Obstfeld, D. (2005). Organizing and the process of sensemaking. Organization Science, 16(4), 409–421.
33.- Womack, J. P., & Jones, D. T. (2003). *Lean Thinking: Banish Waste and Create Wealth in Your Corporation* (2.ª ed.). Free Press.

34.- Zanazzi, J. F. (2025). Desarrollo y validación de un modelo multimetodológico para el diseño de intervenciones organizacionales flexibles y reflexivas [Tesis doctoral]. Universidad Nacional de Córdoba. http://hdl.handle.net/11086/560274.

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Resolving Weight Indeterminacy in the Simos Method

Luis Dias[1] and Rudolf Vetschera[2]

[1]University of Coimbra, Portugal
[2]University of Vienna, Austria

lmcdias@fe.uc.pt, rudolf.vetschera@univie.ac.at

Abstract. The Deck of Cards procedure, also known as the Simos procedure, is a well-known method to elicit weights in multi-attribute/multicriteria decision aiding. It is used especially in the context of outranking methods, where weights represent importance of attributes rather than trade-off rates. The names of attributes are written on cards, and the decision maker first ranks attributes by putting the cards in the desired order (with the option of assigning the same rank to different attributes), and then expresses importance differences by inserting blank cards between attributes of subsequent ranks. As already indicated in earlier literature, this procedure does not provide unique weights. To fix this problem, Figueira and Roy proposed the Revised Simos procedure, in which the ratio between the smallest and largest weight is additionally specified by the decision maker.

In this paper, we propose alternative methods to overcome the weight indeterminacy problem: Fixing individual weights (where we consider both the smallest and the largest weight), or fixing the size of the interval between neighboring cards. We further consider a recently proposed method, in which the difference of the smallest weight to a hypothetical attribute of zero importance is specified by adding blank cards before the least important attribute.

We analyze these different methods (as well as the Revised Simos procedure) in a comprehensive computational study. We compare the performance of these methods both for the case of a decision maker who can provide accurate information as well as a decision maker who makes errors in building the card stack or providing numerical information. We evaluate the methods in terms of closeness of the elicited weights to true weights, as well as in terms of how much weight differences affect outranking (concordance) relations obtained using these weights. We find considerable differences between the methods. Typically, fixing the largest weight performs very well, followed by fixing the ratio, while fixing the smallest weight shows only a weak performance. We also identify systematic biases of the methods in the computed weight vectors and factors such as weight concentration that affect the performance of the methods.

Keywords: Multi-attribute decision making, weight elicitation, deck of cards method

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Mathematical Formalization of the Integrated Autopoietic–Eudaimonic Theory of Organizational Productivity

Silvia Pierotti[1], Víctor Ramírez-Amaya[1], Jose Francisco Zanazzi[1], Jose Luis Zanazzi[1,] Daniel Pontelli[1]

[1]Industrial Engineering and Maintenance Laboratory. Faculty of Exact, Physical and Natural Sciences. National University of Córdoba

silvia.pierotti@unc.edu.ar, victor.ramirez.amaya@unc.edu.ar, jfzanazzi@unc.edu.ar, dpontelli@unc.edu.ar, jose.luis.zanazzi@unc.edu.ar

Abstract: Contemporary productive organizations operate in environments characterized by increasing systemic complexity, uncertainty, and high interdependence. In this context, the Integrated Autopoietic-Eudaimonic Management Model (MIGAE) reinterprets organizational productivity not as a primary variable susceptible to direct optimization, but as an emergent property of eudaimonic states generated by autopoietic and negentropic dynamics. This work develops the analytical and operational foundations of the original model's mathematical formalization. By modeling organizational learning, shared meaning, and structural coherence as interdependent dynamic variables, we represent the recursive interaction that gives rise to organizational eudaimonia and, by systemic consequence, the emergence of productivity. Methodologically, this development articulates with action research through the Flexible and Reflective Intervention Model for Organizations (MInFRO). This paper provides the initial analytical mathematical foundations required for empirical applications in complex productive contexts.

Keywords: mathematical formalization organizational productivity migae model complex systems systemic emergence minfro framework

1 Introduction

Contemporary productive organizations operate in environments characterized by high systemic complexity, uncertainty, and growing interdependence among their components. In this context, understanding the dynamics of organizational processes is one of the main challenges of production engineering, since organizational performance depends on multiple nonlinear interactions that make it difficult to analyze through traditional approaches (Uhl-Bien & Arena, 2018; Duchek, 2020). Traditionally, productivity has been approached as a variable amenable to direct optimization through interventions on resources, processes, or technologies, generally expressed as the ratio between outputs obtained and resources used (Coelli et al., 2005; Tangen, 2005). This approach has given rise to widely used methodologies, such as Lean Manufacturing, Six Sigma, and Total Quality Management, which have contributed significantly to increased operational efficiency (Oakland, 2014; Womack & Jones, 2003). However, organizational evidence shows that local process improvements do not always translate into sustainable increases in overall performance, which suggests that productivity also depends on emergent systemic properties that cannot be explained solely through linear relationships between inputs and outputs.

Several theoretical developments have helped broaden this perspective. Sociotechnical systems theory highlighted the need to consider the technical and social components of the organization jointly (Trist & Bamforth, 1951; Pasmore et al., 1982). Subsequently, complex adaptive systems theory emphasized the role of self-organization, nonlinearity, and emergence as properties inherent to organizational systems (Holland, 1992; Stacey, 1996; Uhl-Bien & Marion, 2009). Complementarily, studies on organizational learning and sensemaking showed that adaptation depends on the capacity to generate knowledge, interpret the environment, and coordinate collective action (Argyris & Schön, 1978; Senge, 1990; Nonaka & Takeuchi, 1995; Weick, 1995; Weick et al., 2005). In this line, the Integrated Autopoietic-Eudaimonic Management Model (MIGAE) proposes interpreting organizational productivity as an emergent property derived from the interaction among four fundamental constructs: organizational autopoiesis, collective sensemaking, organizational learning and structural coherence. In this model, organizational eudaimonia is an emergent state associated with the degree of integration achieved by these processes, while productivity represents a systemic consequence of that state and not a variable amenable to direct control. This interpretation is consistent with the notion of organizations as complex systems capable of preserving their identity and continuously adapting to environmental disturbances (Maturana & Varela, 1980; Luhmann, 1995; Allen, 2001). Although the MIGAE establishes a conceptual framework for interpreting these relationships, its use as an analytical tool requires a mathematical

formulation that makes it possible to explicitly describe the temporal dynamics of its components, analyze their feedback mechanisms, study the stability of the system, and generate predictions amenable to empirical testing. Mathematical formalization is therefore a necessary step in transforming the conceptual model into a dynamic model capable of being analyzed with the tools proper to systems theory.
This work develops this formalization through a system of nonlinear ordinary differential equations that represents the temporal evolution of the four fundamental constructs of the MIGAE. On this basis, organizational eudaimonia and productivity are defined as emergent properties of the system, their interdependence relationships are analyzed, and the mathematical foundations needed for future simulations, stability analyses, and empirical validation processes are established. Methodologically, this proposal is articulated with the Flexible and Reflective Intervention Model for Organizations (MInFRO), which constitutes the framework for applying the model in real organizations (Zanazzi, 2025).

2 Methodology for building the MIGAE model

The mathematical formulation of the Integrated Autopoietic-Eudaimonic Management Model (MIGAE) was developed through a process of progressive formalization aimed at translating the conceptual model into a dynamical system of differential equations. The objective was not to reproduce the behavior of organizations exactly, but to build a mathematical representation consistent with the postulates of the MIGAE that would describe the interaction among its main constructs and serve as a basis for future simulation, calibration, and empirical validation processes. The methodology was structured in four consecutive stages: (i) identification of the fundamental constructs, (ii) definition of the causal structure of the system, (iii) formulation of the temporal dynamics, and (iv) selection of the mathematical functions used to represent the interactions among the variables.

2.1 Stage 1: Identification of the fundamental constructs

First, the processes that make up the model's state vector were identified. Four fundamental constructs were selected: Organizational autopoiesis (A), Collective sensemaking (S), Organizational learning (L), Structural coherence (C). These constructs were considered state variables, since they were assumed to evolve continuously over time and to determine the dynamics of the system. By contrast, organizational eudaimonia (E) and organizational productivity (P) were not modeled as dynamic variables, but as emergent properties derived from the interaction among the four fundamental constructs.

2.2 Stage 2: Construction of the causal diagram

Once the constructs were defined, the influence relationships among them were established in order to build the causal structure of the model. The main sequence proposed was:

$$A \longrightarrow S \longrightarrow L \longrightarrow C$$

accompanied by two feedback mechanisms:

$$C \longrightarrow A$$

And

$$E(A,S,L,C) \longrightarrow A,S$$

This structure made it possible to identify the functional dependencies among the variables and to establish the coupling that was subsequently represented through the system of differential equations.
Although the sequence $A \rightarrow S \rightarrow L \rightarrow C$ represents the main causal direction through which organizational capabilities are developed, the model does not assume a strictly unidirectional evolution. The formulation through a system of coupled differential equations allows the variables to interact recursively during their temporal evolution, so that the state reached by one construct modifies the conditions under which the others

evolve. Consequently, the MIGAE is interpreted as a cyclical dynamical system, in which the main causal sequence coexists with feedback mechanisms that regulate the coevolution of organizational capabilities.

2.3 Stage 3: Definition of the temporal dynamics

Each state variable was assumed to evolve continuously over time. Consequently, each construct was represented by a first-order ordinary differential equation, whose rate of change results from the balance between the processes that strengthen the variable and those that contribute to its deterioration. This approach is widely used in the modeling of dynamical systems in engineering, biology, and systems theory, and makes it possible to represent the temporal evolution of interdependent processes.

2.4 Stage 4: Selection of the mathematical functions

Because there is currently insufficient empirical evidence to establish the exact functional form of the relationships among the MIGAE constructs, simple mathematical functions widely used in the modeling of dynamical systems were adopted in this first formulation. These functions constitute initial working hypotheses and may be refined during future calibration and empirical validation processes.
Once the causal structure of the system was defined, the most suitable mathematical functions were selected to represent each of the mechanisms postulated by the model.

2.4.1 Product of variables

When a process required the simultaneous action of several constructs, the interaction was represented by a product of the variables involved. This criterion was used, for example, to model autopoietic regeneration, assuming that this process depends simultaneously on organizational identity, structural coherence, and the eudaimonic state. This representation is an initial approximation and does not imply that the real relationship is strictly multiplicative.

2.4.2 Linear relationships

Interactions for which a direct influence between variables was postulated were represented by linear relationships as a first approximation. This criterion was applied, for example, to the contribution of organizational learning and shared meaning to structural coherence, favoring the simplicity and interpretability of the model.

2.4.3 Logistic growth

The evolution of organizational learning was described by a logistic growth function. This choice made it possible to incorporate the hypothesis that learning capacity has limits associated with the available resources, accumulated experience, and organizational capabilities, avoiding the assumption of indefinite growth.

2.4.4 Logistic function

Organizational eudaimonia was represented by a logistic (sigmoid) function, since it allows describing the gradual transition between states of low and high systemic coherence, while keeping the variable bounded within a defined interval.

3 Theoretical framework and modeling assumptions

To ground the transition from the conceptual plane of the MIGAE to its analytical formulation, it is essential to establish the systemic rules and principles that govern the interaction of its components. The model does not conceive of the organization as a mechanical structure of linear flows, but as a complex adaptive system characterized by operational closure, nonlinearity, and emergence from dissipative states of order (Maturana & Varela, 1980; Luhmann, 1995). Based on these premises, the mathematical formulation of the MIGAE rests on the following fundamental assumptions:

a. Assumption of Operational Closure and Self-Referentiality: The organizational system generates and regenerates its own boundaries and internal processes (Magalhães & Sanchez, 2009). The dynamics of its state variables depend constitutively on the current level of its own components, which translates mathematically into multiplicative and recursive couplings (Axelsson, 2025).
b. Assumption of Strict Interdependence (Non-Compensatoriness): Organizational dimensions act synergistically. An absolute deficit in a critical capability cannot be compensated by the hyper-optimization of another; the collapse of a fundamental construct nullifies the viability of the overall system (Beer, 1979).
c. Assumption of Synchronic Emergence: Essential properties of the organization, such as eudaimonia and productivity, do not have isolated linear accumulation dynamics (independent differential equations), but emerge as collective, synchronized manifestations of the underlying state vector (Nicolis & Prigogine, 1977; Prigogine & Stengers, 1984).
d. Assumption of Phenomenological Confinement: For reasons of analytical consistency and operational realism, the variables that describe the capabilities and order of the organization must remain bounded within a biologically viable domain (Gershenson, 2025).
The formalization proposed in this work is structured as a deterministic mathematical model based on a system of nonlinear ordinary differential equations. This methodological choice responds to the need to isolate and understand the causal relationships and the internal dynamics of coevolution among autopoiesis, shared meaning (Weick, 1995), learning (Argyris & Schön, 1978), and organizational coherence (Boulding, 1956), without the interference of external stochastic variables. By establishing this deterministic architecture, the model allows an analysis of system stability, the identification of extinction points, and the location of critical emergence thresholds (Allen, 2001)
Although the proposed model is currently deterministic for purposes of analytical abstraction, this stage is recognized as a fundamental step toward future proposals that contemplate and explore models incorporating the variability inherent to complex industrial environments.

4 Formalization of the system state vector

To represent the organization as a complex dynamical system, its state at each instant of time t is defined by a state vector composed of the four fundamental variables of the model:

$$\mathrm{X(t)} = \begin{bmatrix} \mathrm{A(t)} \\ \mathrm{S(t)} \\ \mathrm{L(t)} \\ \mathrm{C(t)} \end{bmatrix} \qquad (1)$$

It is essential to specify the nature of this vector from the standpoint of complex systems theory. The components of the state vector $\mathrm{X}(t)$ are conceptually independent and linearly orthogonal in their definition and measurement; this implies that each variable operationalizes a qualitatively distinct dimension of the system (autopoiesis does not algebraically contain learning, nor does sensemaking contain structural coherence) and each requires its own specific diagnostic instruments within the MInFRO framework (Zanazzi,2025).
However, these variables are dynamically interdependent in their temporal evolution. This means that the current level of one construct directly and nonlinearly affects the rate of change of the others. The system is not decoupled, but coevolves through cross flows in which the dimensions recursively feed each other, enabling the property of emergence.
Each component is normalized to the continuous interval $[0,1]$, where 0 represents the absolute absence of the property and 1 its maximum level of development. The variables are operationalized as follows:

- $\mathrm{A(t)}$: Organizational autopoiesis. Capacity to preserve and reproduce organizational structure and processes through internal dynamics of coordination and self-regulation (Maturana & Varela, 1980).
- $\mathrm{S(t)}$: Collective sensemaking. Capacity to build shared meaning and reduce organizational ambiguity (Weick, 1995).
- $\mathrm{L(t)}$: Organizational learning. Accumulated level of knowledge and adaptive capacity of the system (Argyris & Schön, 1978; Senge, 1990).

- $C(t)$: Structural coherence. Degree of consistency, integration, and alignment among the structure, processes, practices, and shared meanings of the organization, which allows it to preserve its identity and respond adaptively to disturbances.

4.1 Boundary Conditions of the State Space

Beyond its mathematical definition, the state space represents the geography of possibilities of the organization. It should not be understood as an abstract plane, but as the set of all possible configurations of health and capability that the system can adopt. On this multidimensional map, each point is a particular, momentary configuration of the company's state of maturity. Therefore, the evolution of the organization is, in essence, a path through this space (Allen, 2001).
However, this territory is not unlimited. Imposing boundaries on the domain $[0, 1]^4$ responds to a natural principle: all growth and all capability have a limit. If the model's variables were allowed to extend beyond this threshold, a fictitious entity, disconnected from material reality, would be modeled. Therefore, the boundaries do not function as censorship, but as a mechanism of systemic realism, acting as a membrane that allows flexibility and learning but blocks divergence, that is, the tendency toward disorganization or exhaustion from excessive optimization (Beer, 1979; Hollnagel, Woods, & Leveson, 2006).
By confining the system within this hypercube, the MIGAE model guarantees that any trajectory analyzed is, above all, ecologically sustainable, since the system cannot consume more resources than it is able to process, nor sustain an order that its own members cannot understand or maintain.

4.2 Structural and Dimensional Mapping of the State Vector

Once the fundamental constructs of the model were defined, a mapping was established between each variable of the state vector and its interpretation within the organizational system. This procedure made it possible to assign each component a specific function within the dynamics of the model, as well as to define the meaning of the normalized interval ($[0,1]$) used in all state variables. Normalization facilitates comparison among constructs of different nature and allows their evolution to be represented within a common framework, regardless of the scale subsequently used during empirical calibration (table 1). Likewise, this mapping forms the basis for the operationalization of the model within the MInFRO methodological framework (Zanazzi, 2025), by linking each variable to a control mechanism consistent with its systemic function (Beer, 1979; Boulding, 1956).

Table 1. Operationalization and grounding matrix of the State Vector variables $\mathbf{X(t)}$.

Component	Associated Construct	Role in Systems Theory	Scale Meaning $[0, 1]$	Associated Control Mechanism
$\mathbf{A(t)}$	Organizational Autopoiesis	Operational closure and delimitation of systemic boundaries.	0: Absolute dissolution of organizational autopoiesis. 1: Perfect functional self-reproduction.	Recursive self-referentiality.
$\mathbf{S(t)}$	Collective Sensemaking	Reduction of cognitive variety and semantic alignment.	0: Anomie and structural destructive ambiguity. 1: Absolute mutual understanding and unification of purpose.	Linear amplification by eudaimonia.
$\mathbf{L(t)}$	Organizational Learning	Dissipative adaptability and accumulation of information.	0: Amnesia and total operational rigidity. 1: Saturation of cognitive absorption capacity.	Bounded logistic growth.
$\mathbf{C(t)}$	Structural Coherence	Integration and consistency among structures, processes, and shared meanings	0: structural disarticulation. 1: maximum structural coherence.	Balance between generation and degradation of coherence

5 System of coupled differential equations

The dynamics of the MIGAE model is represented by a system of nonlinear ordinary differential equations that describes the temporal evolution of the four state variables: organizational autopoiesis, collective sensemaking, organizational learning, and structural coherence. Each equation expresses the rate of change of a construct as the result of the balance between the mechanisms that favor its development and those that contribute to its deterioration, while also incorporating the interactions with the remaining variables of the system (Beer, 1979; Checkland, 1981; Allen, 2001). The equations are coupled, so that the evolution of each variable depends on the state of the others. This structure makes it possible to represent the feedback processes that characterize the model and to analyze how the interactions among the different constructs condition the overall dynamics of the system (Argyris & Schön, 1978; Weick, 1995; Weick et al., 2005; Holland, 1992). On this basis, the following sections develop the mathematical formulation of each state variable and of the emergent functions derived from the system.

5.1 Dynamics of autopoiesis

Organizational autopoiesis, defined as the system's capacity to generate and maintain its own boundaries and processes, represents the fundamental thermodynamic engine of the MIGAE (Maturana & Varela, 1980; Luhmann, 1995; Magalhães & Sanchez, 2009). Its dynamics, described by equation (2), reveals that the preservation of organizational identity is not a passive process, but an act of constant self-reproduction:

$$\frac{dA}{dt} = \alpha_1 A(t) C(t) E(t) - \gamma_A A(t) \qquad (2)$$

where:

- α_1: autopoietic regeneration rate.
- γ_A: organizational autopoiesis loss rate.

The structure of this equation embodies a principle of operational closure. Looking at the factorization $\frac{dA}{dt} = A(t)[\alpha_1 N(t) E(t) - \gamma_A]$, it becomes evident that the system's regeneration capacity is directly proportional to its current level of autopoiesis A(t). This implies that the system depends on itself in order to exist. Without an initial autopoietic substrate, the system lacks the infrastructure needed to process order C(t) or to integrate eudaimonia E(t).

The presence of eudaimonia in this equation deserves particular consideration. In the MIGAE model, eudaimonia is not an independent state variable, but an emergent property derived from the instantaneous state of the system. However, once emerged, it modifies the organizational context in which autopoietic processes operate, exerting a mechanism of downward causation. Consequently, although E(t) emerges from the state variables, its value actively intervenes in the regeneration of autopoiesis, establishing a cycle between the emergent properties and the processes that gave rise to them. This mechanism implies that the system's dynamics do not depend solely on upward causal relationships, in which state variables generate emergent properties, but also on downward relationships, through which those properties subsequently condition the behavior of the components that originated them. In this sense, eudaimonia synthesizes the overall state reached by the organization and feeds that information back to the system, increasing or limiting its capacity for self-regeneration. The coupling structure can be summarized conceptually as:

$$A \rightarrow S \rightarrow L \rightarrow C \rightarrow E$$

$$\uparrow \text{———————————} \lrcorner$$

where eudaimonia emerges from the interaction of the state variables and subsequently feeds back into the autopoietic dynamics.

Finally, the equation presents a trivial extinction point at A(t) = 0. This value represents a critical threshold of no return. If autopoiesis vanishes, the system loses its closure and, with it, its capacity for self-reference. In this scenario, however favorable the external conditions or however high the eudaimonic states, the system is unable to appropriate them in order to regenerate, since it has lost the basic functional organization required to convert such inputs into living structure. From the standpoint of complex systems, this loss of organization

implies the impossibility of sustaining self-organizing processes and of maintaining far-from-equilibrium states by importing negentropy from the environment (Schrödinger, 1944; Nicolis & Prigogine, 1977; Prigogine & Stengers, 1984). Therefore, autopoiesis is not just another variable, but the anchor that guarantees that the organization does not dissolve into the environment, but continues to be an active, self-regulated agent (Maturana & Varela, 1980; Luhmann, 1995).

5.2 Dynamics of sensemaking

Sensemaking is the system's capacity to reduce ambiguity and build shared meaning in the face of environmental uncertainty (Weick, 1995; Weick et al., 2005; Maitlis & Christianson, 2014). Its dynamics, represented in equation (3), formalizes how the organization translates complexity into common purposes:

$$\frac{dS}{dt} = \beta_1 A(t)\big(1 + \beta_2 E(t)\big) - \gamma_S S(t) \qquad (3)$$

where:

- β_1: basic capacity for meaning generation.
- β_2: amplifying effect of eudaimonia.
- γ_S: rate of deterioration of the capacity for collective meaning construction.

In this formulation, an amplified linear function is adopted to represent the positive effect of eudaimonia on sensemaking, initially assuming an approximately proportional relationship. This choice reduces the model's sensitivity to small variations in the parameters and facilitates its future calibration and empirical validation (Weick et al., 2005; Maitlis & Christianson, 2014; Lengnick-Hall et al., 2011).

Beyond parsimony, the form $(1+\beta_2 E(t))$ responds to two theoretical requirements. First, it guarantees that sensemaking does not depend exclusively on the eudaimonic state: at E=0 the multiplier equals exactly 1, so that the basal generation of meaning remains sustained by A(t). A purely multiplicative form ($\beta_2 \cdot E$, without the unit term) would nullify sensemaking whenever E=0, contradicting the causal chain A→S→L→C postulated in Section 2. Second, the amplifying (rather than generating) character of E(t) is grounded in self-determination theory (Ryan & Deci, 2001): the satisfaction of basic psychological needs expands the cognitive resources available for collective interpretation, increasing the efficiency with which A(t) is translated into S(t), without itself constituting an independent source of meaning. Linearity is retained as the lowest-order defensible hypothesis in the absence of calibration data. Nonlinear forms (for example: $E(t)^k$) remain as a future empirical extension (Section 9).

Through equation 3, it is established that meaning generation does not occur in a vacuum, but is a function strictly dependent on autopoietic stability A(t), which acts as the necessary substrate for dialogue and interpretation to take place. The equation integrates the catalytic effect of eudaimonia E(t) through the parameter β_2, assuming an amplified linear relationship. This methodological choice reflects the hypothesis that elevated eudaimonic states act as facilitators that clarify collective perception, reducing communicative noise and aligning individual interpretations toward an overall vision (Weick, 1995; Weick et al., 2005).

On the other hand, the term $-\gamma_S S(t)$ models the natural degradation of this capacity. In environments of high uncertainty, shared meaning tends to erode due to the appearance of contradictory discourses, departmental isolation, and failures in interpretation channels. The dynamics of sensemaking, therefore, represents a constant struggle to maintain alignment. An organization that does not actively regenerate its collective sense is condemned to anomie, where the lack of a common interpretation fractures its capacity to respond and dismantles the unity of the system (Weick, 1995; Luhmann, 1995).

5.3 Dynamics of organizational learning

Organizational learning is formalized through a logistic dynamics that recognizes the existence of intrinsic limits on the system's absorption capacity (Argyris & Schön, 1978; Senge, 1990; Duchek, 2020). Its evolution is described by equation (4):

$$\frac{dL}{dt} = \mu L(t)\left(1 - \frac{L(t)}{K_L}\right) S(t)[1 + C(t)] - \gamma_L L(t) \qquad (4)$$

where:

- μ: intrinsic learning rate.
- K_L: maximum organizational absorption capacity ($0 < K_L \leq 1$).
- γ_L: organizational knowledge loss rate.

This formulation holds that the consolidation of knowledge does not occur in isolation, but depends primarily on the construction of shared meaning S(t), while structural coherence C(t) acts as a facilitating factor that increases the efficiency with which that meaning can be transformed into organizational learning. Consequently, learning requires both a collective interpretation of experience and an organizational structure sufficiently integrated to incorporate, retain, and disseminate the knowledge generated (Argyris & Schön, 1978; Senge, 1990; Weick, 1995).

The parameter μ defines the intrinsic learning rate, representing the potential speed at which the system acquires, assimilates, and retains information. It is a variable deeply influenced by organizational culture, human capital training, and the resilience of its internal structure (Senge, 1990; Duchek, 2020; Lengnick-Hall et al., 2011).

A critical element in this model is the logistic term $L(t)\left(1-\frac{L(t)}{K_L}\right)$, which incorporates the existence of a maximum organizational absorption capacity represented by the parameter K_L. This parameter defines the upper limit toward which learning tends, reflecting cognitive, technological, and structural constraints that prevent indefinite growth of the capacity to incorporate knowledge. As $L(t)$ approaches K_L, the factor $\left(1-\frac{L(t)}{K_L}\right)$ progressively reduces the growth rate, producing an asymptotic approach to the maximum level of learning and avoiding assumptions of unlimited growth.

Finally, the term $-\gamma_L L(t)$ accounts for the natural loss or obsolescence of knowledge, modeling the constant challenge of keeping the intellectual stock current in the face of environmental dynamics (Argyris & Schön, 1978; Duchek, 2020).

5.4 Dynamics of structural coherence

The MIGAE model introduces the state variable called structural coherence, understood as the degree of consistency and integration that the organization maintains among its structures, processes, practices, and shared meanings. This construct is grounded in the autopoiesis theory of Maturana and Varela (1980), according to which the conservation of the organization depends on maintaining structural relationships compatible with its identity, and it is complemented by contributions from dissipative systems theory (Nicolis & Prigogine, 1977; Prigogine & Stengers, 1984), which explain how open systems are able to preserve organized configurations in the face of permanent perturbations. Within this framework, structural coherence represents an indicator of the degree to which the organization manages to keep its internal capabilities aligned through organizational learning processes and the collective construction of meaning.

Structural coherence C(t) represents the system's capacity to preserve a consistent and adaptive organization through the articulation of organizational learning and collective sensemaking (Argyris & Schön, 1978; Senge, 1990; Weick, 1995; Weick et al., 2005). Its dynamics is defined by equation (5):

$$\frac{dC}{dt} = \theta_1 L(t) + \theta_2 S(t) - (\gamma_N C(t) + \sigma(t)) \qquad (5)$$

where:

- θ_1: efficiency with which learning generates order.
- θ_2: efficiency with which shared meaning generates order.
- γ_N: natural degradation of organizational order.
- $\sigma(t)$: internal generation (or exogenous coupling) of entropy.

This formulation establishes that structural coherence does not arise spontaneously, but as a result of the organization's capacity to transform learning and shared meaning into consistent structures, practices, and coordination patterns. In this way, structural coherence constitutes the main mechanism that allows organizational identity to be preserved and adaptation to be sustained in the face of uncertainty (Beer, 1979; Holland, 1992; Maturana & Varela, 1980).

The term $-\gamma_N C(t)$ represents the natural tendency of every organization to lose coherence as a result of the wear of its processes, environmental changes, and internal fragmentation. To this is added the term $-\sigma(t)$, which models the effect of internal or exogenous perturbations capable of misaligning the organizational

structure. To preserve the analytical consistency of the model, it is assumed that $-\sigma(t)$ as a bounded function (Beer, 1979; Hollnagel et al., 2006).
Taken together, this equation describes the dynamic balance through which the organization preserves its structural coherence against the permanent processes of degradation and perturbation. The ability to maintain such coherence is a necessary condition for preserving the system's identity, favoring its adaptation, and allowing the emergence of eudaimonic states (Beer, 1979; Holland, 1992; Gershenson, 2025).

6 Systemic emergence functions

The MIGAE model postulates a fundamental ontological distinction between the variables that define the internal state of the system and those that manifest its overall performance. From this perspective, organizational eudaimonia and productivity are not conceived as components amenable to direct or linear optimization, but as emergent properties that arise nonlinearly from the dynamic and synergistic interaction of the state vector X(t). This transition from micro-dynamics (learning, autopoiesis, meaning, and order) to macro-manifestation (eudaimonia and productivity) is the core of the systemic proposal. By recognizing these dimensions as emergent, the model abandons the pretension of mechanical control over performance, shifting the management focus toward the calibration of the underlying processes (Holland, 1992; Allen, 2001; Gershenson, 2025).
Emergence, within this framework, acts as a qualitative signal of the state of systemic health; it cannot be injected externally, but flourishes as the consequence of a system that has managed to integrate its fundamental capabilities into a high-level structural coherence (Maturana & Varela, 1980; Luhmann, 1995; Tangen, 2005).

6.1 Emergence of the eudaimonic state

Organizational eudaimonia arises, in the MIGAE model, as the culmination of systemic coherence, operating as an indicator of the degree of integration achieved by the organization. In accordance with complex systems theory, this variable is not considered a state amenable to direct control, but an emergent property derived from the dynamic interaction among the fundamental processes that sustain the functioning of the system (Holland, 1992; Allen, 2001; Gershenson, 2025). In order to represent

this coherence mathematically, this work proposes the Systemic Coherence Index, $\Psi(t)$, as the product of the four fundamental state variables in equation (6):

$$\Psi(t) = A(t) \cdot S(t) \cdot L(t) \cdot C(t) \qquad (6)$$

From this index, organizational eudaimonia is formalized through a logistic function in equation (7):

$$E(t) = \frac{1}{1 + \exp[-\omega(\Psi(t) - \Psi_0)]} \qquad (7)$$

where:

- ω: sensitivity of the system to changes in coherence.
- Ψ_0: critical threshold for the emergence of the eudaimonic state.

Eudaimonia has no differential equation of its own since it is an emergent property of the system. Likewise, the use of a product in (6) reflects a strict multiplicative interdependence: if any of the structural dimensions collapses (tends to zero), the index plummets immediately. In this way, high performance in learning (L), for example, cannot compensate for the absence of autopoiesis (A). The sigmoid function in (7) maps this coherence to the interval $[0,1]$, modeling a critical-threshold behavior before activating eudaimonic fullness (Holland, 1992; Allen, 2001; Gershenson, 2025).
Both functional choices respond to established conventions and are not arbitrary. The product operates under the same weakest-link logic that resilience engineering employs for systems in which all components are necessary and none is sufficient on its own (Hollnagel, Woods & Leveson, 2006), a logic analogous to that of composite efficiency indices (Coelli et al., 2005). The logistic function, for its part, is the canonical form for modeling S-type emergence curves in threshold systems, innovation diffusion, population dynamics, or phase transitions. A linear or power form would not produce the critical-threshold effect that this work proposes,

whereas the logistic is flat far from Ψ_0 and steep in its vicinity, generating the all-or-nothing behavior verified numerically in Section 6.3.

6.2 Emergence of sustainable productivity

Organizational productivity represents the observable manifestation of the systemic functioning of the MIGAE, which can be expressed as shown in equation (8):

$$P(t) = P_{max}[E(t)]^{\chi}C(t) \qquad (8)$$

where:

- P_{max}: maximum productive capacity of the organization.
- χ: nonlinear amplification coefficient ($\chi > 1$).

The structure of this equation constitutes an original modeling proposal of the MIGAE. The exponent χ introduces a penalty that models the reality of sociotechnical environments. If the eudaimonic state E(t) is medium or low, productivity is disproportionately penalized, reflecting how the lack of shared meaning or internal order prevents effort from translating into real results. Conversely, when the organization reaches levels of eudaimonia close to excellence, the return on effort is expansive, allowing the organization to exceed its conventional limits.

Structurally, equation (8) follows the logic of a Cobb-Douglas-type production function, that is, productivity emerges from the joint product of a quality factor (E) and a capacity or infrastructure factor (C), so that neither is sufficient on its own (P=0 if E=0 or if C=0), preserving the same non-compensatory logic that governs Ψ(t). The exponent χ is interpreted, by analogy with economic production functions, as the elasticity of productivity with respect to eudaimonia: $\chi>1$ implies accelerated returns once a certain level of organizational well-being is exceeded, consistent with the notion of critical threshold already introduced; $\chi<1$ would imply diminishing returns. That C enters with a unit exponent, on the other hand, is the parsimonious baseline hypothesis (the particular case $\delta=1$ of a more general form $P=Pmax \cdot E^{\chi} \cdot C^{\delta}$), and it is explicitly posed as an empirical extension to be tested when calibration data become available (Section 9). The parameter P_{max}, for its part, sets the theoretical ceiling of attainable productivity at E=C=1, and can be calibrated against the sectoral benchmarks customary in the productivity measurement literature (Tangen, 2005; Coelli et al., 2005).

From this perspective, productivity cannot be increased exclusively through isolated interventions on incentives, resources, or control mechanisms. Its emergence depends on the degree of integration achieved among autopoiesis, sensemaking, organizational learning, and structural coherence, variables that constitute the dynamic core of the model. This functional dependence represents a central hypothesis of the MIGAE, according to which organizational performance is the consequence of the coordinated functioning of the system and not of the independent optimization of its components.

This interpretation is consistent with sociotechnical systems theory, which holds that organizational performance depends on the interaction between social and technical subsystems rather than on the isolated optimization of each of them (Trist & Bamforth, 1951; Pasmore et al., 1982). Likewise, it coincides with the systemic view of productivity as an expression of the overall performance of the organization and not merely of the efficiency of its individual processes (Tangen, 2005; Beer, 1979).

Consequently, in the MIGAE model, productivity is the final indicator that the organization has reached a sufficient level of internal coherence to sustainably transform its organizational capabilities into value generation

7 Analysis of integrated influence and stability

Having established the dynamic laws that govern the temporal evolution of the organization and the functions that give rise to emergent properties, the next analytical step consists of dissecting the internal topology of the system. In this regard, the Jacobian matrix serves a dual function within the MIGAE. From the mathematical standpoint, it is the classical tool for studying the local stability of the dynamical system around its equilibrium points. From the organizational perspective, it allows analyzing the structural sensitivity of the model, identifying how marginal perturbations in one organizational capability modify the evolution of the others (Beer, 1979; Holland, 1992; Allen, 2001). To formalize this interconnection through the Jacobian matrix, each element $(\frac{\partial f_i}{\partial X_j})$ represents the marginal influence of one construct on another, quantifying how a variation in

capability j accelerates or decelerates the flow of component i. For their part, the functions f_i represent the net flow of the system, defined as the instantaneous balance between the strengthening and degradation forces of each variable, operating within a domain $X_i \in (0,1)$ that reflects the state of development of organizational capabilities in an environment of biological viability (Section 2. model assumptions). In essence, this analysis not only quantifies how much a construct grows or declines, but reveals the strength and direction of the coupling among culture, meaning, knowledge, and structural order.
Through this analysis of derivatives, it is possible to identify which internal levers have the greatest influence on the global stability of the system and to detect, with analytical rigor, the points at which the organization could become vulnerable to destabilization or, on the contrary, reach a state of resilient homeostasis.

7.1 Interdependence Matrix (Jacobian)

The matrix of couplings and cross flows (Jacobian) of the integrated system is defined algebraically as shown in (9). Beyond the algebraic formalization, the Jacobian matrix reveals the survival logic and the resilience thresholds of the MIGAE model.

$$M = \begin{bmatrix} \frac{\partial f_A}{\partial A} & \frac{\partial f_A}{\partial S} & \frac{\partial f_A}{\partial L} & \frac{\partial f_A}{\partial C} \\ \frac{\partial f_S}{\partial A} & \frac{\partial f_S}{\partial S} & \frac{\partial f_S}{\partial L} & \frac{\partial f_S}{\partial C} \\ \frac{\partial f_L}{\partial A} & \frac{\partial f_L}{\partial S} & \frac{\partial f_L}{\partial L} & \frac{\partial f_L}{\partial C} \\ \frac{\partial f_C}{\partial A} & \frac{\partial f_C}{\partial S} & \frac{\partial f_C}{\partial L} & \frac{\partial f_C}{\partial C} \end{bmatrix} \qquad (9)$$

Analytically differentiating each of the relationships stated in the coupled model, and given that eudaimonia E is an emergent function of Ψ=ASLC (Equation 7), and not an exogenous variable, in addition $\frac{\partial \Psi}{\partial X} = \frac{\Psi}{X}$the general identity shown in equation (9a) is obtained:

$$\frac{\partial E}{\partial X} = \omega E(1-E)\frac{\Psi}{X} \quad ; \quad X \in \{A, S, L, C\} \qquad (9a)$$

From this, the following signs and mathematical behaviors are obtained for the following derivatives of interest:

- $\frac{\partial f_A}{\partial A} = \alpha_1 CE + \alpha_1 AC[\omega E(1-E)\Psi] - \gamma_A$: The sign depends on the dynamic balance between the regeneration catalyzed by coherence and the natural loss, which makes it possible to model both expansive processes and structural contractions.
- $\frac{\partial f_A}{\partial S} > 0$ y $\frac{\partial f_A}{\partial L} > 0$: Regulated indirectly through the emergent operator of eudaimonia $E(t)$, since increases in meaning and learning expand the Systemic Coherence Index $\Psi(t)$, forcing the acceleration of the autopoietic flow.
- $\frac{\partial f_S}{\partial A} = \beta_1(1+\beta_2 E) + \beta_1 A\beta_2 \cdot \omega E(1-E)\cdot\frac{\Psi}{A} > 0$: Analytically confirms that the collective construction of meaning biologically requires an active organizational autopoiesis substrate.
- $\frac{\partial f_L}{\partial L} = \mu\left(1 - \frac{2L(t)}{K_L}\right)S(t)[1+C(t)] - \gamma_L$: Shows the characteristic sign change of saturation processes. It is positive when the organization is far from its absorption limit and becomes negative as it approaches K_L, stabilizing excesses of knowledge accumulation.

From the analysis of the interdependence among these variables, it is evident that the system does not operate under linear causality, but through a web of feedbacks in which autopoiesis and structural coherence act as anchor variables, while meaning and learning function as strategic catalysts.
The interpretation of its partial derivatives makes it possible to identify the blocking points where the flow of energy is dissipated. A negative sign in cognitive saturation warns of bureaucratic rigidity, while a low sensitivity in the eudaimonic coupling warns of a culture disconnected from its productive capacity.
Ultimately, this mathematical tool goes beyond descriptive diagnosis to become a prescriptive guide. By understanding how each construct alters the speed of change of the others, the manager can identify which internal levers to activate in order to transform a tendency of stagnation into a cycle of regeneration, ensuring

that productivity is not a forced objective, but the emergent result of a system that has optimized its structural coherence.

7.2 Formal stability analysis of the trivial extinction point

As made explicit in the breakdown of the autopoiesis dynamics of equation (2), the system has a critical stationary state when the autopoietic capacity collapses to zero ($A(t) = 0$). If the state vector is evaluated at the origin of organizational autopoiesis $X_0 = [0, S^*, L^*, C^*]^T$, the Systemic Coherence Index of equation (6) vanishes, as seen in equation (10)

$$\Psi = 0 \cdot S^*.L^*.C^* = 0 \qquad (10)$$

Consequently, the value of eudaimonia from equation (7) in this limiting state reduces to a fixed basal constant determined by the critical threshold, as shown in equation (11):

$$E_0 = \frac{1}{1 + \exp(\omega\Psi_0)} \qquad (11)$$

Evaluating the eigenvalue λ_A associated with the autopoiesis direction on the diagonal of the Jacobian matrix M, equation (12) is obtained directly:

$$\lambda_A = \frac{\partial f_A}{\partial A}|_{X_0} = \alpha_1 C^* E_0 - \gamma_A \qquad (12)$$

If the natural loss rate exceeds the initial regeneration threshold ($\gamma_A > \alpha_1 C^* E_0$), the eigenvalue λ_A is negative, which guarantees the local stability of the autopoietic dynamics in the direction associated with A(t). Complete asymptotic stability of the extinction point further requires that the remaining eigenvalues of the Jacobian matrix have negative real part. This mathematically demonstrates the theoretical postulate of the MIGAE: once autopoiesis falls below a critical limit, the internal mechanisms of learning (L) and meaning (S) become decoupled from the material structure, preventing the system's self-generation and causing its irreversible structural obsolescence, in accordance with the notion of loss of autopoietic organization developed by Maturana and Varela (1980) and subsequently extended to the realm of social systems by Luhmann (1995).
This stability analysis shows that organizational collapse is not a fortuitous event, but an irreversible transition toward the extinction regime when the internal regeneration capacity is insufficient to compensate for the degradation processes. If the remaining dynamic directions of the system likewise satisfy the conditions of local stability, the extinction point becomes a stable attractor of the model. In that scenario, once the state of null autopoiesis is reached, the system progressively loses its capacity for self-reference and for retaining an operative organizational memory, becoming trapped in a configuration of anomie in which the organizational structure is fragmented and the collective construction of meaning ceases to exert influence on the evolution of the system.
In management terms, this result underscores the importance of early intervention. The dynamics of the extinction attractor indicates that the system loses its internal capacity for self-regeneration when autopoiesis vanishes, so spontaneous recovery is no longer possible. Consequently, the mathematical analysis of the MIGAE supports the hypothesis that organizational survival depends on preserving the autopoietic cycle as an indispensable boundary condition for maintaining the identity, adaptive capacity, and functional continuity of the organization (Maturana & Varela, 1980; Luhmann, 1995).

7.3 Analysis of equilibrium, stability, and critical thresholds

It is emphasized, as in the previous sections, that these values do not derive from empirical measurements (see Section 10) and that their sole purpose is to exhibit what kind of analysis the mathematical structure of the MIGAE allows.

7.3.1 Equilibrium of the trivial extinction point

Evaluating equations (3)-(5) at A(t)=0 yields that S(t) and L(t) decay exponentially ($dS/dt=-\gamma_S S$; $dL/dt=-\gamma_l L$) and that C(t) converges to $C^*=-\sigma/\gamma_N$, (the latter is clipped to 0, since the boundary is $[0,1]^4$). The trivial extinction point is, therefore, the origin of the state space, X*=(0,0,0,0). When evaluating the Jacobian matrix (9) at X*, the structure reduces to a lower triangular form whose eigenvalues coincide with its diagonal: $\lambda_1=-\gamma_A$, $\lambda_2=-\gamma_S$, $\lambda_3=-\gamma_L$, $\lambda_4=-\gamma_N$. Since the four deterioration rates are positive by definition (Sections 4.1–4.4), the four real parts are always negative, the origin is a locally and asymptotically stable equilibrium for any admissible combination of parameters, without exception. This was verified numerically in the three regimes described below (eigenvalues reported in each case).

7.3.2 Necessary condition for the existence of a basin of escape

Equation (2) can be written as $dA/dt = A(t)[\alpha 1C(t)E(t) - \gamma_A]$. Given that $C(t)\leq 1$ and $E(t)<1$ by construction (Section 3.1 and equation 7), it always holds that $\alpha 1C(t)E(t) < \alpha_1$. Consequently, $dA/dt < A(t)(\alpha_1-\gamma_A)$ for every possible trajectory. If $\alpha_1\leq\gamma_A$, the right-hand side is always ≤ 0, so A(t) is monotonically nonincreasing for any initial condition and converges to the origin. In that case no basin of escape can exist, regardless of the value of the other parameters. The condition $\alpha_1>\gamma_A$ is, therefore, necessary (though not necessarily sufficient) for the model to exhibit bistability (that is, the coexistence of two alternative stable futures, one of collapse and total extinction, and another of escape and organizational survival). This is a structural property derived algebraically from eq. (2), not a numerical adjustment, which demonstrates that the fate of the organization is not predetermined by a single path, but depends on its initial capacity to overcome the critical threshold that separates the two scenarios

7.3.3 Numerical verification in three predefined regimes

To verify the preceding condition, simple common parameters were fixed ($\beta_1=1$; $\beta_2=1$; $\gamma_S=0,5$; $\mu=1$; $K_L=1$; $\gamma_L=0,3$; $\theta_1=0,5$; $\theta_2=0,5$; $\gamma_N=0,5$; $\sigma=0,05$; $\omega=10$; $\Psi_0=0,05$) and three regimes, R, were defined, varying only the ratio α_1/γ_A: R1 subcritical ($\alpha_1=0,6$; $\gamma_A=0,9$; ratio 0,67), R2 supercritical ($\alpha_1=0,9$; $\gamma_A=0,6$; ratio 1,50) and R3 marginal ($\alpha_1=\gamma_A=0,75$; ratio 1,00). In each regime the system was integrated (RK45) from a grid of 19 values of A(0) between 0,05 and 0,95, with S(0)=L(0)=C(0)=0,2 fixed in all three cases. The results, reported without modification: in R1, no initial condition escapes, even starting from A(0)=0,95, every trajectory converges to extinction, confirming the analytical prediction. In R3 (exact equality $\alpha_1=\gamma_A$) the same occurs: there is no bistability either, an expected result because equality is not enough to sustain the positive sign of dA/dt persistently. Only in R2 does a genuine threshold appear, located between A(0)=0,65 (converges to extinction) and A(0)=0,70 (escapes toward the upper boundary of the domain). Figure 1(a)-(c) shows the R2 trajectories on both sides of that threshold.

7.3.4 Locating the threshold in parameter space

To independently verify the condition $\alpha_1>\gamma_A$, the sweep over A(0) was repeated, fixing $\gamma_A=0,6$ and varying α_1 over 16 values such that the ratio α_1/γ_A spans the interval [0,5; 2,0], generating the phase map of Figure 1(d). The escape region (in black) is almost entirely confined above the line $\alpha_1=\gamma_A$ (dotted red line), which is exactly the analytical prediction of the previous section, corroborating that the critical threshold is not an artifact of a single experiment but a robust property under the joint variation of A(0) and of the ratio α_1/γ_A.

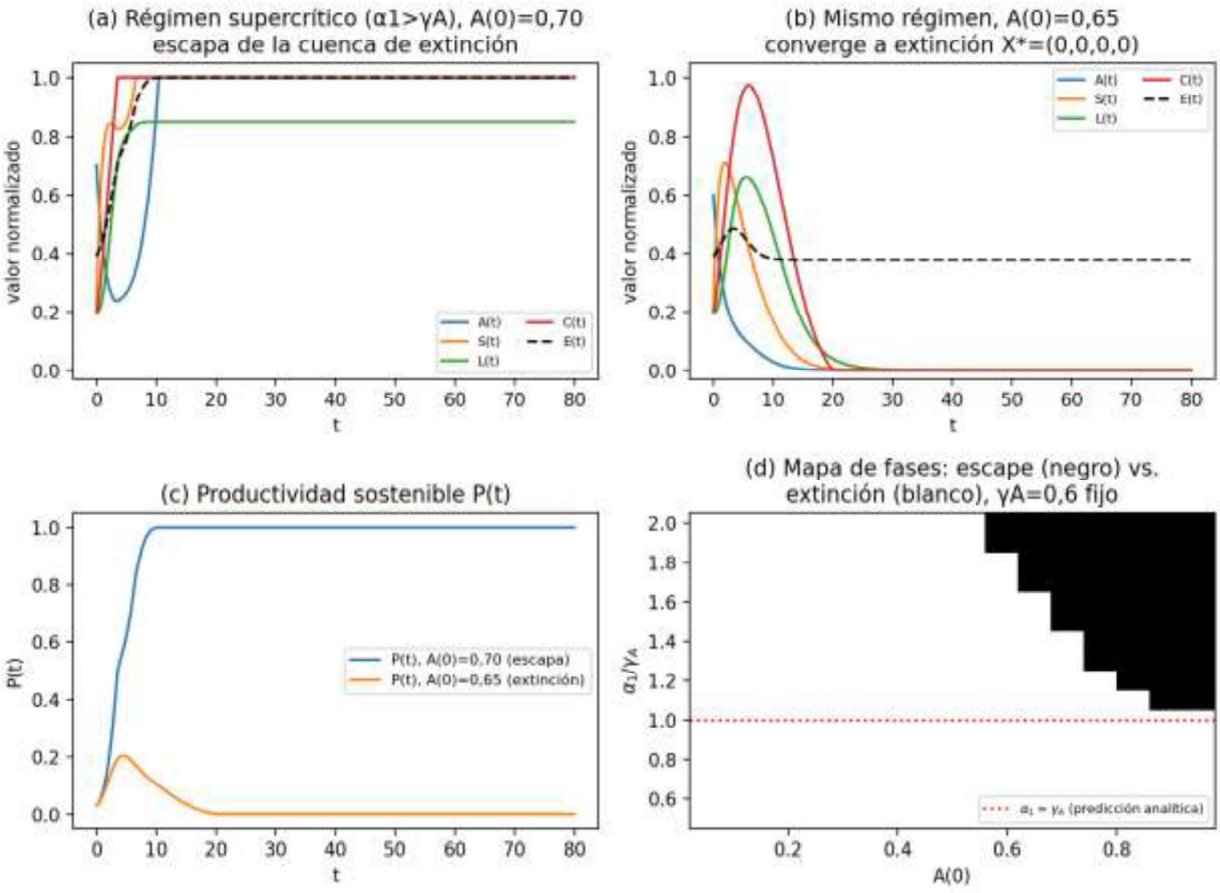

Figure 1. Numerical analysis in three regimes predefined a priori. (a)-(b) Trajectories of the supercritical regime (R2, α_1=0,9>γ_A=0,6) on both sides of the threshold A(0)∈(0,65; 0,70): escape toward the domain boundary vs. convergence to the extinction point X*=(0,0,0,0). (c) Sustainable productivity P(t) for both trajectories. (d) Phase map A(0) × α_1/γ_A (γ_A=0,6 fixed): the escape region (black) is bounded by the line $\alpha_1=\gamma_A$ predicted analytically.

7.3.5 Nature of the escape states: the boundary as a theoretical mechanism, not as an artifact

The states to which R2 converges above the threshold are not a second interior equilibrium point of system (2)-(5) taken in isolation: Equation (2) lacks a self-limiting term of its own (unlike L(t) in equation (4), so that, without additional restriction, A(t) would grow unboundedly once the threshold is exceeded. However, this does not constitute a failure of the analysis, since Section 3.1 explicitly establishes that confinement to $[0,1]^4$ is not a numerical artifice but a central theoretical principle of the MIGAE (a membrane that blocks divergence (Beer, 1979; Hollnagel, Woods & Leveson, 2006)). The simulation presented here operates exactly under that principle. It should also be stressed that the specific numerical value of the threshold (A(0)≈0,65–0,70 in R2) has no empirical meaning and would change under another, equally illustrative, choice of parameters, as shown by the displacement of the threshold in Figure 1(d) when varying α_1/γ_A. What is robust, and constitutes the substantive result of this section, is the conditional existence of the threshold subject to $\alpha_1>\gamma_A$ and the universal stability of the extinction point.

8 Operational connection: the MInFRO methodological framework

A common criticism of formal models in organizational sciences is parametric abstraction, manifested in the difficulty of measuring abstract constants such as μ, α_1 or β_1 (Simon, 1996; Checkland, 1981; Checkland & Scholes, 1990; Mingers, 2014; Mingers & Rosenhead, 2004). In the MIGAE, this gap is proposed to be resolved

by coupling it with the MInFRO methodological framework (Flexible and Reflective Intervention Model for Organizations) (Zanazzi, 2025).
MInFRO functions as the bridge for empirical calibration and operational drive of the model through two fundamental lines of action:
1. Diagnostic Audits: It makes it possible to translate the abstract variables of the state vector through specific qualitative-quantitative indicators designed for field data collection (for example, through unstructured meaning-climate surveys to evaluate $S(t)$, or knowledge-retention audits to estimate the loss rate γ_L) (Checkland & Scholes, 1990; Coelli et al., 2005).
2. Intervention on Exogenous Parameters: The ultimate purpose of MInFRO does not lie in pushing or forcing productivity directly, but in designing and implementing operational intervention policies that optimize the system's intrinsic rates (such as raising the learning rate μ through innovation cells and flexible design, or lowering the entropy term $\sigma(t)$ by stabilizing the organization's sociotechnical flows). (Trist & Bamforth, 1951; Pasmore et al., 1982).

9 Discussion

The analysis of the MIGAE's system of nonlinear differential equations provides formal theoretical evidence regarding the postulates of the model. The mathematical relationships demonstrate how nonlinearity and critical-threshold emergence phenomena operate in complex sociotechnical systems (Holland, 1992; Allen, 2001; Gershenson, 2025).

9.1 Analysis of the dynamic phases of the system

Over the time horizon of the system's behavior, the evolution of the organization can be subdivided into three qualitatively differentiated phases:

1. Phase of latency and structural inertia: At the beginning of the process, although the organization has intermediate autopoiesis, the basal capabilities of Learning (L) and Sensemaking (S) start at restrictive levels. Because of this, the Systemic Coherence Index $\Psi(t)$ in (6) is unable to exceed the critical activation threshold Ψ_0. Consequently, the Eudaimonia of equation (7) remains stagnant at basal levels. Sustainable Productivity $P(t)$, being affected by the nonlinear penalty in equation (8), exhibits low performance, which analytically proves that isolated efforts of an operational nature do not generate expansive returns without the maturation of macroscopic properties (Senge, 1990; Weick, 1995).
2. Phase of emergent explosion and self-organization: After the gradual accumulation of learning and collective meaning, driven by structural forces, the multiplicative product of the state vector exceeds the critical threshold Ψ_0. At this moment the logistic function is activated, causing accelerated sigmoid-type growth in the Eudaimonia curve. This eruption acts as a positive feedback loop on equation (2), accelerating the regeneration of autopoiesis. Sustainable Productivity $P(t)$ reacts with an exponentially lagged expansive growth, validating the central hypothesis: efficiency is the emergent result of the flourishing of the internal ecosystem (Allen, 2001).
3. Phase of stabilization and asymptotic homeostasis: In the final stage, the system reaches a state of balanced maturity. The logistic dynamics of Organizational Learning dampens its slope as it approaches the maximum structural absorption capacity (K_L). The forces of natural degradation and the external entropy rate are equated with the self-organization gradients of the system. The variables converge toward a nontrivial steady state, ensuring a stable and lasting productivity plateau in the face of minor perturbations (Beer, 1979; Uhl-Bien & Arena, 2018).

9.2 Operational implications for flexible and reflective intervention (MInFRO)

The dynamic analysis of the MIGAE justifies the intervention architecture of the MInFRO methodological framework at the Industrial Engineering and Maintenance Laboratory (LIMI) (Beer, 1979; Hollnagel et al., 2006; Uhl-Bien & Arena, 2018). If productivity were a linear and mechanically controllable variable, traditional local optimization methodologies would be sufficient. However, the multiplicative interdependence of $\Psi(t)$ shows that any focused intervention that ignores the adaptive balance is subject to temporal degradation.
Industrial managers and engineers should use this formal apparatus under the following reflective guidelines:

- Avoid the error of isolated optimization: Forcing an increase in order or production by pressing exclusively on organizational coherence (N), without strengthening shared meaning (S), produces an acceleration of the system's cognitive saturation, reducing the speed of knowledge absorption according to the logistic constraint of equation (4) (Senge, 1990; Checkland, 1981; Pasmore et al., 1982).
- Threshold management and temporal flexibility: The MInFRO framework must diagnose in which region of the logistic curve the organization is operating. If the system is located to the left of the inflection point ($\Psi < \Psi_0$), decision-makers must be flexible and understand that resources invested in learning culture or semantic alignment will not reflect immediate impacts on productivity, since the system is in a critical stage of accumulating internal resilience prior to macroscopic emergence (Holland, 1992; Allen, 2001; Nicolis & Prigogine, 1977).

10 Limitations of the Model

The Integrated Autopoietic-Eudaimonic Management Model (MIGAE), in its current deterministic formulation, has limitations inherent to its nature of analytical abstraction. The main limitation lies in the assumption of closure with respect to stochastic variability, which implies that the model, by treating the differential equations as systems perfectly isolated from random disturbances, omits severe exogenous fluctuations, such as drastic changes in legislation, sudden market crises, or unanticipated technological disruptions, which could abruptly alter the trajectory of the state variables. Likewise, the strict dependence of the variables on a closed interval [0, 1] and their multiplicative character in the Systemic Coherence Index $\Psi(t)$ impose an analytical rigidity in which the collapse of a single variable nullifies the emergence of eudaimonia, a simplification that, although useful for demonstrating systemic criticality, may underestimate the capacity for resistance or redundancy that real organizations tend to develop in the face of partial failures.
Finally, the modeling assumes that the rate and efficiency coefficients are parametric constants, whereas in organizational practice these values tend to be dynamic and dependent on the life cycle of the company itself, which suggests that the stability of the system is, in reality, a much more volatile state than the deterministic solution suggests.

11 Measurement challenges and transition to stochastic models

The transition from the present deterministic structure toward stochastic models that incorporate the uncertainty of the industrial environment entails critical methodological challenges, especially when attempting to operationalize the state vector X(t) in real environments.
The main challenge lies in data capture, given that many of the dimensions, particularly shared meaning, S(t), and organizational autopoiesis, A(t), are qualitative constructs that are usually assessed through surveys and perception scales, which are highly susceptible to cognitive biases, respondent fatigue, and lack of candor in high-pressure environments.
When moving to the stochastic domain, the risk of introducing measurement noise is high; if surveys are not calibrated with robust metrics, the variance observed in the data could reflect instrument bias rather than the real dynamics of the system. Therefore, it is imperative to design a system of hybrid indicators: for autopoiesis, direct measurements should be sought related to the retention rate of key personnel and the stability of formal processes; for learning, indirect measurements based on the adoption cycle time of new competencies or the reduction of errors in repetitive tasks; for negentropy, indicators of operational efficiency and waste reduction; and for shared meaning, the analysis of internal social networks or the consistency of documented corporate discourse.
The integration of these direct and indirect measurements is the only way to provide the model with the necessary precision before applying stochastic diffusion models, ensuring that the model is a faithful reflection of industrial complexity and not a statistical construction lacking empirical anchoring.

12 Conclusion

The mathematical formalization of the MIGAE makes it possible to move beyond theoretical intuition toward a rigorous management framework, positioning productivity not as a goal to be achieved through direct pressure, but as an emergent property of systemic coherence. The development presented shows that organizational success is conditioned by the capacity to maintain the autopoietic and learning cycle within

biologically viable limits, avoiding both the rigidity of excess order and the chaos of a lack of shared meaning. By integrating this analytical apparatus with the MInFRO intervention framework, managers are offered a technical roadmap that makes it possible to diagnose the state of the system in terms of its internal levers, overcoming the limitations of traditional linear models which, by ignoring recursivity, tend to fail in environments of high uncertainty. This work not only validates the fundamental hypotheses of the MIGAE through the demonstration of critical states and extinction points, but also redefines the role of industrial leadership toward that of a systemic gardener, where the priority is not forced control, but the creation of conditions for organizational eudaimonia to flourish.

The analysis of the Jacobian matrix confirms that the state variables possess an interdependence that cannot be ignored; an isolated improvement in technical efficiency, if not backed by semantic alignment and a robust autopoietic capacity, will inevitably be neutralized by the entropy of the system. Therefore, the proposal made here represents a necessary paradigm shift: the transition from management based on mechanical optimization toward management based on resilience and structural coherence.

Ultimately, this development provides the mandatory analytical foundations for future efforts of empirical and computational validation, allowing productive organizations not only to survive complexity, but to use it as an engine for their own evolution. Long-term sustainability, as has been shown, lies in the system's capacity to self-manage and preserve its functional integrity in the face of environmental disturbances; this is the essence of an organization that, by understanding its own mathematical dynamics, reaches a state of functional fullness capable of manifesting genuinely superior and lasting productivity.

13 References

Allen, P. M. (2001). A complex systems approach to learning in adaptive networks. *International Journal of Innovation Management*, 5(2), 149–180. https://doi.org/10.1142/S136391960100035X

Argyris, C., & Schön, D. A. (1978). *Organizational learning: A theory of action perspective*. Addison-Wesley.

Axelsson, R. (2025). Autopoiesis and organizational dynamics: Contemporary perspectives in systems research. *Systems Research and Behavioral Science*, 42(1), 35–48.

Beer, S. (1979). *The heart of enterprise*. John Wiley & Sons.

Boulding, K. (1956). General systems theory: The skeleton of science. *Management Science*, 2(3), 197–208.

Checkland, P. (1981). *Systems thinking, systems practice*. John Wiley & Sons.

Checkland, P., & Scholes, J. (1990). *Soft systems methodology in action*. John Wiley & Sons.

Coelli, T., Rao, D. S. P., O'Donnell, C., & Battese, G. (2005). *An introduction to efficiency and productivity analysis* (2nd ed.). Springer.

Duchek, S. (2020). Organizational resilience: A capability-based conceptualization. *Business Research*, 13, 215–246.

Gershenson, C. (2025). *Complexity and self-organization in socio-technical systems*.

Holland, J. H. (1992). Complex adaptive systems. *Daedalus*, 121(1), 17–30.

Hollnagel, E., Woods, D. D., & Leveson, N. (2006). *Resilience engineering: Concepts and precepts*. Ashgate.

Lengnick-Hall, C. A., Beck, T. E., & Lengnick-Hall, M. L. (2011). Developing a capacity for organizational resilience through strategic human resource management. *Human Resource Management Review*, 21(3), 243–255.

Luhmann, N. (1995). *Social systems*. Stanford University Press.

Magalhães, R., & Sanchez, R. (2009). Autopoiesis in organization theory and practice. *Journal of Organizational Change Management*, 22(3), 276–289.

Maitlis, S., & Christianson, M. (2014). Sensemaking in organizations: Taking stock and moving forward. *Academy of Management Annals*, 8(1), 57–125.

Maturana, H. R., & Varela, F. J. (1980). *Autopoiesis and cognition: The realization of the living*. D. Reidel.

Mingers, J. (2014). *Systems thinking, critical realism and philosophy: A confluence of ideas*. Routledge.

Mingers, J., & Rosenhead, J. (2004). Problem structuring methods in action. *European Journal of Operational Research*, 152(3), 530–554.

Nicolis, G., & Prigogine, I. (1977). *Self-organization in nonequilibrium systems*. Wiley.

Nonaka, I., & Takeuchi, H. (1995). *The knowledge-creating company: How Japanese companies create the dynamics of innovation*. Oxford University Press.

Oakland, J. S. (2014). *Total quality management and operational excellence: Text with cases* (4th ed.). Routledge.

Pasmore, W. A., Francis, C., Haldeman, J., & Shani, A. B. (1982). Sociotechnical systems: A North American reflection on empirical studies of the seventies. *Human Relations*, 35(12), 1179–1204.

Prigogine, I., & Stengers, I. (1984). *Order out of chaos: Man's new dialogue with nature*. Bantam.

Ryan, R. M., & Deci, E. L. (2001). On happiness and human potentials: A review of research on hedonic and eudaimonic well-being. *Annual Review of Psychology*, 52, 141–166.

Schrödinger, E. (1944). *What is Life? The Physical Aspect of the Living Cell*. Cambridge University Press.

Senge, P. (1990). *The fifth discipline: The art and practice of the learning organization*. Doubleday.

Simon, H. A. (1996). *The sciences of the artificial* (3rd ed.). MIT Press.

Stacey, R. D. (1996). *Complexity and creativity in organizations*. Berrett-Koehler.

Tangen, S. (2005). Demystifying productivity and performance. *International Journal of Productivity and Performance Management*, 54(1), 34–46.

Trist, E., & Bamforth, K. (1951). Some social and psychological consequences of the longwall method of coal-getting. *Human Relations*, 4(1), 3–38.

Uhl-Bien, M., & Arena, M. (2018). Leadership for organizational adaptability: A theoretical synthesis and integrative framework. *The Leadership Quarterly*, 29(1), 89–104.

Uhl-Bien, M., & Marion, R. (2009). Complexity leadership in bureaucratic forms of organizing: A meso model. *The Leadership Quarterly*, 20(4), 631–650.

Weick, K. E. (1995). *Sensemaking in organizations*. Sage Publications.

Weick, K. E., Sutcliffe, K. M., & Obstfeld, D. (2005). Organizing and the process of sensemaking. *Organization Science*, 16(4), 409–421.

Womack, J. P., & Jones, D. T. (2003). *Lean thinking: Banish waste and create wealth in your corporation* (Rev. ed.). Free Press.

Zanazzi, J. F. (2025). *Desarrollo y validación de un modelo multimetodológico para el diseño de intervenciones organizacionales flexibles y reflexivas* [Doctoral thesis]. Universidad Nacional de Córdoba.

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SIDTeleAsma: Telemedicine Information and Decision System for Asthma

Nilton Rodrigo da Silva Araújo[1], Lucia Reis Peixoto Roselli[1], Eduarda Asfora Frej[1], Rodrigo José Pires Ferreira[1], Murilo Carlos Amorim de Britto[2], Ana Paula Cabral Seixas Costa[1], Adiel Teixeira de Almeida[1]

[1] Universidade Federal de Pernambuco, Av. Acadêmico Hélio Ramos, s/n – Cidade Universitária, Recife, PE, CEP 50.740-530, Brazil
[2] IMIP – Instituto de Medicina Integral Professor Fernando Figueira, R. dos Coelhos, 300 – Boa Vista, Recife, PE. CEP 50.070-550, Brazil

nilton.araujo@ufpe.br, lrpr@cdsid.org.br, eafrej@cdsid.org.br, rodrigo@insid.org.br, murilodebritto@gmail.com, apcabral@cdsid.org.br
almeida@cdsid.org.br

Abstract. The challenges faced by the Brazilian healthcare system during the COVID-19 pandemic, particularly in the state of Pernambuco, highlighted the need to improve healthcare practices and encouraged the development of innovative technological solutions. In this context, telemedicine, combined with information systems and decision-support technologies, offers opportunities to improve medical consultations and facilitate communication between healthcare professionals and patients. Accordingly, SIDTeleAsma, a Telemedicine Information and Decision System for Asthma, was developed to support physicians and patients throughout the asthma care process. The system was designed for use on mobile devices running Android and iOS, providing accessibility and flexibility for healthcare professionals and patients in distinct locations. SIDTeleAsma incorporates functionalities designed to support both clinical care and communication. The system includes distinct modules for physicians and patients, appointment and attendance management, consultation history, and an integrated video call module that enables remote consultations between physicians and patients. In addition, the system incorporates a decision-support model designed to assist physicians in identifying an appropriate course of action based on the information collected during the consultation. The proposed solution may generate social, economic, and environmental benefits. From a social perspective, SIDTeleAsma can facilitate communication and access to healthcare services, particularly for patients living in municipalities located far from specialized healthcare centers in the interior of Pernambuco. From an economic perspective, remote consultations may reduce transportation-related costs and minimize the need for patients to travel long distances to access medical care. Additionally, the use of telemedicine may help reduce demand for face-to-face consultations and overcrowding in healthcare facilities. In conclusion, SIDTeleAsma represents a technological approach to supporting asthma care by integrating telemedicine, patient management, video consultations, and decision-support capabilities into a single system. The proposed solution has the potential to improve accessibility, facilitate communication between physicians and patients, improve healthcare processes, and contribute to more efficient asthma management, particularly for patients living in geographically distant areas.

Keywords: Decision System; Information; Telemedicine; Asthma; Healthcare.

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Caracterização de pacotes de compromissos estratégicos para a expansão latino-americana de uma plataforma SaaS de tecnologia logística: uma aplicação do Strategic Choice Approach

Amanda Meira da Silva[1], João Henrique Ferreira Barbosa da Silva[1], Douglas Junior Ferreira de Queiróz[1], Evelyn Torres Siqueira[1], Rafael Sanaiotte Pinheiro[1], João Batista Sarmento dos Santos Neto[1], Carolina Lino Martins[1], Kassia Tonheiro Rodrigues[1].
[1]Universidade Federal de Mato Grosso do Sul - UFMS

amanda.meira@ufms.br, joao.h.ferreira@ufms.br, douglas.queiroz@ufms.br, evelyn.siqueira@ufms.br, rafael.sanaiotte@ufms.br, joao.sarmento@ufms.br, carolina.lino@ufms.br, kassia.rodrigues@ufms.br

Resumo. Este estudo caracterizou os pacotes de compromissos estratégicos para a expansão latino-americana de uma empresa de tecnologia logística, cujo produto é uma plataforma SaaS integrada aos ERPs de indústrias embarcadoras. Adotou-se pesquisa aplicada e qualitativa, conduzida como estudo de caso único, em que se operacionalizou o Strategic Choice Approach (SCA) em dez etapas distribuídas pelos quatro modos do método: shaping, designing, comparing e choosing, a partir de duas rodadas de estruturação com o decisor (CEO), com a participação de uma especialista interna e de um especialista externo ibero-americano e com apoio da literatura. Como resultado, identificaram-se doze áreas de decisão interdependentes, entre as quais PAÍSES? exerce papel articulador (nove conexões), delimitando-se um foco de quatro áreas; a técnica AIDA reduziu 180 combinações a três esquemas viáveis e a comparação por vantagem comparativa, somada ao mapeamento de nove incertezas, predominantemente ambientais, mas com incertezas de valor no centro, mostrou que permanecem incertezas relevantes, especialmente relacionadas aos valores orientadores da decisão, dificultando a consolidação de uma preferência robusta entre os esquemas. O pacote resultante não elege um esquema definitivo: adota o Esquema A como preferência provisória, mantém aberto o conjunto {A, B, C}, e estrutura ações exploratórias, escolhas adiadas e contingências destinadas à redução das incertezas identificadas. O estudo transpõe o SCA para um domínio pouco explorado da internacionalização de plataformas digitais B2B logísticas e evidencia que a expansão internacional dessas plataformas envolve decisões interdependentes sobre mercado, comercialização, suporte e parcerias, demonstrando como o pacote de compromissos estrutura esse processo sob incerteza.

Palavras-chave: Métodos de Estruturação de Problemas; Internacionalização de plataformas digitais; Decisão sob incerteza.

Abstract. This study characterized strategic commitment packages for the Latin American expansion of a logistics technology company whose core product is a SaaS platform integrated with the ERPs of shipping industries. An applied qualitative research design was adopted and conducted as a single case study. The Strategic Choice Approach (SCA) was operationalized through ten stages organized according to the four modes of the method: shaping, designing, comparing, and choosing. Data were collected through two structuring rounds with the CEO, the participation of an internal and an Ibero-American external specialist, supported by the literature. The results identified twelve interdependent decision areas, among which COUNTRIES? played an articulating role with nine connections, leading to the delimitation of a four-area decision focus. The AIDA technique reduced 180 possible combinations to three feasible expansion schemes. Comparative advantage analysis, combined with the mapping of nine uncertainties—predominantly environmental, but with value-related uncertainties at the core—showed that significant uncertainties remain, particularly those related to the values guiding the decision, hindering the consolidation of a robust preference among the schemes. The resulting commitment package does not select a definitive scheme; it adopts Scheme A as a provisional preference, keeps the set {A, B, C} open, and structures exploratory actions, deferred choices, and contingencies to reduce the identified uncertainties. The study extends the application of SCA to the underexplored context of B2B digital logistics platform internationalization and shows how commitment packages structure interdependent expansion decisions under uncertainty.

Keywords: Problem Structuring Methods; Digital Platform Internationalization; Decision-Making under Uncertainty.

1 Introdução

A expansão internacional de empresas de tecnologia logística constitui uma decisão estratégica complexa, pois envolve a articulação simultânea entre mercado, produto, infraestrutura tecnológica, capacidade operacional, regulação, modelo comercial e integração com ecossistemas locais de transporte e suprimentos (García-Canal e Guillén, 2026). Diferentemente da internacionalização de produtos físicos padronizados, a expansão de uma plataforma digital aplicada à logística depende não apenas da replicação de uma solução tecnológica em novos mercados, mas também de sua adaptação a sistemas fiscais, arranjos institucionais, práticas logísticas, padrões de integração com ERPs, modelos de contratação de transportadores, sistemas de pagamento e níveis distintos de maturidade digital dos embarcadores (Stallkamp e Schotter, 2021). Na economia digital, as estratégias de internacionalização e as estratégias digitais tornam-se interdependentes, uma vez que a atuação internacional de empresas digitais é condicionada por diferenças entre instituições formais, instituições informais, recursos disponíveis e estruturas de mercado nos países de destino (Meyer et al., 2023).

Essa interdependência é ainda mais relevante no setor logístico, no qual plataformas digitais não operam isoladamente, mas como infraestruturas de coordenação entre múltiplos agentes da cadeia de suprimentos. Nesses casos, a decisão de expansão não pode ser reduzida à escolha de um país-alvo ou de uma estratégia comercial genérica; ela exige a configuração de alternativas estratégicas compostas por múltiplas decisões interdependentes (Ivanov, Dolgui e Sokolov, 2022). Apesar da relevância dessas decisões para empresas de tecnologia logística, a estruturação de alternativas estratégicas em contextos reais de expansão internacional permanece um desafio prático, especialmente quando múltiplas decisões interdependentes precisam ser consideradas simultaneamente. A caracterização dos pacotes de compromissos torna-se necessária porque decisões de expansão internacional em ambientes digitais e logísticos raramente são compostas por uma única escolha. Ao contrário, envolvem combinações de decisões sobre entrada em mercados, seleção de países prioritários, adaptação do produto, integração fiscal e tecnológica, estrutura comercial, parcerias locais, suporte operacional, governança de dados, compliance regulatório e priorização de funcionalidades (García-Canal e Guillén, 2026; Stallkamp e Schotter, 2021; Meyer et al., 2023). Cada combinação possível constitui uma alternativa estratégica com implicações distintas de custo, risco, tempo de implementação, escalabilidade e reversibilidade. Assim, caracterizar os pacotes de compromissos significa identificar quais decisões devem ser assumidas no curto prazo, quais podem permanecer abertas, quais incertezas precisam ser reduzidas antes do comprometimento e quais ações exploratórias são necessárias para sustentar escolhas futuras. Essa perspectiva desloca a análise de uma lógica prescritiva de "melhor alternativa" para uma lógica estruturante, na qual alternativas são construídas progressivamente sob condições de incerteza (Rosenhead e Mingers, 2001).

No campo dos Problem Structuring Methods, o SCA pertence a um conjunto de abordagens voltadas à estruturação de problemas complexos, caracterizados por ambiguidade, múltiplos atores, objetivos parcialmente conflitantes e ausência de solução única previamente definida (Mingers e Rosenhead, 2004). Por isso, sua aplicação é coerente com decisões de expansão internacional nas quais a qualidade do processo de estruturação das alternativas pode ser tão relevante quanto a avaliação final entre elas. Diante da necessidade de estruturar alternativas estratégicas compostas por múltiplas decisões interdependentes, o SCA oferece uma base metodológica adequada para apoiar esse tipo de processo decisório, pois foi desenvolvido para lidar com situações marcadas por pressão, incerteza e pluralidade de perspectivas. A abordagem permite estruturar situações problemáticas por meio da identificação de áreas de decisão, opções disponíveis, relações de interdependência, áreas de comparação e fontes de incerteza. Sua contribuição central está na noção de pacote de compromissos, pela qual os decisores estabelecem um equilíbrio explícito entre decisões a serem assumidas imediatamente e decisões que devem permanecer em aberto até que novas informações estejam disponíveis (Friend e Hickling, 2004; Friend, 2010). No SCA, decisões são interdependentes quando a escolha em uma área amplia, restringe ou inviabiliza as opções de outra, de modo que não podem ser tomadas isoladamente; e ocorrem sob incerteza quando o compromisso depende de conhecimento incompleto sobre o ambiente (UE), sobre os valores que orientam a escolha (UV) ou sobre decisões de agendas conexas (UR) (Friend e Hickling, 2004).

Aplicações recentes do SCA incluem a estruturação de processos de projeto em arquitetura (Todella, Lami e Armando, 2018), a combinação multimetodológica com técnicas multicritério (Lami e Todella, 2023), a gestão de conflitos em recursos hídricos no Brasil (Carvalho e Magrini, 2006), decisões de atualização tecnológica no setor de defesa (Freitas, Almeida e Bergiante, 2024) e a formalização computacional da AIDA (Georgiou, Heck e Mrvar, 2019). Carvalho e Magrini (2006) destacam que o método é particularmente pertinente quando as decisões são tomadas de forma incremental, sob incertezas políticas, administrativas e legais, condição análoga à da expansão aqui analisada. Essa trajetória evidencia a maturidade do método e,

simultaneamente, a escassez de aplicações à expansão internacional de plataformas digitais logísticas, lacuna que este estudo busca explorar.

A condição diferencial da expansão latino-americana reforça a pertinência dessa abordagem. A América Latina apresenta oportunidades significativas para soluções digitais em transporte e logística, especialmente pela necessidade de ampliar visibilidade, integração, rastreabilidade, eficiência operacional e coordenação entre atores da cadeia (Mashalah et al., 2022). Ao mesmo tempo, a região é marcada por heterogeneidade institucional, diferenças tributárias e regulatórias entre países, assimetrias de infraestrutura, distintos níveis de digitalização de empresas transportadoras e embarcadoras, além de variações na qualidade dos serviços logísticos e na confiabilidade das cadeias internacionais. Estudos regionais sobre transformação digital do transporte indicam que a adoção de tecnologias aplicadas à logística na América Latina e no Caribe depende de capacidades institucionais, políticas públicas, infraestrutura digital e maturidade dos agentes privados (Calatayud, Katz e Riobó, 2022). Tais características se refletem em incertezas comerciais, operacionais, regulatórias e decisórias posteriormente identificadas pelo SCA. De modo complementar, indicadores internacionais de desempenho logístico demonstram a importância de dimensões como conectividade, velocidade, confiabilidade, infraestrutura, rastreamento e eficiência dos processos de comércio e transporte (World Bank, 2025).

Nesse contexto, a expansão de uma empresa de tecnologia logística para a América Latina não deve ser tratada apenas como uma decisão de mercado, mas como um problema estratégico estruturado por incertezas técnicas, comerciais, operacionais, institucionais e processuais. A caracterização dos pacotes de compromissos permite explicitar essas incertezas, organizar alternativas de entrada e expansão, comparar implicações entre diferentes configurações estratégicas e orientar compromissos graduais em ambientes de informação incompleta. Essa contribuição é relevante tanto para a literatura de estruturação de problemas e apoio à decisão quanto para estudos sobre internacionalização digital e plataformas logísticas B2B, pois aproxima uma abordagem clássica de decisão estratégica sob incerteza de um problema contemporâneo de expansão internacional em tecnologia aplicada à logística. O caso analisado é o de uma empresa brasileira de tecnologia logística cuja plataforma SaaS, integrada aos ERPs de indústrias embarcadoras (como o SAP), reúne gestão de viagens e de transportadores, rastreabilidade de cargas, auditoria de frete, conferência fiscal e documental, integração de pagamentos, gestão de pátio e controle de agendamentos. Sua expansão para a América Latina articula decisões sobre países prioritários, adequação fiscal e documental, integração com ERPs locais, localização linguística, operação comercial, suporte e parcerias, em condições culturais e regulatórias heterogêneas. Diante disso, esta pesquisa é orientada pela seguinte questão de pesquisa: Como estruturar decisões interdependentes de expansão internacional de plataformas logísticas sob incerteza? Para tanto, este estudo tem como objetivo caracterizar os pacotes de compromissos estratégicos para a expansão latino-americana de uma empresa de tecnologia focada em soluções logísticas.

2 Procedimentos Metodológicos

Trata-se de pesquisa aplicada, qualitativa e exploratório-descritiva, conduzida como estudo de caso único, formato típico dos relatos de aplicação de Problem Structuring Methods (Rosenhead e Mingers, 2001; Mingers e Rosenhead, 2004). O SCA (Friend e Hickling, 2004; Friend, 2010) foi adotado porque o caso reúne as condições para as quais o método foi concebido: múltiplas áreas de decisão interdependentes, atores com perspectivas parcialmente distintas, incertezas de naturezas diversas e impossibilidade de formulação fechada, o que exige progressão por compromissos parciais.

2.1 Coleta e Tratamento dos Dados

As evidências provêm de quatro fontes: (i) a transcrição integral de duas rodadas de estruturação conduzidas remotamente com o decisor, o CEO da empresa, com duração total de 2 horas, nas quais foram percorridos os quatro modos do SCA; (ii) a consulta a um especialista externo à empresa, com 15 anos de experiência em transferência de tecnologia digital no contexto ibero-americano, mobilizado para apoiar a definição dos países-alvo, as opções e as compatibilidades e incompatibilidades, e que conduziu a facilitação nessa etapa; (iii) literatura de apoio sobre internacionalização digital e logística latino-americana, usada para contextualizar e confrontar as formulações do decisor, e não como evidência primária do caso; e (iv) uma especialista interna, gerente de projetos da empresa, que conduziu a facilitação das demais etapas e aportou conhecimento sobre processos, operação e viabilidade de execução, complementar ao conhecimento de mercado do especialista externo. O conselho e as áreas comerciais são partes interessadas que não participaram das sessões, mas foram consultados pela especialista interna. As fontes cumpriram papéis

distintos: o decisor forneceu o conteúdo substantivo (áreas, opções, incompatibilidades e julgamentos); o especialista externo aportou conhecimento sobre os mercados-alvo, sobretudo na definição das opções de PAÍSES? e na identificação de exigências regulatórias; e a literatura serviu de contraponto às formulações do decisor. A triangulação foi operacionalizada pelo confronto das formulações do decisor com as da especialista interna, do especialista externo, da literatura; quando havia divergência, ela era explicitada e devolvida ao decisor, a quem coube a formulação final, conforme detalhado adiante. Para apoiar a condução das rodadas, utilizou-se uma aplicação web desenvolvida especificamente para operacionalizar o SCA, convertendo os quatro modos em um roteiro semiestruturado guiado. Esse instrumento definiu a sequência analítica, os construtos a serem elicitados e as relações lógicas entre eles, mas manteve aberto o conteúdo substantivo das respostas, preenchido a partir das formulações do próprio decisor durante a facilitação. Dessa forma, a aplicação estruturou o processo sem predeterminar os resultados, permitindo registrar áreas de decisão, opções, conexões, incompatibilidades, áreas de comparação, incertezas e compromissos de forma rastreável.

As áreas de decisão foram extraídas da leitura integral das transcrições das reuniões e validadas na interação entre CEO, especialistas e analistas. Considerou-se área de decisão todo trecho que expressasse uma escolha sob controle do decisor, com ao menos duas opções mutuamente excludentes; trechos que descreviam estados do ambiente fora desse controle foram classificados como áreas de incerteza (etapa 8). A codificação ocorreu por meio da identificação de trechos associados aos construtos do SCA, especialmente decisões, alternativas, dependências, restrições, incertezas e compromissos. Não houve dupla codificação independente em sentido estrito; contudo, os analistas revisaram conjuntamente os registros, buscando consistência entre os trechos empíricos e os rótulos atribuídos. As conexões entre áreas foram definidas por análise par a par com o decisor, considerando se uma decisão condicionava, restringia ou modificava outra. As incompatibilidades entre opções, correspondentes às *option bars* da técnica AIDA, foram declaradas durante a facilitação e revisadas pelos analistas, resultando na poda das combinações teoricamente possíveis e na identificação dos esquemas viáveis. Os julgamentos de vantagem comparativa foram emitidos exclusivamente pelo decisor, na segunda rodada: para cada par de esquemas e área de comparação, ele indicou primeiro a melhor estimativa e, em seguida, a amplitude considerada plausível (intervalo de crença). Os facilitadores e os analistas apenas conduziram as perguntas, sem emitir julgamentos; não houve, portanto, agregação de avaliações de múltiplos participantes. Os intervalos não são estatísticos, mas expressões qualitativas da incerteza associada às avaliações. Quando a formulação do especialista ou a literatura divergiu da do decisor, a divergência foi explicitada na própria sessão e devolvida ao decisor, a quem coube a formulação final. Reconhece-se que não houve controle formal independente do viés do decisor, dado seu papel central no processo; contudo, esse risco foi parcialmente mitigado pela facilitação especializada, pela revisão conjunta dos analistas e pela rastreabilidade dos registros gerados pela aplicação web.

2.2 Operacionalização do *Strategic Choice Approach*

O SCA organiza o processo decisório em quatro modos complementares e interativos: *shaping* (modelagem da situação problemática), *designing* (concepção de alternativas), *comparing* (comparação entre alternativas) e *choosing* (escolha e compromisso) (Fig. 1), entre os quais os participantes transitam de forma não linear (Friend e Hickling, 2004). No presente estudo, a operacionalização do método percorreu esses quatro modos por meio de dez etapas analíticas, descritas a seguir.

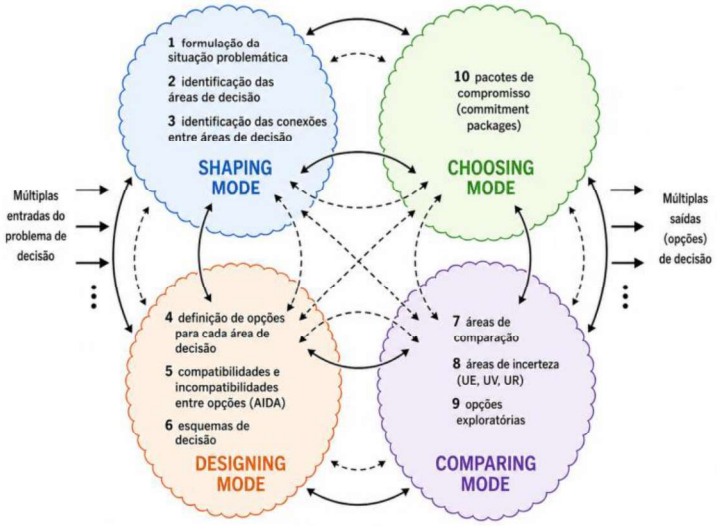

Fig. 1. Estrutura operacional dos modos do Strategic Choice Approach (SCA). Cada círculo representa um dos quatro modos do método: *shaping*, *designing*, *comparing* e *choosing*. Os números indicam as 10 etapas analíticas adotadas no estudo. O *shaping* estrutura a situação problemática; o *designing* define opções e esquemas de decisão; o *comparing* avalia áreas de comparação, incertezas e opções exploratórias; e o *choosing* consolida os pacotes de compromisso. As setas contínuas indicam transições entre os modos, enquanto as setas tracejadas representam retornos iterativos e alternâncias temporárias, evidenciando o caráter não linear do SCA. Fonte: Elaborada pelos autores, 2026.

No modo *shaping*, a primeira etapa consistiu na formulação da situação problemática, convertendo o desafio amplo da expansão latino-americana na seguinte questão estruturante: como estruturar pacotes de compromissos estratégicos para a expansão latino-americana da plataforma, considerando decisões interdependentes sobre países prioritários, operação comercial, suporte, parcerias, adequação fiscal e documental, localização linguística, módulos e integração com ERPs. A segunda etapa correspondeu à identificação das áreas de decisão, definidas a partir dos trechos da transcrição que atendiam ao critério descrito na seção 2.1 e rotuladas de forma sintética, conforme a convenção notacional do método. A terceira etapa compreendeu a identificação das conexões entre áreas de decisão, mediante análise par a par das relações de dependência, por exemplo, a escolha dos países prioritários condiciona as exigências de adequação fiscal e documental e as necessidades de localização linguística da plataforma, resultando no grafo de decisão que delimitou o foco do problema.

No modo *designing*, a quarta etapa consistiu na definição de opções para cada área de decisão, formuladas como cursos de ação mutuamente excludentes no interior de cada área. A quinta etapa examinou as compatibilidades e incompatibilidades entre opções de áreas distintas, conforme a técnica de Analysis of Interconnected Decision Areas (AIDA), na qual barras de opção (*option bars*) explicitam as combinações inviáveis por restrições técnicas, regulatórias ou estratégicas (Friend e Hickling, 2004; Georgiou, Heck e Mrvar, 2019). A sexta etapa derivou os esquemas de decisão, isto é, as combinações de opções mutuamente compatíveis, uma opção por área, que constituem as alternativas estratégicas viáveis para a expansão.

No modo comparing, a sétima etapa identificou as áreas de comparação, definidas, na tradição do método, como as dimensões de consequência que os decisores reconhecem como capazes de discriminar entre os esquemas de decisão (Friend e Hickling, 2004; Friend, 2010). Diferentemente de abordagens multicritério compensatórias, que exigem mensuração e elicitação de pesos, o SCA mantém essas dimensões em nível qualitativo e as confronta por vantagem comparativa, avaliação par a par, relativa a um esquema de referência, da direção e da magnitude da diferença em cada dimensão, preservando a estruturação progressiva sob informação incompleta características dos PSMs (Rosenhead e Mingers, 2001; Mingers e Rosenhead, 2004).

Foram retidas cinco áreas de comparação, deliberadamente parcimoniosas e ancoradas no problema-foco, abrangendo tanto dimensões predominantemente factuais: investimento de entrada; custo de operação; retorno esperado. Quanto às dimensões predominantemente valorativas: risco de vazamento de conhecimento proprietário e controle sobre a operação e o cliente, em conformidade com a articulação fatos–valores que caracteriza o modo de comparação do SCA (Lami e Todella, 2023). A oitava etapa consistiu na identificação e classificação das áreas de incerteza segundo a tipologia do método: incertezas sobre o ambiente de trabalho (UE), que demandam respostas de natureza investigativa, como estudos técnicos e levantamentos de mercado; incertezas sobre valores orientadores (UV), que demandam clarificação de objetivos e políticas organizacionais; e incertezas sobre decisões relacionadas em agendas conexas (UR), que demandam coordenação ou negociação com outros decisores (Friend e Hickling, 2004; Friend, 2010). Cada incerteza identificada na transcrição foi classificada com justificativa explícita do enquadramento adotado. Na sequência, a nona etapa definiu opções exploratórias, isto é, ações destinadas a reduzir as incertezas mais salientes antes do comprometimento definitivo com determinado esquema de decisão.

Por fim, no modo *choosing*, a décima etapa construiu os pacotes de compromisso (*commitment packages*), estruturas que distribuem as decisões no tempo ao combinar, para cada área de decisão, ações imediatas, escolhas deliberadamente adiadas, com indicação das condições para sua retomada, ações exploratórias vinculadas às incertezas que justificam o adiamento e arranjos de contingência (Friend e Hickling, 2004). A caracterização desses pacotes, que constitui o objetivo central deste estudo, resulta da aplicação encadeada das etapas anteriores e é apresentada na seção de resultados.

3 Resultados e discussão

A aplicação do SCA ao problema de expansão latino-americana da plataforma SaaS de tecnologia logística percorreu os quatro modos do método: shaping, designing, comparing e choosing. Operacionalizados nas dez etapas analíticas descritas na seção 2.2. Os resultados são apresentados na mesma ordem, culminando na caracterização dos pacotes de compromisso, objetivo central deste estudo.

3.1 Áreas de decisão e delimitação do foco (shaping)

A formulação da situação problemática converteu o desafio amplo da expansão na questão de decisões interdependentes enunciada na seção 2.2. A partir das transcrições das reuniões de facilitação, identificaram-se doze áreas de decisão, rotuladas de forma sintética conforme a convenção notacional do método (rótulos terminados em "?"). A Tabela 1 sintetiza as áreas e seus rótulos.

Tabela 1. Áreas de decisão identificadas.

Área de decisão	Rótulo	Conexões
Como será realizada a operação comercial nos países-alvo?	**COMERCIAL?**	6
Quais países latino-americanos devem ser priorizados na expansão inicial?	**PAÍSES?**	9
Como é o nível de transformação digital dos embarcadores nos países?	**NÍVEL.LOG?**	2
Quais módulos devem ser oferecidos inicialmente em cada país?	**MÓDULOS?**	3
Qual nível de adaptação linguística, terminológica e de nomenclatura necessário?	**NOMEN?**	2
Quais ERPs locais existem nos países?	**ERP?**	3
Qual nível de adaptação documental e fiscal será necessário?	**ADQ.DOC?**	2
Como adaptar os processos de auditoria de frete aos países-alvo?	**AUD.FRT?**	2
Como será estruturado o processo de projeto?	**PROJETO?**	2
O mercado aceita atendimento remoto?	**REMOTO.SUP?**	3
Será necessária presença física comercial nos países-alvo?	**ESC.COM?**	3
Serão necessárias parcerias locais?	**PARCERIAS?**	3

Fonte: Elaborada pelos autores, 2026.

A terceira etapa estabeleceu as conexões de interdependência entre as áreas (análise par a par), gerando o grafo de decisão apresentado na Figura 2. A área PAÍSES? concentra o maior número de conexões (nove), confirmando seu papel articulador: a escolha dos países condiciona a adequação fiscal e documental, a localização linguística, o modelo comercial e as parcerias. Diante da impossibilidade de tratar simultaneamente as doze áreas, delimitou-se o foco deste ciclo de análise às quatro áreas mais densamente conectadas e mais urgentes para o decisor: COMERCIAL?, PAÍSES?, REMOTO.SUP? e PARCERIAS? sem descartar as demais, que permanecem em espera para ciclos subsequentes.

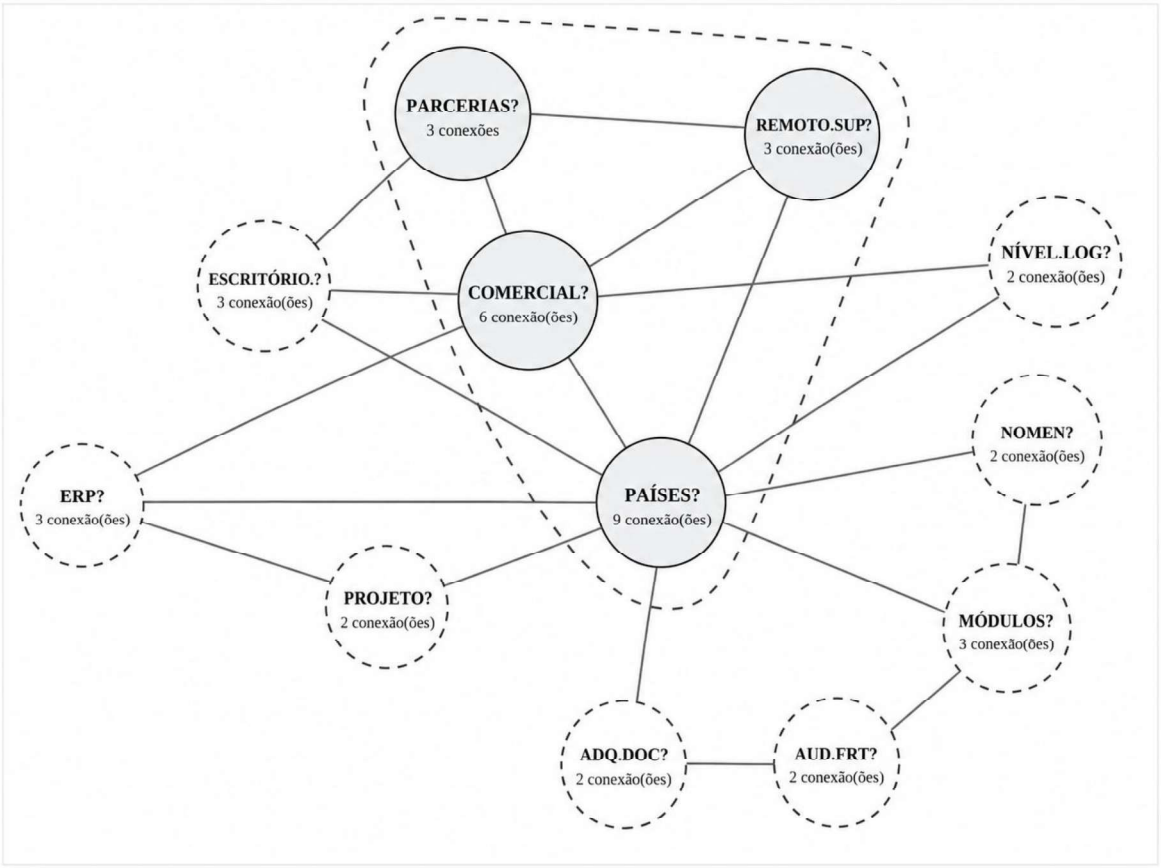

Fig. 2. Grafo de áreas de decisão e delimitação do foco do problema. Cada nó corresponde a uma área de decisão, e o número indicado em seu interior expressa o grau do nó. A área PAÍSES? ocupa a posição mais central da rede, com nove conexões, seguida por COMERCIAL? (seis), o que confirma seu papel articulador. A linha tracejada delimita o foco do problema, composto pelas quatro áreas mais densamente conectadas e prioritárias para o decisor: COMERCIAL?, PAÍSES?, REMOTO.SUP? e PARCERIAS? (nós sombreados). Fonte: Elaborada pelos autores, 2026.

3.2 Opções e esquemas de decisão viáveis (designing)

Para cada área de decisão em foco definiram-se as opções como cursos de ação mutuamente excludentes (Tabela 2). As quatro áreas combinam 3 × 5 × 3 × 4 = 180 esquemas teoricamente possíveis.

Tabela 2. Opções por área de decisão em foco.

Área de decisão	Opções	Rótulo
COMERCIAL?	- Comercial remoto a partir do Brasil - Comercial híbrido - Comercial local	- Remoto - Híbrido - Local
PAÍSES?	- México - Colômbia - Chile - Argentina	- México - Colômbia - Chile - Argentina

	- Paraguai	- Paraguai
REMOTO.SUP?	- Mercado aceita operação remota - Mercado exige modelo híbrido - Mercado exige presença local	- Remoto - Híbrido - Local
PARCERIAS?	- Sem parceiros - Parceiros comerciais - Parceiros comerciais e técnicos - Parceiros técnicos	- Sem - Comercial - Ambos - Técnicos

Fonte: Elaborada pelos autores, 2026.

A quinta etapa examinou as compatibilidades e incompatibilidades entre opções de áreas distintas por meio da técnica Analysis of Interconnected Decision Areas (AIDA). Foram registradas 42 option bars, combinações vetadas por restrições técnicas, comerciais, regulatórias ou de mercado. Por exemplo, a operação comercial local é incompatível com a ausência de presença/parceria de suporte em determinados países, e a operação remota pura é incompatível com mercados que exigem presença local. As incompatibilidades reduziram as 180 combinações a apenas três esquemas de decisão viáveis (Figura 3), que constituem as alternativas estratégicas comparáveis para a expansão.

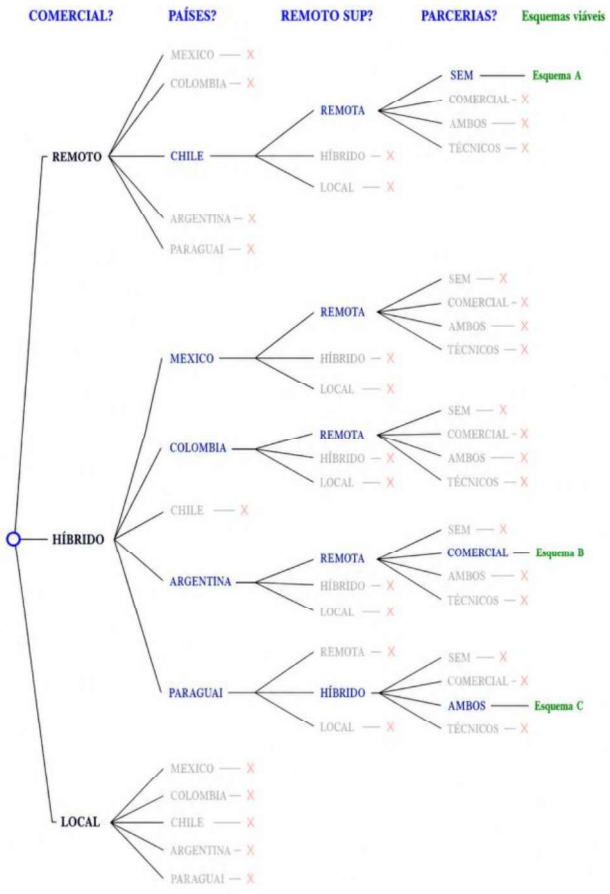

Fig. 3. Árvore de enumeração e poda dos esquemas de decisão viáveis (AIDA). A partir do nó-raiz (○), cada ramificação representa uma opção da área correspondente, de modo que cada caminho completo da raiz até a coluna PARCERIAS? constitui uma combinação candidata. As combinações que violam ao menos uma das *option bars* (incompatibilidades técnicas, comerciais, regulatórias ou de mercado) são interrompidas e assinaladas com ✕ (em vermelho), os caminhos completos remanescentes, destacados em verde à direita, correspondem aos esquemas de decisão viáveis. Fonte: Elaborada pelos autores, 2026.

3.3 Comparação entre esquemas (comparing)

A sétima etapa identificou cinco áreas de comparação, as dimensões de consequência relevantes para o decisor, agrupadas em critérios econômico-financeiros e estratégicos: investimento de entrada (INVESTIMENTO:), custo de operação (OPERAÇÃO:), retorno esperado (RETORNO:), risco de vazamento de conhecimento proprietário ao parceiro (R.CONHECIMENTO:) e controle sobre a operação e o cliente (CONTROLE:). Os esquemas foram confrontados em relação à linha de base (Esquema A); a pergunta orientadora não é "quanto custa?", mas "o que muda ao escolher este esquema em vez da base?". A Figura 4 sintetiza a avaliação relativa, com a respectiva confiança atribuída pelo decisor.

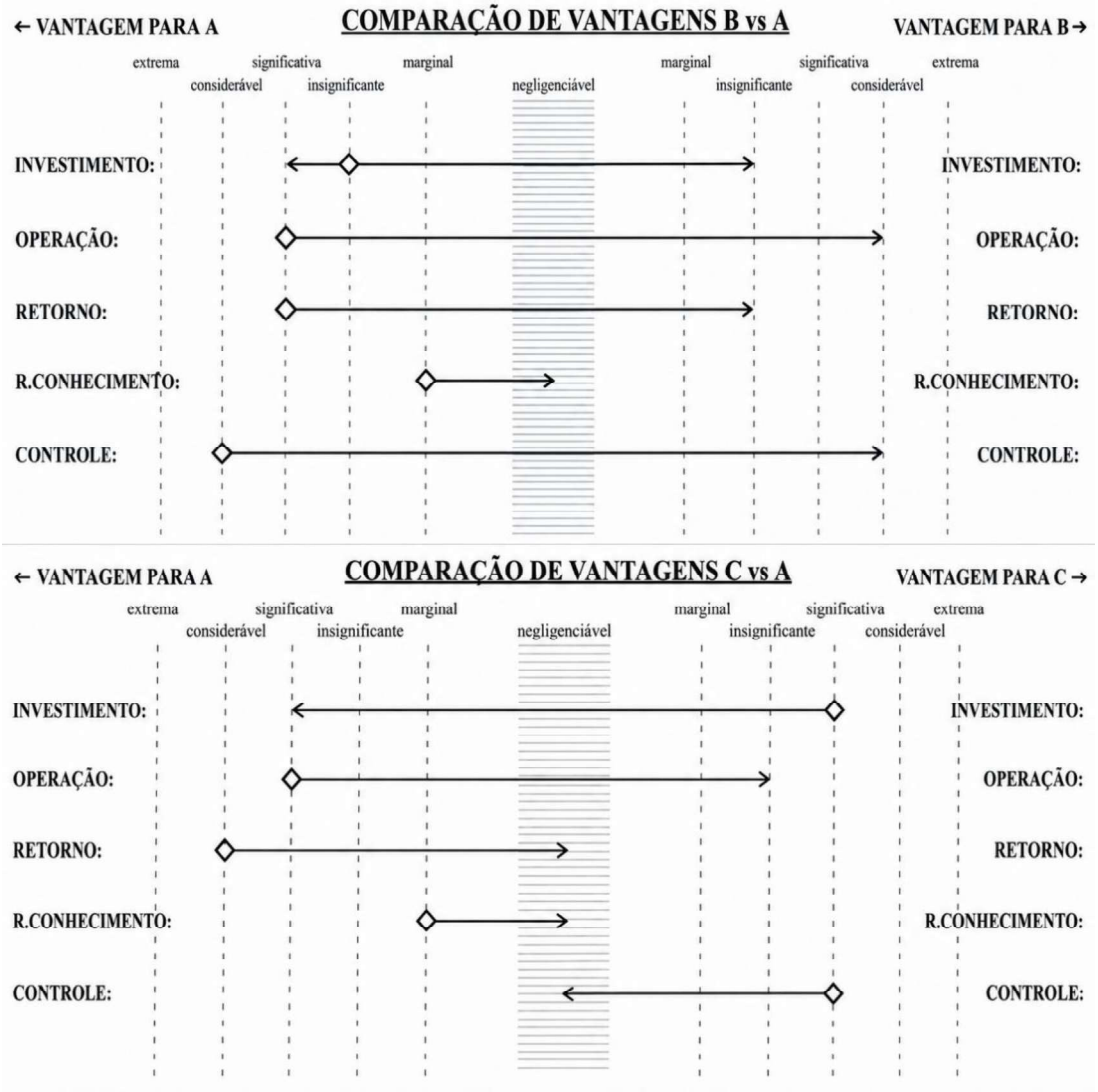

Fig. 4. Julgamentos de vantagem comparativa entre os esquemas de decisão viáveis sob incerteza. Avaliação par a par das alternativas estratégicas, tomando o Esquema A (operação remota, Chile, sem parceiros) como linha de base. **a**, Esquema B (híbrido, Argentina, remota, comercial) *versus* A; **b**, Esquema C (híbrido, Paraguai, híbrido, ambos) *versus* A. As cinco linhas correspondem às áreas de comparação consideradas pelo decisor. O eixo horizontal é uma escala bipolar que expressa, simultaneamente, a direção e a magnitude da vantagem comparativa. O losango (◇) marca a melhor estimativa do decisor, e o segmento com extremidades em seta (⟷) representa o intervalo de crença, que incorpora tanto a incerteza factual quanto a incerteza sobre valores. Fonte: Elaborada pelos autores, 2026.

Na comparação entre B e A, todas as melhores estimativas favorecem A: nas estimativas pontuais do decisor, B é dominado por A, e nenhuma ponderação dos critérios inverteria essa ordem. Essa dominância, porém, não é robusta, pois os intervalos de crença das cinco áreas alcançam ou cruzam o eixo neutro, chegando à vantagem considerável para B em OPERAÇÃO e CONTROLE. Na comparação entre C e A, há um trade-off genuíno: C supera A em CONTROLE e em INVESTIMENTO, mas é inferior em OPERAÇÃO e RETORNO. Assim, o Esquema A configura-se como preferência provisória, não como escolha robusta, e é no trade-off entre A e C que as incertezas de valor (seção 3.4) se tornam decisivas.

3.4 Áreas de incerteza e opções exploratórias

A oitava etapa identificou e classificou as áreas de incerteza segundo a tipologia do método: incertezas sobre o ambiente de trabalho (UE), sobre valores orientadores (UV) e sobre decisões relacionadas em agendas conexas (UR). As Tabelas 3 a 5 apresentam as nove incertezas mapeadas, com a justificativa do enquadramento.

Tabela 3. Áreas de incerteza sobre o ambiente de trabalho (UE).

Área de Incerteza	Descrição	Evidência	Ação Exploratória
? LOCUS-DECISÃO	Onde reside efetivamente o poder de decisão de compra dos embarcadores em cada país, se na operação local ou em matriz situada em outro país.	*CEO: a viabilidade "vai depender de onde a sede da empresa está localizada, onde se toma a decisão".*	Mapeamento da estrutura decisória dos embarcadores-alvo por país.
? ACEITA-COMERCIAL	Se o mercado de cada país aceita a operação comercial remota a partir do Brasil.	*CEO: "minha preocupação maior é o comercial, se aceita o comercial remoto (...) será que ele realmente aceita? Como as pessoas vão reagir?".*	Pesquisa cultural (Hofstede, 2001; Hall, 1976) por país; entrevistas com compradores; benchmarking de entrantes SaaS B2B.
? CUSTO-HÍBRIDO	Quanto efetivamente custa operar em modelo híbrido (Esquemas B e C) frente ao remoto puro (Esquema A). No custo de operação, o decisor avalia B e C como piores que A; no investimento de entrada, avalia B como pior e C como vantajoso frente a A. A direção é afirmada com firmeza; a magnitude, não.	*CEO: "não tenho nem noção de valor"; melhor estimativa "bastante pior" (B) e "não muito pior" (C).*	Orçamentação detalhada das configurações híbridas; cotação de presença leve e capacitação do parceiro paraguaio.
? RETORNO-MERCADO	Se o retorno esperado difere de fato entre os mercados. Embora o decisor tenha verbalizado que o retorno seria "igual", a estimativa registrada favorece A frente a B e C, com baixa confiança: os intervalos cruzam o eixo neutro.	*CEO: "acho que é igual (...) sem mudança relevante", nos gráficos, o intervalo de retorno cruza o eixo neutro.*	Dimensionamento do mercado logístico.

Fonte: Elaborada pelos autores, 2026.

As incertezas sobre o ambiente de trabalho, embora numerosas, são em princípio redutíveis por pesquisa e orçamentação. Mais estruturais são as incertezas sobre os valores orientadores da decisão (UV), apresentadas na Tabela 4, pois refletem ausência de consenso interno sobre o que a empresa prioriza, não falta de dados externos.

Tabela 4. Áreas de incerteza sobre valores orientadores (UV).

Área de Incerteza	Descrição	Evidência	Ação Exploratória
? PESO-R.CONHEC	Se o risco de vazamento de conhecimento deve permanecer como critério e, em caso afirmativo, com que peso. O decisor questiona sua relevância: produto se copia, estratégia comercial não.	*CEO: é "o menos impactante (...) para mim não tem muita importância, mas vale a pena deixar".*	Nova reunião para decidir entre manter, reponderar ou remover o critério.
? PESO-CONTROLE	Quanto a empresa valoriza o controle sobre operação e cliente face ao custo de obtê-lo. A presença local é tida como "muito boa", mas eleva o custo.	*CEO: "ter pessoas no local é melhor (...) mas daí o custo vai lá em cima".*	Entrevista de elicitação de pesos; expressar o valor do controle em unidades comparáveis a custo.
? PESO-CRITÉRIOS	Incerteza quanto à importância relativa dos critérios utilizados para avaliar os esquemas viáveis. O decisor demonstra preferência por alguns critérios, mas não explicita uma hierarquia consolidada entre objetivos econômicos (investimento, operação e retorno) e estratégicos (controle e risco de compartilhamento de conhecimento). Essa indefinição pode alterar a preferência final entre os esquemas.	*CEO: "o menos impactante (...) para mim não tem muita importância, mas vale a pena deixar" (sobre risco de conhecimento).* *CEO: "ter pessoas no local é melhor (...) mas daí o custo vai lá em cima".*	Realizar elicitação das preferências do decisor para estabelecer a importância relativa dos critérios e identificar quais objetivos devem prevalecer em situações de conflito entre custo, retorno, controle e risco.

Fonte: Elaborada pelos autores, 2026.

Além das incertezas informacionais e valorativas, o processo identificou incertezas decorrentes de agendas decisórias paralelas (UR), sistematizadas na Tabela 5. Nesse caso, a limitação não é cognitiva nem axiológica, mas de coordenação: a resolução depende de decisões que transcendem o escopo deste ciclo de análise.

Tabela 5. Áreas de incerteza sobre decisões relacionadas (UR).

Área de Incerteza	Descrição	Evidência	Ação Exploratória
? LICENÇAS-TERCEIROS	Dependência de autorizações, credenciamentos ou validações emitidas por órgãos reguladores ou terceiros necessários à operação da plataforma em	*Especialista: "onde eu dependo de um terceiro (...) não está sob meu controle (...) talvez a do Paraguai".*	Mapear requisitos regulatórios por país e coordenar tratativas com órgãos e instituições relevantes.

	determinados mercados latino-americanos.		
? AGENDA-ERP/PRODUTO	Decisões de roadmap e de integração com ERPs locais (área ERP?, fora do foco) que alteram a viabilidade técnica das parcerias dos Esquemas.	*Estrutural do mapa de interdependências: a área ERP? permanece fora do laço de foco deste ciclo.*	Coordenar com a equipe de produto a priorização das integrações com ERPs locais; condicionar a viabilidade técnica das parcerias dos Esquemas B e C ao resultado dessas negociações antes de avançar para compromissos mais firmes.

Fonte: Elaborada pelos autores, 2026.

A predominância de incertezas do tipo UE (quatro das nove) indica que a principal barreira ao comprometimento é informacional, decorrente da ausência de conhecimento consolidado sobre mercado, custos e estrutura decisória dos embarcadores. Todavia, as incertezas do tipo UV assumem papel central no processo decisório, uma vez que dizem respeito à forma como a organização valoriza critérios concorrentes e resolve trade-offs entre controle, custo, retorno e risco. Dessa forma, mesmo que as incertezas ambientais sejam reduzidas por meio de pesquisas e análises complementares, a escolha entre os esquemas viáveis continuará dependente da explicitação das prioridades estratégicas da empresa.

3.5 Pacote de compromisso (choosing)

A décima etapa construiu o pacote de compromisso, estrutura que distribui as decisões no tempo, distinguindo, para cada área, o que se assume agora (ações imediatas), o que se investiga agora (explorações), o que fica deliberadamente adiado com indicação das condições de retomada, e as respostas preparadas caso um pressuposto mude (contingências). Coerente com o diagnóstico da seção 3.4, o pacote não elege um esquema ótimo. As incertezas identificadas, particularmente aquelas relacionadas aos valores orientadores da decisão, ainda impedem a consolidação de uma preferência robusta entre os esquemas viáveis. Assim, o compromisso imediato consiste em manter aberto o conjunto {A, B, C} e disparar as explorações necessárias para reduzir essas incertezas, adiando a escolha final. A Tabela 6 caracteriza esse pacote para as quatro áreas em foco.

Tabela 6. Pacote de compromisso para as áreas de decisão em foco.

Área de decisão	Exploração em curso	Escolha adiada e horizonte	Plano de Contingência
COMERCIAL?	Orçamentar configs híbridas (CUSTO-HÍBRIDO); pesquisa cultural Hofstede/Hall + entrevistas com compradores (ACEITA-COMERCIAL);	Definir em 3 meses: modelo comercial por país.	SE mercado-âncora rejeitar remoto, então ativar híbrido nesse país.
PAÍSES?	Mapear estrutura decisória dos embarcadores (LOCUS-DECISÃO);	Definir em 6 meses.	SE corredor Brasil–Paraguai render mais, ENTÃO reordenar sequência de entrada.
REMOTO.SUP?	Verificar exigências regulatórias/de presença por país (LICENÇAS-TERCEIROS); sondar aceitação de suporte remoto;	Definir em 6 meses.	SE exigida presença local, ENTÃO acionar parceiro técnico.
PARCERIAS?	Coordenar roadmap de integração com ERPs locais (AGENDA-	Definir em 6 meses.	SE integração com ERP local for inviável internamente, ENTÃO firmar parceria técnica.

	ERP); mapear requisitos regulatórios (LICENÇAS-TERCEIROS);		
ESQUEMA {A,B,C} ***(decisão final)***	Elicitação de pesos/critérios e adoção de uma decisão multicritério com o decisor.	Após sanear as incertezas.	SE a elicitação não consolidar hierarquia de critérios, ENTÃO permanecer no Esquema A e reabrir em ciclo posterior.

Fonte: Elaborada pelos autores, 2026.

Em síntese, a caracterização dos pacotes de compromisso evidencia que, no estágio atual, o curso de ação mais consistente não consiste em selecionar definitivamente um esquema de expansão, mas em manter abertas as alternativas viáveis enquanto são conduzidas as explorações necessárias para reduzir as incertezas críticas identificadas. Dessa forma, a decisão estratégica é deslocada de uma lógica de escolha pontual para um processo estruturado de comprometimento gradual sob incerteza, no qual diferentes trajetórias permanecem simultaneamente viáveis até que novas informações e preferências organizacionais permitam uma comparação mais robusta entre elas. Essa lógica representa uma das principais contribuições do SCA para a gestão de decisões estratégicas complexas. Os resultados indicam que a internacionalização de SaaS não se estrutura como uma decisão de entrada em mercados isolados, mas como um sistema de decisões interdependentes no qual a escolha de países organiza e condiciona todas as demais dimensões operacionais e estratégicas. Nesse contexto, a redução do espaço de alternativas viáveis por meio do SCA não conduz diretamente a uma solução ótima, mas à delimitação de esquemas condicionais cuja avaliação permanece dependente de restrições estruturais e interdependências do sistema decisório. Do ponto de vista do SCA, os achados mostram que o método não apenas estrutura a decisão, mas reorganiza o problema sob incerteza, separando incertezas informacionais (reduzíveis por investigação) de incertezas axiológicas (dependentes de preferências). Assim, a decisão final permanece condicionada pela explicitação de valores organizacionais, deslocando o foco de uma lógica de escolha ótima para uma lógica de comprometimento sob incerteza.

4 Conclusão

Este estudo teve como objetivo caracterizar os pacotes de compromissos estratégicos para a expansão latino-americana de uma empresa de tecnologia voltada a soluções logísticas, cujo produto central consiste em uma plataforma SaaS integrada a sistemas ERP de indústrias embarcadoras. Para tanto, operacionalizou-se o SCA em dez etapas analíticas distribuídas entre os modos *shaping*, *designing*, *comparing* e *choosing*. Essa aplicação permitiu transformar uma situação estratégica ampla, ambígua e marcada por múltiplas interdependências em um problema de decisão estruturada, no qual alternativas, incertezas, compromissos imediatos e escolhas adiadas puderam ser explicitados de forma sistemática.

Os resultados evidenciaram que a expansão internacional da plataforma não pode ser compreendida como uma decisão isolada de seleção de país-alvo, mas como um conjunto articulado de decisões interdependentes envolvendo modelo comercial, escolha de mercados, estrutura de suporte remoto ou presencial e necessidade de parcerias locais. Das doze áreas de decisão identificadas, quatro foram priorizadas em razão de sua maior densidade relacional e urgência estratégica: COMERCIAL?, PAÍSES?, REMOTO.SUP? e PARCERIAS?. A área PAÍSES? assumiu papel estruturante no problema, pois condiciona diretamente exigências fiscais, documentais, linguísticas, comerciais, operacionais e relacionais associadas à entrada em novos mercados latino-americanos.

A aplicação da técnica AIDA demonstrou que, embora houvesse 180 combinações teoricamente possíveis entre as opções das áreas de decisão em foco, apenas três esquemas permaneceram viáveis após a consideração das incompatibilidades técnicas, comerciais, regulatórias e estratégicas. Entretanto, embora o Esquema A não seja superado nas melhores estimativas do decisor, a comparação por vantagem comparativa e o mapeamento das incertezas indicaram que essa vantagem não é robusta o suficiente para sustentar uma preferência inequívoca no estágio atual de informação. Essa impossibilidade decorre não apenas da presença de incertezas ambientais, relacionadas a custos, aceitação de mercado, estrutura decisória dos embarcadores e requisitos regulatórios, mas também da centralidade das incertezas de valor, especialmente quanto à

importância relativa atribuída ao controle operacional, ao custo de entrada, ao retorno esperado e ao risco de compartilhamento de conhecimento proprietário.

Diante do nível atual de incerteza, a decisão estratégica mais consistente não consiste em eleger imediatamente uma alternativa ótima, mas em assumir um compromisso gradual, reversível e orientado à aprendizagem. O pacote de compromissos também dialoga com a teoria de internacionalização: operacionaliza, no nível da decisão, o comprometimento incremental descrito pelo modelo de Uppsala (Johanson e Vahlne, 2009) e preserva o valor de opção associado à flexibilidade (Kogut e Kulatilaka, 1994), ao adiar compromissos de difícil reversão até que a incerteza seja reduzida. Nesse sentido, o pacote de compromissos resultante recomenda manter aberto o conjunto de esquemas viáveis {A, B, C}, enquanto são executadas ações exploratórias destinadas a reduzir as incertezas identificadas, explicitar as prioridades estratégicas da organização e criar condições para uma comparação mais robusta entre as alternativas. Assim, o processo decisório desloca-se de uma lógica de escolha definitiva para uma lógica de comprometimento progressivo sob incerteza.

Do ponto de vista teórico-metodológico, o estudo contribui ao transpor o *SCA* para um domínio ainda pouco explorado na literatura de estruturação de problemas: a internacionalização de plataformas digitais B2B aplicadas à logística. Além disso, evidencia que o valor do SCA reside não apenas na geração de alternativas, mas principalmente na explicitação das interdependências decisórias, das fontes de incerteza e dos compromissos possíveis em situações nas quais a informação disponível é incompleta e os critérios de decisão ainda não estão plenamente estabilizados. Ao articular decisões imediatas, escolhas adiadas, ações exploratórias e contingências, o pacote de compromissos produzido oferece um dispositivo gerencial capaz de apoiar decisões estratégicas complexas em ambientes de elevada ambiguidade.

Em termos práticos, a aplicação ofereceu ao decisor três contribuições gerenciais. Primeiro, reduziu um problema difuso, de doze frentes, a quatro decisões prioritárias e três configurações viáveis de entrada. Segundo, deslocou a discussão de "qual país escolher" para quais incertezas precisam ser resolvidas, por meio de quais explorações e em que prazo (três a seis meses). Terceiro, revelou que o principal obstáculo à escolha não é apenas a falta de dados de mercado, mas a ausência de uma hierarquia explícita entre controle, custo e retorno, o que redireciona parte do esforço da direção para uma deliberação interna antes de novos investimentos em pesquisa. Essa contribuição é particularmente relevante para empresas digitais de base logística, cujos processos de internacionalização dependem simultaneamente de adaptação tecnológica, aderência regulatória, aceitação comercial, capacidade operacional e articulação com ecossistemas locais.

Quanto ao uso do método, três limitações merecem registro. Primeiro, a especialista interna acumulou os papéis de facilitadora de processo e de fonte de conteúdo, que a literatura de modelagem facilitada distingue (Franco e Montibeller, 2010). Segundo, as duas horas de sessão limitaram a profundidade da elicitação, e parte das option bars pode expressar preferências fortes do decisor, e não incompatibilidades estritas, reduzindo prematuramente o espaço de esquemas. Terceiro, a escala de vantagem comparativa não define limiares entre seus níveis, o que dificulta a replicação dos julgamentos. Em aplicações futuras, recomenda-se separar facilitação e especialidade de conteúdo e prever limiares explícitos para os níveis da escala de vantagem comparativa.

Como agenda futura, recomenda-se a execução das ações exploratórias identificadas, a realização de novos ciclos de estruturação com a reincorporação das áreas de decisão deixadas em espera e a ampliação da participação de atores organizacionais e externos no processo decisório. Estudos posteriores também podem combinar o SCA com métodos multicritério baseados em informação parcial de preferências, como o FITradeoff (de Almeida et al., 2016), adequados a um decisor que ainda não explicita uma hierarquia completa entre critérios, para ordenar esquemas viáveis e testar a sensibilidade das preferências do decisor. Por fim, pesquisas longitudinais podem acompanhar a implementação do pacote de compromissos, avaliando em que medida a abordagem contribui para reduzir incertezas, qualificar o processo decisório e sustentar a internacionalização gradual de plataformas digitais logísticas em mercados latino-americanos.

Referências

Calatayud, A., Katz, R., Riobó, A. (2022), Driving the Digital Transformation of Transportation in Latin America and the Caribbean. Inter-American Development Bank, Washington, D.C. https://doi.org/10.18235/0004233

Carvalho, R.C., Magrini, A. (2006), Conflicts over Water Resource Management in Brazil: A Case Study of Inter-Basin Transfers. Water Resources Management, 20(2), 193-213. https://doi.org/10.1007/s11269-006-7377-3

de Almeida, A.T., Almeida, J.A., Costa, A.P.C.S., Almeida-Filho, A.T. (2016), A New Method for Elicitation of Criteria Weights in Additive Models: Flexible and Interactive Tradeoff. European Journal of Operational Research, 250(1), 179-191. https://doi.org/10.1016/j.ejor.2015.08.058

Franco, L.A., Montibeller, G. (2010), Facilitated Modelling in Operational Research. European Journal of Operational Research, 205(3), 489-500. https://doi.org/10.1016/j.ejor.2009.09.030

Freitas, E.S., Almeida, J.A., Bergiante, N.C.R. (2024), Atualizações Tecnológicas de Produtos de Defesa: Uso do Método Strategic Choice Approach na Análise e Apoio à Decisão. In: Anais do LVI Simpósio Brasileiro de Pesquisa Operacional, Fortaleza. Galoá, Campinas. https://doi.org/10.59254/sbpo-2024-193646

Friend, J. (2010), The Strategic Choice Approach. In: Cochran, J.J., Cox, L.A., Keskinocak, P., Kharoufeh, J.P., Smith, J.C. (eds.), Wiley Encyclopedia of Operations Research and Management Science. John Wiley & Sons, Hoboken. https://doi.org/10.1002/9780470400531.eorms0971

Friend, J., Hickling, A. (2004), Planning Under Pressure: The Strategic Choice Approach. 3rd edn. Routledge, Oxford. https://doi.org/10.4324/9780080480053

García-Canal, E., Guillén, M.F. (2026), The International Expansion of Digital Platforms: A Dynamic Setting for Challenging and Advancing Theories of the Multinational Enterprise. Business Research Quarterly, 29(1), 62-77. https://doi.org/10.1177/23409444251382952

Georgiou, I., Heck, J., Mrvar, A. (2019), The Analysis of Interconnected Decision Areas: A Computational Approach to Finding All Feasible Solutions. Group Decision and Negotiation, 28(3), 543-563. https://doi.org/10.1007/s10726-018-9607-5

Hall, E.T. (1976), Beyond Culture. Anchor Books/Doubleday, New York.

Hofstede, G. (2001), Culture's Consequences: Comparing Values, Behaviors, Institutions and Organizations Across Nations. 2nd edn. Sage, Thousand Oaks.

Ivanov, D., Dolgui, A., Sokolov, B. (2022), Cloud Supply Chain: Integrating Industry 4.0 and Digital Platforms in the "Supply Chain-as-a-Service". Transportation Research Part E: Logistics and Transportation Review, 160, 102676. https://doi.org/10.1016/j.tre.2022.102676

Johanson, J., Vahlne, J.-E. (2009), The Uppsala Internationalization Process Model Revisited: From Liability of Foreignness to Liability of Outsidership. Journal of International Business Studies, 40(9), 1411-1431. https://doi.org/10.1057/jibs.2009.24

Kogut, B., Kulatilaka, N. (1994), Operating Flexibility, Global Manufacturing, and the Option Value of a Multinational Network. Management Science, 40(1), 123-139. https://doi.org/10.1287/mnsc.40.1.123

Lami, I.M., Todella, E. (2023), A Multi-Methodological Combination of the Strategic Choice Approach and the Analytic Network Process: From Facts to Values and Vice Versa. European Journal of Operational Research, 307(2), 802-812. https://doi.org/10.1016/j.ejor.2022.10.029

Mashalah, H.A., Hassini, E., Gunasekaran, A., Bhatt, D. (2022), The Impact of Digital Transformation on Supply Chains through E-commerce: Literature Review and a Conceptual Framework. Transportation Research Part E: Logistics and Transportation Review, 165, 102837. https://doi.org/10.1016/j.tre.2022.102837

Meyer, K.E., Li, J., Brouthers, K.D., Jean, R.J.B. (2023), International Business in the Digital Age: Global Strategies in a World of National Institutions. Journal of International Business Studies, 54(4), 577-598. https://doi.org/10.1057/s41267-023-00618-x

Mingers, J., Rosenhead, J. (2004), Problem Structuring Methods in Action. European Journal of Operational Research, 152(3), 530-554. https://doi.org/10.1016/S0377-2217(03)00056-0

Rosenhead, J., Mingers, J. (2001), Rational Analysis for a Problematic World Revisited: Problem Structuring Methods for Complexity, Uncertainty and Conflict. 2nd edn. John Wiley & Sons, Chichester.

Stallkamp, M., Schotter, A.P.J. (2021), Platforms without Borders? The International Strategies of Digital Platform Firms. Global Strategy Journal, 11(1), 58-80. https://doi.org/10.1002/gsj.1336

Todella, E., Lami, I.M., Armando, A. (2018), Experimental Use of Strategic Choice Approach (SCA) by Individuals as an Architectural Design Tool. Group Decision and Negotiation, 27(5), 811-826. https://doi.org/10.1007/s10726-018-9567-9

World Bank (2025), Logistics Performance Index: Connecting to Compete. World Bank, Washington, D.C.

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ANÁLISE DINÂMICA DE CONFLITOS BILATERAIS COM HORIZONTE DE PREVISÃO LIMITADO E VARIÁVEL

Paula Cristina de Amorim Andrade[1], Leandro Chaves Rêgo[2], Maísa Mendonça Silva[3]

[1,2,3] Universidade Federal de Pernambuco (UFPE) & Av. da Arquitetura, s/n - Cidade Universitária, Recife - PE, 50740-550

paula.amorim@ufpe.br, leandro@dema.ufc.br, maisa.ufpe@yahoo.com.br

Abstract. Em diversos contextos, os conflitos emergem de interações estratégicas entre decisores com interesses distintos. Diante disso, o presente trabalho propõe uma abordagem dinâmica para modelagem e análise de conflitos com horizonte variável envolvendo dois tomadores de decisões no âmbito do Modelo de Grafos para Resolução de Conflitos. No estudo proposto, os decisores movimentam-se sequencialmente a fim de obter os melhores resultados individuais de acordo com a lógica da estabilidade do movimento limitado e assume-se que assim que algum decisor permanecer em algum estado, o conflito termina neste estado. Nessa perspectiva, a partir da análise de um conflito real, descrito na literatura, para exportação de água entre dois países, sob restrições comerciais e ambientais foram explorados 2.200 cenários obtidos por meio da combinação entre todos os estados viáveis, a definição do decisor a realizar o primeiro movimento e a quantidade de horizontes para análise de cada decisor. Em cada cenário, observou-se o ganho ou perda entre os estados inicial e final do conflito para ambos os decisores. Com isso, o estudo visa reduzir a lacuna existente na literatura atual, a qual é restrita à análise estática de estados com abordagem individualizada em relação aos decisores. Além disso, os resultados sinalizam a expansão da capacidade para a representação de maneira mais realística de comportamentos distintos estratégicos dos decisores para resolução de conflitos.

Keywords: Análise de conflito, GMCR, Movimento Limitado

Literature Mapping of Operational Decision-Making in the Judiciary

Altair Junior Ancelmo Soares[1][0009-0002-9591-2282] and Carolina Lino Martins[2][0000-0002-5531-335X]

[12] SIMAD Research Group – Information Systems and Decision Support Methods, Federal University of Mato Grosso do Sul (UFMS), Av. Costa e Silva, S/N – Campo Grande, MS, 79070-900, Brazil
altair.soares@ufms.br, carolina.lino@ufms.br

Abstract. Judicial management faces challenges related to high demand, case backlog accumulation, case heterogeneity, and capacity constraints. In this context, this article maps the recent scientific literature on operational decision-making in the Judiciary. This decision-making layer involves management decisions on case prioritization, workload weighting, sequencing, resource allocation, and capacity management. **Methodology.** A literature mapping was conducted in the Scopus and Web of Science databases, with a time frame from 2021 onward. The screening was supported by a large language model, used in an assistive and supervised manner, and resulted in a portfolio of 27 articles. The studies were organized into two analytical layers: operational dimensions derived from Slack, Brandon-Jones and Burgess (direct, design, deliver, and develop the operation) and methodological-instrumental families identified in the portfolio. **Findings.** The results indicate that the literature has relevant methods to address performance, case weighting, queues, scheduling, analytics, artificial intelligence, and judicial governance. However, these contributions still appear in a fragmented manner. The main gap identified is the absence of models that integrate institutional objectives, case heterogeneity, available capacity, prioritization criteria, and continuous improvement, also considering the tension between the decision-making autonomy of judicial units and the strategic goals of the judicial body. **Originality/value.** The article contributes by delimiting operational decision-making as a layer distinct from adjudicative merit decisions and by proposing an analytical matrix to organize methods, themes, and research gaps in the Judiciary. It also highlights room for multicriteria and sociotechnical decision-support models capable of making trade-offs explicit, structuring preferences, and supporting participatory prioritization processes among local and institutional actors.

Keywords: operational decision-making; judicial management; case prioritization; case weighting; MCDA

1 Introduction/Purpose

The functioning of the Judiciary is central to the effectiveness of the rule of law, the protection of rights, legal certainty, and trust in institutions. At the same time, judicial

activity occurs in an environment marked by high demand, large case backlogs, case heterogeneity, capacity constraints, procedural variability, and pressure for results. In Brazil, the 2025 Justiça em Números Report shows the scale of this challenge: in 2024, 39.4 million cases were filed, 44.8 million were closed, and the year ended with 80.6 million cases pending. Although the congestion rate reached its lowest level in the last 16 years, remaining at 64.3%, the volume of pending cases still reveals a system under strong pressure from demand and capacity [1].

This scenario indicates that judicial management cannot be understood solely as a normative, technological, or budgetary issue. It also involves decisions about work organization, flow, capacity, prioritization, and resource allocation. From this perspective, the Judiciary can be analyzed as a knowledge-intensive public service operation, in which social demands and legally formalized conflicts enter the system, go through procedural stages, consume human, technological, and informational resources, and generate institutional outputs, such as decisions, rulings, settlements, case closures, fulfillment of rights, and social pacification.

The conceptual basis for this framing lies in operations management. From the perspective of Slack, Brandon-Jones and Burgess [2], every operation can be analyzed as an input–transformation–output system, in which transformed resources are converted into products or services through transforming resources. Applied to the Judiciary, this logic allows judicial cases, documents, information, parties, and social demands to be understood as transformed resources, while judges, court staff, information systems, procedural rules, infrastructure, routines, and management methods act as transforming resources.

It is important to clarify, however, that this article does not address adjudicative merit decisions. It does not analyze the judgment rendered by judges, panels, or collegiate bodies regarding the merits, dismissal, conviction, acquittal, or interpretation of the law applicable to a specific case. The focus is on operational decision-making in the Judiciary. These are management decisions related to case prioritization, sequencing of activities, resource allocation, capacity distribution, docket organization, backlog control, and workload weighting. This decision-making layer is distinct from adjudicative activity, although it influences the organizational conditions that allow it to be carried out in a timely manner.

Judicial delay is a recurring theme in the national and international literature. Comparative studies show that Brazilian courts, especially at the first-instance level, have processing times significantly longer than those observed in European systems. Castelliano and Guimarães [3] estimate that the disposition time for civil and commercial cases in Brazilian first-instance courts reaches 600 days, almost three times the European average of 232 days. At the same time, the authors note that Brazilian courts have achieved clearance rates above 100%, indicating that, despite the accumulated backlog, more cases are being resolved than received, which suggests a trend toward a gradual reduction in the stock if productivity is maintained.

However, an operational reading of the Judiciary does not imply reducing the justice system to a merely productivist logic. The delivery of justice involves fundamental rights, judicial independence, impartiality, due process, the right to a full defense, decision-making quality, and institutional legitimacy. For this reason, operational

decisions cannot be guided solely by volume or speed. The literature on judicial efficiency points out that productivity models need to consider case complexity, the severity of the matters involved, and the quality of decisions, under penalty of producing tensions between speed and institutional reliability [4].

A central problem for operational decision-making in the Judiciary is that judicial cases are not homogeneous. Simple case counting treats different cases as equivalent, even though they vary in subject matter, evidentiary complexity, number of parties, urgency, risk, social value, adjudication effort, and the number of procedural acts required. For this reason, the literature on case weighting, or weighted caseload, advocates assigning different weights to cases in order to better reflect workload, complexity, and the effort required. The Commission Européenne pour l'Efficacité de la Justice (CEPEJ) [5] highlights that case-weighting systems can support decisions such as estimating the need for judges and staff, personnel allocation, case distribution, budget requests, and planning procedural improvements.

In addition to case weighting, recent literature mobilizes different techniques to support operational decisions in courts. These include efficiency analysis, queueing models, simulation, mathematical programming, scheduling, process mining, multicriteria methods, analytics, and artificial intelligence [6,7,8,9,10,11]. These approaches help investigate bottlenecks, compare flows, estimate duration, evaluate performance, and support decisions on prioritization and capacity. Despite these advances, the literature remains fragmented. Studies address relevant parts of the problem, but they are not always articulated into an integrated structure for operational decision-making.

Given the multiplicity of methods and the absence of a synthesis that organizes them, literature mapping is the most appropriate technique to characterize this set of contributions in a systematic and replicable way, especially in an emerging field dispersed across journals in operations management, law, computer science, and public policy.

In this sense, this article aims to characterize the recent scientific literature on operational decision-making in the Judiciary, understood as the set of management decisions related to prioritization, weighting, sequencing, resource allocation, and capacity management in judicial systems, in terms of its operational dimensions, methodological-instrumental families, and research gaps, in order to guide the construction of operational decision-support models, without conflating such models with adjudicative merit decisions.

The research questions guiding this study are:

Q1: Which operational problems of the Judiciary are addressed by the recent literature, especially in relation to backlog, capacity, flow, prioritization, workload weighting, and performance?

Q2: Which methods and approaches have been used to support operational decisions in courts?

Q3: Which criteria or dimensions appear as relevant for prioritization, weighting, sequencing, or allocation of judicial cases?

Q4: Which gaps remain for the construction of operational decision-support models in the Judiciary based on integrated, institutionally justifiable criteria capable of reconciling the autonomy of judicial units with the strategic objectives of the judicial body?

Based on these questions, the following specific objectives are defined, aligned with the operational variables of the mapping: (i) identify the operational problems of the Judiciary addressed by the recent literature (Q1); (ii) characterize the methods and approaches used to support operational decisions in courts (Q2); (iii) identify the criteria and dimensions mobilized for prioritization, weighting, sequencing, and allocation of cases (Q3); and (iv) characterize the research gaps related to the integration of these criteria into decision-support models (Q4).

This study makes three contributions. Conceptually, it delimits operational decision-making as a management layer distinct from adjudicative merit decisions. Analytically, it proposes a two-layer matrix that crosses the operational dimensions of Slack, Brandon-Jones and Burgess [2] with the methodological-instrumental families identified in the literature, making visible where research is concentrated and where it is scarce. From a research-agenda perspective, it shows that the main gap lies less in the availability of techniques than in their integration with explicit prioritization criteria and institutional governance, pointing to multicriteria and participatory decision-support models.

2 Methodology

To characterize the literature on operational decision-making in the Judiciary in line with the proposed objective, this study was conducted as a literature mapping, with qualitative analysis and thematic classification of the selected studies, structured as the design needed to achieve the operational dimensions, methodological families, and research gaps defined as specific objectives. The choice of a mapping approach is justified by the multidisciplinary nature of the topic, which involves operations management, operations research, public administration, law, data science, artificial intelligence, multicriteria methods, queueing theory, simulation, judicial efficiency, and decision-support systems.

The methodological procedure was structured into three macro-stages: (1) search strategy and identification of records; (2) screening and selection of studies; and (3) evaluation and classification of articles. The process sought to preserve traceability, transparency, and analytical coherence, drawing on review and mapping practices, particularly regarding the explicit reporting of the databases consulted, inclusion and exclusion criteria, screening stages, and the final composition of the portfolio.

2.1 Search strategy

The search was conducted on May 30, 2026, in the Scopus and Web of Science databases. The string was built to retrieve studies that approached the Judiciary from an operational perspective, combining terms associated with performance, governance, operation, efficiency, courts, prioritization, decision, allocation, backlog, workload, and congestion. The query was adapted to the syntax of each database, while preserving the same semantic search blocks.

The string used was:

```
(TITLE-ABS-KEY( (governance OR performance OR "opera-
tion*" OR efficiency) AND (justice OR judicia* OR
"court*" OR tribunal*) AND (priorit* OR rank* OR triage
OR "decision*" OR allocation) AND (backlog OR case* OR
workload OR "pendenc*" OR congestion) ) AND PUBYEAR >
2020)
```

The string was organized into four conceptual blocks. The first block sought to capture studies related to performance, governance, operation, and efficiency. The second delimited the empirical field to the Judiciary, courts, and justice systems. The third incorporated terms associated with prioritization, ranking, triage, decision, and allocation. The fourth sought studies related to backlog, cases, workload, pendency, and congestion.

The time frame was set from 2021 onward, with the aim of capturing the recent scientific literature on operational decision-making in the Judiciary, especially in a context of intensifying use of data, digital transformation, analytics, artificial intelligence, quantitative methods, and decision-support systems applied to judicial management.

2.2 Screening and selection of articles

The search initially retrieved 3,885 records, 1,635 in Web of Science and 2,250 in Scopus. After removing duplicates between the two databases, 2,742 unique records remained, which were subjected to the screening stages described below (see Fig. 1).

The initial screening was carried out with the support of a large language model (LLM), used as an auxiliary instrument to classify records according to their adherence to the theme of operational decision-making in the Judiciary. This methodological choice was motivated by the volume of records, the multidisciplinary nature of the topic, and the need to distinguish properly operational studies from those focused exclusively on legal-dogmatic discussion, generic legal technology, or adjudicative merit decisions.

The use of the LLM was assistive and supervised in nature. The model was employed to support the preliminary classification of records, but the final inclusion or exclusion decision remained the responsibility of the authors. This caution is in line with the recent literature on artificial intelligence-assisted systematic reviews. Alshami et al. [12] propose the use of ChatGPT in stages such as formulating search terms, screening titles and abstracts, full-text filtering, information extraction, and content analysis, pointing to efficiency gains in the review process. At the same time, the authors highlight limitations related to reference extraction, dependence on prompt quality, context constraints, and the need for human validation. In a complementary manner, Qureshi et al. [13] discuss the potential of LLMs to bring systematic reviews closer to automation, but recommend caution regarding the reliability of responses and the need for critical evaluation by experts.

The initial classification considered five thematic groups: (1) backlog, procedural flow, and processing time; (2) workload, capacity, and resource allocation; (3) performance, efficiency, and judicial indicators; (4) prioritization, triage, scheduling,

sequencing, and decision support; and (5) Judiciary or courts without a clear operational focus.

This LLM-assisted screening stage reduced the set of 2,742 records to 167 potentially relevant articles. Titles and abstracts were then read, considering the following inclusion criteria:

1. studies on judicial efficiency, court performance, backlog, congestion, or processing time;
2. studies on workload, capacity, resource allocation, or case weighting;
3. studies on prioritization, triage, scheduling, sequencing, or operational decision-making in courts;
4. studies using quantitative, multicriteria, simulation, optimization, analytics, artificial intelligence, or decision-support methods applied to the Judiciary;
5. studies on procedural flow, process mining, bottlenecks, processing dynamics, or operational organization of judicial cases.

Studies were excluded if they:

1. addressed the Judiciary only from a legal-dogmatic perspective, with no relation to management, operation, or performance;
2. addressed justice, courts, or governance without a clear connection to operational decision-making;
3. discussed legal technology without relation to prioritization, flow, performance, capacity, or decision support;
4. addressed adjudicative merit decisions, legal outcome prediction, or legal interpretation without connection to operational decision-making; and
5. did not present an abstract or sufficient information for adherence assessment.

The result was the selection of 27 articles to compose the review portfolio.

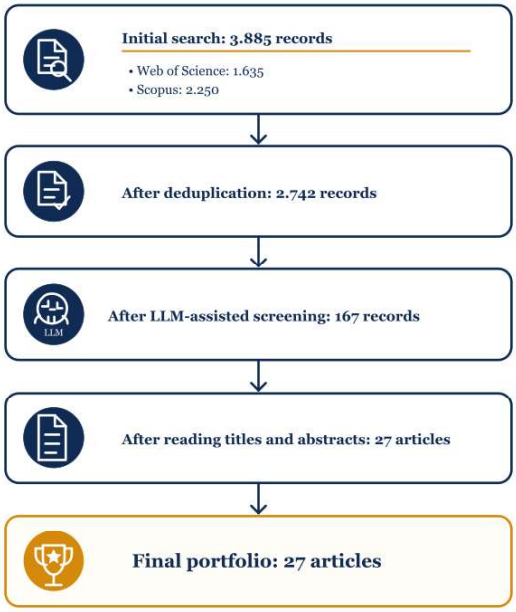

Fig. 1. Flow of the bibliographic portfolio selection

2.3 Evaluation and Classification

The 27 selected articles were evaluated across two complementary analytical layers. The first corresponds to the operational dimensions derived from Slack, Brandon-Jones and Burgess [2]: direct, design, deliver, and develop the operation. This layer indicates which aspect of the judicial operation is addressed by each study. The second corresponds to the methodological-instrumental families identified in the portfolio, indicating which methods or approaches were used to measure, explain, model, or support operational decision-making in the Judiciary.

In the first layer, the studies were classified into four dimensions.

- DS1: Direct the operation dimension brings together studies on objectives, indicators, performance, strategy, legitimacy, and evaluation criteria.
- DS2: Design the operation dimension covers studies on process design, flows, technology, case heterogeneity, procedural complexity, and workload weighting.
- DS3: Deliver the operation dimension brings together studies on capacity, queues, sequencing, scheduling, resource allocation, docket management, and backlog control.
- DS4: Develop the operation dimension covers studies on continuous improvement, innovation, analytics, artificial intelligence, organizational learning, quality, risk, and digital transformation.

While the first layer derives directly from the theoretical framework of Slack, Brandon-Jones and Burgess [2], the second layer was built inductively, based on a reading

of the selected portfolio, a procedure characteristic of literature mapping, in which methodological categories emerge from the analysis of the set of studies itself, rather than from a predefined taxonomy. This inductive construction sought to group the articles according to the type of method, technique, or instrument used to address operational decision-making in the Judiciary, in order to complement the reading by operational dimension with a reading by methodological-instrumental approach.

In the second layer, the studies were classified into seven methodological-instrumental families:

- FM1: performance evaluation, benchmarking, and efficiency frontiers;
- FM2: temporal modeling, queues, and congestion;
- FM3: case weighting and workload measurement;
- FM4: optimization, scheduling, and allocation;
- FM5: multicriteria methods and preference structuring;
- FM6: analytics, artificial intelligence, NLP, and process mining; and
- FM7: governance, budget, and institutional analysis.

3 Findings

3.1 Composition of the Final Portfolio

The portfolio of 27 articles is presented in Table 1, organized by operational dimension and methodological-instrumental family:

Table 1. Final review portfolio

Code	Reference	Objective	Dimension	Methodological-instrumental
A01	Viapiana [14]	Effects of performance-based budget on resource allocation and variability	DS1	FM7
A02	Pereira [6]	Critiques clearance rate/disposition time vs. DEA efficiency scores	DS1	FM1
A03	Aithala et al. [15]	District court performance via median days-to-decision metric	DS1	FM2
A04	Troisi and Alfano [4]	Tests productivity-quality trade-off in Italian criminal justice	DS1	FM1
A05	Di Vita et al. [16]	Factors affecting civil dispute duration in Sicilian courts	DS2	FM2
A06	Pistone et al. [17]	Automatic case-weighting system for environmental crimes (SDG-aligned)	DS2	FM3

A07	Gajda-Roszczynialska [18]	Reviews case-weighting systems in the Polish Judiciary	DS2	FM3
A08	Bogetoft and Wittrup [19]	Benefit-of-the-doubt DEA approach for imprecise case weights	DS2	FM3
A09	Caponecchia et al. [9]	Process mining of Italian divorce proceedings to identify bottlenecks	DS2	FM6
A10	Peyrache and Zago [20]	Models capacity, congestion, and reallocation in Italian courts	DS3	FM4
A11	Bakshi et al. [7]	Two-stage queueing model of India's Supreme Court	DS3	FM2
A12	Gupta and Bolia [8]	Integer programming to optimize hearing schedules	DS3	FM4
A13	Sangeetha et al. [21]	NLP-based case-listing and prioritization solution	DS3	FM6
A14	Kandie et al. [22]	Survival models predicting case duration in Kenyan courts	DS3	FM2
A15	Gupta and Bolia [10]	Ranks judicial efficiency factors via Fuzzy Best-Worst Method	DS1	FM5
A16	Patil and Desai [11]	AI-assisted analytics architecture for classification and scheduling	DS4	FM6
A17	Bhatt et al. [23]	Reviews Industry 4.0 technologies in court administration	DS4	FM6
A18	Roy et al. [24]	AI/digitalization in Indian family courts: triage and access	DS4	FM6
A19	Saini et al. [25]	Systemic problems and corrective measures in Indian judiciary	DS4	FM7
A20	Xue [26]	HyperSoft Set algorithm for civil litigation efficiency	DS4	FM5
A21	Shulgin et al. [27]	ML prediction of congestion and institutional efficiency	DS4	FM6
A22	Málaga Cruz et al. [28]	Reviews AI/analytics in legal management and transparency	DS4	FM7
A23	Burdina [29]	Court funding models in Russia and other countries	DS1	FM7
A24	Zhuravskyi [30]	Institutional factors in Ukrainian judicial reform	DS1	FM7
A25	Madambakam et al. [31]	Deep-learning system extracting semantics from legal documents	DS4	FM6
A26	Ignatovich et al. [32]	Synthetic data/ML for predicting decisions in Kazakhstan	DS4	FM6
A27	Chami Yassine et al. [33]	Normative analysis of interest requirement in Algerian law	DS1	FM7

Regarding geographic coverage, there is a notable concentration of studies on the Indian context (8 of the 27 articles: A03, A11, A12, A13, A15, A16, A18, and A19) and the Italian context (4 articles: A04, A05, A09, and A10), which together account for almost half of the portfolio. This concentration likely reflects the large backlogs of both systems and their recent investment in digitalization and procedural reform. The remaining articles in the portfolio are distributed among multinational comparative studies (A01, A02), studies from other specific jurisdictions, Poland, Kenya, Russia, Ukraine, Kazakhstan and Algeria, and proposals for systems, frameworks, or reviews of a generic nature, without a single-country focus (7 articles).

The temporal distribution of the portfolio also reveals a growth trajectory. The number of publications per year evolved from 3 articles in 2021 to 3 in 2023, 6 in 2024, and 9 in 2025, indicating a recent intensification of scientific interest in the topic. The 6 articles already identified in 2026, the year in which the search was conducted, on May 30, suggest that this growth trend is likely to continue. This pattern is consistent with the hypothesis, already discussed in the Introduction, that the intensification of data use, digital transformation, and artificial intelligence in judicial management has driven academic output on operational decision-making in the Judiciary in recent years.

Regarding methodological nature, empirical-quantitative or computational studies predominate (17 of the 27 articles), applying statistical, optimization, simulation, or machine learning techniques to real or simulated judicial data. Four articles are legal-normative or doctrinal in nature, addressing operational decision-making from an institutional or regulatory perspective, without direct empirical application. Another four present proposals for systems or models formulated as proof of concept, still without robust empirical validation in a real environment. The remaining two articles are literature reviews. This distribution reinforces the reading presented in Section 3.3: the literature has a relevant empirical repertoire, but proposals for decision-support systems largely remain at the proof-of-concept stage, without consolidated evidence of adoption or institutional validation in real courts.

3.2 Thematic Mapping

The classification of the articles made it possible to build the thematic map of the literature on operational decision-making in the Judiciary (See Fig. 2). The aim of the map is to highlight how different operational problems have been addressed and which methodological approaches are mobilized in each part of the judicial operation.

The distribution of the 27 articles shows a greater concentration in the DS4, Develop the operation dimension, with 9 studies, and DS1, Direct the operation, with 8 studies. The DS2, Design the operation and DS3, Deliver the operation dimensions each bring together 5 studies. This distribution suggests that the recent literature has concentrated on two fronts: indicators, performance, efficiency, and governance; and analytics, artificial intelligence, data mining, and digital transformation. In contrast, there is a smaller volume of studies directly focused on the design of the judicial operation and the day-to-day delivery of the operation, such as case weighting, queue management, scheduling, sequencing, and capacity allocation.

Reading by methodological-instrumental families shows a greater presence of family FM6, Analytics, artificial intelligence, NLP, and process mining, with 8 studies, followed by family FM7, Governance, budget, and institutional analysis, with 6 studies. Families FM2 and FM3 appear as intermediate clusters, while FM1, FM4, and FM5 appear less frequently. This result indicates that the literature has varied instruments to observe, measure, model, and support parts of the judicial operation, but few studies connect these approaches into a single architecture for operational decision support.



Fig. 2. Thematic map of the literature on operational decision-making in the Judiciary

Fig. 2 thus shows where the studies are located, but not what this distribution means for operational decision-making. The concentration in DS1 and DS4, and in FM6 and FM7, contrasts with the scarcity of studies on day-to-day delivery of the operation and on explicit preference structuring. The next section interprets this pattern, focusing on the fragmentation of approaches and on the conditions for their integration.

3.3 Discussion of Results

The mapping suggests that the literature on operational decision-making in the Judiciary already has a relevant repertoire of methods. Even so, it has not consolidated an integrated decision-support architecture. This is the main interpretive finding of the study. The fragmentation does not stem from a lack of techniques, indicators, or models. It stems from the way these contributions are distributed. Some measure performance. Others recognize case heterogeneity. Others model queues and capacity. Others apply analytics and artificial intelligence. Few, however, connect these stages into a single decision-making chain.

A first implication of this result is that part of the literature still remains closer to diagnosis than to operational decision-making itself. Studies on performance, efficiency, budget, and governance help to understand what should be monitored and which institutional objectives should be preserved [4,6,14,29]. They are essential to avoid a limited view of judicial efficiency, centered only on volume or speed. However, indicators such as processing time, clearance rate, productivity, congestion, or quality need to be converted into rules, criteria, or models capable of guiding concrete decisions: which cases to prioritize, where to allocate capacity, which queues to address first, and how to balance urgency, complexity, and institutional impact.

A second implication relates to the heterogeneity of judicial cases. The literature on case weighting, procedural complexity, and workload measurement shows that cases cannot be treated as equivalent units, since they differ in required effort, severity, regulatory complexity, social impact, and procedural trajectory [5,16,17,18,19]. This contribution is central to judicial management, since simple case counting can obscure relevant differences in effort, severity, risk, social impact, and procedural trajectory. However, recognizing that cases have different weights is only part of the problem. The next challenge is to transform this differentiation into operational mechanisms for planning, distribution, sequencing, and flow control.

A third implication concerns the distance between analytical models and institutional governance. Studies on queues, optimization, scheduling, simulation, process mining, analytics, and artificial intelligence bring the literature closer to more concrete operational decisions, especially those linked to capacity, duration, and prioritization. However, these methods tend to gain practical usefulness only when connected to institutionally legitimized criteria. In the Judiciary, an operational decision does not just need to be efficient; it also needs to be explainable, auditable, compliant with procedural guarantees, and acceptable to the actors involved. This limits the adoption of purely algorithmic solutions or solutions exclusively oriented toward maximizing productivity.

At this point, multicriteria and preference-structuring methods appear as both a gap and an opportunity. The limited presence of this family in the portfolio indicates that the literature still makes little use of approaches aimed at making criteria, weights, preferences, and trade-offs between conflicting objectives explicit, although studies such as Gupta and Bolia [10] and Xue [26] indicate the applicability of multicriteria methods to evaluating efficiency factors and improvement alternatives in the Judiciary. This gap is relevant because operational judicial decision-making simultaneously involves technical, legal, social, and institutional criteria. Prioritizing cases or allocating capacity can involve processing time, the risk of a right lapsing, the vulnerability of the parties, the age of the backlog, complexity, institutional goals, resource availability, social impact, and the quality of the justice delivered. In this sense, multicriteria decision-support methods can serve as a bridge between quantitative models, specialized judgment, and participatory governance, by structuring preferences, making trade-offs explicit, and supporting decisions in contexts with multiple conflicting objectives [10].

This gap also reveals a dimension still little explored by the literature: the need to reconcile the local perspective of judicial units with the institutional objectives of the judicial body. At the local level, judges and staff know the specificities of the docket,

the schedule, the parties, the bottlenecks, and the everyday capacity constraints. At the institutional level, the court needs to observe goals, equity among units, strategic priorities, transparency, and public accountability. This tension is consistent with the organizational reading of Troisi and Alfano [4], for whom the judicial structure involves a balance between autonomy and control, and with Gajda-Roszczynialska [18], who associates case-weighting and distribution systems with judicial independence, transparency, and the participation of judges in defining and reviewing these mechanisms. Operational decision-making occurs precisely at this interface. Therefore, decision-support models should not be understood merely as algorithmic ranking instruments, but as mechanisms for making criteria explicit, structuring preferences, negotiating among actors, and building operational agreements. At this point, multicriteria decision-support and group decision-making approaches can help structure preference conflicts, make trade-offs visible, and produce recommendations that are more legitimate, auditable, and adaptable to the judicial context [10,18].

The discussion also reinforces the need to understand operational judicial decision-making as a sociotechnical system. Data, algorithms, and mathematical models are relevant components, but not sufficient ones. Studies on queues, scheduling, and process mining show the potential of analytical models to support decisions on capacity, duration, and flow [7,8,9]. However, in the judicial context, these models need to be combined with institutional rules, the tacit knowledge of judges and staff, transparency criteria, review mechanisms, and normative limits, especially when they affect workload distribution, priorities, and procedural guarantees [4,18].

Thus, the main analytical contribution of the map is to show that progress in research on operational decision-making in the Judiciary depends less on the isolated creation of new methods and more on the integration of existing methods. A promising agenda involves combining performance indicators, case-weighting systems, duration and queueing models, schedule optimization, process mining, analytics, and multicriteria methods into transparent decision-support models.

3.4 Answers to the research questions

The research questions stated in Section 1 can now be answered.

Q1 – Which operational problems are addressed? The literature covers performance and efficiency, processing time, congestion and backlog, case heterogeneity and workload, capacity, queues, and scheduling (Table 1). Coverage is uneven: DS1 and DS4 hold 8 and 9 studies, whereas DS2 and DS3, closest to day-to-day flow and capacity, hold 5 each.

Q2 – Which methods are used? Seven families were identified, led by FM6 (8 studies) and FM7 (6), followed by FM2 (4) and FM3 (3); FM1, FM4, and FM5 have 2 each. The repertoire is diverse, but each method tends to address an isolated part of the decision problem.

Q3 – Which criteria are relevant? At the case level, effort, complexity, severity, social impact, and duration [5,15,16,17,18,19]; at the organizational level, capacity, decision quality, and institutional goals [4,6,14,20,29]. No single measure, such as productivity or speed, captures them all.

Q4 – Which gaps remain? Not a lack of techniques but of integration: few studies link these criteria and methods into a single decision chain, and the scarcity of FM5 shows that competing criteria are rarely made explicit, weighted, and negotiated between judicial units and the institution (Section 3.3).

4 Originality and Value

Based on Sections 3.1 to 3.4, the mapping offers the three contributions anticipated in the Introduction. Conceptually, it delimits operational decision-making as a layer distinct from adjudicative merit decisions. Analytically, it organizes the literature by crossing operations management dimensions with methodological-instrumental families. From a research-agenda perspective, it shows that progress depends on integrating existing method families (performance assessment, case weighting, flow and capacity models, analytics, and preference structuring) with institutional governance.

Building on the integration agenda outlined in Section 3.3, the limited presence of multicriteria methods (FM5) in the portfolio points this agenda directly toward the multicriteria decision-making/decision-aiding (MCDM/MCDA) community. A natural extension of this mapping is the development of a decision-support system (DSS) for the prioritization and ranking of judicial cases at the intra-unit level, that is, within a specific court unit — and not for resource allocation among courts, a scope of a different nature. Such a system would consider the interface between the local perspective of the judicial unit and the institutional objectives of the judicial body, weighing criteria such as urgency, complexity, vulnerability, social impact, age of the backlog, and available capacity together with institutional goals and procedural guarantees [4,18,19].

This study has limitations. The analysis was based on the portfolio selected from the databases, string, and criteria defined in the methodology, and may not cover the entire literature on judicial management, court administration, or digital transformation in courts. In addition, the classification of articles by operational dimension and methodological family involves the authors' interpretive judgment, even though guided by explicit criteria. Future research could expand the portfolio through broader search strings, additional databases, and citation snowballing, validate the classification with experts, and develop empirical applications that integrate case weighting, multicriteria methods, analytics, and optimization in concrete judicial contexts. It is also recommended to investigate participatory strategies for criteria structuring, such as workshops with judges, staff, and managers, and group decision-making methods capable of addressing preference conflicts between the local priorities of judicial units and the institutional objectives of courts [10,18].

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screening, language editing and translation. All AI-assisted outputs were critically reviewed by the authors, who made all final methodological and editorial decisions and assume full responsibility for the manuscript.

References

1. CNJ – Conselho Nacional de Justiça: Relatório Justiça em Números 2025. CNJ, Brasília. (2025)
2. Slack, N., Brandon-Jones, A., Burgess, N.: Operations Management. 10th ed. Pearson, Harlow. (2022)
3. Castelliano, C., Guimarães, T.A.: Court disposition time in Brazil and in European countries. Revista Direito GV, 19, e2302. (2023)
4. Troisi, R., Alfano, G.: Is 'justice hurried actually justice buried'? An organisational perspective of the Italian criminal justice. International Journal of Public Sector Management, 36(1), 94-109. (2023)
5. Commission Européenne pour l'Efficacité de la Justice (CEPEJ): Case weighting in judicial systems. CEPEJ Studies No. 28. Council of Europe, Strasbourg. (2020)
6. Pereira, M.A.: Clearance rates and disposition times: not the whole story of judicial efficiency. International Review of Law and Economics, 83, art. 106283. (2025)
7. Bakshi, N., Kim, J., Randhawa, R.S.: Service operations for justice-on-time: a data-driven queueing approach. Manufacturing & Service Operations Management, 27(1), 305-321. (2025)
8. Gupta, M., Bolia, N.B.: Case scheduling system for enhanced judicial performance. Socio-Economic Planning Sciences, 103, art. 102350. (2026)
9. Caponecchia, V., D'Agostino, B., Ahrabi, S.S., Comandè, G., Licari, D., Vandin, A.: Process Mining for legal Courts: visualising, analysing and comparing Italian divorce proceedings. Computer Law & Security Review, 59, art. 106210. (2025)
10. Gupta, M., Bolia, N.B.: Factors affecting efficient discharge of judicial functions: insights from Indian courts. Socio-Economic Planning Sciences, 91, art. 101755. (2024)
11. Patil, S., Desai, D.: AI-assisted case analytics for the Indian judicial system: enhancing efficiency and transparency. In: Proceedings of the IEEE International Conference on Advanced Computing Technologies (ICACT) 2025. IEEE. (2025)
12. Alshami, A., Elsayed, M., Ali, E., Eltoukhy, A.E.E., Zayed, T.: Harnessing the power of ChatGPT for automating systematic review process: methodology, case study, limitations, and future directions. Systems, 11(7), art. 351. (2023)
13. Qureshi, R., Shaughnessy, D., Gill, K.A.R., Robinson, K.A., Li, T., Agai, E.: Are ChatGPT and large language models 'the answer' to bringing us closer to systematic review automation? Systematic Reviews, 12, art. 72. (2023)
14. Viapiana, F.: A performance-based budget in the judiciary: allocation of resources and performance variability in first instance courts. An analysis of three case studies. Journal of Public Budgeting, Accounting & Financial Management, 33(2), 177-206. (2021)
15. Aithala, V., Sachan, A., Sen, S., Payal, H., Bhattacharya, C.: Decision time: illuminating performance in India's district courts. Data & Policy, 6, e32. (2024)
16. Di Vita, G., Ferrara, P.L., Patti, A.: Analysis of time duration of civil disputes in Italy: a case study with microdata from Sicilian courts. The Annals of Regional Science, 74, art. 7. (2025)
17. Pistone, V., Sovrano, F., Distefano, B.: Aligning UN goals and legal norms in a case weighting system: a case study on environmental crimes in Italy. In: Proceedings of the 16th

International Conference on Theory and Practice of Electronic Governance (ICEGOV 2023), pp. 324-331. ACM, New York. (2023)
18. Gajda-Roszczynialska, K.: System ważenia spraw – klucz do efektywności w zarządzaniu sądownictwem. Polski Proces Cywilny, 1/2026, 56-79. (2026)
19. Bogetoft, P., Wittrup, J.: Benefit-of-the-doubt approach to workload indicators: simplifying the use of case weights in court evaluations. Omega, 103, art. 102375. (2021)
20. Peyrache, A., Zago, A.: The inefficiency of courts of justice: industry structure, capacity and misallocation. Journal of Productivity Analysis, 62, 217-238. (2024)
21. Sangeetha, V., Pani, I., Jariwala, J., Dargar, A., Rai, R.H., Agarwala, S.: Optimizing judicial efficiency: a software solution for case listing with customized case flow management. In: Proceedings of the 8th International Conference on Computational System and Information Technology for Sustainable Solutions (CSITSS) 2024, pp. 1-6. IEEE. (2024)
22. Kandie, A.K., Atitwa, E.B., Nyaluke, W.: Perspectives on judicial efficiency: case study of predictive modeling in Kenyan High Courts. International Journal for Court Administration, 16(2), art. 5. (2025)
23. Bhatt, H., Bahuguna, R., Swami, S., Singh, R., Gehlot, A., Akram, S.V., Gupta, L.R., Thakur, A.K., Priyadarshi, N., Twala, B.: Integrating industry 4.0 technologies for the administration of courts and justice dispensation: a systematic review. Humanities and Social Sciences Communications, 11, art. 1076. (2024)
24. Roy, S., Kumar, A., Tripathi, S.: Digital justice and the future of family courts: the role of AI in transforming access to justice in India. In: Sharma, S., Sehrawat, S., Chandola, V. (eds.), Humanities and Social Sciences. CRC Press/Taylor & Francis, Boca Raton. (2026)
25. Saini, J.S., Saini, J., Tripathi, P.M., Saini, D.K.: The systemic issues with the lower judiciary in India and proposed remedial measures. Crime, Law and Social Change, 84(1), art. 6. (2026)
26. Xue, F.: Multi-criteria decision-making algorithm based on HyperSoft Set for civil litigation efficiency evaluation in the context of artificial intelligence. Neutrosophic Sets and Systems, 82(1), art. 58, 898-910. (2025)
27. Shulgin, Y., Omarova, A., Mabiyev, Y., Kenzhebekov, R., Kussainova, L., Isaeva, K.: Machine learning in legal and economic systems: enhancing institutional efficiency and judicial predictability. Journal of Applied Economic Sciences, 21(2(92)), 579-594. (2026)
28. Málaga Cruz, J.F., Malaga Davila, C.P., Gonzales Laguna, H.A., Gonzales Malaga, E.J.: Innovative management in the legal world: keys to making the right decisions. PETITA: Jurnal Kajian Ilmu Hukum dan Syariah, 10(2), 489-510. (2025)
29. Burdina, E.V.: Court funding: new approaches in Russia and foreign countries. Law. Journal of the Higher School of Economics, 16(2), 70-91. (2023)
30. Zhuravskyi, V.: What to take into account in judicial reform. European Political and Law Discourse, 8(2), 58-62. (2021)
31. Madambakam, P., Rajmohan, S., Sarma, H., Gupta, T.A.C.P.: Supervised multi-stage semantics expanded decision system for Indian legal context. Artificial Intelligence and Law. (2026)
32. Ignatovich, A., Yessengeldina, A., Baidullayeva, G., Ussipbekova, D., Jakhanova, B., Saduakassova, G., Serimbetov, B., Tynykulova, A.: Generating data for predicting court decisions in Kazakhstan using machine learning. Bulletin of Electrical Engineering and Informatics, 14(6), 4507-4520. (2025)
33. Chami Yassine, A., Ahmad, A., Muhtar, M.H., Rivera, K.M., Putri, V.S.: Admissibility of lawsuits based on interest under Algerian civil and administrative procedures. Jambura Law Review, 6(2), 286-303. (2024)

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APPLICATION OF THE MULTICRITERIA APPROACH TO CONSTRUCTION MANAGEMENT IN THE JUDICIARY

Pedro Rodrigo de Menezes Almeida[1],
Universidade Federal de Sergipe – Programa de Pós-Graduação em Administração,
Av. Marechal Rondon, s/n, Jardim Rosa Elze, São Cristóvão – SE, 49100000, Brazil
pedro.eng87@gmail.com

Ana Paula Henriques Gusmão de Araújo Lima [2]
Universidade Federal de Sergipe – Programa de Pós-Graduação em Administração,
Av. Marechal Rondon, s/n, Jardim Rosa Elze, São Cristóvão – SE, 49100000, Brazil
anapaulahg@academico.ufs.br

Abstract. The planning, execution, and monitoring of construction projects within the Judiciary are regulated by CNJ Resolution No. 652/2025, which establishes that courts must develop their construction plans based on the needs assessment, institutional strategic planning, and the guidelines of the National Council of Justice (CNJ). The Resolution determines that each project must be assigned a priority indicator, obtained through a technical assessment system based on scoring and weighting criteria related to the physical structure of the occupied property and its suitability for the provision of judicial services. Although the Resolution establishes the criteria to be considered, it does not define a specific method for aggregating preferences and prioritizing construction projects. In this context, this study proposes a Multicriteria Decision Analysis (MCDA) approach to support the development of the construction plan, considering the multicriteria and strategic nature of the problem, the existence of potentially conflicting criteria, and the need to establish an ordering of alternatives over a long-term planning horizon. Considering the compensatory nature of the assessment and the decision-maker's difficulty in providing precise preference assessments, the FITradeoff method is proposed for ranking the alternatives. The proposed application is contextualized within the Federal Regional Court of the 5th Region (TRF5), considering the court unit located in the state of Sergipe, and covers the 2024–2027 planning horizon. The decision-maker is the individual responsible for the planning and execution of construction projects, taking into account the financial resources allocated by the Federal Government in each Annual Budget Law (LOA). The criteria, defined based on the guidelines of CNJ Resolution No. 652/2025, are: Physical Integrity, Safety, Habitability, Functionality, Accessibility and Mobility, Sustainability, Property Adequacy, Capacity Adequacy, Judicial Demand, and Strategic Alignment. The set of alternatives comprises the construction and renovation projects identified in the court's needs planning process, whose prioritization is necessary due to the limited resources available for the simultaneous execution of all planned interventions. The proposed model seeks to contribute to a more structured, transparent, and consistent prioritization of infrastructure investments, aligning the physical needs of properties with judicial demands and institutional strategic guidelines.

Keywords: *Public Infrastructure Management, CNJ Resolution No. 652/2025, MCDA, FITradeoff.*

1 Introduction

According to Souza (2024), projects are instruments that, when properly selected and accompanied by adequate resource allocation, contribute to maximizing an organization’s results and can be considered important pillars for the achievement of intended strategies. Construction management plays a critical role in the success of real estate investments, since project performance in terms of schedule, cost, and quality directly depends on the effectiveness of managerial functions such as planning and financial control (NGUYEN, 2020). As highlighted in the literature, inadequate decisions during the initial stages of project definition establish a strategic framework that, if misguided, may compromise profitability and value delivery to the organization over extended periods (NGUYEN, 2020; FERREIRA et al., 2025).

Managerial failures, particularly deficient planning and inadequate cash flow management, are identified as the main causes of construction delays and their consequent negative impact on the value of real estate assets (NGUYEN, 2020). Investments in this sector should be planned based on principles of sustainability and socioeconomic responsibility, using robust risk assessments to ensure that projects remain profitable and competitive in the face of market fluctuations and economic cycles (SOARES et al., 2022).

Drawing a parallel with the approach discussed by Nguyen (2020), within the context of Public Administration, construction management also plays an important role, since the performance of a construction project in terms of schedule, cost, and quality also directly depends on the effectiveness of managerial functions such as planning and financial control. Law No. 14,133/2021, known as the New Law on Public Procurement and Administrative Contracts, plays a central and modernizing role in the management of construction projects and establishes rigorous guidelines ranging from initial planning to post-delivery responsibilities. Law No. 14,133/2021 includes provisions such as the Preliminary Technical Study and the Risk Allocation Matrix, which address, respectively, the analysis of the problem to be solved and the best solution (allowing for the assessment of technical and economic feasibility), as well as the identification of potential events occurring after contract signing that may generate financial impacts and the anticipation of the need for contractual amendments.

Within the Judiciary, in addition to procurement legislation, the Administration must base its decisions concerning construction management on its 2021–2026 strategic planning, established by the CNJ through Resolution No. 325, dated June 29, 2020, and, from a more technical perspective, on Resolution No. 652, dated September 29, 2025, which addresses the planning, execution, and monitoring of construction projects within the Judiciary. The Resolution establishes parameters and guidelines for pricing, tender document preparation, among other aspects, which should serve as a basis for the selection of evaluation criteria. CNJ Resolution No. 652/2025 defines metrics for construction management, establishing that each project must have a priority indicator based on technical criteria related to physical structure and judicial suitability.

These priority indicators are organized into two dimensions: a Technical Dimension (Physical Structure), in which the assessment is conducted through scoring the conditions of roofing, building systems (electrical and plumbing), fire safety, accessibility, and building pathologies; and a Strategic Dimension (Judicial Suitability), in which the assessment is based on the weighting of the impact on judicial activities, considering caseload, population demand, sustainability, and policies for replacing leased properties. However, this construction prioritization process within the Judiciary, governed by the aforementioned Resolution, presents a methodological gap, as it defines priority indicators and requires a technical assessment system but does not specify a particular methodology for preference aggregation and project prioritization.

Within this context, this study aims to employ the Multicriteria Decision Analysis (MCDA) approach, specifically the FITradeoff method, to support the decision-making process concerning the prioritization of construction projects within the Judiciary. The objective is to provide methodological rigor, transparency, and efficiency in the allocation of public resources, particularly in the development of construction plans, considering the multicriteria and strategic nature of the problem, the existence of potentially conflicting criteria, and the need to establish a ranking of alternatives over a long-term planning horizon.

2 Methodology

The research is conducted as an applied case study with an exploratory objective, within the perspective of the Decision Support Framework proposed by De Almeida (2013), which organizes the study into three main phases: Problem Structuring (1), Preference Modeling (2), and Finalization and Analysis (3).

Developed by De Almeida et al. (2016), the FITradeoff method was selected due to the interactivity and flexibility features of its decision support system, which allow decision-makers to conduct the decision-making process according to their preferences, making it possible to perform holistic judgments between alternatives and help resolve otherwise undefined preference relations between them (De Almeida et al., 2023). The FITradeoff Decision Support System (DSS) (De Almeida et al., 2021) is freely available at www.fitradeoff.org.

Within this framework, the first stage formally identifies who holds decision-making authority and who the other participants are, such as analysts (methodological support), experts (technical support), and stakeholders involved in the decision-making process regarding the selection of construction projects and projects included in the Multi-Year Construction Plan of the Judicial Section of Sergipe. At this stage, the criteria, objectives, and other relevant components of the decision problem are also defined. In the following

stage, intra-criteria and inter-criteria evaluations are conducted as part of the elicitation process, through preference comparisons using the FITradeoff DSS. Finally, the concluding stage of the decision framework involves validating the results generated by the model and transforming them into practical recommendations for the decision-maker.

Initially, at least two perspectives can be identified in which the FITradeoff method may be tested in light of CNJ Resolution No. 652/2025, with the priority indicators from Sets 1 and 2 being treated as criteria. These two perspectives are identified as Scenario 1 and Scenario 2. This classification is based on the purpose of the decision-making process and the way in which the criteria are applied. In Scenario 1, the decision-making process focuses on the assessment of different properties, with the purpose of supporting decisions such as the acquisition, leasing, or renovation of existing properties. In Scenario 2, the decision-making process evaluates the impact of constructing new facilities or the impact of each renovation carried out within the same existing property.

In Scenario 1, which is the focus of this study, FITradeoff will be tested to evaluate the alternatives (candidate properties or construction projects) on an equal basis. The criteria from Set 1 will be used to technically assess the actual condition of the property's conservation and infrastructure: Physical Integrity (C1), Safety (C2), Habitability (C3), Functionality (C4), and Accessibility and Mobility (C5). The criteria from Set 2 will measure the property's strategic alignment with judicial demand and the Court's planning: Sustainability (C6), Property Adequacy (C7), Capacity Adequacy (C8), Judicial Demand (C9), and Strategic Alignment (C10). Scenario 2 is presented as a complementary potential application and does not constitute the focus of the present research.

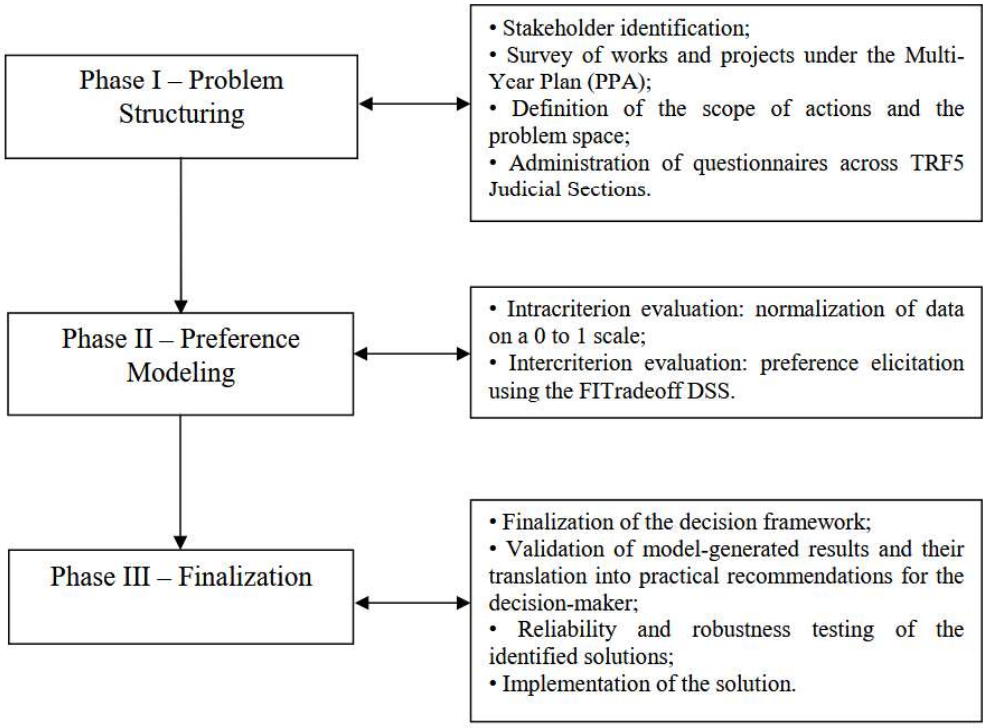

Fig. 1. Proposed decision framework for implementing the FITradeoff method.

3 What would be explected

In the absence of a formal method for prioritization, the use of a multicriteria decision support model seeks to integrate the technical and strategic guidelines established by CNJ Resolution No. 652/2025, addressing the methodological gap in the Resolution, which establishes technical and strategic guidelines and indicators for prioritizing judicial construction projects but does not prescribe a specific algorithm or scientific procedure for aggregating these indicators.

It is expected that the interactivity and flexibility of the FITradeoff method will contribute to reducing cognitive effort in the context of Scenario 1, addressing the difficulties inherent in the judgment task when dealing with the numerous criteria established by the Resolution. The method is also expected to promote the integration of objective data and support the selection of proposals with the highest economic return, as required by Article 41 of the regulation, thereby ensuring greater transparency and efficiency in the allocation of public resources.

More broadly, the FITradeoff method is expected to constitute an effective tool for standardizing assessment procedures related to Scenario 1, addressing the difficulties inherent in decision-making when faced with the numerous criteria established by the Resolution. In this way, the method may support not only the preparation of the Multi-Year Construction Plan, but also serve as a strategic management tool capable of promoting transparency, auditability, and optimization of public investments in judicial construction projects. Furthermore, it may facilitate the integration of objective data and support the selection of proposals with the highest economic return, as required by Article 41 of the Resolution, thereby contributing to greater transparency and efficiency in the allocation of public resources.

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References

Almeida, A. T. Processo de decisão nas organizações: construindo modelos de decisão multicritério. São Paulo: Atlas, 2013.

Brasil. Lei nº 14.133, de 1º de abril de 2021. Institui a Lei de Licitações e Contratos Administrativos. Diário Oficial da União: seção 1, Brasília, DF, 1 abr. 2021.

Conselho Nacional de Justiça (Brasil). Resolução nº 652, de 29 de setembro de 2025. Dispõe sobre o planejamento, a execução e o monitoramento de obras no Poder Judiciário. Brasília, DF: CNJ, 2025.

Conselho Nacional de Justiça (Brasil). Resolução n. 325, de 29 de junho de 2020. Diário da Justiça [do] Conselho Nacional de Justiça, Brasília, DF, n. 201, p. 2-10, 30 jun. 2020.

De Almeida, A. T., de Almeida, J. A., Costa, A. P. C. S., & de Almeida-Filho, A. T. 2016. A new method for elicitation of criteria weights in additive models: Flexible and interactive tradeoff. European Journal of Operational Research, 250(1), 179-191.

De Almeida, A. T. et al. A summary on FITradeoff method with methodological land practical developments and future perspectives. Pesquisa Operacional, v. 43, e268356, 2023.

De Almeida, A. T.; Frej, E. A.; Almeida, J. A.; Ribeiro, M. L. S.; Roselli, L. R. P.; Vieira, M. J. L.; Borba, L. B.; Santo, P. P. P. E. FITradeoff-Web. 2021. Programa de Computador. Número do registro: BR512021001368-9, data de registro: 29/06/2021, título: "FITradeoff-Web", Instituição de registro: INPI - Instituto Nacional da Propriedade Industrial.

Ferreira, D. V. et al. Decision model for selecting a portfolio of non-technical loss mitigation projects for power distribution systems. Utilities Policy, v. 95, 101967, 2025.

Ferreira, E. B. et al. Benefit-to-cost analysis in a portfolio problem for the context the construction sector: a multi-criteria approach. Engineering, Construction and Architectural Management, 2025.

Nguyen, L. H. Empirical analysis of a management function's failures in construction project delay. Journal of Open Innovation: Technology, Market, and Complexity, v. 6, n. 2, 26, 2020

Soares, R. S. B. S. et al. A multicriteria evaluation system for large real estate investments. International Journal of Strategic Property Management, v. 26, n. 4, p. 305–317, 2022

Souza, R. A. C. Modelo de decisão multicritério para seleção de portfólio de projetos de uma mineradora. 2024. 107 f. Dissertação (Mestrado Profissional em Engenharia de Produção) – Universidade Federal de Pernambuco, Recife, 2024.

INSID 2026, Nov. 17-19, 2026.
Recife-PE, Brazil

Aplicação do Método FITradeoff à Ordenação de Ordens de Produção em uma Fábrica de Embalagens Plásticas Personalizadas

Beatriz Cipolla Moreira[1], Fabiana Hernandes Detogni[1], Maria Luiza de Lima Souza[1], Shannian Nan[1], Ruan Renato Oliveira[1], Jaini Barbosa[1] e Ricardo Pires de Souza[1]

[1]Universidade Federal do Rio Grande do Norte (UFRN), Campus Universitário Lagoa Nova, Natal-RN, Brasil, 59078-970.
ricardo.pires@ufrn.br, beatrizcipollamoreira@gmail.com, fabianadetogni@gmail.com, maria.lima.705@ufrn.edu.br, shan2000nan@gmail.com, ruanrenato77@gmail.com, jaini.barbosa@ufrn.edu.br

Resumo. Objetivo: a programação e o controle da produção (PCP) em ambientes job-shop com recursos limitados exige a definição de prioridades entre ordens de produção que competem por capacidade e por matéria-prima em estoque; este trabalho estrutura o problema de decisão e ordena as ordens de produção em carteira de uma fábrica de embalagens plásticas personalizadas. **Metodologia:** o problema foi estruturado por meio do Value-Focused Thinking (VFT) e modelado com o método multicritério FITradeoff (Flexible and Interactive Tradeoff), fundamentado na Teoria do Valor Multiatributo e na agregação aditiva, escolhido por elicitar as constantes de escala a partir de informação parcial e preferencial do decisor, reduzindo o esforço cognitivo; ao final, realizou-se uma análise de sensibilidade sobre os pesos elicitados. **Resultados:** a estruturação produziu quatro critérios validados junto à gestão — prioridade do cliente, antecipação de recebíveis, tempo de setup de máquina e abastecimento do gargalo — e a modelagem ordenou seis ordens de produção; a análise de sensibilidade confirmou a robustez dos extremos do ranking e localizou a indeterminação remanescente nas posições intermediárias. **Originalidade/valor:** o trabalho evidencia que a combinação entre VFT e FITradeoff fornece um resultado auditável e aderente às prioridades estratégicas da fábrica, orientando também a alocação de matéria-prima escassa em um contexto de pequena empresa raramente coberto pela literatura multicritério.

Palavras-chave: FITradeoff; Value-Focused Thinking; Apoio multicritério à decisão; Programação da produção; Job-shop.

Abstract. Purpose: production planning and control in job-shop environments with limited resources requires setting priorities among production orders that compete for capacity and for raw material in stock; this paper structures the decision problem and ranks the open production orders of a customized plastic packaging factory. **Methodology:** the problem was structured through Value-Focused Thinking (VFT) and modelled with the Flexible and Interactive Tradeoff (FITradeoff) method, grounded in Multi-Attribute Value Theory and additive aggregation, chosen because it elicits the scaling constants from partial preference information, thus reducing the decision-maker's cognitive effort; a sensitivity analysis on the elicited weights was then performed. **Findings:** the structuring stage produced four criteria validated with management — customer priority, receivables anticipation, machine setup time and bottleneck feeding — and the model ranked six production orders; the sensitivity analysis confirmed the robustness of the extremes of the ranking and located the remaining indeterminacy in the intermediate positions. **Originality/value:** the work shows that combining VFT and FITradeoff yields an auditable result aligned with the strategic priorities of the factory, also guiding the allocation of scarce raw material in a small-business context rarely covered by the multi-criteria literature.

Keywords: FITradeoff; Value-Focused Thinking; Multi-criteria decision aid; Production scheduling; Job-shop.

1 Introdução/Objetivo

A decisão sobre o que produzir, em qual ordem e com que prioridade é central na Programação e Controle da Produção (PCP), sobretudo em sistemas do tipo job-shop que operam sob encomenda. Nesses ambientes, ordens de produção distintas competem simultaneamente por capacidade de máquina, por matéria-prima limitada em estoque e por compromissos de prazo com diferentes clientes. A escolha de uma regra de sequenciamento puramente operacional, como menor tempo de processamento ou data de entrega mais próxima, tende a ignorar dimensões estratégicas e financeiras relevantes para a sobrevivência da empresa.

O problema torna-se, por natureza, multicritério: o decisor precisa equilibrar objetivos conflitantes, como atender o prazo do cliente, preservar o fluxo de caixa por meio da antecipação de recebíveis, minimizar perdas de capacidade por setup e garantir o abastecimento do recurso gargalo. Conforme de Almeida et al. (2015), problemas de tomada de decisão multicritério (MCDM/A) caracterizam-se pela presença de ao menos duas alternativas avaliadas segundo dois ou mais critérios, buscando a solução que melhor reflita as preferências do decisor.

Essa insuficiência das regras clássicas tem uma razão estrutural. Regras como menor tempo de processamento ou menor folga foram concebidas para otimizar medidas de desempenho definidas sobre o próprio fluxo produtivo — tempo médio de fluxo, atraso médio, número de ordens atrasadas — e o fazem bem dentro desse recorte. Ocorre que, em uma pequena empresa, a decisão de sequenciamento é simultaneamente uma decisão de caixa e uma decisão comercial: a ordem liberada consome matéria-prima que talvez não possa ser reposta antes do próximo recebimento, e compromete capacidade de um recurso cuja ociosidade não é recuperável. Nenhuma dessas consequências é observável no espaço de medidas em que as regras clássicas operam, de modo que a limitação não decorre de uma escolha inadequada de regra, mas do fato de o problema real ter mais dimensões do que a formulação admite.

Este trabalho tem por objetivo estruturar o problema de decisão por meio do Value-Focused Thinking (VFT) e aplicar o método FITradeoff à ordenação de ordens de produção em uma fábrica de embalagens plásticas personalizadas de pequeno porte, localizada em Extremoz/RN e atuante há doze anos nos segmentos alimentício e cosmético, de modo a apoiar a decisão sobre o que produzir com a quantidade disponível em estoque.

1.1 Referencial Teórico

Os métodos de Apoio Multicritério à Decisão têm por finalidade auxiliar o decisor a resolver racionalmente problemas que envolvem múltiplos critérios conflitantes, segundo suas preferências (de Almeida et al., 2015). Dentro desse campo, a Teoria do Valor Multiatributo (MAVT), formalizada por Keeney e Raiffa (1976), pressupõe um decisor de racionalidade compensatória, isto é, disposto a aceitar um desempenho inferior em um critério em troca de um desempenho superior em outro. No modelo aditivo da MAVT, o valor global de uma alternativa a é obtido pela soma ponderada dos valores parciais em cada critério, conforme a Equação (1):

$$v(a) = \Sigma\, k_j \cdot v_j(a)\,, \qquad (1)$$

em que k_j são as constantes de escala de cada critério j, com $\Sigma\, k_j = 1$ e $k_j > 0$, e $v_j(a)$ é o valor parcial da alternativa no critério j, normalizado no intervalo [0,1]. O principal obstáculo prático da MAVT reside na obtenção das constantes de escala, etapa que tradicionalmente impõe grande esforço cognitivo ao decisor.

O FITradeoff foi desenvolvido por de Almeida et al. (2016) como uma evolução do procedimento clássico de tradeoff para elicitação de constantes de escala em modelos aditivos. Em vez de exigir que o decisor estabeleça pontos exatos de indiferença entre consequências, tarefa cognitivamente difícil e propensa a inconsistências, o método utiliza informação parcial: o decisor responde a comparações estritas de preferência, mais fáceis e confiáveis. A partir dessas respostas, o método define um espaço de pesos compatíveis com as preferências declaradas e, por meio de programação linear, identifica quais alternativas podem ser ótimas dentro desse espaço. O processo é flexível e interativo: a cada interação o decisor fornece nova informação, restringindo progressivamente o espaço de pesos até que se obtenha a solução (de Almeida, Frej e Roselli, 2021). O método atende a diferentes problemáticas de decisão — escolha (de Almeida et al., 2016), ordenação (Frej, de Almeida e Costa, 2019), classificação (Kang, Frej e de Almeida, 2020) e portfólio (Marques, Frej e de Almeida, 2022). Para o problema aqui tratado utiliza-se a problemática de ordenação, na qual o método produz um ranking completo das alternativas a partir da informação parcial sobre os pesos.

Duas consequências práticas dessa formulação merecem destaque no contexto deste trabalho. A primeira é que o método não exige que o decisor conheça de antemão os valores exatos dos pesos: basta que suas

respostas sejam consistentes, e o resultado é obtido sobre todo o conjunto de vetores compatíveis com elas. A segunda é que o processo pode ser interrompido assim que a informação acumulada for suficiente para a decisão em questão, o que significa que o esforço de elicitação é proporcional à dificuldade do problema e não a um protocolo fixo — característica particularmente relevante quando o decisor é um gerente de produção que precisa liberar ordens no mesmo turno.

Além dos métodos que partem de um conjunto de alternativas já definido (alternative-focused thinking), Keeney (1992) propõe o Value-Focused Thinking, abordagem em que o decisor explicita, antes de qualquer geração de alternativas, aquilo que realmente importa na decisão: seus objetivos. Esses objetivos são organizados em uma hierarquia que distingue objetivos fundamentais, que expressam a razão de ser da decisão, de objetivos meio, que contribuem para o alcance dos primeiros sem constituírem um fim em si mesmos. A estruturação via VFT resulta em uma rede de objetivos que orienta diretamente a escolha dos critérios de avaliação. Para que esse conjunto seja adequado à modelagem multicritério, de Almeida et al. (2015) recomendam que ele atenda a propriedades como essencialidade, controlabilidade, mensurabilidade, operacionalidade, compreensibilidade, não redundância e minimalidade.

2 Metodologia

A pesquisa caracteriza-se como aplicada, de natureza quantitativa, conduzida por meio de um estudo de caso. O procedimento metodológico seguiu as etapas do processo decisório multicritério estruturado por de Almeida et al. (2015), adaptadas ao método FITradeoff: (a) estruturação do problema, com definição do decisor (gerente de PCP), identificação das alternativas (ordens de produção em carteira) e dos critérios relevantes, levantados em reunião com a gestão; (b) definição da matriz de consequências, com a avaliação de cada ordem de produção em cada critério a partir de dados operacionais e financeiros da empresa; (c) elicitação das constantes de escala, com ordenação dos pesos pelo decisor e refinamento por comparações de preferência; e (d) cálculo do valor global de cada alternativa pelo modelo aditivo e construção do ranking.

2.1 Caracterização da Empresa

O estudo foi conduzido em uma fábrica de embalagens plásticas personalizadas localizada em Extremoz/RN, que atua há doze anos no mercado de embalagens para os segmentos alimentício e cosmético. A empresa é classificada como pequena empresa, segundo o critério de número de funcionários adotado pelo SEBRAE para a indústria, contando com 42 colaboradores e faturamento médio mensal de R$ 380 mil. Quanto à Classificação Nacional de Atividades Econômicas, enquadra-se na atividade 2222-6/00 — Fabricação de embalagens de material plástico —, sob regime tributário de Lucro Presumido.

O sistema produtivo opera predominantemente sob encomenda (make-to-order), caracterizando um arranjo do tipo job-shop, em que cada pedido envolve especificações próprias de cliente (dimensão, material, arte e impressão). O parque fabril é composto pelas etapas de extrusão de filme plástico, impressão flexográfica e corte e solda, sendo o recurso gargalo identificado como a impressora flexográfica, responsável por limitar a capacidade global da fábrica. A matéria-prima principal é o polietileno de baixa densidade (PEBD), adquirida de quatro fornecedores e mantida em estoque com nível médio equivalente a dez dias de produção. A gestão financeira recorre à antecipação de recebíveis junto a uma factoring, de modo que a liberação de novas ordens fica condicionada ao saldo de crédito aprovado — fator que justifica a inclusão desse aspecto entre os critérios de decisão. A decisão sobre o sequenciamento é, atualmente, tomada pelo gerente de PCP com base em planilha eletrônica e em uma regra informal de priorização por menor prazo de entrega, o que motiva a adoção de um método estruturado de apoio à decisão.

A identificação da impressora flexográfica como recurso gargalo tem implicações que extrapolam a etapa em que ela se encontra. Como a extrusão a precede e o corte e solda a sucede, qualquer hora ociosa na impressão é uma hora perdida para o sistema como um todo e não pode ser recuperada por aumento de ritmo nas demais etapas. É esse raciocínio que converte o abastecimento do gargalo em objetivo próprio, e não em consequência automática do sequenciamento: uma sequência que atenda todos os prazos, mas deixe a impressora parada à espera de material extrudado ou de liberação financeira, reduz a capacidade efetiva da fábrica sem que isso apareça em qualquer indicador de pontualidade.

2.2 Estruturação dos Objetivos e Definição dos Critérios

A estruturação do problema seguiu o Value-Focused Thinking (Keeney, 1992), aplicado antes da definição operacional dos critérios. Em reunião de elicitação com o gerente de PCP foram levantadas as preocupações que efetivamente orientam a decisão sobre o que produzir com o estoque disponível, organizadas em uma hierarquia de objetivos. No topo foi definido o objetivo fundamental do problema: maximizar o desempenho da decisão de sequenciamento das ordens de produção, conciliando o cumprimento dos compromissos comerciais com a saúde financeira e a capacidade produtiva da fábrica. Esse objetivo foi desdobrado em quatro objetivos meio, considerados suficientes e não redundantes: (i) honrar os prazos contratados com os clientes; (ii) preservar o fluxo de caixa por meio da antecipação de recebíveis; (iii) minimizar as perdas de capacidade decorrentes de setup de máquina; e (iv) manter o recurso gargalo ocupado e abastecido. Cada objetivo meio foi operacionalizado em um critério mensurável, com sentido de otimização definido, conforme a Tabela 1.

Tabela 1. Critérios de decisão para a ordenação de ordens de produção. Fonte: elaborado pelos autores.

Critério	Descrição	Tipo	Sentido
C1 – Prioridade do cliente	Urgência do compromisso de entrega; ordens com prazo mais curto têm maior prioridade.	Dias até a entrega	Minimizar
C2 – Antecipação de recebíveis	Liberação de produção condicionada ao saldo aprovado na factoring; maior saldo liberado favorece a ordem.	R$ liberado	Maximizar
C3 – Tempo de setup de máquina	Tempo de preparação da máquina para a ordem; setups maiores tendem a ser sequenciados por último.	Horas de setup	Minimizar
C4 – Abastecimento do gargalo	Grau em que a ordem mantém o recurso gargalo ocupado e abastecido, evitando ociosidade.	Escala 0–10	Maximizar

A escolha desses critérios decorre diretamente das características da empresa. O critério C1 reflete a carteira de clientes, com predominância de contratos sujeitos a cláusula de multa por atraso, em que o cumprimento de prazo é determinante para a retenção de clientes. O critério C2 está associado à dependência da factoring para capital de giro. O critério C3 relaciona-se ao tempo de troca de bobina e ferramental na impressora flexográfica, enquanto o critério C4 deriva da identificação do gargalo no processo produtivo, cuja ociosidade representa perda direta de capacidade.

2.3 Matriz de Consequências e Ordenação dos Pesos

Foram consideradas seis ordens de produção (OP1 a OP6) em carteira, cujos desempenhos em cada critério são apresentados na Tabela 2. Os valores são ilustrativos e devem ser substituídos pelos dados reais da operação no momento da decisão.

Tabela 2. Matriz de consequências das ordens de produção. Fonte: elaborado pelos autores.

Ordem	C1 – Prazo (dias)	C2 – Recebível (R$ mil)	C3 – Setup (h)	C4 – Gargalo (0–10)
OP1	3	12	1,5	9
OP2	10	30	0,8	6
OP3	5	8	2,5	8
OP4	15	45	1,2	4
OP5	7	20	3,0	7
OP6	2	15	2,0	5

Para tornar os critérios comparáveis, os desempenhos foram normalizados no intervalo [0,1] por normalização linear, respeitando o sentido de otimização de cada critério (valor 1 para o melhor desempenho e 0 para o pior). Em seguida, o decisor ordenou as constantes de escala segundo sua importância estratégica,

considerando a faixa de variação de cada critério. A ordem declarada foi k1 > k4 > k2 > k3, refletindo que o cumprimento de prazo e a manutenção do gargalo em operação são as preocupações dominantes da fábrica.

Cabe observar que a normalização adotada é interna ao conjunto de alternativas avaliadas, isto é, os extremos da escala correspondem ao melhor e ao pior desempenho observados entre as seis ordens em carteira, e não a limites absolutos do processo produtivo. Essa escolha é coerente com o procedimento de elicitação por tradeoff, no qual o decisor compara consequências dentro das faixas efetivamente possíveis, mas implica que as constantes de escala obtidas são válidas para essa carteira específica. A entrada de uma ordem com prazo substancialmente mais longo ou com recebível muito superior aos atuais altera as faixas de variação e, portanto, exige nova elicitação — ponto que precisa ficar claro para quem opere o modelo na rotina da fábrica.

3 Resultados

3.1 Ordenação das Ordens de Produção

A partir da ordenação dos pesos e das comparações de preferência fornecidas pelo decisor no procedimento interativo do FITradeoff, obteve-se um conjunto de constantes de escala compatível com a informação parcial declarada. O vetor representativo desse espaço, utilizado para o cálculo do valor global pelo modelo aditivo da Equação (1), é k1 = 0,40 (prazo), k4 = 0,30 (gargalo), k2 = 0,18 (recebível) e k3 = 0,12 (setup). Aplicando-se esses pesos aos valores parciais normalizados, obteve-se o ranking apresentado na Tabela 3.

Tabela 3. Valor global e ordenação das ordens de produção. Fonte: elaborado pelos autores.

Posição	Ordem	Valor global v(a)	Posição	Ordem	Valor global v(a)
1º	OP1	0,841	4º	OP5	0,521
2º	OP6	0,649	5º	OP2	0,494
3º	OP3	0,608	6º	OP4	0,418

O ranking obtido posiciona a OP1 como a ordem de maior prioridade, resultado coerente com as preferências do decisor: a OP1 combina prazo de entrega curto (três dias), o melhor desempenho no abastecimento do gargalo (nota 9) e um tempo de setup reduzido — exatamente os critérios de maior peso. A OP6, em segundo lugar, é favorecida pelo prazo mais curto da carteira (dois dias), porém penalizada pelo menor desempenho no gargalo, o que a coloca atrás da OP1.

Na outra extremidade, a OP4 ocupa a última posição apesar de apresentar o maior recebível liberado (R$ 45 mil). Como a antecipação de recebíveis tem peso intermediário e a OP4 possui o prazo mais longo (quinze dias) e o pior desempenho no gargalo, seu valor global é o menor do conjunto. Isso evidencia o caráter compensatório do modelo: um desempenho excelente em um único critério não garante prioridade quando os critérios dominantes apontam em sentido contrário.

Do ponto de vista gerencial, o ranking orienta diretamente a alocação da matéria-prima escassa em estoque: a produção deve ser liberada na sequência OP1, OP6, OP3, até o esgotamento do saldo disponível, garantindo que as ordens de maior valor estratégico sejam atendidas primeiro. Considerando que o gargalo é a impressora flexográfica e que a liberação financeira depende do saldo aproximado de R$ 55 mil disponível na factoring no período, a priorização da OP1 assegura o cumprimento do prazo contratual junto a um cliente do segmento alimentício sujeito a multa por atraso, ao mesmo tempo em que mantém elevada a ocupação da impressora. Em comparação com a prática anterior de sequenciamento por ordem de chegada, espera-se, portanto, redução dos atrasos de entrega e aumento da ocupação do gargalo — efeitos cuja mensuração depende da substituição dos valores ilustrativos da Tabela 2 pelos dados reais da operação. O método também torna a decisão auditável, pois explicita os pesos e o desempenho que justificam cada posição.

Vale examinar o caso da OP6 com mais atenção, porque ele ilustra o que a modelagem acrescenta em relação à regra informal praticada anteriormente. Sob priorização por menor prazo de entrega, a OP6 seria a primeira da fila, já que possui o prazo mais curto da carteira. O modelo a desloca para a segunda posição não por desconsiderar o prazo — que permanece o critério de maior peso — mas porque a OP1, com prazo apenas um dia maior, é substancialmente superior no abastecimento do gargalo, segundo critério em importância. Em termos operacionais, a recomendação equivale a afirmar que vale a pena consumir um dia de folga no atendimento de um compromisso comercial para evitar ociosidade na impressora flexográfica, e

essa é exatamente a espécie de compensação que uma regra unidimensional é incapaz de expressar, ainda que o gerente a realize intuitivamente em alguns casos e não em outros.

Na direção oposta, a posição da OP2 também merece registro. Trata-se da ordem com o menor tempo de setup da carteira, condição que a regra de sequenciamento por menor tempo de processamento colocaria entre as primeiras, e que aqui a leva apenas à quinta posição. O motivo é que o setup recebeu o menor peso entre os quatro critérios, decisão do próprio decisor ao ordenar as constantes de escala: em uma operação cujo horizonte de decisão é o saldo de matéria-prima disponível, o tempo de preparação representa uma perda de capacidade marginal frente ao risco de multa contratual ou de parada do gargalo. Reconhecer isso explicitamente é um ganho, porque a mesma fábrica, em um período de estoque folgado e carteira sem urgências, poderia legitimamente ordenar os pesos de outra maneira — e o modelo torna essa mudança de contexto uma decisão consciente, e não uma inconsistência.

3.2 Análise de Sensibilidade

Como o FITradeoff opera com informação parcial sobre os pesos, o vetor utilizado é apenas representativo do espaço compatível com as preferências declaradas pelo decisor (k1 > k4 > k2 > k3). Para verificar a robustez do ranking, cada peso k_j foi variado individualmente em torno desse vetor, com renormalização proporcional dos demais, respeitando os limites impostos pela própria ordenação declarada. A Tabela 4 sintetiza os resultados por critério.

Tabela 4. Síntese da análise de sensibilidade por critério. Fonte: elaborado pelos autores.

Critério	Variação testada	Efeito sobre o ranking
C1 – Prazo	até −30% em k1 (limite: k1 > k4)	OP1 mantém a 1ª posição em todos os cenários admissíveis
C2 – Recebível	até +40% em k2	Extremos do ranking inalterados; pode inverter OP2 e OP5
C3 – Setup	até ±30% em k3 (peso mais incerto)	Extremos do ranking inalterados; pode inverter OP3 e OP6
C4 – Gargalo	até −30% em k4 (limite: k4 > k2)	OP1 mantém a 1ª posição em todos os cenários admissíveis

A primeira posição da OP1 mostrou-se estável mesmo diante de reduções de até 30% em k1 ou em k4, uma vez que a alternativa combina bom desempenho simultâneo nos dois critérios de maior peso; apenas reduções que violassem a própria ordenação k1 > k4 elicitada pelo decisor — portanto fora do espaço de pesos admissível pelo método — poderiam alterar esse resultado. De modo semelhante, a última posição da OP4 permaneceu inalterada em todos os cenários testados, já que seu desempenho fraco em prazo e em gargalo não é compensado pelo bom resultado em C2, mesmo elevando k2 até seu limite superior admissível.

Já a ordenação intermediária mostrou-se mais sensível: variações de aproximadamente 20% em k3 foram suficientes para aproximar os valores globais de OP3 e OP6, e variações semelhantes em k2 aproximaram OP2 e OP5, podendo inverter suas posições relativas. Em conjunto, a análise confirma que a recomendação central do modelo — priorizar a OP1 e deixar a OP4 por último — é robusta a variações moderadas nos pesos, enquanto a ordenação das posições intermediárias depende da precisão da informação sobre k2 e k3. Nesse último caso, o próprio caráter interativo do FITradeoff permite ao decisor fornecer novas comparações de preferência para reduzir essa indeterminação sempre que a distinção entre essas alternativas for relevante para a decisão.

Por fim, a análise de sensibilidade cumpre aqui um papel distinto do que desempenharia em um modelo de pesos exatos. Como o FITradeoff já opera sobre um espaço de vetores admissíveis, a variação dos pesos não testa uma hipótese externa ao modelo, mas percorre justamente o conjunto que a informação parcial deixou em aberto. O que a análise informa, portanto, é onde a indeterminação remanescente importa: entre OP1 e OP4 ela é irrelevante, porque nenhum vetor admissível inverte esses extremos, ao passo que entre OP3 e OP6 e entre OP2 e OP5 ela é decisiva. Essa leitura orienta o próprio uso do método na prática, indicando que novas rodadas de elicitação só se justificam quando a distinção entre alternativas intermediárias for operacionalmente relevante — por exemplo, quando o saldo de matéria-prima alcançar exatamente três ordens.

4 Originalidade/Valor

A contribuição deste trabalho está em mostrar que, em uma pequena empresa job-shop, a decisão de sequenciamento não é um problema puramente operacional. A estruturação prévia por VFT — ausente nas abordagens convencionais de sequenciamento — é o que garante que os critérios utilizados reflitam efetivamente os valores do decisor, e não apenas as variáveis já disponíveis nos sistemas de informação da fábrica. Foi essa etapa que trouxe para o modelo um critério financeiro (a antecipação de recebíveis junto à factoring) que nenhuma regra clássica de sequenciamento contemplaria, embora seja ele que, na prática, condiciona a liberação da produção.

O FITradeoff, por sua vez, viabilizou a modelagem em um contexto de recursos cognitivos e de tempo escassos: por exigir apenas informação parcial sobre os pesos, dispensou o decisor de declarar pontos exatos de indiferença e permitiu obter um ranking completo e justificável a partir de comparações estritas de preferência. O resultado integra dimensões operacionais, financeiras e estratégicas em um único modelo aditivo e oferece critério objetivo para a alocação do estoque escasso, substituindo a regra informal de priorização por menor prazo anteriormente praticada.

Do ponto de vista da replicabilidade, importa distinguir o que é próprio desta fábrica do que pode ser transposto. Os quatro critérios refletem uma configuração específica: um gargalo único e identificado, dependência de antecipação de recebíveis para liberação de produção e contratos com cláusula de multa por atraso. Alterada qualquer dessas condições — por exemplo, com a eliminação da dependência da factoring —, o conjunto de critérios deve ser reestruturado, e não apenas reponderado. O que se transfere é o procedimento: partir dos valores do decisor para chegar aos critérios, verificar as propriedades de essencialidade e não redundância antes de operacionalizá-los, e resolver a ordenação com informação parcial sobre os pesos em vez de exigir precisão que o decisor não possui.

Como limitações, destacam-se o uso de um conjunto ilustrativo de ordens de produção e a consideração de um único decisor, o que recomenda a recalibração da matriz de consequências com dados reais antes do uso em decisões efetivas. Como trabalhos futuros, sugere-se a aplicação do FITradeoff em contexto de decisão em grupo, incorporando as preferências das áreas comercial, financeira e de produção, bem como a integração do ranking a um modelo de sequenciamento que considere explicitamente as restrições de capacidade do gargalo ao longo do horizonte de planejamento. Recomenda-se ainda acompanhar, ao longo de alguns ciclos de liberação, a divergência entre a sequência recomendada pelo modelo e a efetivamente executada: divergências recorrentes na mesma direção indicariam que algum aspecto relevante da decisão permaneceu fora dos quatro critérios estruturados, sinalizando a necessidade de revisão da hierarquia de objetivos e não apenas dos pesos.

Referências

de Almeida, A.T., Cavalcante, C.A.V., Alencar, M.H., Ferreira, R.J.P., Almeida-Filho, A.T., Garcez, T.V. (2015), *Multicriteria and Multiobjective Models for Risk, Reliability and Maintenance Decision Analysis*. Springer, New York.

de Almeida, A.T., Almeida, J.A., Costa, A.P.C.S., Almeida-Filho, A.T. (2016), A new method for elicitation of criteria weights in additive models: flexible and interactive tradeoff. *European Journal of Operational Research*, 250(1), 179-191.

de Almeida, A.T., Frej, E.A., Roselli, L.R.P. (2021), Combining holistic and decomposition paradigms in preference modeling with the flexibility of FITradeoff. *Central European Journal of Operations Research*, 29, 7-47.

Frej, E.A., de Almeida, A.T., Costa, A.P.C.S. (2019), Using data visualization for ranking alternatives with partial information and interactive tradeoff elicitation. *Operational Research*, 19, 909-931.

Kang, T.H.A., Frej, E.A., de Almeida, A.T. (2020), Flexible and interactive tradeoff elicitation for multicriteria sorting problems. *Asia-Pacific Journal of Operational Research*, 37(5), 2050020.

Keeney, R.L. (1992), *Value-Focused Thinking: A Path to Creative Decisionmaking*. Harvard University Press, Cambridge, MA.

Keeney, R.L., Raiffa, H. (1976), *Decisions with Multiple Objectives: Preferences and Value Trade-offs*. Wiley, New York.

Marques, A.C., Frej, E.A., de Almeida, A.T. (2022), Multicriteria decision support for project portfolio selection with the FITradeoff method. *Omega*, 111, 102661.

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Machine Learning applied to eco-innovation assessment

Isadora Valentim Vieira da Motta[1], Edilvando Pereira Eufrazio[2] and Helder Gomes Costa

[1]Universidade Federal Fluminense, Rua Passos da Pátria, 156, Blodo D, Niterói, 24210-240, Brazil
[1]EMBRAPA, Rodovia dos Pioneiros MT-222, Km 2,5, Zona Rural, Sinop,78550-970, Brazil

isadoravvm@id.uff.br, heldergc@id.uff.br, edilvando.eufrazio@embrapa.br

Abstract. This study proposes a cluster-based approach to complement the traditional assessment of eco-innovation performance based on the Eco-Innovation Index (EII). While the EII provides a synthetic score and ranking, the representation of performance through an aggregate score may hide multidimensional differences among countries with heterogeneous structural and economic characteristics. Using the 2024 EII dataset, which covers the 27 European Union Member States, this study applies the unsupervised machine learning algorithm K-means to identify groups of countries with similar eco-innovation profiles across the 12 EII indicators. Missing values in the Water Productivity indicator were addressed through alternative imputation strategies, and the resulting cluster solutions were compared as a sensitivity analysis. The results indicate the formation of three interpretable clusters: a group of leading eco-innovation countries, a group with intermediate and heterogeneous performance, and a group with lower overall performance and structural limitations. The comparison with the official EII 2024 classification shows partial agreement, suggesting that the proposed approach captures relevant multidimensional patterns that are not fully represented by the aggregate score. The study contributes by offering a profile-oriented interpretation of eco-innovation performance, allowing the identification of groups of countries with distinct needs and supporting more targeted strategic recommendations.

Keywords: Eco-innovation Index, K-means, Machine Learning, Clustering

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Toward Intelligent Decision-Making: A systematic review of hybrid frameworks combining multi-criteria analysis and generative AI

Brunno e Souza Rodrigues[1], Carla Martins Floriano[1], Diogo Ferreira de Lima Silva[1], and Helder Gomes Costa[1]

Universidade Federal Fluminense, Campus Praia Vermelha, Niterói, RJ, Brazil

Abstract. The convergence of Multi-criteria Decision Analysis (MCDA) and Generative Artificial Intelligence (Gen AI) represents a promising frontier in Decision Sciences, offering new capabilities for structured, adaptive and context-aware decision-making. At this stage of development, there is a lack of knowledge about what are the gaps and tendencies of research in this subject. This study presents a structured examination of frameworks that integrated both techniques (MCDA and Gen AI), organizing them into four categories based on the nature of integration: 'Selection', 'Integration', 'Improvement', and 'Analog'. The research highlights the methodological synergies between MCDA and Gen AI, such as enhanced decision quality, improved scalability, and greater inclusivity. This study contributes a foundational synthesis of the emerging AI-MCDA paradigm and outlines a roadmap for advancing intelligent decision-making frameworks.

Keywords: Multi-Criteria · Generative artificial intelligence · Hybrid frameworks.

1 Introduction

Multi-Criteria Decision Analysis (MCDA) encompasses a suite of methodologies designed to support decision-making processes evaluating alternatives involving multiple, often conflicting, criteria [9]. These criteria may originate from both quantitative and qualitative sources, as many MCDA techniques are capable of incorporating subjective judgments and non-numeric information.

In complex decision-making contexts, the ability to appropriately structure the problem is critical. Well-structured problems are more likely to lead to effective and robust decisions, as they facilitate the integration of abstract preferences and subjective values throughout both the problem formulation and resolution processes [24]. However, as data environments become increasingly voluminous, heterogeneous, and dynamic, traditional MCDA approaches face growing limitations in terms of scalability, adaptability, and interpretability [3]. In parallel, the emergence of generative artificial intelligence (Gen AI) – particularly large language models (LLMs) – has introduced transformative capabilities in data

synthesis, natural language understanding, and human-machine interaction. As stated by [19], these models exhibit significant potential in supporting complex decision-making by generating structured insights, simulating expert reasoning, and/or facilitating stakeholder engagement.

These developments point out to a paradigm shift in the field of Decision Sciences, characterized by the convergence of structured decision methodologies and adaptive, generative technologies.

While MCDA provides a robust foundation for structured decision-making, Gen AI contributes with novel capabilities in knowledge elicitation, contextual reasoning, and adaptive modeling. Together, these approaches offer a hybrid framework capable of addressing the increasing complexity and dynamism of real-world decision environments.

Yet, as highlighted by [13], the literature remains sparse in terms of comprehensive studies that systematically integrate Gen AI techniques with MCDA methods. This gap can hinder the consolidation of knowledge and the development of a cohesive understanding of the potential synergies between these domains.

In this context, the primary objective of this study is to present a systematic review of the existing literature on the integration of MCDA methods with Gen AI techniques. Specifically, the study aims to identify emerging patterns, highlight methodological opportunities, and propose future research directions that can support the development of more adaptive and intelligent decision support systems. Ultimately, this review seeks to advance the understanding of how the convergence of MCDA and Gen AI can enhance decision-making processes across diverse application domains.

2 Method

This systematic literature review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines, as developed by [16]. The PRISMA 2020 protocol was adopted due to its widespread acceptance and methodological rigor, evidenced by its extensive citation record in the Scopus database. It serves as a guidance for ensuring transparency, reproducibility, and comprehensiveness in systematic reviews.

2.1 Search strategy

A comprehensive bibliographic search was performed across two major scientific databases: Scopus and Web of Science (WoS). The objective was to identify the relevant peer-reviewed studies that provide a technical foundation for the integration of multi-criteria methods with generative artificial intelligence models.

The search strategy was structured into five sequential filtering layers to maximize the retrieval of relevant literature (see Table 1).

Table 1. Keywords for literature review

Layer	Keywords	Operator	No. of papers
1	"multi criteria" OR "multi-criteria" OR "multi-criteria" OR MCDA OR MCDM	AND	149,575
2	llm OR "large language model*" OR "generative ai" OR "generative artificial intelligence" OR "gen-ai"	AND	82
3	EXCLUDE (DOCTYPE , "tb")	AND	82
4	LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "cp")	AND	59
5	LIMIT-TO (LANGUAGE , "English")	AND	59

2.2 Study selection

The study selection process followed the PRISMA 2020 flow diagram, which provides a structured and transparent approach for identifying, screening, and including relevant studies. The initial search yielded 59 records. After the removal of 28 duplicates, 31 unique records remained for screening.

Metadata from these records – including titles, authors name, source titles, publication years, abstracts, and keywords – were exported to a Microsoft Excel spreadsheet to facilitate eligibility assessment and data extraction. During the initial screening phase, 9 studies were excluded based on their titles and/or abstracts, as they did not align with the research scope. The remaining 22 studies were retrieved in full-text format, all of which were accessible and included in the final review.

To ensure accessibility throughout the research process, all selected articles were stored in a local digital repository, enabling both online and offline access for analysis and reference.

3 Descriptive Statistics

Following the retrieval of the articles from the Scopus and WoS databases, a systematic screening process was undertaken to identify studies aligned with the scope of this study. Subsequently, a descriptive statistical analysis was performed to characterize the selected literature. Table 2 consolidates the key attributes of the 22 studies deemed relevant to the intersection of multi-criteria decision analysis methods and generative artificial intelligence models.

Table 2: Selected studies.

Citation	Technique		Classification				Domain
	MCDA	AI	S	I	Ip	A	
[3]	FWZIC; MAIRCA	GatorTron GPT; Clinical BERT	✓	×	×	×	Healthcare
[19]	AHP; TISM; MICMAC	ChatGPT	×	×	✓	×	Healthcare
[12]	Delphi	ChatGPT	×	×	✓	×	Civil engineering
[21]	H-ANP	Generic LLM	×	✓	×	×	Social computing
[7]	Entropy-FlowSort	ChatGPT-4	×	✓	×	×	Social computing
[8]	AHP; TOPSIS	BTM; ChatGPT; Midjourney	×	✓	×	×	Industrial design
[15]	TOPSIS	GPT3.5; GPT4; Bard; Llama2; Mistral	✓	×	×	×	Healthcare
[20]	DEMATEL	ChatGPT; Perplexity; Claude; Gemini; Scite.ai	✓	×	×	×	Academic research
[22]	Generic MCDA framework	ChatGPT-4	×	×	✓	×	Healthcare
[14]	DEMATEL; TOPSIS	ChatGPT	×	✓	×	×	Automotive
[6]	Fuzzy DEMATEL	GAN; GLM; RNN; CNN; VAE; GNN	✓	×	×	×	Energy
[4]	FBWM	ChatGPT-4	×	×	✓	×	Project management
[17]	AHP	ChatGPT-4	×	✓	×	✓	Agriculture
[25]	TOPSIS; AHP; WPHFS	GAN	×	✓	×	×	Logistics
[11]	TSFV	VLT	✓	×	×	×	Journalism

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Citation	Technique		Classification				Domain
	MCDA	**AI**	S	I	**Ip**	**A**	
[10]	TOPSIS	ChatGPT; Copilot; Gemini; Claude; Perplexity	✓	×	×	×	Computing
[5]	TOPSIS; VIKOR; RIM	LLAMA 3; RAG	×	×	✓	×	Politics
[23]	Gaussian AHP	GAN	×	×	✓	×	Computing
[2]	Fuzzy AHP	16 different LLMs	×	✓	×	×	Healthcare
[1]	MAIRCA	10 different blockchain platforms based in LLM	✓	×	×	×	Computing
[13]	Generic MCDA framework	Generic LLM-based chatbot	×	✓	×	×	Transport
[18]	FWZICbIP + C-q-ROFS + CPOS	40 different LLMs	✓	×	×	×	Computing

S= Selection; I= Integration; Ip= Improvement; A=Analog

The analytical procedure was structured in four stages: initially, the studies were classified according with the specific MCDA method employed; in the second stage, the type of generative AI model utilized in each study was identified; the third stage involved examining the nature of the interaction between the MCDA method and the AI model, which was categorized into one of four types ('Selection', 'Integration', 'Improvement' or 'Analog'); and, finally, the domain or source of the data used in each study was recorded to provide contextual grounding.

Among the MCDA techniques employed, AHP (Analytic Hierarchy Process) and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) emerged as the most frequently used methods, appearing in 6 studies each, followed by DEMATEL (Decision-Making Trial and Evaluation Laboratory) in 3 studies, and FWZIC (Fuzzy-Weighted Zero-Inconsistency) and MAIRCA (Multi-Attributive Ideal-Real Comparative Analysis) in 2 studies each. These methods were often adapted or extended using fuzzy logic or hybrid frameworks to better accommodate the uncertainty and complexity inherent in AI-driven decision environments.

The generative artificial intelligence studies were predominantly represented by ChatGPT (and its variations), which were utilized in 15 of the 22 papers. Other notable models included GANs (Generative Adversarial Networks; 3 papers), Claude, Gemini, LLAMA, and Perplexity (2 papers each) indicating a diverse but concentrated use of state-of-the-art generative models.

The predominance of ChatGPT-based studies also introduces a potential technological concentration bias into this review. The observed frequencies of Selection, Integration, Improvement, and Analog interactions may partly reflect the accessibility, popularity, and conversational affordances of this platform rather than the full range of relationships between MCDA and GenAI. For example, models designed for image generation, multimodal reasoning, domain-specific inference, or synthetic data generation may support interaction patterns that are underrepresented in the current taxonomy. The proposed framework should therefore be interpreted as an evidence-based representation of the current literature rather than as an exhaustive or technology-neutral classification. Its stability should be reassessed as studies involving alternative LLMs, multimodal transformers, diffusion models, and domain-specific generative architectures become more prevalent.

The reviewed studies span a wide range of application domains, with computing being the most prominent (5 studies), followed by healthcare (4 studies), and industrial and logistics (2 studies each). Other domains include civil engineering, industrial design, agriculture, and energy, demonstrating the broad applicability of MCDA-AI integration (Figure 1a).

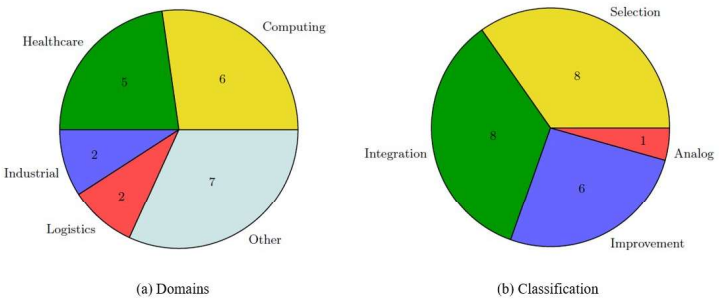

Fig. 1. Domain and classification.

All the 22 studies analyzed were published between 2024 and 2025. This reflects the emergent and rapidly evolving nature of this interdisciplinary research area. The average citation count is 1.18, reflecting the early stage but growing influence of this research area.

The studies could also be categorized into four interaction types based on how MCDA and generative AI were combined. These paper's applications were consistently observed to fall within at least one or more of the four categories:

'Selection' (where MCDA supports the selection/evaluation of AI models), 'Integration' (where both techniques are jointly applied), 'Improvement' (where one method enhances the performance of the other), or Analog (where conceptual parallels are drawn between the two paradigms).

In Figure 1b, the studies are aggregated by classification type. It is possible to see that the classification with the highest predominance is 'Selection', with 34.8% occurrence among the 22 articles (8 studies), followed by 'Improvement' and 'Integration', both with 30.4% occurrence (7 studies), and 'Analog', with 4.3% (only 1 study). This distribution highlights the balanced exploration of both evaluative and transformative uses of AI-MCDA combination.

The 'Selection' classification (Figure 2a) was identified in studies that applied Multi-Criteria Decision Analysis methods to determine the most effective generative artificial intelligence model. In this context, "effectiveness" refers to the model's ability to produce the most promising outcomes when applied to specific inputs. Through the application of MCDA techniques, generative AI models are systematically evaluated and/or ranked, thereby enabling the identification of the model that exhibits superior performance across predefined criteria.

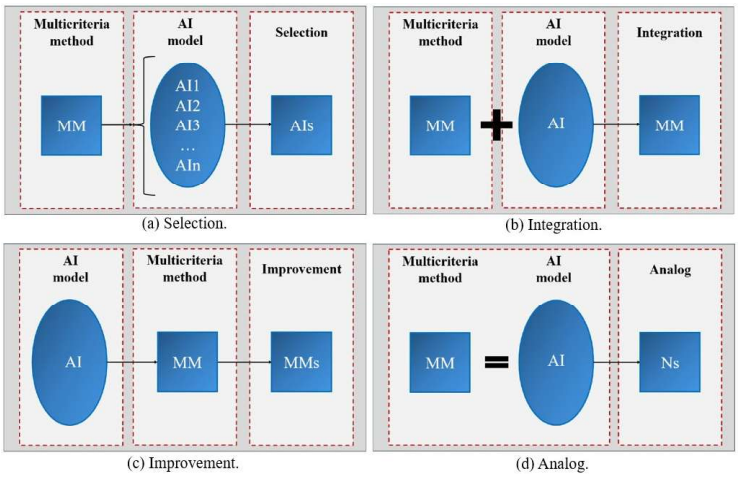

Fig. 2. MCDA and AI interactions.

The 'Integration' classification (Figure 2b) refers to studies in which Multi-Criteria Decision Analysis methods were employed in a synergistic manner with generative artificial intelligence models. This integrated approach is mainly adopted with the objective of enhancing the robustness and reliability of the analytical outcomes, leveraging the complementary strengths of both methodologies.

The 'Improvement' classification (see Figure 2c) encompasses studies in which Multi-Criteria Decision Analysis methods were enhanced through the combina-

tion with generative artificial intelligence models. In these instances, the generative AI models were employed to adjust or optimize the parameters of the MCDA frameworks, thereby improving the methodological precision and accuracy of the decision-making process.

Finally, the 'Analog' classification (Figure 2d) refers to studies in which the generative artificial intelligence model is utilized directly as a decision-making mechanism, effectively assuming the role traditionally occupied by structured decision-support methodologies.

4 Results

This section synthesizes findings from the 22 included studies according to the interaction typology introduced earlier, which distinguishes four modes of coupling between MCDA and GenAI: Selection, Integration, Improvement, and Analog.

Overall, the results indicate that the literature is currently oriented toward: (i) structuring model/tool choice for generative systems through MCDA (Selection), (ii) embedding LLMs or generative models into the MCDA workflow to transform unstructured information into decision-analytic inputs (Integration), (iii) mutual performance enhancement (Improvement), and (iv) exploratory attempts to use LLMs as functional analogs of established MCDA procedures (Analog).

4.1 Studies classified as 'Selection'

The "Selection" comprises studies in which MCDA is used as a formal evaluation layer to compare, benchmark, and rank alternative GenAI systems (e.g., LLMs, chatbots, or GenAI-enabled platforms) against multiple criteria. This body of work is motivated by a recurring methodological concern: GenAI evaluation is typically multi-dimensional and therefore benefits from explicit trade-off modelling and traceable aggregation, which are defining features of MCDA-based decision support.

A consistent pattern within this category is the use of MCDA to consolidate heterogeneous evidence into a single, interpretable ranking that can be communicated to stakeholders. In the healthcare domain, [3] operationalize this logic by combining FWZIC and MAIRCA in a fuzzy environment to evaluate medical LLM variants for clinical relation and concept extraction, thereby embedding uncertainty representation into the weighting and ranking process.

A second methodologically distinct pattern is Selection via causal-structure modelling, where the goal is not only to rank tools but also to clarify which criteria drive others. [20] use an improved group DEMATEL formulation to model interdependencies among criteria for selecting GenAI tools in academic research, distinguishing "driving" from "dependent" criteria and thereby supporting a more explanatory selection rationale.

The Selection logic has been applied to emerging GenAI modalities and application settings. [11] proposes a multi-criteria group decision approach based on

T-spherical fuzzy sets to evaluate vision-language transformers for multimodal news authenticity and integrity, demonstrating that MCDA can impose transparent evaluation logic even when model outputs are multimodal and the notion of "quality" is intrinsically multi-attribute.

Taken together, Selection studies position MCDA as a response to two practical challenges in GenAI adoption: (i) the need to make multi-dimensional evaluation explicit, and (ii) the need to justify choices under uncertainty in a manner that can be scrutinized and reproduced.

4.2 Studies classified as 'Integration'

The "Integration" category includes studies in which GenAI is embedded into the MCDA workflow as an operational component, typically to transform unstructured information into structured decision inputs (criteria, weights, performance scores), to generate alternatives, or to support stakeholder interaction at scale. Whereas Selection treats GenAI systems as the objects being evaluated, Integration treats GenAI as a mechanism that reshapes how MCDA models are populated and executed, especially in contexts where information is predominantly textual, qualitative, or otherwise difficult to encode.

One integration pattern is "LLM-to-decision-matrix" translation, where generative models are used to operationalize qualitative judgments in a format suitable for MCDA computations. [7] illustrate this by using ChatGPT-4 to assess social media posts on sensitivity-related attributes and then applying FlowSort to classify content into ordered categories; here, GenAI is not the decision rule but rather the mechanism that produces structured evaluations that MCDA can aggregate and audit.

A second integration pattern centers on generative creation of alternatives followed by MCDA evaluation. [8] propose a design workflow in which AHP structures and prioritizes packaging design requirements, an LLM translates those priorities into prompts for generative content creation (via a text-to-image pipeline), and TOPSIS ranks the generated designs; importantly, MCDA is preserved as the explicit preference model while GenAI expands the feasible design space.

A third integration pattern is data augmentation and synthetic evidence generation. [25] integrate GAN-based synthetic data generation with fuzzy MCDA weighting and TOPSIS ranking in a weighted Pythagorean hesitant fuzzy environment, targeting decision contexts characterized by uncertainty and dynamic conditions; in this case, the generative model expands the empirical basis on which MCDA is applied.

Finally, a prominent conceptual contribution in the Integration cluster is the introduction of synthetic stakeholder representations. [13] propose Synthetic MCDA (S-MCDA), embedding LLMs as "synthetic actors" trained on domain-specific data to emulate stakeholder perspectives for criteria elicitation, alternative generation, and mediation of conflicting viewpoints, while explicitly emphasizing the necessity of human oversight for contextual, ethical, and methodological integrity.

Across these studies, Integration work can be interpreted as addressing a practical bottleneck in real-world MCDA: the conversion of complex, qualitative, and evolving information into stable representations suitable for formal evaluation. By positioning GenAI as a structuring and augmentation layer — rather than as the final decision rule — these papers preserve the core MCDA promise of transparency while extending feasibility to domains dominated by unstructured evidence.

4.3 Studies classified as 'Improvement'

The "Improvement" category comprises studies where MCDA and GenAI are coupled such that one component is used to enhance the performance, scalability, or usability of the other. In contrast to Integration — which embeds GenAI mainly to generate decision inputs — Improvement work typically targets methodological optimization: GenAI is used to reduce elicitation burden or refine MCDA parameterization, or MCDA is used to guide multi-objective optimization and governance of GenAI systems.

One dominant pattern is the use of LLMs as "virtual experts" or elicitation aids within MCDA. [4] integrate ChatGPT-4 with a fuzzy Best–Worst Method (FBWM), tasking the LLM with selecting best/worst criteria and producing fuzzy pairwise comparisons that are then converted to triangular fuzzy numbers to derive weights; the central claim is improved efficiency and consistency in settings where expert time is limited.

A second pattern involves using MCDA to structure and optimize GenAI deployment decisions, especially when non-technical criteria (e.g. accountability, fairness, usability) must be balanced with performance. [19] develop a framework for safer and more effective LLM implementation in medical education by combining AHP prioritization with interpretive structural modelling and MICMAC analysis to map interdependencies among enabling factors (e.g. transparency and explainability), thereby producing an actionable roadmap grounded in structured multi-criteria reasoning.

A third, technically oriented pattern positions MCDA as a multi-objective optimizer for GenAI configurations. [5] combine an LLM and retrieval-augmented generation with MCDA methods (RIM, TOPSIS, VIKOR) to guide the optimization of system hyperparameters under multiple objectives that include ethical alignment and efficiency; here MCDA functions as the explicit trade-off engine linking technical decisions to normative requirements.

Collectively, Improvement studies underscore that hybrid MCDA–GenAI artifacts are not confined to using LLMs inside decision models but also include using decision models to govern LLMs. This bidirectionality is particularly relevant for adaptive decision support systems: GenAI can increase speed and coverage of elicitation and synthesis, while MCDA can preserve explicitness of values and constraints, which becomes crucial when GenAI systems are tuned or deployed under competing objectives and stakeholder requirements.

4.4 Studies classified as 'Analog'

The "Analog" category refers to studies that use GenAI in a role functionally comparable to an MCDA method; i.e., GenAI is not merely generating inputs or assisting optimization but is tasked with reproducing substantive elements of MCDA reasoning such as criteria structuring, hierarchy construction, and pairwise comparison generation. Within the present evidence base, this remains the least developed stream, represented by a single study, which signals both novelty and the absence of consolidated evaluation standards for this class of hybridization.

[17] examine whether fine-tuned LLMs can emulate core AHP modelling steps, including constructing AHP hierarchies, identifying criteria and sub-criteria, and generating pairwise comparison matrices. The authors report that fine-tuned models align more closely with expert judgements and can exhibit improved consistency compared with baseline configurations; additionally, when criteria are not predefined, the models can propose plausible evaluation dimensions, suggesting a generative capacity that extends beyond rote replication of provided structures.

From a MCDA perspective, the relevance of Analog work lies in its challenge to the conventional separation between (i) a formal preference model and (ii) a computational aid. If a LLM can generate not only candidate criteria but also the relational structures and comparison matrices that constitute the MCDA model itself, then validation shifts from verifying calculations to verifying the legitimacy of model construction, raising questions about accountability, reproducibility, and the extent to which "AI-generated preferences" can be treated as decision-analytic inputs.

Although this stream is nascent, it connects logically to the Integration and Improvement findings: Integration shows that LLMs can translate unstructured evidence into MCDA-ready structures, while Improvement shows that LLMs can reduce elicitation burden and MCDA can govern GenAI systems. Analog approaches can be understood as an extreme point on this continuum, where the generative model attempts to internalize the representational tasks traditionally performed through structured elicitation.

The limited empirical basis of the Analog category must nevertheless be acknowledged. The category may represent an isolated exploratory configuration rather than a consolidated mode of MCDA–GenAI interaction. Its conceptual relevance is supported by the distinctive role assigned to the LLM, but its empirical robustness, internal diversity, and boundaries in relation to Integration and Improvement cannot yet be established. Therefore, the Analog class should be interpreted as a provisional analytical category and a hypothesis for future validation, rather than as a mature stream with stable characteristics.

5 GAPs in the Field

Despite the promising convergence between Multi-Criteria Decision Analysis methods and Generative Artificial Intelligence, this systematic literature review

revealed critical gaps that hinder the full realization of this interdisciplinary potential. These gaps spanned methodological, technological, and application-oriented dimensions, but show fertile ground for future research.

The combination of MCDA and Gen AI remains in its formative stages, and several methodological limitations are evident across the reviewed literature. While the convergence of these domains offers significant potential, current approaches often lack theoretical cohesion, standardized procedures, and methodological rigor. Most studies adopt narrowly scoped frameworks, which limits comparability and scalability. Furthermore, the reliance on a small subset of MCDA techniques suggests that the methodological landscape is still maturing. The key methodological gaps identified in the literature were:

- Limited standardization of hybrid frameworks: Most reviewed studies propose ad hoc integrations of MCDA and Gen AI, lacking standardized protocols or design patterns. This limits reproducibility and cross-domain applicability.
- Sparse use of advanced MCDA techniques: The dominance of AHP and TOPSIS suggests underutilization of other MCDA methods (e.g. ELECTRE, PROMETHEE) that could offer different perspectives to handle uncertainty, imprecision, and conflicting decision-maker preferences.

Furthermore, although Gen AI technologies have introduced powerful capabilities into decision-support systems, their integration with MCDA frameworks remains technologically restricted. The reviewed studies revealed a predominant reliance on a narrow set of generative models — particularly ChatGPT — while overlooking the broader spectrum of available architectures, such as multimodal transformers and diffusion models. Moreover, the lack of mechanisms for explainability and transparency limits the practical deployment of these hybrid systems in dynamic environments. The key technological limitations observed were:

- Overreliance on ChatGPT and similar LLMs: While ChatGPT and its variants dominate the reviewed literature, there is limited exploration of other generative models (e.g. diffusion models, multimodal transformers) that could enrich decision-making contexts.
- Lack of explainability and transparency mechanisms: Few studies address the interpretability of Gen AI outputs within MCDA frameworks, which is critical for decision-maker trust and ethical deployment.

Finally, this research also revealed a concentration in a few domains — most notably computing and healthcare — while many other areas remain underrepresented. The practical deployment of these hybrid frameworks often lacks empirical validation, particularly in real-world decision-making contexts involving diverse decision-maker groups. The use of synthetic actors and AI-generated inputs is conceptually promising, yet their effectiveness in capturing nuanced human perspectives has not been rigorously tested. Moreover, ethical, social, and governance dimensions of applying Gen AI in decision-making are seldom addressed, despite their growing relevance. The key application were:

- Narrow domain coverage: Despite of computing and healthcare were well represented, other domains such as environmental, education and public safety remain underexplored.
- Limited stakeholder engagement: While synthetic actors are proposed in some studies, there is a lack of empirical validation regarding their effectiveness in simulating diverse decision-maker perspectives.
- Ethical and governance considerations: The ethical implications of using Gen AI in decision-making, such as bias propagation, accountability and data privacy, were rarely addressed in depth.
- Reliability, error propagation and output instability: Gen AI may generate hallucinated facts, unsupported criteria, inconsistent pairwise comparisons, omitted alternatives, or unstable scores that do not represent actual preferences. The formal consistency of the MCDA calculation does not guarantee the validity of its inputs.

Building upon the identified methodological, technological and application gaps, different promising avenues emerge for future research at the intersection of MCDA and Gen AI. As this interdisciplinary field continues to evolve, there is a need for more robust, scalable, and ethically grounded frameworks that can support intelligent decision-making across diverse contexts. Future studies should aim to deepen theoretical foundations, broaden technological experimentation, and validate practical implementations through real-world case studies.

6 Conclusion

This study was set out to systematically explore the intersection of Multi-Criteria Decision Analysis and generative artificial intelligence, with the main research goals of identify emerging patterns, highlight methodological opportunities, propose future research directions that can support the development of more adaptive and intelligent decision support systems, and advance the understanding of how the convergence of MCDA and Gen AI can enhance decision-making processes across diverse application domains. The aim was to identify, classify, and analyze the existing literature to understand the current landscape and future potential of this interdisciplinary convergence.

The systematic review identified 22 peer-reviewed studies published between 2024 and 2025, which were categorized into four functional classifications: 'Selection' (usage of MCDA methods to evaluate and/or rank generative AI models); 'Integration' (Gen AI to generate synthetic MCDA inputs); 'Improvement' (Gen AI techniques to optimize MCDA parameters or vice versa); and Analog (LLMs to replicate MCDA logic).

The most frequently used MCDA techniques were AHP and TOPSIS, while ChatGPT and its variants dominated the generative AI landscape. Applications spanned diverse domains, including healthcare, computing, logistics, energy, and public policy.

This study reveals a rapidly emerging research frontier where structured decision-making methodologies are being enhanced by the adaptive, generative

capabilities of AI. The integration of MCDA and generative AI offers several transformative benefits, including:

- Improved inclusivity and scalability in participatory decision-making (via synthetic stakeholders).
- Enhanced decision quality through hybrid reasoning and data synthesis.
- Greater methodological flexibility in handling uncertainty, subjectivity, and qualitative data.

These findings underscore the potential of AI-MCDA frameworks to support more intelligent, transparent, and context-aware decision-support systems across different domains.

From the point of view of practical implications, the four-category framework can support the design and governance of hybrid decision-support systems. Selection is appropriate when an organization must compare alternative Gen AI models or platforms against technical, economic, ethical, or operational criteria. Integration is suitable when Gen AI is used to transform unstructured evidence into candidate criteria, alternatives, or performance assessments, while MCDA retains responsibility for preference modelling. Improvement applies when Gen AI reduces elicitation effort or when MCDA governs the configuration of Gen AI systems under competing objectives. Analog should currently be restricted to exploratory and low-risk settings because the generative model assumes tasks traditionally performed through structured preference elicitation.

For implementation, the framework suggests a staged workflow: define the decision problem and accountability structure; select the appropriate interaction category; specify which inputs may be generated by AI; verify AI-generated criteria, alternatives, comparisons, and scores; execute the MCDA model; perform consistency and sensitivity analyses; and retain a human decision-maker as the final approval authority. Thus, the taxonomy is not only descriptive. It provides a practical basis for allocating responsibilities between Gen AI, the MCDA model, experts, and final decision-makers.

Based on this, several avenues for future research are recommended, including: assess the real-world impact and sustainability of adoption of this hybrid approach; exploration of ethical and governance implications of using generative AI in decision-making; advancement of 'Analog' approaches, where LLMs autonomously perform or augment MCDA tasks, potentially leading to fully AI-driven decision systems.

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References

1. Ahmed, H., Gamal, A., Abdelmouty, A.: Optimizing blockchain platform selection: A decision-making approach using llms, type-2 neutrosophic numbers, critic, and mairca. Neutrosophic Sets and Systems **83**, 413 – 455 (2025). https://doi.org/10.5281/zenodo.15127966

2. Alabool, H.M.: Large language model evaluation criteria framework in healthcare: Fuzzy mcdm approach. SN Computer Science **6**(1) (2025). https://doi.org/10.1007/s42979-024-03533-6
3. Alamoodi, A., Zughoul, O., David, D., Garfan, S., Pamucar, D., Albahri, O., Albahri, A., Yussof, S., Sharaf, I.M.: A novel evaluation framework for medical llms: Combining fuzzy logic and mcdm for medical relation and clinical concept extraction. Journal of Medical Systems **48**(1) (2024). https://doi.org/10.1007/s10916-024-02090-y
4. Aljohani, B., Aljuhani, A., Alsanoosy, T.: Enhancing agile requirements change management: Integrating llms with fuzzy best-worst method for decision support. International Journal of Advanced Computer Science and Applications **16**(3), 1071 – 1079 (2025). https://doi.org/10.14569/IJACSA.2025.01603103
5. Castellanos-Nieves, D., García-Forte, L.: Human-centered ai for migrant integration through llm and rag optimization. Applied Sciences (Switzerland) **15**(1) (2025). https://doi.org/10.3390/app15010325
6. Fontoura, L., Luiz de Mattos Nascimento, D., Neto, J.V., Gusmão Caiado, R.G.: Energy gen-ai technology framework: A perspective of energy efficiency and business ethics in operation management. Technology in Society **81** (2025). https://doi.org/10.1016/j.techsoc.2025.102847
7. Galamiton, N., Bacus, S., Fuentes, N., Ugang, J., Villarosa, R., Wenceslao, C., Ocampo, L.: Predictive modelling for sensitive social media contents using entropy-flowsort and artificial neural networks initialized by large language models. International Journal of Computational Intelligence Systems **17**(1) (2024). https://doi.org/10.1007/s44196-024-00668-5
8. Gao, Z., Li, Z.: A tea packaging design method based on artificial intelligence generated content. Journal of Engineering Design (2025). https://doi.org/10.1080/09544828.2025.2489647
9. Greco, S., Słowiński, R., Wallenius, J.: Fifty years of multiple criteria decision analysis: From classical methods to robust ordinal regression. European Journal of Operational Research **323**(2), 351–377 (2025). https://doi.org/10.1016/j.ejor.2024.07.038
10. Ilieva, G.: Extension of interval-valued hesitant fermatean fuzzy topsis for evaluating and benchmarking of generative ai chatbots. Electronics (Switzerland) **14**(3) (2025). https://doi.org/10.3390/electronics14030555
11. Liu, J.: Evaluation of vision-language transformers for multimodal news authenticity and integrity in journalism: A multi-criteria decision-making approach. IEEE Access **13**, 2424 – 2435 (2025). https://doi.org/10.1109/ACCESS.2024.3523704
12. Maceika, A., Bugajev, A., Šostak, O.R.: Evaluating modular house construction projects: A delphi method enhanced by conversational ai. Buildings **14**(6) (2024). https://doi.org/10.3390/buildings14061696
13. Manzolli, J.A., Yu, J., Miranda-Moreno, L.: Synthetic multi-criteria decision analysis (s-mcda): A new framework for participatory transportation planning. Transportation Research Interdisciplinary Perspectives **31** (2025). https://doi.org/10.1016/j.trip.2025.101463
14. Mohammed, A., Al Balushi, F.A., Zubairu, N., Govindan, K.: Dynamics capabilities 5.0 toward inner business resiliency: A conceptual and evaluation panacea. Computers and Industrial Engineering **206** (2025). https://doi.org/10.1016/j.cie.2025.111223
15. Nemati, A., Assadi Shalmani, M., Lu, Q., Luo, J.: Benchmarking large language models from open and closed source models to apply data annotation for free-text

criteria in healthcare. Future Internet **17**(4) (2025). https://doi.org/10.3390/fi17040138
16. Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., Shamseer, L., Tetzlaff, J.M., Akl, E.A., Brennan, S.E., Chou, R., Glanville, J., Grimshaw, J.M., Hróbjartsson, A., Lalu, M.M., Li, T., Loder, E.W., Mayo-Wilson, E., McDonald, S., McGuinness, L.A., Stewart, L.A., Thomas, J., Tricco, A.C., Welch, V.A., Whiting, P., Moher, D.: The prisma 2020 statement: An updated guideline for reporting systematic reviews. BMJ **372** (2021). https://doi.org/10.1136/bmj.n71
17. Park, H., Oh, H., Gao, F., Kwon, O.: Enhancing analytic hierarchy process modelling under uncertainty with fine-tuning llm. Expert Systems **42**(6) (2025). https://doi.org/10.1111/exsy.70051
18. Qahtan, S., Mourad, N., Alsattar, H., Zaidan, A., Zaidan, B., Pamucar, D., Simic, V., Ding, W., Yatim, K.: Three-way decision approach based on utility and dynamic localization transformational procedures within a circular q-rung orthopair fuzzy set for ranking and grading large language models. Cognitive Computation **17**(2) (2025). https://doi.org/10.1007/s12559-025-10432-2
19. Quttainah, M., Mishra, V., Madakam, S., Lurie, Y., Mark, S.: Cost, usability, credibility, fairness, accountability, transparency, and explainability framework for safe and effective large language models in medical education: Narrative review and qualitative study. JMIR AI **3**(1) (2024). https://doi.org/10.2196/51834
20. Radulescu, C.Z., Radulescu, M.: Criteria analysis for the selection of a generative artificial intelligence tool for academic research based on an improved group dematel method. Applied Sciences (Switzerland) **15**(10) (2025). https://doi.org/10.3390/app15105416
21. Rezaei, E., Mosallanezhad, B.: Identifying social concerns in virtual reality technology through text mining and large language models, and prioritizing them with the fuzzy hierarchized analytic network process. Computers and Electrical Engineering **120** (2024). https://doi.org/10.1016/j.compeleceng.2024.109770
22. Sales, Reneepearl Kim; Ong, L.A.O.J.F.F.P.L.d.V.C.D.K.G.G.A.K.: Development of the philippine national unified health research agenda 2023-2028. DISCOVER PUBLIC HEALTH **22** (2025). https://doi.org/10.1186/s12982-025-00460-6
23. Serafim Rodrigues, T., Rogerio Pinheiro, P.: Hyperparameter optimization in generative adversarial networks (gans) using gaussian ahp. IEEE Access **13**, 770 – 788 (2025). https://doi.org/10.1109/ACCESS.2024.3518979
24. e Souza Rodrigues, B., Martins Floriano, C., Pereira, V., Costa Roboredo, M.: An algorithm to elicitate electre ii, iii and iv parameters. Data Technologies and Applications **55**(1), 82 – 96 (2021). https://doi.org/10.1108/DTA-07-2020-0161
25. Zhang, C., Tang, C., Wang, H., Lian, B., Zhang, L.: Evaluate and make decisions on cooperative positioning systems in weighted pythagorean hesitant fuzzy environment combined with gan. IEEE Sensors Journal (2024). https://doi.org/10.1109/JSEN.2024.3503595

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MAC-PNet: A Milestone-Based Adaptive Control System for Probabilistic Project Performance Monitoring.

Ikenna Ravel Okonkwo [1] and Caroline Maria de Miranda Mota [2]

[1]PPGEP, Universidade Federal de Pernambuco (UFPE) & Brazil
[2]Departamento de Engenharia de Produção, Universidade Federal de Pernambuco (UFPE) & Brazil

ikenna.okonkwo@ufpe.br, caroline.mota@ufpe.br

Abstract
Monte Carlo simulation is widely used to quantify duration and cost uncertainty in project networks, yet its application remains concentrated almost exclusively in the pre-execution planning phase. This paper presents MAC-PNet (Milestone-based Adaptive Control for Project Networks), a system that extends an existing Monte Carlo simulation framework to support structured reforecasting during project execution. MAC-PNet pauses the simulation at 25%, 50% and 75% of the baseline planned duration (BPD) and computes, at each checkpoint, the principal Earned Duration Management (EDM) and Earned Value Management (EVM) indicators, EDI, SPI-t, EDAC, TCPI-t, CPI, SPI and EAC, together with simulation-derived control bands for early-warning detection. The system is demonstrated on a real residential construction project comprising 29 active activities and incorporating epistemic, aleatory and uncertain risk typologies, over 5,000 Monte Carlo simulation iterations under a fixed random seed. At the 25% completion milestone, the time-based SPI-t indicator detects schedule deterioration that the cost-based SPI misses in 12.68% of simulations, an advantage that narrows to 0.34% by 75% completion as the two indicator families converge. The median cost performance index declines from 0.816 to 0.627 across milestones, implying a projected cost overrun of approximately 59.5% if unaddressed. Beyond this common-indicator core, MAC-PNet also supports an extended analytical layer, risk-level cruciality, a cruciality-adjusted forecast correction and structured risk-treatment scenario comparison, briefly summarized here and validated in full in an extended study. These results demonstrate that milestone-structured, simulation-based monitoring provides earlier and more reliable schedule signals than conventional cost-based tracking alone.

Keywords: Monte Carlo Simulation; Project Risk Management; Earned Duration Management; Milestone-Based Control; Project Monitoring System.

1 Introduction

Project-based organizations in engineering, construction and industrial manufacturing operate under irreducible uncertainty. The Critical Path Method and the Program Evaluation and Review Technique supply the structural logic for sequencing and timing activities [8, 11], but both assume that project conditions can be adequately anticipated in advance, an assumption execution consistently contradicts. Uncertainty manifests as aleatory variability in labour productivity and equipment performance [15, 20] and epistemic uncertainty arising from incomplete knowledge or unverified assumptions [6, 14]. Monte Carlo simulation (MCS) has become the dominant technique for propagating this uncertainty through project networks, producing probabilistic duration and cost distributions rather than single-point estimates.

Despite this maturity, a systematic review of 96 deduplicated peer-reviewed studies, of which 40 were deep-coded for the research underlying this paper, found that 60% concentrate exclusively on planning-phase analysis or passive monitoring, while only 10% implement genuine execution-phase reforecasting in which the simulation model is updated to incorporate realized activity outcomes [17]. Earned Value Management (EVM) is the most widely adopted execution-monitoring framework, but its Schedule Performance Index (SPI) converges mathematically to unity at project completion regardless of actual schedule performance, obscuring genuine schedule signals [13, 9]. Earned Duration Management (EDM) corrects this by expressing schedule performance in time rather than cost units. Acebes et al. [2] combined stochastic simulation with EDM for schedule management, while Liang, Tao and Lei [12] examined multi-point EDM monitoring at 25%, 50% and 75% checkpoints. These studies provide direct antecedents for execution-stage probabilistic monitoring, while the integration of milestone-structured Monte Carlo reforecasting with joint probabilistic EDM and EVM indicators remains comparatively limited.

This paper presents MAC-PNet as a working system: its architecture, its computation of the principal EDM and EVM indicators at defined execution milestones and a demonstration of its monitoring capability on a real construction project. The system additionally supports a risk-level analytical layer, cruciality scoring, cruciality-adjusted forecasting and treatment scenario comparison, which is summarized briefly in Section 3.4 as evidence of the system's extensibility; its full derivation and experimental validation are reported in an extended study and are outside the scope of this paper. The contribution here is threefold: (1) a milestone-structured reforecasting architecture pausing simulation at 25%, 50% and 75% of the Baseline Planned Duration; (2) probabilistic computation of the principal EDM and EVM indicators at each checkpoint, with simulation-derived control bands for anomaly detection; and (3) an empirical demonstration, on a real 29-activity, 15-risk construction project over 5,000 Monte Carlo iterations, that time-based indicators provide earlier and more reliable schedule signals than cost-based indicators under realistic execution uncertainty.

2 Related Work

Acebes et al. [1, 2] advanced execution-phase control by combining Monte Carlo simulation with percentile-based control bands and subsequently, with Earned Duration Management indicators in the Stochastic Earned Duration Methodology (SEDM), introducing simulation-derived anomaly detection but stopping short of structured percentage-based milestone checkpoints. Khamooshi and Golafshani [9] established the core EDM indicators, EDI, SPI-t and EDAC, as a duration-denominated alternative to EVM's cost-denominated SPI, correcting the mathematical convergence pathology by which SPI collapses to unity at project completion regardless of actual schedule performance [13]. Votto, Lee Ho and Bressaneti [22, 23] integrated cost- and time-based indicators within a multivariate Hotelling's T^2 control chart and characterized how control-limit width trades off detection sensitivity against false-alarm rate, but as a static rather than milestone-recalculated diagnostic. Liang, Tao and Lei [12] combined machine learning with multi-point EDM monitoring at 25/50/75% checkpoints, the closest antecedent to the milestone architecture adopted here, though their multi-point structure serves as a predictive input rather than a system-level monitoring architecture generating full indicator distributions at each stage.

Across the reviewed literature, limited evidence was identified of systems integrating milestone-structured Monte Carlo reforecasting with joint, probabilistic computation of the full EDM and EVM indicator suite and simulation-derived early-warning control bands within one coherent architecture; MAC-PNet was designed to address this integration gap [17]. A companion strand of the literature addresses risk-level structural analysis, activity and risk cruciality [5, 4], dynamic risk ranking [18, 19] and treatment-scenario decision making [3, 24]; MAC-PNet's extended analytical layer draws on this strand and is summarized briefly in Section 3.4.

3 The Mac-PNet System

MAC-PNet is a milestone-based monitoring system that supports probabilistic project performance assessment during project execution. The system integrates Monte Carlo simulation with Earned Duration Management (EDM) and Earned Value Management (EVM) indicators to provide performance monitoring at predefined project milestones. Unlike conventional Monte Carlo-based project monitoring approaches reported in the literature, MAC-PNet computes key EDM and EVM indicators at each milestone, enabling systematic monitoring throughout project execution. Figure 1 presents the system workflow and its principal components.

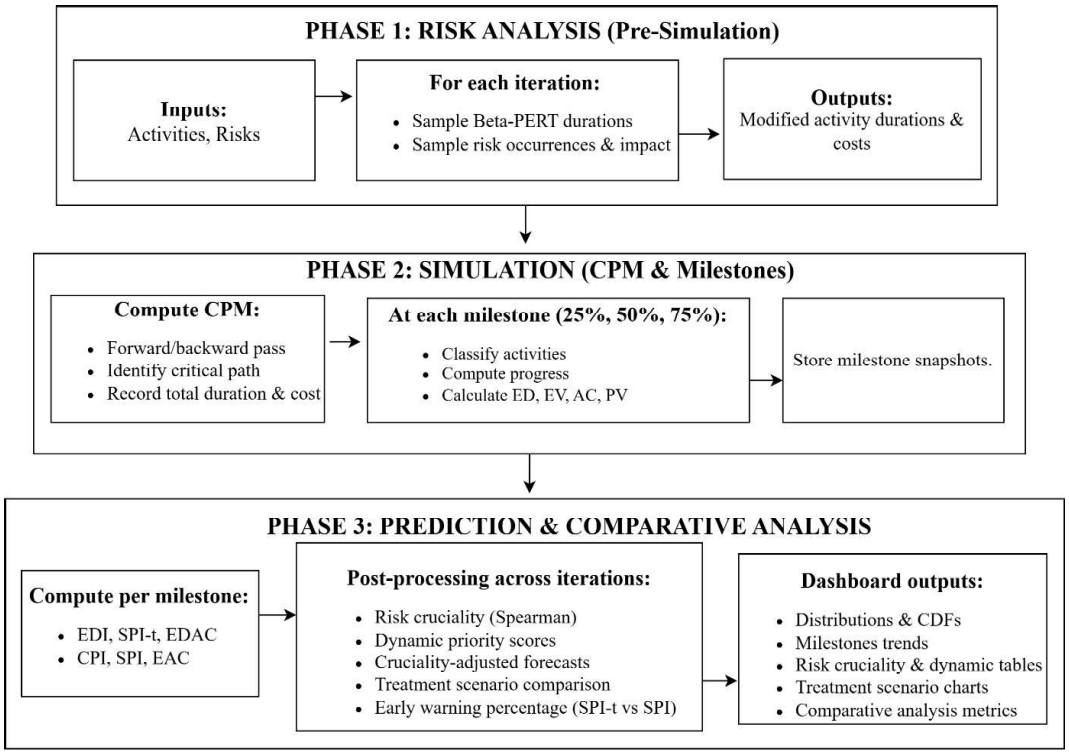

Fig. 1. Schematic representation of the milestone-structured simulation procedure: MAC-PNet computational implementation, adapted from the author's dissertation.

Milestone-Structured Simulation Procedure: For each of 'S' Monte Carlo iterations, activity durations are sampled from Beta-PERT distributions and risk occurrences from their specified probability distributions; the CPM forward/backward pass is executed and performance indicators are recorded at three predefined checkpoints, τ_25, τ_50 and τ_75, corresponding to 25%, 50% and 75% of the Baseline Planned Duration (BPD). At each checkpoint, each activity's completion state is classified as completed, in progress, or not yet started and a completion proportion prog_i(s)(τ_m) is derived for use in indicator computation.

Earned Duration Management and Earned Value Management Indicators: The Earned Duration ED(s)(τ_m) is the sum of each activity's completion proportion weighted by its most-likely duration. From it, the system computes the Earned Duration Index EDI = ED/PD(τ_m), the time-based Schedule Performance Index SPI-t = ED/τ_m, the Estimated Duration at Completion EDAC = BPD/SPI-t and the Time-based To-Complete Performance Index TCPI-t = (BPD − ED)/(BPD − τ_m). In parallel, the system computes the EVM indicators Planned Value, Earned Value, Actual Cost, CPI = EV/AC, SPI = EV/PV and the cost Estimate at Completion EAC = BAC/CPI [7, 21]. Unlike SPI, EDI and SPI-t do not converge to unity at completion unless the project finishes exactly on schedule, which motivates their use as the primary schedule diagnostics reported in Section 4.

Aleatory-Epistemic Risk Classification: Each explicitly modeled risk event is classified as aleatory, epistemic, mixed or uncertain through a transparent, auditable keyword-matching procedure applied to its name and description; ties are classified as mixed and unmatched risks as uncertain, requiring user validation. Activity duration variability is inherently aleatory by construction and is not subject to this classification. This classification is used by the extended analytical layer described below and is included in the system for completeness.

Extended Analytical Layer: Beyond the principal indicators, MAC-PNet includes a risk-level analytical layer summarized here for completeness rather than derived in full. The system computes risk cruciality, the

Spearman rank correlation between a risk's occurrence and final project duration, extending the activity-level cruciality concept [5, 4] to discrete risk events; a dynamic risk priority score combining normalized expected time impact with milestone-specific cruciality; a cruciality-adjusted forecast correction (EDAC_adj) governed by a calibrated parameter γ, which counteracts the standard EDAC's assumption that all schedule deviations are equivalent regardless of which risks drove them; and an automated comparison of risk-treatment scenarios (baseline, treat-by-cruciality, treat-by-impact, treat-by-probability), which re-runs the full simulation under each scenario to compare resulting duration, cost and forecast accuracy. Section 4.4 reports a brief illustrative snapshot of this layer on the case study; its full calibration procedure, experimental design and validation are reported in an extended study and fall outside this paper's scope.

Control Bands and Early Warning Detection: For each principal indicator and milestone, a control band is derived from the 10th and 90th percentiles of the simulated indicator distribution [16], an approach whose limit-width trade-offs Votto, Lee Ho and Bressaneti [23] characterized in detail; observations outside this band are classified as anomalous. The central comparative metric is the Early Warning Percentage:

$$\mathrm{EWP}^{(m)} = \frac{1}{S_m}\sum_{s=1}^{S_m} \mathbb{1}\left[\text{SPI-t}^{(s)}(\tau_m) < 0.95 \ \wedge \ \text{SPI}^{(s)}(\tau_m) \geq 0.95\right] \times 100 \qquad (1)$$

As defined in Equation (1), a positive EWP indicates that SPI-t detects schedule deterioration that the cost-denominated SPI does not, operationalizing the early-warning advantage that EDM theory predicts for time-based indicators. This comparison is the central empirical result reported in Section 4.

4 Application and Results

MAC-PNet was applied to a real residential construction case project in northeastern Brazil, comprising 29 active activities, 3 dummy nodes and 15 explicitly modeled risk events spanning epistemic, aleatory and uncertain typologies. Activity durations, precedence relationships and risk parameters were derived from project execution records covering June 2022 to March 2026. The simulation used S = 5,000 iterations with a fixed seed to ensure reproducibility; Figure 2 shows the resulting activity network with the critical path highlighted.

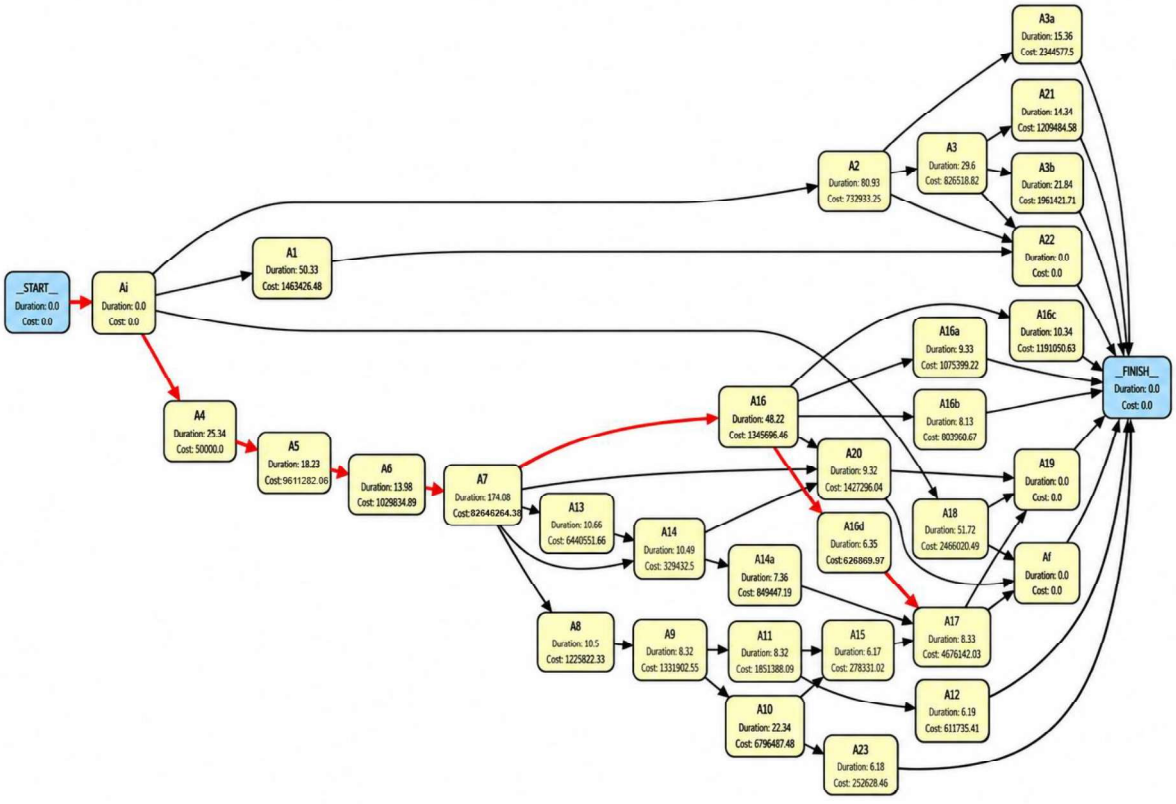

Fig. 2. Case project activity network with critical path identification: MAC-PNet simulation output.

4.1 Baseline Distributions

The baseline simulation, with all 15 risks active, produces a right-skewed duration distribution with mean 299.14 days, median (P50) 305.36 days and P90 367.52 days, a P90-P50 spread of 62.16 days (20.4%), visible in the cumulative distribution functions of Figure 3. The cost distribution has mean R$ 181,998,751 and median R$ 184,996,796, implying a median cost overrun of approximately 134% relative to the Budget at Completion of R$ 79,032,668 under full activation of all 15 risks. This asymmetry is consistent with a network in which a small number of activities carry disproportionate schedule risk, the kind of condition the principal indicators reported below are designed to surface during execution rather than only at completion.

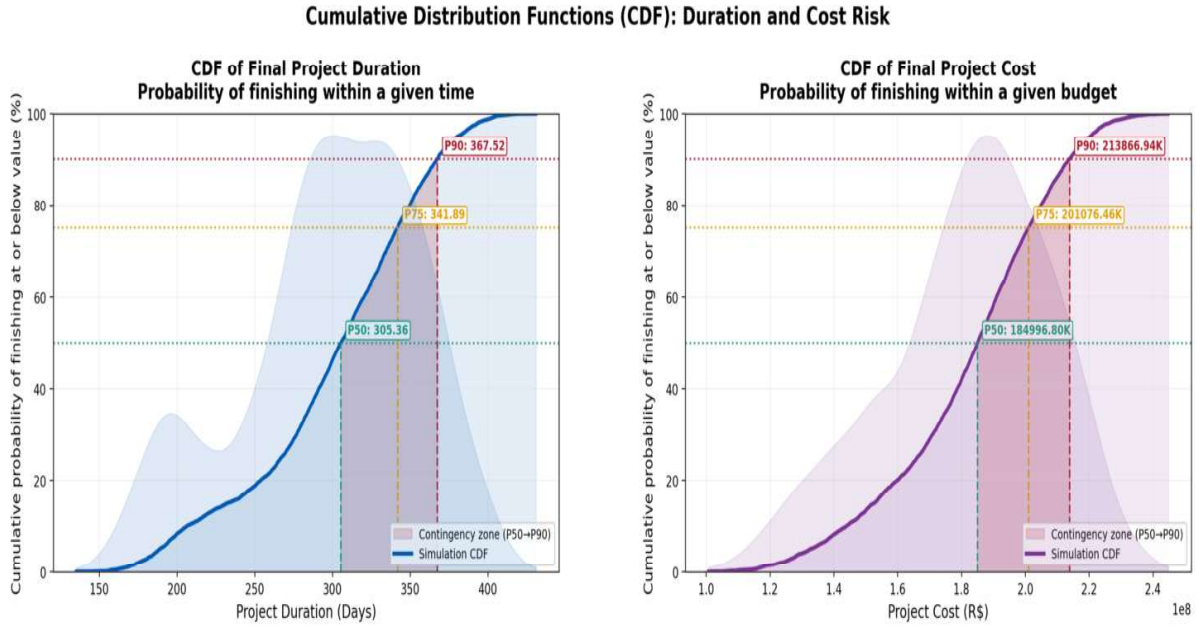

Fig. 3. Monte Carlo-based cumulative distribution functions of project duration and total cost: MAC-PNet simulation output, case project.

Table 1. Baseline probabilistic distribution summary: duration and cost MAC-PNet simulation output, case project.

Metric	Duration (days)	Cost (R$)
Mean	299.14	181,998,751
P50 (Median)	305.36	184,996,796
P90	367.52	213,866,940
P90 − P50 Spread	62.16 (20.4%)	28,870,144 (15.6%)

4.2 Milestone Indicator Trends

Figure 4 tracks the principal EDM and EVM indicators across the three execution milestones. The median SPI-t follows a non- steady trend pattern, 0.875 at 25% completion, rising to 0.915 at 50%, then declining to 0.887 at 75%, while the median CPI declines in a steady trend and steeply, from 0.816 at 25% to 0.696 at 50% and 0.627 at 75%, implying, if sustained through completion, a projected final cost overrun of approximately 59.5% above plan. The mean EDAC rises from 132.51 days at 25% through 141.78 at 50% to 155.90 at 75%, a clear signal of accumulating schedule pressure, while the median EDI declines from 1.026 to 0.880 over the same interval. Taken together, these trends illustrate the system's core monitoring function: indicator values computed from the simulated distribution at each milestone, rather than a single planning-phase estimate.

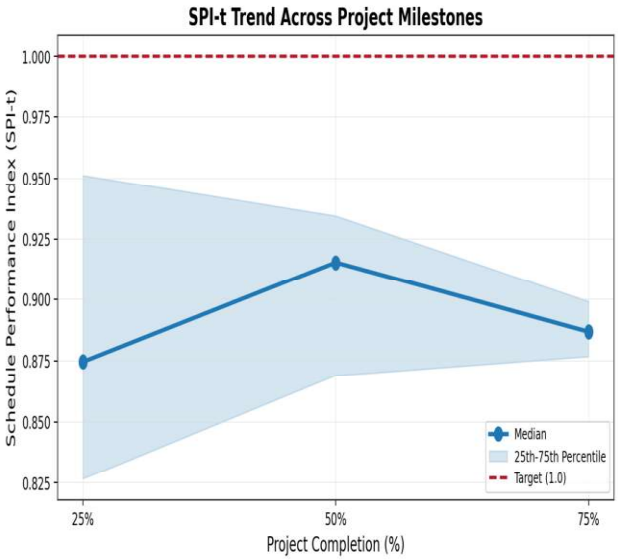

Fig. 4. Milestone indicator trend: median SPI-t across project milestones: MAC-PNet simulation output, case project.

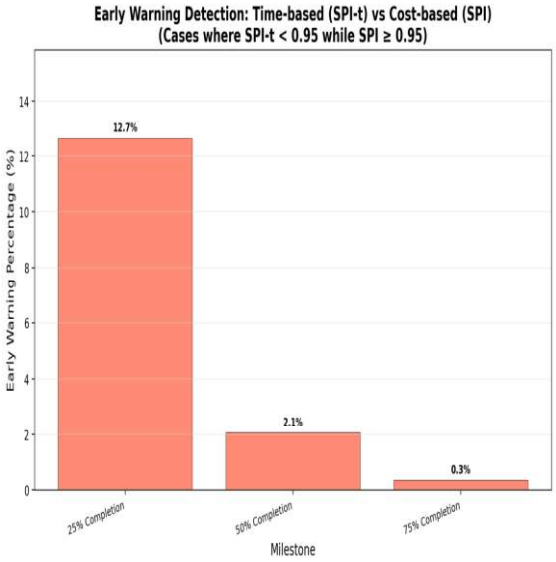

Fig. 5. Early warning detection performance across project milestones: MAC-PNet simulation output, case project.

Table 2. Principal indicator summary across milestones (median values) Source: MAC-PNet simulation output, case project. Median values from 5,000 simulations per milestone.

Milestone	Median EDI	Median SPI-t	Median SPI	Median CPI	Mean EDAC (days)
25% Completion	1.026	0.875	0.889	0.816	132.51
50% Completion	0.980	0.915	0.863	0.696	141.78
75% Completion	0.880	0.887	0.785	0.627	155.90

4.3 Comparative Indicator Analysis: SPI-t versus SPI

At the 25% milestone, SPI-t falls below the 0.95 anomaly threshold while SPI remains at or above it in 12.68% of simulations, identifying schedule delays a cost-based monitoring system would miss entirely; this advantage declines to 2.06% at 50% and 0.34% at 75% as both indicators converge, shown in Figure 5. The variance ratio Var (SPI-t)/Var (SPI) is 0.904 at 25% (SPI-t marginally more stable), rises to 1.608 at 50% and falls to 0.280 at 75% (SPI-t 3.57 times more stable). The Pearson correlation between the two indicator families is low through the first half of execution (0.353 at 25%, 0.365 at 50%) but rises sharply to 0.919 at 75%, showing that the indicators carry complementary information early in execution but converge as the project nears completion. This is the central practical demonstration of the system: SPI-t and EDI provide an earlier and for most of the execution window, more stable schedule signal than the conventional EVM SPI.

4.4 Extended Analytical Layer: Illustrative Snapshot

As a demonstration of the system's extensibility, the extended analytical layer described in Section 3.3 was applied to the same case study. Risk R15 (Progress Stagnation and Regression), affecting the structural-phase activity A7, registers the highest risk cruciality in the register (0.613) and the highest dynamic priority score, more than 2.8 times the second-ranked risk. In an illustrative treatment scenario reducing R15's burden by 50%, mean project duration falls from 299.14 to 223.70 days (25.2%). These figures are reported here only as a functional demonstration that the extended layer operates correctly on real project data; the calibration procedure

behind the cruciality-adjusted forecast, the full risk-ranking experiment and the complete treatment-scenario comparison are developed and validated in an extended study.

5 Discussion, Conclusion and Future Work

Two findings are of direct practical relevance to project managers. First, the milestone-structured architecture makes it possible to compute a full probabilistic indicator suite, rather than a single point estimate, at defined execution checkpoints, giving managers a distribution of likely outcomes rather than a single number at each review. Second and more specifically, time-based indicators detect schedule deterioration earlier than cost-based indicators under the uncertainty conditions modeled here, most sharply at the 25% milestone, where SPI-t identifies problems in roughly one of eight simulations that SPI does not flag. This finding is specific to the case project and should not be generalized without further validation on projects with different risk structures, but it is consistent with the theoretical expectation that duration-denominated indicators avoid the convergence pathology of cost-denominated schedule metrics [13, 9].

The brief snapshot of the extended analytical layer in Section 4.4 indicates that risk-level cruciality and treatment-scenario analysis produce results consistent with, but going beyond, what the principal indicators alone reveal; a full account of this layer's calibration, validation and comparative performance is deliberately left to an extended study, consistent with this paper's scope as a system and common-indicator demonstration.

This paper presented MAC-PNet as a milestone-structured monitoring system that extends Monte Carlo project simulation with the principal Earned Duration Management and Earned Value Management indicators, computed probabilistically at 25%, 50% and 75% of the baseline planned duration, together with simulation-derived control bands for early-warning detection. Applied to a real construction project, the system demonstrates that time-based indicators provide an earlier and for most of execution, more stable schedule signal than conventional cost-based tracking. The system additionally supports an extended, risk-level analytical layer, briefly demonstrated here, whose full derivation, calibration and experimental validation are reported in an extended study.

Future work should evaluate the system across project networks with more distributed risk registers, integrate continuous execution data rather than discrete milestone checkpoints [10] and formally validate the extended analytical layer against a broader set of case projects.

Acknowledgments.

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References

[1] Acebes, F., Pajares, J., Galán, J. M., López-Paredes, A. (2014), A new approach for project control under uncertainty: Going back to the basics. International Journal of Project Management, v. 32, n. 3, p. 423-434.

[2] Acebes, F., Poza, D., González-Varona, J. M., López-Paredes, A. (2022), Stochastic earned duration analysis for project schedule management. Engineering, v. 9, p. 148-161.

[3] Ahmadi, E., Mousavi, S. M., Khojasteh Eghbali, S. (2024), A multi-objective model for selecting response strategies of primary risk events in construction portfolios under uncertainty. Journal of Construction Engineering and Management, v. 150, n. 4, p. 1-15.

[4] Andrade, P. A. de, Vanhoucke, M. (2017), Combining EDM and EVM: A proposed simplification for project time and cost management. Journal of Modern Project Management, v. 5, n. 2, p. 100-111.

[5] Batselier, J., Vanhoucke, M. (2015), Empirical evaluation of earned value management forecasting accuracy for time and cost. Journal of Construction Engineering and Management, v. 141, n. 11, p. 05015010.

[6] Carr, V., Tah, J. H. M. (2001), A fuzzy approach to construction project risk assessment and analysis: Construction project risk management system. Advances in Engineering Software, v. 32, n. 10-11, p. 847-857.

[7] Chen, H. L., Chen, W. T., Lin, Y. L. (2016), Earned value project management: improving the predictive power of planned value. International Journal of Project Management, v. 34, n. 1, p. 22-29.

[8] Cottrell, W. D. (1999), Simplified program evaluation and review technique (PERT). Journal of Construction Engineering and Management, v. 125, n. 1, p. 16-22.

[9] Khamooshi, H., Golafshani, H. (2014), EDM: earned duration management, a new approach to schedule performance management and measurement. International Journal of Project Management, v. 32, n. 6, p. 1019-1041.

[10] Kula, E., Greuter, E., Van der Aalst, W., Gousios, G. (2023), Dynamic prediction of delays in construction project networks using real-time event logs. Automation in Construction, v. 156, p. 104208.

[11] Lawrence, F. P., Cochran, J. K. (1995), A new computational approach for project management under uncertainty. Computers & Industrial Engineering, v. 29, n. 1-4, p. 155-159.

[12] Liang, A., Tao, L., Lei, H. (2023), Combined machine-learning and EDM to monitor and predict a complex project with a GERT-type network: a multi-point perspective. Computers & Industrial Engineering, v. 180, n. 109256, p. 1-17.

[13] Lipke, W. (2009), Project duration forecasting: a comparison of earned value management methods to earned schedule. The Measurable News, n. 2, p. 24-32.

[14] Lorterapong, P., Moselhi, O. (1996), Project-network analysis using fuzzy sets theory. Journal of Construction Engineering and Management, v. 122, n. 4, p. 308-318.

[15] McCahon, C. S. (1993), Using PERT as an approximation of fuzzy project-network analysis. IEEE Transactions on Engineering Management, v. 40, n. 2, p. 146-152.

[16] Mortaji, S. T. H., Noori, S., Noorossana, R., Bagherpour, M. (2018), Ex ante control chart for project monitoring using earned duration. Journal of Industrial Engineering International, v. 14, n. 3, p. 793-806.

[17] Okonkwo, I. R., Camara, A. A. S., Mota, C. M. de M., Faveri, M. A. (2025), Uncertainty modeling in project networks: A systematic review of methods and integration challenges. In: Proceeding XIX Congresso Nacional de Excelência em Gestão & INOVARSE, 19.

[18] Ünsal-Altuncan, İ., Vanhoucke, M. (2024), A hybrid forecasting model to predict the duration and cost performance of projects with Bayesian networks. European Journal of Operational Research, v. 315, p. 511-527.

[19] Ünsal-Altuncan, İ., Vanhoucke, M. (2025), Duration forecasting in resource constrained projects: A hybrid risk model combining complexity indicators with sensitivity measures. European Journal of Operational Research, v. 325, p. 329-343.

[20] Van Dorp, J. R., Duffey, M. R. (1999), Statistical dependence in risk analysis for project networks using Monte Carlo methods. International Journal of Production Economics, v. 58, n. 1, p. 17-29.

[21] Vandevoorde, S., Vanhoucke, M. (2006), A comparison of different project duration forecasting methods using earned value metrics. International Journal of Project Management, v. 24, n. 4, p. 289-302.

[22] Votto, R., Lee Ho, L., Bressaneti, F. (2020), Multivariate control charts using earned value and earned duration management observations to monitor project performance. Computers & Industrial Engineering, v. 148, n. 106691, p. 1-12.

[23] Votto, R., Lee Ho, L., Bressaneti, F. (2021), Earned duration management control charts: role of control limit width definition for construction project duration monitoring. Journal of Construction Engineering and Management, v. 147, n. 9, p. 04021108.

[24] Zhang, X., Goh, M., Bai, S., Wang, Z., Wang, Q. (2024), Project risk response decision making under uncertain project interdependencies. IEEE Transactions on Engineering Management, v. 71, p. 7364-7380.

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Recife-PE, Brazil

Ranked-Clustering of Countries on SDG9 Indicators with a No-Code Visual Clustering Web Application

Helder Gomes Costa[1], L. Fernandes Costa[1], and F. Aquino[1]

[1]Universidade Federal Fluminense, Rua Passos da Pátria, 156, Blodo D, Niterói, Brasil

heldergc@id.uff.br, leo_costa@id.uff.br, fabioaquino@id.uff.br

Abstract. Aggregate SDG scores computed as arithmetic means allow strong performance in one dimension to compensate for weakness in another, concealing trade-offs that matter for policy. This paper focuses into Sustainable Development Goal~9 (industry, innovation and infrastructure) and applies a ranked-clustering approach --- K-means clustering followed by the multicriteria ordering of the resulting clusters --- to the SDG9 indicator scores of a 2026 country-level sustainability database. The analysis is carried out entirely in Visual Clustering, a free no-code web application that integrates K-means with four cluster-ranking methods (ELECTRE~III, PROMETHEE~II, weighted mean and TOPSIS), covering both non-compensatory and compensatory preference aggregation. From 208 entities, the application's default data-quality rules retained 159 entities described by nine normalized indicator scores, grouped into k=4 clusters (silhouette =0.365, seed =790, equal weights) --- a choice supported by the elbow and silhouette diagnostics and matched to the number of clusters adopted in a companion goal-level study on the same countries. All four ranking methods agree on a strict ordering ofthe clusters, and the outranking credibility structure is completely dominant: every pairwise credibility is exactly 0 or 1. Splitting the criteria into an infrastructure/connectivity pillar and an innovation pillar reveals a graded four-tier structure: a nearly balanced top tier of 33 economies; an upper-middle tier of 32 economies --- a composite of EU-accession and resource-rich economies --- with a moderate innovation shortfall; a lower-middle tier of 57 economies with the largest infrastructure-innovation gap of the four; and a bottom tier of 37 economies whose innovation output is roughly 6.5 times below its own infrastructure level, the largest relative shortfall of the four. A choropleth map shows this structure is broadly continental, separating an EU-accession/Gulf-states bloc from the historical Western European and North American core. None of the 13 income-group or regional aggregates in the dataset lands in the upper-middle tier, a face-validity signal that this tier reflects genuine cross-regional similarity rather than a forced subdivision.

Keywords: Decision, Ranked clustering, K-means, SDG, No-code, Visual Clustering

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Integração de Value-Focused Thinking (VFT), Análise Multicritério AHP e Sistema de Informação Geográfica (GIS) para o Mapeamento de Áreas Suscetíveis a Inundações na Bacia do Rio Ceará-Mirim/RN

Oliveira, M. S. R.[1], Costa, S. A. B.[1], Alves, A. S. A.[1], Pedrosa, M. E. C.[1], Barbosa, J.[1] e Souza, R.P[1]

[1]Universidade Federal do Rio Grande do Norte (UFRN), Campus Universitário Lagoa Nova, Natal-RN, Brasil, 59078-970.
monalisa.reboucas.103@ufrn.edu.br, stefani.arend.069@ufrn.edu.br, andrea.alves.714@ufrn.edu.br, maria.correia.155@ufrn.edu.br, jaini.barbosa@ufrn.edu.br, ricardo.pires@ufrn.br

Resumo. Objetivo: a bacia hidrográfica do Rio Ceará-Mirim/RN, com área aproximada de 2.635,70 km², enfrenta graves problemas de inundações decorrentes da dinâmica flúvio-marinha e da falha na infraestrutura de contenção (diques). Este estudo, em andamento, objetiva estruturar o problema das inundações e classificar as áreas de vulnerabilidade para orientar intervenções de gestão territorial. **Metodologia:** a abordagem integra a estruturação de problemas via Value-Focused Thinking (VFT) com a Análise Multicritério de Decisão (MCDA), utilizando o Processo Hierárquico Analítico (AHP) em ambiente de Sistemas de Informação Geográfica (GIS). Os critérios foram divididos em fatores de perigo físico (elevação, declividade, tipo e uso do solo, TWI, distância do rio e distância da falha dos diques) e de vulnerabilidade (densidade populacional, uso agrícola e densidade de infraestrutura). **Resultados esperados:** na aplicação do AHP, a distância da falha dos diques e a elevação foram identificadas como as variáveis de maior peso para o perigo físico, visto que as áreas próximas ao nível do mar são as primeiras atingidas pelo refluxo da maré quando os diques falham; espera-se que os resultados permitam classificar a bacia em cinco classes de suscetibilidade, de Muito Baixa a Muito Alta, fornecendo um mapa de risco que subsidie a priorização de intervenções de engenharia e o planejamento urbano. Conclui-se que a integração de métodos de decisão estruturados com ferramentas geoespaciais oferece uma base robusta para a mitigação de danos socioeconômicos e a proteção das terras agrícolas contra a salinização em ecossistemas costeiros vulneráveis.

Palavras-chave: Rio Ceará-Mirim; Inundações; MCDA; VFT; Gestão de recursos hídricos.

Abstract. Purpose: the Ceará-Mirim river basin (Rio Grande do Norte, Brazil), covering approximately 2,635.70 km², faces severe flooding driven by fluvial-marine dynamics and by the failure of its containment infrastructure (dikes). This research in progress aims to structure the flooding problem and to classify vulnerability areas in order to guide territorial management interventions. **Methodology:** the approach integrates problem structuring through Value-Focused Thinking (VFT) with Multi-Criteria Decision Analysis, applying the Analytic Hierarchy Process (AHP) within a Geographic Information System (GIS). Criteria were split into physical hazard factors (elevation, slope, soil type and land use, TWI, distance to the river and distance to the dike failure) and vulnerability factors (population density, agricultural land use and infrastructure density). **What would be expected:** in the AHP application, distance to the dike failure and elevation were identified as the highest-weighted variables for physical hazard, since areas close to sea level are the first to be reached by tidal backflow when the dikes fail; the results are expected to classify the basin into five susceptibility classes, from Very Low to Very High, yielding a risk map that supports the prioritization of engineering interventions and urban planning. Integrating structured decision methods with geospatial tools offers a robust basis for mitigating socioeconomic damage and protecting farmland against salinization in vulnerable coastal ecosystems.

Keywords: Ceará-Mirim river; Floods; MCDA; VFT; Water resources management.

1 Introdução/Objetivo

O Rio Ceará-Mirim está localizado no estado do Rio Grande do Norte e integra uma bacia hidrográfica com área aproximada de 2.635,70 km², distribuída por dezesseis municípios — Angicos, Fernando Pedroza, Pedro Avelino, Pedra Preta, Caiçara do Rio dos Ventos, Riachuelo, Santa Maria, Jardim de Angicos, Bento Fernandes, João Câmara, Poço Branco, Taipu, Ielmo Marinho, Ceará-Mirim, Extremoz e Lajes —, de acordo com os dados fornecidos pelo Instituto de Gestão das Águas do Estado do Rio Grande do Norte (IGARN, 2009).

Com cerca de 129 km de extensão e vazão de 51,85 l/s, a bacia desempenha papel fundamental no desenvolvimento socioeconômico da região, sustentando atividades como agricultura, pesca, turismo e abastecimento humano, além de alimentar o lençol freático (Araújo et al., 2023). Geologicamente, a foz do rio situa-se em uma planície flúvio-marinha, zona de transição crítica onde a dinâmica fluvial encontra a influência das marés (IGARN, 2009); a região é ainda marcada pela presença do enxame de diques Rio Ceará-Mirim, feição estrutural característica da porção leste do estado (Vasconcelos, 2018).

Atualmente, essa bacia enfrenta desafios severos relacionados à gestão territorial e à ocorrência de inundações. Um problema central identificado pelos gestores é a falha na infraestrutura de contenção: os diques projetados para controlar o refluxo da água do mar durante a maré alta não estão funcionando adequadamente, gerando descontrole do fluxo de água, com inundações em algumas regiões do rio e falta de água em outros pontos (Araújo et al., 2023). Esse descontrole não apenas causa danos físicos por alagamento, mas introduz a salinidade da água marinha nos solos, degradando as terras agricultáveis a longo prazo e aumentando a vulnerabilidade das comunidades locais. A ausência de um planejamento eficiente e a supressão da vegetação nativa têm agravado a degradação ambiental e a instabilidade hidrológica na região.

A dinâmica que produz o problema é, portanto, dupla. De um lado, há um componente hidrológico continental, associado ao regime de chuvas e ao escoamento superficial ao longo dos 129 km de curso; de outro, um componente marinho, associado ao avanço da maré sobre a planície flúvio-marinha da foz. Os diques foram concebidos justamente para desacoplar esses dois regimes, permitindo o escoamento fluvial em direção ao mar e impedindo o caminho inverso. Quando essa barreira falha, o sistema passa a operar de forma invertida em parte do ciclo de maré, e a água salina penetra em áreas que, do ponto de vista topográfico, deveriam estar protegidas. Isso explica por que o problema não pode ser tratado apenas como risco de alagamento: o dano relevante inclui a perda progressiva de aptidão agrícola por salinização, um efeito cumulativo e de reversão lenta que não aparece em abordagens centradas exclusivamente na lâmina d'água.

Nesse contexto, a utilização de métodos científicos para a tomada de decisão torna-se indispensável. A literatura acadêmica destaca que a integração de Sistemas de Informação Geográfica (GIS) com o Processo Hierárquico Analítico (AHP) é uma abordagem robusta para mapear o perigo de inundação e a vulnerabilidade das populações, com aplicações consolidadas em bacias de diferentes contextos geográficos (Mukherjee e Deb, 2023; Dar et al., 2026; Rashid et al., 2026; Tefera et al., 2026). Ao aplicar a Análise Multicritério de Decisão (MCDA), é possível ponderar variáveis biofísicas, como elevação, declividade e distância da falha dos diques, para classificar áreas em diferentes níveis de vulnerabilidade. Além disso, a estruturação do problema por meio do Value-Focused Thinking (VFT) permite que os gestores identifiquem claramente seus objetivos fundamentais — como a proteção da infraestrutura e a minimização dos danos socioeconômicos — antes de avaliar as alternativas de intervenção (Keeney, 1992).

Observa-se, contudo, que boa parte dos estudos que integram GIS e AHP para mapeamento de inundações parte diretamente da seleção de variáveis biofísicas consagradas na literatura, sem uma etapa prévia de explicitação dos objetivos dos gestores responsáveis pela intervenção. Essa ausência tende a produzir mapas tecnicamente corretos, porém pouco acionáveis, porque não deixam claro qual objetivo institucional cada camada está servindo. A incorporação do VFT antes da montagem da hierarquia AHP busca preencher essa lacuna: é ela que justifica, por exemplo, a inclusão da distância da falha dos diques como critério autônomo — variável ausente dos modelos genéricos de suscetibilidade, mas central quando o objetivo declarado do gestor é decidir onde recuperar a infraestrutura de contenção.

Portanto, este estudo busca estruturar e aplicar um modelo MCDA para fornecer um diagnóstico preciso da bacia do Rio Ceará-Mirim, subsidiando decisões estratégicas para a restauração das estruturas de controle e o zoneamento das áreas de risco.

2 Metodologia

A metodologia proposta baseia-se em uma abordagem integrada que combina o Value-Focused Thinking para a estruturação do problema e a Análise Multicritério de Decisão para a avaliação e priorização dos critérios, utilizando como suporte os Sistemas de Informação Geográfica.

2.1 Estruturação do Problema e Definição dos Critérios

Inicialmente, o VFT é empregado para identificar os valores e objetivos dos gestores relacionados à mitigação dos impactos das inundações, permitindo a definição dos objetivos fundamentais: minimizar o perigo físico de inundações e minimizar a vulnerabilidade socioeconômica decorrentes da dinâmica flúvio-marinha e da falha na infraestrutura de contenção. A partir desses objetivos são estabelecidos critérios mensuráveis, organizados nessas duas dimensões, conforme sintetizado na Fig. 1.

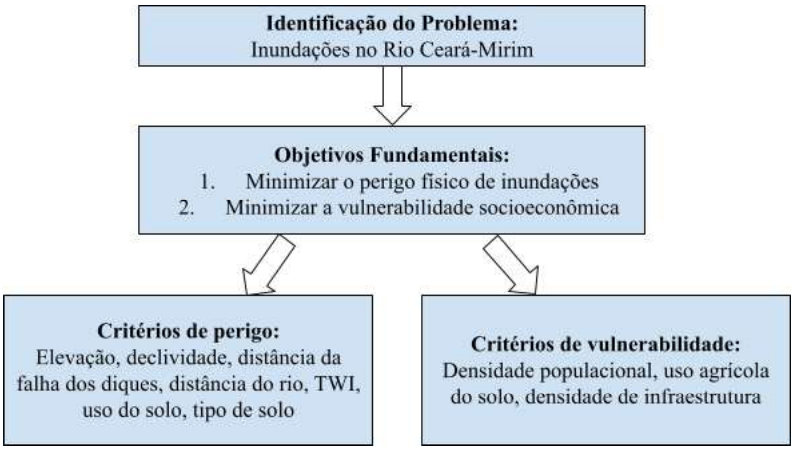

Fig. 1. Estruturação do problema através do Value-Focused Thinking (VFT). O fluxo demonstra a transição do problema central (caixa superior) para os objetivos fundamentais (caixa central) até o desdobramento na rede de critérios mensuráveis (caixas inferiores). Fonte: elaborado pelos autores.

Os **critérios de perigo** dizem respeito aos fatores causadores e medem a predisposição física de uma área sofrer inundação. A **elevação** é um fator crítico, pois a água sempre flui para áreas de menor altitude, e locais baixos são os primeiros a serem inundados; em Ceará-Mirim, áreas próximas ao nível do mar são altamente suscetíveis ao retorno da maré. A **declividade** atua no sentido de que terrenos com baixa inclinação retêm a água por mais tempo, enquanto terrenos íngremes a escoam rapidamente. A **distância do rio** reflete que o perigo é mais severo em áreas próximas às margens, devido à probabilidade de transbordamento, e a **distância da falha dos diques** mede a proximidade em relação aos diques que não funcionam: quanto mais próximo do dique falho ou da foz, maior a intensidade do alagamento por água do mar. O **índice de umidade topográfica (TWI)** avalia a probabilidade geomorfológica de acumulação de água, enquanto o **uso e cobertura do solo** capta a impermeabilização em áreas urbanizadas, que reduz a infiltração e acelera o escoamento superficial, e o **tipo do solo** distingue solos arenosos, que drenam rapidamente, de solos argilosos, que favorecem o acúmulo superficial.

Já os **critérios de vulnerabilidade** representam o potencial de danos associados ao evento, medindo o grau de impacto caso a área mapeada seja atingida pelas águas. A **densidade populacional** é o critério central da vulnerabilidade, por indicar a concentração de pessoas sob ameaça direta. O **uso agrícola do solo** capta os danos severos às lavouras e a redução da produção, agravados pelo fato de que o retorno da água do mar degrada a terra a longo prazo por salinização. Por fim, a **densidade e proximidade de estradas e infraestrutura** reflete tanto a alteração dos caminhos naturais de drenagem pelas vias de transporte, que favorece o acúmulo local de água, quanto as maiores perdas financeiras em caso de desastre.

2.2 Dados Espaciais e Aplicação do AHP em Ambiente GIS

Na etapa seguinte são adquiridos e processados dados espaciais provenientes de diferentes fontes. Os dados topográficos obtidos pela missão Shuttle Radar Topography Mission (SRTM) são utilizados para gerar informações de elevação, declividade e rede de drenagem. Paralelamente, imagens do satélite Landsat 8 são submetidas à classificação supervisionada para a obtenção do mapa de uso e cobertura da terra, permitindo identificar áreas urbanas, agrícolas e de vegetação nativa. Complementarmente, mapas geológicos e pedológicos são incorporados à análise para identificar características do terreno que favorecem a ocorrência de inundações, como planícies aluviais e solos hidromórficos com baixa capacidade de drenagem.

Posteriormente, aplica-se a MCDA por meio do Processo Hierárquico Analítico (AHP), utilizado para determinar a importância relativa de cada critério considerado. Nesse processo, especialistas realizam comparações paritárias entre os critérios com base na Escala Fundamental de Saaty (1 a 9), avaliando sua influência relativa na suscetibilidade às inundações (Saaty, 2008). A árvore hierárquica que organiza o objetivo central, os grupos de critérios e as variáveis espaciais utilizadas na avaliação em GIS é apresentada na Fig. 2.

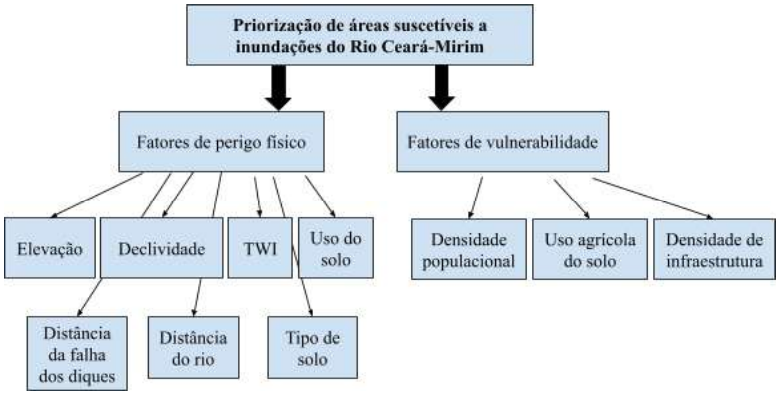

Fig. 2. Árvore hierárquica do Analytic Hierarchy Process (AHP). A estrutura apresenta o objetivo central no topo (Nível 1), os grupos de critérios no meio (Nível 2) e as variáveis espaciais utilizadas para a avaliação no GIS na base (Nível 3). Fonte: elaborado pelos autores.

Com base nessas comparações são calculados os pesos de cada variável, sendo posteriormente verificada a consistência dos julgamentos por meio da Razão de Consistência (CR), adotando-se como aceitável valores inferiores a 0,1. Após a definição dos pesos, realiza-se a integração das informações em ambiente GIS por meio da técnica de Sobreposição Ponderada (Weighted Overlay). O índice final de perigo é obtido pela soma ponderada dos pesos atribuídos aos critérios e seus respectivos valores espaciais, resultando em um mapa de suscetibilidade à inundação classificado em cinco níveis: muito baixa, baixa, moderada, alta e muito alta. Por fim, a análise é complementada pela integração do mapa de perigo com o Índice de Vulnerabilidade dos Meios de Vida (LVI-IPCC), possibilitando uma avaliação conjunta da exposição física, da sensibilidade socioambiental e da capacidade adaptativa da população.

2.3 Reclassificação das Camadas e Escala de Suscetibilidade

Para que critérios expressos em unidades distintas — metros, graus, hectares, habitantes por km² e classes categóricas de solo e uso — possam ser combinados em uma única soma ponderada, cada camada é previamente reclassificada em uma escala ordinal comum de cinco níveis, na qual o nível mais alto corresponde à maior contribuição para o perigo ou para a vulnerabilidade. Nos critérios contínuos, os limiares de classe são definidos a partir da distribuição observada dos valores na bacia e do sentido de otimização do critério: para a elevação e a declividade, os menores valores recebem as classes mais altas, ao passo que para o TWI e para as densidades populacional e de infraestrutura a relação é direta. Para a distância do rio e a distância da falha dos diques, a proximidade é que agrava o fenômeno, de modo que as faixas mais próximas recebem as classes superiores. Nos critérios categóricos, a atribuição decorre do comportamento hidrológico esperado: solos argilosos e hidromórficos e superfícies impermeabilizadas recebem classes altas, enquanto solos arenosos e coberturas com vegetação nativa recebem classes baixas.

Essa etapa é sensível e merece registro explícito, pois a escolha dos limiares de classe afeta o mapa final tanto quanto a ponderação dos critérios. Por essa razão, os limiares adotados são documentados junto com a

matriz de comparação paritária, de modo que o mapa resultante possa ser auditado e reproduzido, e não apenas consultado. O índice final de cada célula é obtido pela soma ponderada das classes reclassificadas, e o resultado é então dividido em cinco intervalos de suscetibilidade, descritos no Quadro 1.

Quadro 1. Interpretação das classes de suscetibilidade à inundação adotadas na Sobreposição Ponderada. Fonte: elaborado pelos autores.

Classe	Interpretação e implicação para a gestão territorial
Muito baixa	Áreas elevadas e distantes da rede de drenagem, sem histórico de acumulação; compatíveis com ocupação e uso agrícola sem restrições adicionais.
Baixa	Áreas de perigo residual, associado a eventos pluviométricos extremos; requerem apenas manutenção do sistema de drenagem existente.
Moderada	Áreas de transição, sensíveis a alterações no uso do solo; indicam necessidade de disciplina de ocupação e de controle da impermeabilização.
Alta	Áreas de planície com baixa declividade e proximidade da rede de drenagem; demandam restrição de novas ocupações e obras de drenagem.
Muito alta	Áreas estuarinas próximas à cota do mar e às falhas de dique; concentram o risco de alagamento por refluxo de maré e de salinização do solo, exigindo intervenção prioritária na infraestrutura de contenção.

3 Resultados Esperados

3.1 Ponderação dos Critérios e Consistência dos Julgamentos

Para a aplicação do modelo AHP, um decisor especialista atribuiu graus de importância aos critérios baseando-se na Escala Fundamental de Saaty, refletindo a dinâmica de inundação flúvio-marinha da bacia. As Tabelas 1 e 2 apresentam as matrizes de comparação paritária desenvolvidas para as dimensões de vulnerabilidade e de perigo físico, respectivamente. Os pesos são obtidos dividindo-se cada elemento pela soma de sua coluna e calculando-se a média das linhas.

Tabela 1. Matriz de comparação paritária e pesos: dimensão de vulnerabilidade. Fonte: elaborado pelos autores.

Critérios	DP	DI	UA	Peso
Densidade Populacional (DP)	1	3	5	0,648
Densidade de Infraestrutura (DI)	0,33	1	2	0,226
Uso Agrícola (UA)	0,20	0,50	1	0,126
Soma das colunas	1,53	4,50	8,00	1,000

A Razão de Consistência calculada para essa matriz é de 0,016, valor inferior a 0,1 e, portanto, indicativo de julgamentos altamente consistentes. A densidade populacional confirma-se como o critério central da vulnerabilidade, indicando a concentração de pessoas sob ameaça direta.

Tabela 2. Matriz de comparação paritária e pesos: dimensão de perigo físico. Fonte: elaborado pelos autores.

Critérios	DIQ	ELE	RIO	DEC	TWI	USO	SOL	Peso
Diques (DIQ)	1	1	3	4	4	5	5	0,305
Elevação (ELE)	1	1	2	3	3	4	4	0,243
Rio (RIO)	0,33	0,50	1	2	2	3	3	0,158
Declividade (DEC)	0,25	0,33	0,50	1	1	2	2	0,103
TWI	0,25	0,33	0,50	1	1	2	2	0,103
Uso do solo (USO)	0,20	0,25	0,33	0,50	0,50	1	1	0,044

Tipo de solo (SOL)	0,20	0,25	0,33	0,50	0,50	1	1	0,044
Soma das colunas	3,23	3,66	7,66	12,00	12,00	18,00	18,00	1,000

A Razão de Consistência calculada para essa matriz 7×7 resulta em 0,03, o que demonstra que os julgamentos possuem coerência matemática e não foram atribuídos aleatoriamente. Para a reclassificação das camadas em ambiente GIS, os pesos foram arredondados para 30% (distância da falha dos diques), 25% (elevação), 15% (distância do rio), 10% (declividade), 10% (TWI), 5% (uso do solo) e 5% (tipo de solo), e, na dimensão de vulnerabilidade, para 60% (densidade populacional), 25% (densidade de infraestrutura) e 15% (uso agrícola). A distância da falha dos diques foi priorizada devido ao descontrole do fluxo e refluxo da maré, e a elevação considerada essencial, visto que áreas próximas ao nível do mar são as primeiras a serem inundadas.

A leitura conjunta das duas matrizes revela uma estrutura de preferências coerente com o diagnóstico da bacia. Na dimensão de perigo, os dois critérios de maior peso — diques e elevação — somam 55% da ponderação e descrevem, juntos, o mesmo mecanismo físico: a entrada de água marinha por uma barreira que falhou, em terrenos cuja cota não oferece resistência natural a esse avanço. Os critérios seguintes, distância do rio, declividade e TWI, somam 35% e capturam o componente continental do problema, isto é, a propensão do terreno a receber e a reter água de origem pluvial. Por fim, uso e tipo de solo recebem 10% conjuntamente: são fatores modificadores, que aceleram ou retardam a infiltração, mas que não determinam por si sós a ocorrência do evento. Na dimensão de vulnerabilidade, o predomínio da densidade populacional traduz a prioridade atribuída à proteção da vida sobre a proteção do patrimônio, ainda que o uso agrícola do solo permaneça no modelo por concentrar o dano de longo prazo associado à salinização.

3.2 Classificação da Bacia e Priorização de Intervenções

A integração desses pesos em ambiente GIS através da Sobreposição Ponderada deverá resultar na identificação espacial concreta das áreas de risco. O Quadro 2 sintetiza a classificação esperada, articulando suscetibilidade física, vulnerabilidade social e prioridade de ação para cada setor da bacia.

Quadro 2. Expectativa de resultados para priorização de intervenções. Fonte: elaborado pelos autores.

Setor da bacia	Suscetibilidade física	Vulnerabilidade social	Prioridade de ação
Baixo curso	Muito Alta	Alta	Imediata (infraestrutura)
Médio curso	Moderada	Moderada	Planejamento (uso do solo)
Alto curso	Baixa	Baixa	Preventiva (conservação)

Essa integração permite identificar as áreas de maior risco e subsidiar a priorização de intervenções, como a recuperação e o reforço de diques, especialmente nas regiões onde os impactos potenciais sobre a população, a infraestrutura e as atividades agrícolas são mais significativos.

A leitura do Quadro 2 evidencia que suscetibilidade física e vulnerabilidade social se sobrepõem no baixo curso, mas não são a mesma coisa: um setor pode apresentar alta exposição física e baixa vulnerabilidade, caso esteja pouco ocupado, e o inverso também é possível. É justamente essa distinção que a integração com o LVI-IPCC procura preservar, ao decompor o risco em exposição física, sensibilidade socioambiental e capacidade adaptativa da população. Do ponto de vista da gestão, a consequência prática é que a prioridade de ação não decorre diretamente do mapa de perigo: ela resulta do cruzamento entre o perigo e a presença de pessoas, lavouras e infraestrutura no território atingido, o que explica por que o médio curso, ainda que fisicamente menos exposto, demanda instrumentos de planejamento do uso do solo em vez de obras de contenção.

3.3 Teste de Sensibilidade

Conforme recomendado pela literatura de apoio à decisão, foi realizado um teste de sensibilidade do modelo para atestar sua robustez matemática. O critério de maior peso no perigo físico, a distância da falha dos diques, teve seu valor alterado em ±20%, com a consequente redistribuição proporcional dos pesos aos demais critérios, conforme a Tabela 3.

Tabela 3. Teste de sensibilidade: variação de ±20% no critério principal de perigo físico. Fonte: elaborado pelos autores.

Critérios de perigo físico	Cenário base	Cenário 1 (+20% em diques)	Cenário 2 (−20% em diques)
Distância da falha dos diques	30,00%	36,00%	24,00%
Elevação	25,00%	21,90%	26,00%
Distância do rio	15,00%	14,60%	17,40%
Declividade	10,00%	9,10%	10,90%
TWI	10,00%	9,10%	10,90%
Uso do solo	5,00%	4,60%	5,40%
Tipo de solo	5,00%	4,60%	5,40%
Total	100,00%	100,00%	100,00%

Observa-se que, mesmo no Cenário 2, em que o peso dos diques é reduzido e os pesos da elevação e da distância do rio aumentam, as áreas estuarinas do baixo curso continuariam sendo classificadas com suscetibilidade Muito Alta. Isso ocorre porque a elevação atua em sinergia com os diques na foz do rio. Conclui-se que o ranqueamento das áreas de intervenção não sofre inversões significativas, comprovando que o modelo AHP construído é estatisticamente robusto, não sofrendo variações drásticas por pequenas flutuações de julgamento do decisor.

Cabe registrar, entretanto, o alcance e os limites desse teste. A análise conduzida é do tipo uma-a-uma e verifica a estabilidade do ranqueamento setorial diante da variação do critério dominante, mantendo fixas as razões entre os demais pesos. Ela não substitui, portanto, uma avaliação da incerteza dos próprios dados de entrada — a resolução vertical do modelo digital de elevação derivado do SRTM, por exemplo, é da ordem de alguns metros, magnitude relevante em uma planície costeira onde as diferenças de cota decisivas são pequenas. Da mesma forma, o modelo é aplicado por um único decisor especialista, o que assegura consistência interna dos julgamentos, mas não incorpora eventuais divergências entre os órgãos envolvidos na gestão da bacia.

Como próximos passos da pesquisa, prevê-se a execução completa do processamento geoespacial das camadas descritas na Seção 2.2, a geração do mapa de suscetibilidade em cinco classes e sua integração ao Índice de Vulnerabilidade dos Meios de Vida, de modo a validar empiricamente a classificação antecipada no Quadro 2 e a converter o diagnóstico em recomendações espacialmente explícitas para a recuperação dos diques e o zoneamento das áreas de risco. Prevê-se ainda a validação do mapa obtido contra registros históricos de alagamento na bacia, a realização de uma análise de sensibilidade estendida aos demais critérios e aos limiares de reclassificação, e a discussão dos resultados com os gestores municipais dos dezesseis municípios abrangidos, de modo que a priorização de intervenções incorpore também as restrições orçamentárias e de competência institucional que condicionam a recuperação dos diques.

Referências

Araújo, F.O., Cunha, G.K.G., Silva, A.L.B. (2023), Uso e ocupação do solo na bacia hidrográfica do rio Ceará-Mirim/RN. In: *XXV Simpósio Brasileiro de Recursos Hídricos*. ABRHidro, Aracaju.

Dar, H.M.u.d., Bhat, D.M., Mir, K.H. (2026), Flood Susceptibility Mapping Using GIS with AHP and MCDA Technique for Jhelum River Basin, Union Territory of Kashmir, India. *Journal of the Indian Society of Remote Sensing*, 54, 755-767.

IGARN – Instituto de Gestão das Águas do Estado do Rio Grande do Norte (2009), *Mapa da Bacia Hidrográfica do Rio Ceará-Mirim*. Programa Água Azul, Natal.

Keeney, R.L. (1992), *Value-Focused Thinking: A Path to Creative Decisionmaking*. Harvard University Press, Cambridge, MA.

Mukherjee, R., Deb, P. (2023), Application of GIS-based analytical hierarchy process for assessment and mapping of flood risk zone in the lower Ramganga River Basin, Western Gangetic Plain, India. *Environment, Development and Sustainability*, 26, 1-24.

Rashid, M., Ullah, S., Farnaz, Farooq, S., Haider, S., Liso, I.S., Parise, M. (2026), Integrated Data-Driven Multi-Criteria Analysis and Machine Learning Approaches for Assessment of Flood Susceptibility Mapping. *Water*, 18, 844.

Saaty, T.L. (2008), Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, 1(1), 83-98.

Tefera, S.A., Thatiparthi, V.L., Tadesse, T.B., Asmare, G.W. (2026), Flood hazard assessment and livelihoods vulnerability of agropastoral households in lower Awash river Basin, Ethiopia. *Discover Sustainability*, 7, 308.

Vasconcelos, T.Q.F. (2018), *Geologia e controle estrutural do enxame de diques Rio Ceará-Mirim na porção Leste do Rio Grande do Norte*. Monografia (Bacharelado em Geologia), Universidade Federal do Rio Grande do Norte, Natal.

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A Preference-Constrained Hierarchical Benefit-of-the-Doubt Framework for Electricity Distribution Quality Assessment

Adriana Cavalcante Marques[1], Lívia Mariana Lopes Souza Torres[2]

[1] Department of Production Engineering, Federal University of Rio Grande do Norte (UFRN), Natal, RN, Brazil
[2] Department of Production Engineering, Federal Rural University of Semi-Arid Region (UFERSA), Angicos, RN, Brazil

adriana.marques.1@ufrn.br, livia.mariana@ufersa.edu.br

Abstract. This research in progress proposes a preference-constrained composite indicator for the quality of electricity distribution in Brazil. The framework integrates partial-preference elicitation through FITradeoff with a two-level directional Benefit-of-the-Doubt model. An ANEEL representative will provide preference information at two distinct levels: within each quality dimension and across the dimensions. The resulting feasible weight spaces will constrain endogenous aggregation while preserving the compensatory nature of the Benefit-of-the-Doubt approach. The expected result is a global index accompanied by dimension scores and interpretable local and global weights, providing an integrated yet diagnostically transparent representation of regulatory quality.

Keywords: Benefit-of-the-Doubt; composite indicator; electricity distribution; FITradeoff; multicriteria decision analysis.

1 Purpose

Electricity distribution quality is multidimensional. In Brazil, the National Electric Energy Agency (ANEEL) monitors continuity, voltage conformity, commercial-service performance, complaint handling and consumer perception through the ANEEL Consumer Satisfaction Index (IASC) (ANEEL, 2021a, 2021b). Although these measures are essential for diagnosis, their differences in units, directions, periodicities and regulatory meanings hinder a unique auditable synthesis of overall quality performance across distribution system operators. ANEEL also publishes the Global Continuity Performance Indicator (DGC), which assesses DEC and FEC relative to their regulatory limits but remains restricted to continuity.

The classic Benefit-of-the-Doubt (BoD) consists of a specific formulation of Data Envelopment Analysis (DEA) models, and it provides a data-driven alternative to fixed-weight aggregation by allowing each evaluated unit to select its most favorable admissible weights (Cherchye et al., 2007). Benefit-of-the-Doubt (BoD) models are input-oriented DEA models in which only outputs are evaluated, using a dummy variable equal to one for all DMUs as the input. In this framework, which is fundamental to the construction of composite indices, all sub-indicators are treated as outputs. Although this flexibility accommodates heterogeneous performance profiles and non-commensurate indicators (Pascoe et al., 2023), unrestricted weighting may assign negligible importance to weakly performing indicators. Libório et al. (2025) associate this flexibility with sensitivity to extreme values and potential bias, proposing the Extreme Values Reduction–Ordered Weighted Averaging approach. Zhang et al. (2026) address ranking instability through the graph subset dominance BoD model, whereas Fusco and Magrini (2026) extend BoD assessment from a static setting to dynamic performance decomposition. Complementarily, Gong et al. (2020) employs compromise weights, while the hierarchical constrained directional model of Mosnier et al. (2023) uses weight restrictions to preserve endogenous aggregation and the internal structure of multidimensional assessments. Collectively, these studies demonstrate the need to retain the analytical advantages of endogenous weighting while constraining the admissible weight space. However, incorporating incomplete regulatory preferences into a hierarchical BoD model without requiring a single precise weight vector remains an unresolved issue.

This study therefore proposes a preference-constrained hierarchical index of electricity distribution quality, with indicators forming the lower level and regulatory dimensions forming the upper level. The candidate indicators comprise DEC and FEC for continuity; DRPe and DRCe for steady-state voltage non-conformity; PLA for compliance with commercial-service deadlines; IPSFP for complaint resolution; and IASC for commercial-service quality (Fig. 1). The DGC will not be included alongside DEC and FEC, thereby avoiding double counting. An ANEEL representative will act as the primary decision maker, supported by technical experts responsible for clarifying regulatory and data definitions without replacing institutional preference judgements. The central research question is whether FITradeoff-derived preference spaces can guide the endogenous weights of a hierarchical BoD model and produce a more credible synthesis than equal, fixed, common or unrestricted weighting schemes.

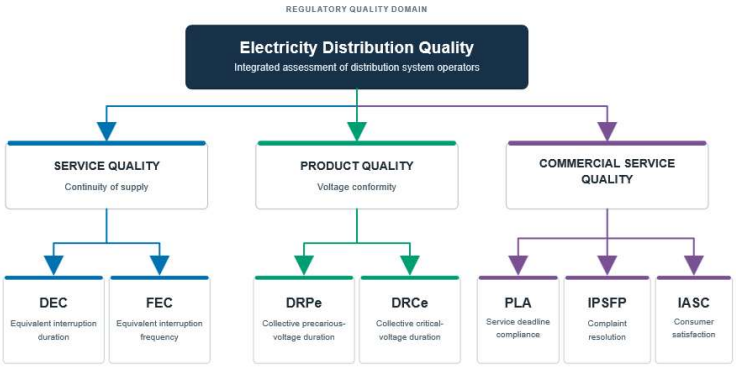

Fig. 1. Hierarchical structure of the quality dimensions and indicators considered in the proposed electricity distribution quality assessment model.

2 Methodology

Fig. 2 presents the proposed framework for constructing a preference-constrained composite indicator for electricity distribution quality. The first stage will structure the regulatory problem and the empirical basis of the index. Regulatory documents, data dictionaries, interviews and a facilitated workshop with the ANEEL representative and technical experts will identify the intended use of the index, the fundamental quality objectives, the dimensions, the operational indicators and their directions of preference. This stage will also distinguish comparative monitoring from sanctioning or incentive design, because the proposed index is intended primarily as a transparent benchmarking and diagnostic instrument.

Second, indicators will be screened for regulatory legitimacy, availability, consistent coverage across operators and years, controllability, non-redundancy and resistance to gaming. The unit of analysis will be the distribution system operator-year. ANEEL open data will be assembled for a common period in a versioned data dictionary documenting regulatory changes, concession-area modifications, missing values and denominator effects. Regulatory limits will anchor performance interpretation whenever available. Desirable and undesirable measures will retain their regulatory direction, and the directional formulation will support their joint treatment without arbitrary reciprocal transformations.

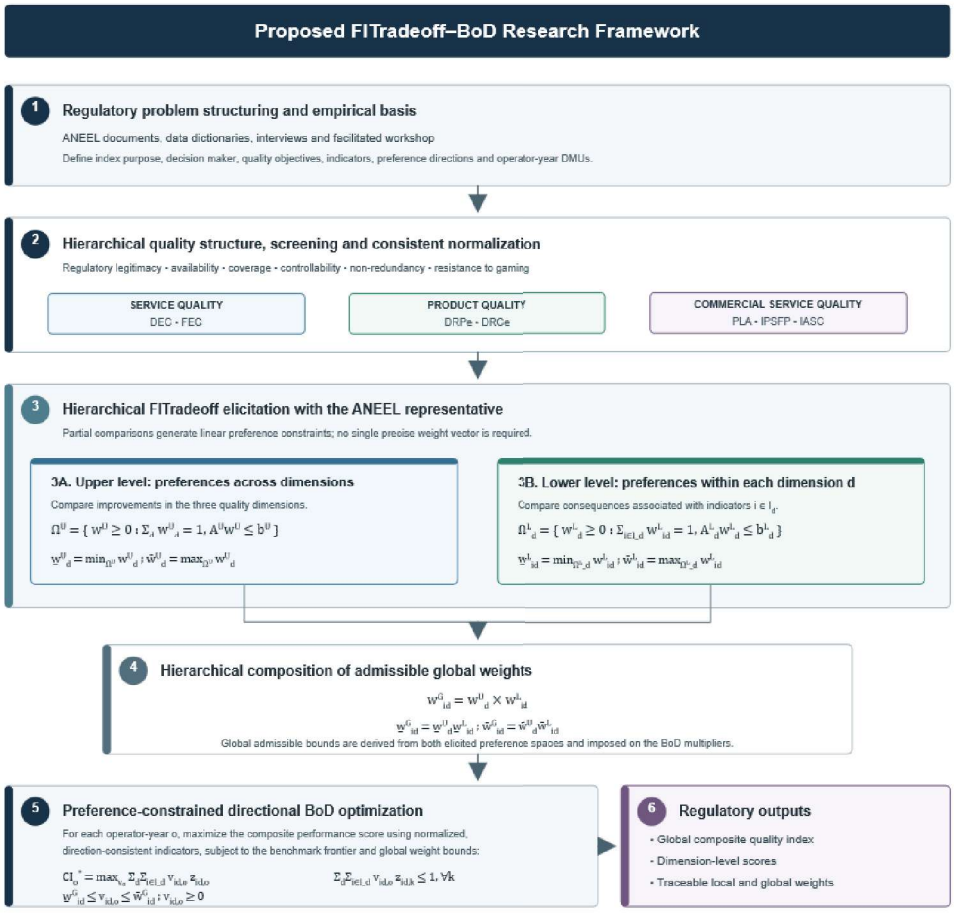

Fig. 2. Proposed research framework for constructing a preference-constrained composite indicator for electricity distribution quality.

Third, the quality assessment will be structured into three dimensions defined within the ANEEL regulatory framework: service quality, represented by the continuity indicators DEC and FEC; product quality, represented by the voltage-conformity indicators DRP and DRC; and commercial service quality, represented by PLA, IPSFP and IASC. FITradeoff (de Almeida et al., 2016) will be applied hierarchically at two complementary levels. At the upper level, comparisons among improvements in the three quality dimensions will generate linear inequalities defining the feasible preference space Ω^U for the dimension weights. Subsequently, within each dimension (*d*), comparisons among the consequences associated with its respective indicators will define the feasible lower-level preference space $\Omega_d{}^L$. Therefore, $w^U{}_d$ will denote the admissible weight of dimension (*d*), whereas $w^L{}_{id}$ will denote the admissible local weight of indicator (*i*) within that dimension (*d*). Although lower and upper weight bounds will be reported to facilitate interpretation, the complete sets of preference constraints elicited from the ANEEL representative will be retained to ensure that only jointly compatible weight combinations are considered.

Fourth, the proposed model will extend the classic Benefit-of-the-Doubt formulation of Cherchye et al. (2007) and the hierarchical constrained directional model of Mosnier et al. (2023). The global weight of indicator (*i*) belonging to dimension (*d*) will be defined as $w^G{}_{id} = w^U{}_d \times w^L{}_{id}$, thereby preserving the hierarchical relationship between the three quality dimensions and their respective indicators. After consistent indicator normalization, these global bounds will be imposed on the corresponding multipliers of the directional BoD model, restricting its endogenous optimization to weighting structures compatible with the preferences elicited from the ANEEL representative. The formulation will remain compensatory, allowing stronger performance in one indicator to offset weaker performance in another, but only within the admissible hierarchical weight ranges.

The resulting model will produce a single composite quality index for each electricity distribution company, while retaining dimension-level scores and traceable indicator weights for regulatory interpretation. A formal uncertainty, sensitivity and ranking-robustness analysis, following the concerns raised by Cherchye et al. (2008), is reserved for future research after the core FITradeoff-BoD formulation and database have been validated.

3 What would be expected

The first expected result is a regulator-validated hierarchy connecting quality objectives, dimensions, indicators, data sources and directions of preference. The second is the elicitation of the lower-level spaces Ω_d^L and the upper-level space Ω^U, making explicit which weight relationships are institutionally admissible without requiring precise weights. The third is an integrated quality index for Brazilian distribution operators, accompanied by dimension scores, local weights and decomposed global indicator weights.

Methodologically, the study is expected to demonstrate how partial preferences obtained through FITradeoff can constrain a hierarchical directional BoD model at two aggregation levels. The approach preserves operator-specific endogenous weighting while preventing combinations that contradict the regulator's stated trade-offs. Because the model is explicitly compensatory, its transparency will depend on reporting both the global index and the disaggregated dimension scores, allowing users to identify which strengths and weaknesses underlie each overall result.

For ANEEL, the proposed tool is expected to support comparative monitoring, prioritization of deeper analyses and clearer communication of multidimensional performance. It is not intended to replace the underlying indicators, automate sanctions or establish causal effects. Its principal contribution is an integrated MCDA-DEA design in which FITradeoff represents incomplete institutional preferences and a hierarchical directional BoD model composes the indicator under two coherent preference spaces. Future research may extend the framework through uncertainty, sensitivity, temporal and ranking-robustness analyses.

References

Agência Nacional de Energia Elétrica – ANEEL (2021a), Resolução Normativa nº 956, de 7 de dezembro de 2021: Procedimentos de Distribuição de Energia Elétrica no Sistema Elétrico Nacional – PRODIST. Brasília, Brazil.

Agência Nacional de Energia Elétrica – ANEEL (2021b), Resolução Normativa nº 1.000, de 7 de dezembro de 2021: Regras de Prestação do Serviço Público de Distribuição de Energia Elétrica. Brasília, Brazil.

Cherchye, L., Moesen, W., Rogge, N., Van Puyenbroeck, T. (2007), An introduction to 'benefit of the doubt' composite indicators. *Social Indicators Research*, 82(1), 111–145. https://doi.org/10.1007/s11205-006-9029-7.

Cherchye, L., Moesen, W., Rogge, N., Van Puyenbroeck, T., Saisana, M., Saltelli, A., Liska, R., Tarantola, S. (2008), Creating composite indicators with DEA and robustness analysis: The case of the Technology Achievement Index. *Journal of the Operational Research Society*, 59(2), 239–251. https://doi.org/10.1057/palgrave.jors.2602445.

de Almeida, A.T., de Almeida, J.A., Costa, A.P.C.S., de Almeida-Filho, A.T. (2016), A new method for elicitation of criteria weights in additive models: Flexible and interactive tradeoff. *European Journal of Operational Research*, 250(1), 179–191. https://doi.org/10.1016/j.ejor.2015.08.058.

Fusco, E., & Magrini, A. (2026). Dynamic benefit of the doubt decomposition for panel data: Evidence from sustainable energy in the EU. *Sustainability*, *18*(05835).

Gong, C., Gong, N., Qi, R., & Yu, S. (2020). Assessment of natural gas supply security in Asia Pacific: Composite indicators with compromise Benefit-of-the-Doubt weights. *Resources Policy*, *67*, 101671.

Libório, M. P., Ekel, P., D'Angelo, M. F. S. V., Martínez, L., & Rabiei, H. (2025). Constructing composite indicators through extreme values reductions-ordered weighted averaging: Human development index. *IEEE Access*, *13*.

Mosnier, C., Boukhriss, S., & Minviel, J.-J. (2023). Does pig production improve cattle farm sustainability in the French Massif Central? A hierarchical constrained directional benefit-of-the-doubt approach. *Agricultural Systems*, *210*, 103692. https://doi.org/10.1016/j.agsy.2023.103692.

Pascoe, S., Cannard, T., Dowling, N. A., Dichmont, C. M., Asche, F., & Little, L. R. (2023). Use of Data Envelopment Analysis (DEA) to assess management alternatives in the presence of multiple objectives. *Marine Policy*, *148*, 105444.

Zhang, C., Chen, S., Su, W., Balezentis, T., & Benjamin, L. (2026). Addressing rank reversal in subgroup dominance benefit of the doubt model: A case study of the human development index. *European Journal of Operational Research*, *334*, 562–574.

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Plant-Based Packaging and Visual Attention: An Eye-Tracking Study of Vegetarian and Non-Vegetarian Consumers

Aline Amaral Leal Barbosa[1], Gabrielly Caroline Mendes da Cunha[2], Weslley Thiago Martins Fernandes[3], Denise Dumke de Medeiros[4]

[1]Universidade Federal de Campina Grande, Brazil
[2,3, 4]Universidade Fedral de Pernambuco, Brazil
[3]

aline.amaral@professor.ufcg.edu.brg, gabrielly.mendes@ufpe.br, weslley.thiago@ufpe.br. denise.medeiros@ufpe.br

Abstract. Food packaging not only serves to protect the product physically, but also serves as a powerful communication tool to attract consumers' attention, support a visual identity, influce emotiond, and convey messages regarding the product taste. Although packaging is perceived as a single and integrated visual unit, each design attribute can communicate specific product characteristics and elicit distinct consumer responses. This role becomes particularly relevant in the rapidly growing market for plant-based alternatives, where packaging design is used to communicate product characteristics and position these products relative to their animal-based counterparts. In this context, packaging has increasingly incorporated visual and verbal attributes traditionally associated with meat-based products, such as images of animals and animal-related terminology. However, little is known about how these attributes affect consumers' visual attention, emotional responses, and purchase decisions, particularly whether these effects differ between vegetarian and non-vegetarian consumers. Thus, this research-in-progress investigates how images of animals and animal-related terminology on plant-based burger and nugget packaging influence visual attention, emotional responses, and purchase decisions. For that, a laboratory experiment was conducted with 58 participants, using eye-tracking to objectively measure visual attention through fixation count and fixation duration. Participants were exposed to plant-based food packaging that varied in the presence of visual (animal images) and verbal (animal-related terminology) elements. The study is expected to identify whether these elements generate different patterns of visual attention, emotional valence, and purchase decisions between vegetarian and non-vegetarian consumers. It also examines whether greater visual attention is associated with differences in emotional responses and purchase decisions. Finally, by combining eye-tracking measures with self-reported responses, the research is expected to provide a more comprehensive understanding of consumer reactions to plant-based packaging and offer insights for developing packaging strategies targeted at both vegetarian and non-vegetarian consumers.

Keywords: Plant-based packaging; Visual attention; Purchase decision

Complex Intelligence and the Systemic Investigation Network: A Complementary Approach to CHAP²

Marcos Antonio Rodrigues De Souza Junior[1] [0009-0003-6583-6538] and. Marcos Pereira Estellita Lins[1][0000-0003-1980-0764]

[1]Federal University of Rio de Janeiro, 550 Pedro Calmon Ave, Cidade Universitária, Rio de Janeiro RJ 21941-901, Brazil
marcos.rodrigues@pep.ufrj.br
estellita@pep.ufrj.br

Abstract. This article applies the first three phases of the Complex Holographic Assessment of Paradoxical Problems (CHAP²) methodology to the Social Responsibility Management Department (SRMD) of a nonprofit organization, incorporating Complex Intelligence—operationalized through the Systemic Investigation Network (SIN) and supported by Generative Artificial Intelligence (GAI)—as a complementary cognitive layer for problem structuring. The study is applied in nature and adopts a qualitative, exploratory-descriptive approach. The organizational system of the SRMD was characterized, six organizational agents were selected and trained, and their perspectives were elicited through semi-structured interviews and represented in metacognitive maps organized into five thematic clusters. The results indicate that many observed difficulties are associated not with isolated individual failures, but with organizational design, fragmented governance interfaces, and the coexistence of distinct organizational rationalities. The coordinated use of the eight intelligences expanded the interpretive scope of the investigation by making explicit conceptual ambiguities, systemic relationships, organizational tensions, mental models, and ethical implications distributed across the empirical material. The contribution of the SIN was not necessarily the discovery of new empirical problems, but the recursive reinterpretation of agents' perceptions into differentiated and interconnected organizational knowledge. GAI was used only as a supporting resource for question and hypothesis generation, with interpretation and validation remaining under the responsibility of the researcher.

Keywords: CHAP², Systemic Investigation Network, Generative Artificial Intelligence.

1 Introduction

Contemporary organizations operate in environments characterized by high complexity, volatility, and accelerated change, requiring more adaptive structures and governance mechanisms capable of integrating different areas [1, 2]. The reconfiguration of structures, processes, and responsibilities increases adaptive capacity and institutional value creation, but also intensifies the complexity of internal relationships,

making the flexibility of organizational boundaries an important governance mechanism [3, 4].

In this context, the Social Responsibility Management Department (SRMD) of the nonprofit organization Prisma Social (a fictitious name used for confidentiality purposes) consists of three coordination units responsible for social development programs, projects, and services, requiring constant interaction among areas, multidisciplinary teams, and stakeholders. The coexistence of a permanent hierarchical-functional structure with cross-functional project execution generates role ambiguity, overlapping activities, and priority conflicts - characteristics that bring the SRMD context closer to complex or paradoxical organizational problems, whose understanding requires the integration of multiple perspectives and recognition of distinct organizational rationalities [5].

Problems of this nature cannot be adequately represented through a single analytical perspective, as they involve multiple agents, divergent interpretations, ambiguities, interdependencies, and continuous learning. Accordingly, Problem Structuring Methods (PSMs) have been developed to support the exploration and structuring of complex problematic situations through multiple perspectives and participatory processes [6, 7]. The Complex Holographic Assessment of Paradoxical Problems (CHAP²) methodology is adopted in this study as a problem-structuring approach that integrates systems thinking, metacognition, multiple perspectives, and paradox management [8, 9].

Although these approaches provide important mechanisms for representing perspectives and structuring complex situations, the cognitive operations through which the evidence generated during the investigation is recursively questioned and reinterpreted are not necessarily made explicit as an integrated investigative architecture. In the context of the initial phases of problem structuring, this creates an opportunity to complement the methodological structure of CHAP² with a coordinated cognitive architecture capable of examining the same organizational evidence through different cognitive lenses before the problem is consolidated into a representation.

In response to this gap, this study incorporates the Complex Intelligence proposed by Lins [10], operationalized through the Systemic Investigation Network (SIN). Complex Intelligence provides a cognitive architecture composed of eight complementary intelligences that can be used as investigative lenses, while the SIN coordinates their application throughout the inquiry. In this configuration, CHAP² provides the methodological structure for problem structuring, whereas the SIN provides a complementary cognitive layer through which the evidence generated during this process can be recursively interrogated from different perspectives. Generative Artificial Intelligence (GAI) is used only as a supporting resource for the operationalization of this architecture, assisting in the formulation of investigative questions, the exploration of potential relationships, and the organization of preliminary interpretations under the critical validation of the researcher.

The novelty of this study therefore does not lie in the use of multiple perspectives, stakeholder participation, or problem representation, which are already established elements of the PSM tradition [6, 7, 11]. Rather, it lies in the explicit coordination of eight complementary cognitive operations within the problem-structuring process through the SIN, integrated with the initial phases of CHAP². The proposed architecture

does not replace CHAP² or introduce a new stakeholder-elicitation procedure; instead, it makes explicit how empirical evidence can be recursively examined in relation to conceptual assumptions, alternative perspectives, organizational interdependencies, tensions and paradoxes, mental models, symbolic representations, and ethical implications. The empirical application to the SRMD demonstrates this integration in an organizational setting, while GAI remains a supporting resource and not an autonomous source of empirical or scientific knowledge.

Accordingly, this study aims to investigate how the complementary integration of Complex Intelligence, operationalized through the Systemic Investigation Network, can expand the investigative capacity of the first three phases of CHAP² in structuring an organizational problem. Specifically, the study seeks to: (i) characterize the organizational system of the SRMD and its interdependent relationships; (ii) identify agents' patterns of perception; (iii) identify organizational convergences, divergences, and tensions; and (iv) examine how the complementary integration of Complex Intelligence, operationalized through the SIN, contributes to the investigative process during the first three phases of CHAP².

The contribution of the study is therefore primarily methodological and epistemic. Methodologically, it demonstrates how Complex Intelligence, operationalized through the SIN, can be integrated with CHAP² to systematically revisit the evidence generated during problem structuring through coordinated cognitive perspectives. Epistemically, the contribution lies not necessarily in generating new empirical facts, but in making explicit and connecting assumptions, meanings, relationships, tensions, and implications that may remain dispersed across organizational accounts. In this sense, the SIN transforms dispersed perceptions and experiences into differentiated and interconnected organizational knowledge, while the empirical application illustrates how this transformation can occur in a complex organizational context. Interpretation, validation, and knowledge integration remain the responsibility of the researcher, supported by the participation of the organizational agents and by empirical evidence [9, 10].

2 Theoretical background

2.1 Structuring Complex Problems and CHAP²

Complex organizational problems are characterized by high interdependence among elements, the coexistence of multiple agents and rationalities, and dynamic, context-dependent causal relationships, which makes the application of traditional analytical approaches difficult and requires problem structuring before solutions are proposed [5, 12]. Problem Structuring Methods (PSMs) emerged in this context as approaches aimed at constructing a shared understanding of situations characterized by uncertainty, multiple perspectives, and a lack of consensus, assuming that organizational problems are also social and political, and that structuring the problem is as important as identifying solutions [6, 7, 11].

The Complex Holographic Assessment of Paradoxical Problems (CHAP²) constitutes a problem-structuring methodology for complex problems characterized by multiple perspectives, ambiguities, and organizational paradoxes. It is designed to integrate

systems thinking, metacognition, multiple perspectives, and paradox management into a participatory process organized into six successive phases [8, 9]. This study is restricted to the first three phases—system characterization, agent training, and characterization of agents' perspectives—as they constitute the initial structuring of the problem under investigation.

2.2 Complex Intelligence and the Systemic Investigation Network

Complex Intelligence constitutes a cognitive framework designed to expand researchers' investigative capacity when addressing complex problems. It comprises eight complementary intelligences whose coordinated operation enables organizational phenomena to be understood from different perspectives (Table 1) [10].

Table 1. Cognitive Architecture of Complex Intelligence. Source: adapted from Lins [10].

Intelligence	Description and function in system analysis
Epistemological-Ontological	Understands the limits of knowledge and the assumptions underlying the investigation; recognizes that every representation of the system is incomplete. Delimits what remains outside the model and makes explicit the conditions that are tolerated.
Multiperspective	Generates, represents, and moves among different interpretations of reality. Encompasses and explores the interpretive diversity of agents.
Paradoxical	Understands and sustains tensions between contradictory elements without prematurely collapsing them into a simplifying solution; mediates the coexistence of incompleteness and inconsistency.
Metacognitive	Monitors, evaluates, and regulates its own thought processes, including the use of the other intelligences; manages the trade-off between completeness and decision-making under uncertainty.
Analytical	Decomposes complex problems into comprehensible elements, identifies variables and categories, and formalizes concepts, reducing logical-linguistic ambiguities.
Systemic	Understands interdependencies, causal relationships, feedback loops, and emergent effects; models the functioning of the system as a whole.
Sensory-Metaphorical	Uses metaphors and symbolic representations to integrate and make explicit meanings that technical language does not capture.
Civic and Civilizational Ethics	Evaluates the ethical, social, and collective implications of decisions, normatively guiding processes in light of justice and institutional sustainability.

The operationalization of this architecture occurs through the Systemic Investigation Network (SIN), in which each intelligence acts as a cognitive lens aimed at exploring convergences, ambiguities, paradoxes, and the construction of metacognitive maps. The relationship between Complex Intelligence and CHAP² is therefore complementary rather than substitutive. CHAP² provides the methodological sequence through which the problematic situation is progressively characterized and structured, whereas Complex Intelligence provides complementary cognitive lenses for examining the evidence, assumptions, perspectives, relationships, and tensions encountered throughout this process. The SIN operationalizes

this relationship by coordinating the use of the eight intelligences as an integrated investigative architecture rather than as isolated analytical techniques [8, 10].

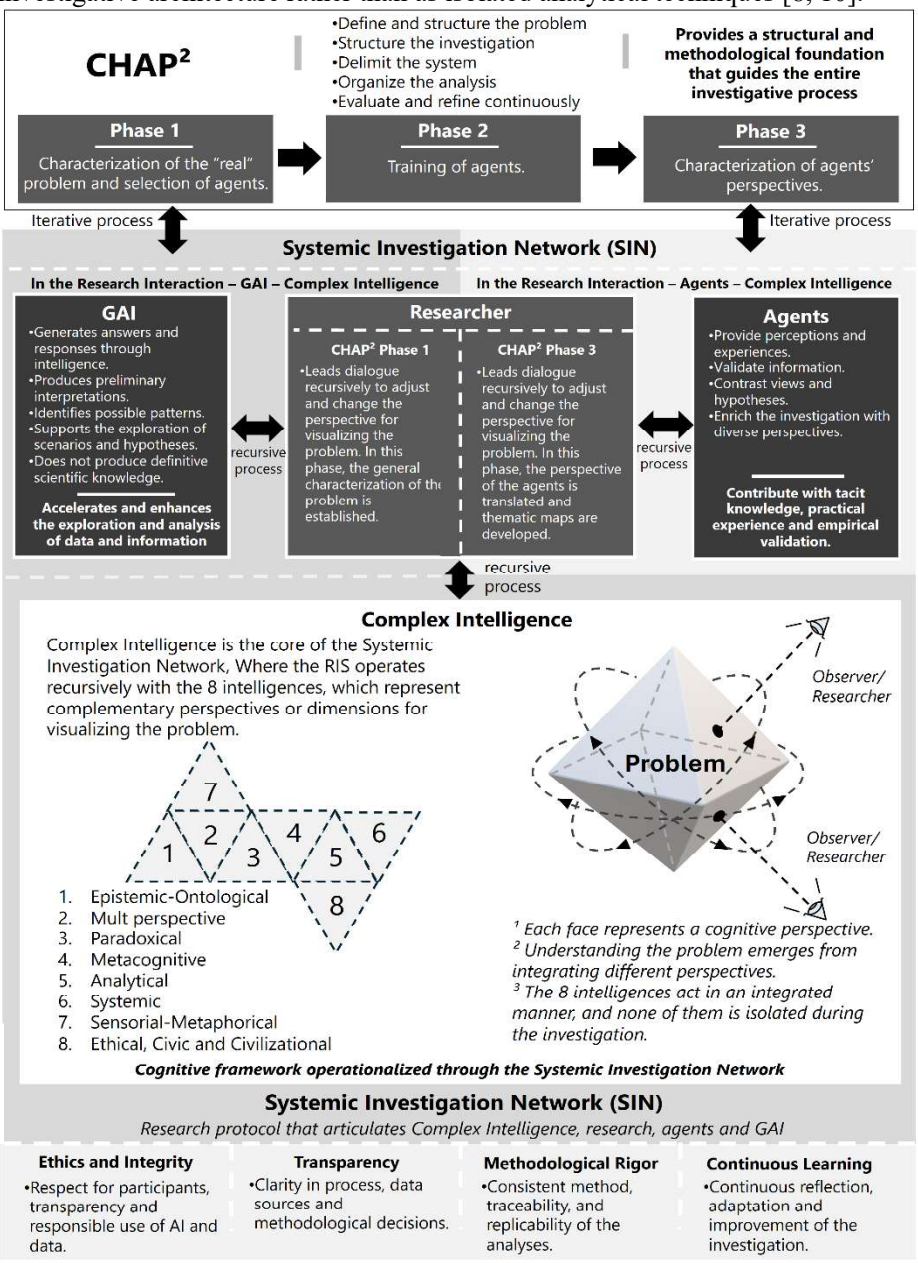

Fig. 1. Conceptual and operational architecture for applying Complex Intelligence through the SIN during the first three phases of CHAP². Source: prepared by the authors, based on Lins [10].

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This distinction is important for the positioning of the present study: the contribution does not consist in proposing a new problem-structuring methodology, but in demonstrating how a cognitive architecture based on Complex Intelligence and operationalized through the SIN can be integrated with an established problem-structuring methodology. Figure 1 summarizes this conceptual architecture, highlighting the relationship among CHAP², Complex Intelligence, the SIN, the researcher, the agents, and GAI.

3 Research method

The study is characterized as applied, adopting a qualitative, exploratory-descriptive approach aimed at providing an overview of the challenges and opportunities of the SRMD [13]. Regarding technical procedures, a case study was adopted, applying CHAP², a methodology structured into six successive phases: (1) characterization of the real system and dialogue group; (2) training of agents; (3) characterization of agents' perspectives; (4) workshops on conceptual and paradoxical models; (5) articulation with indicator and process models; and (6) identification and implementation of feasible actions, with monitoring [8]. This study is restricted to Phases 1 through 3, whose objectives are summarized in Table 2.

Table 2. CHAP² phases covered in this study. Source: Lins and Antoun Netto [8].

Phase	Objective
1	Characterize the real system through a conceptual map based on interviews with privileged agents and a literature review, in addition to selecting the agents (stakeholders) with the most divergent and representative perspectives.
2	Train the selected agents through a seminar introducing the CHAP² methodology and developing metacognition.
3	Elicit the expression of the system from the perspective of each agent through interviews and the development and validation of metacognitive maps, subsequently aggregated and organized by themes (thematic metacognitive maps).

Within Phases 1 and 3, Complex Intelligence was operationalized through the SIN as a complementary cognitive architecture to CHAP². In Phase 1, it was used to broaden the initial characterization of the "real" problem by articulating the researcher, GAI, and the eight intelligences. In Phase 3, it supported the formulation of the interview questions and the subsequent interpretation of agents' perspectives through the interaction between the researcher and the selected agents. The use of GAI does not replace the researcher's analysis and judgment or the participation of the agents; its role is restricted to supporting the formulation of investigative questions, suggesting hypotheses, and organizing preliminary interpretations, with the researcher responsible for critically validating the results (Table 3).

Table 3. Operational protocol for the SIN with GAI support. Source: adapted from Lins [10].

Element	Input / operation	Output	Validation and use
GAI	Organizational documents, preliminary understanding of the SRMD, and one of the eight intelligence lenses.	Investigative questions, candidate hypotheses, categories and preliminary interpretations.	Screened by the researcher; unsupported assumptions were excluded.
SIN / eight intelligences	Recursive questioning of the same organizational situation through complementary cognitive lenses.	Differentiated interpretations concerning concepts, perspectives, paradoxes, mental models, relations, metaphors and ethical implications.	Interpretations were confronted with empirical evidence.
Organizational agents	Investigative questions and interview prompts derived from the SIN.	Perceptions, tacit knowledge, convergences, divergences and examples from organizational practice.	Individual maps were validated with each agent.
Researcher	Documents, GAI outputs, interviews and validated maps.	Integrated interpretation and scientific synthesis.	Final responsibility for interpretation and validation.

The GAI-supported SIN followed a sequential and recursive protocol. First, the researcher provided the organizational context available for the investigation, including organizational documents, responsibilities, processes, and preliminary perceptions of the SRMD. Second, the situation was interrogated through the eight intelligence lenses, with GAI instructed to formulate investigative questions, suggest candidate hypotheses, identify potentially relevant relationships, and organize preliminary interpretations. These outputs were treated as exploratory material rather than empirical findings. Third, the researcher critically screened the outputs, excluding unsupported assumptions and retaining questions or hypotheses considered relevant for empirical investigation. In Phase 3, selected questions were incorporated into a semi-structured interview guide oriented by the eight intelligences, which was applied to the selected organizational agents. Their responses were then translated into individual conceptual maps, validated with the respective agents, and aggregated into thematic metacognitive maps.

Finally, GAI-generated hypotheses were confronted with documentary evidence, interview material, and validated maps, with the researcher responsible for the final interpretation and synthesis.

For transparency and reproducibility, the GAI-supported investigation followed a standardized structure (Fig 2). Appendix A summarizes the investigative protocol for each intelligence.

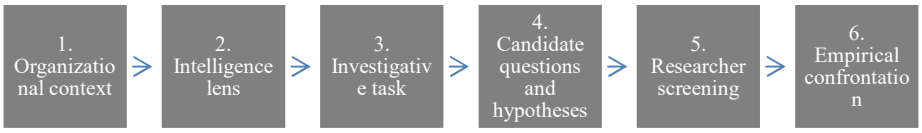


Fig. 2. Standardized structure for the GAI-supported investigation. Source: prepared by the authors.

4 Application of the first three phases of CHAP²

4.1 Phase 1 – System Characterization and Agent Selection

The following procedures were adopted in this phase: (a) analysis of general and regulatory documentation concerning the SRMD (organizational chart, functions, responsibilities, flowcharts, and performance reports); (b) operationalization of the SIN with GAI support to obtain a general understanding of the problem; and (c) preliminary interviews with two employees (management and one coordination unit).

The document analysis revealed that the SRMD consists of three coordination units. Coordination A concentrates on prospecting and partnerships with companies (third-party resources), development of social methodologies, consulting, administrative support functions and communication. Coordination B replicates this same breadth of functions but operates with its own institutional resources and leads institutional projects and social actions. Coordination C concentrates on human development support (social assistance) and the execution of integrated projects in partnership with companies. This configuration reveals redundancies between core and support functions performed by the three coordination units (Fig. 3), further aggravated by the fact that the SRMD is embedded within an institutional structure that already centralizes administrative, financial, procurement, and communications functions, to which management must be subordinate—a scope limitation for the application of the methodology.

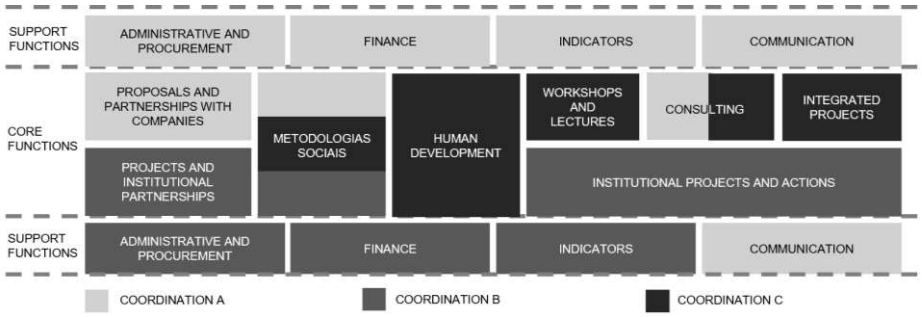


Fig. 3. Coordination units vs. organizational functions of the SRMD. Source: prepared by the authors.

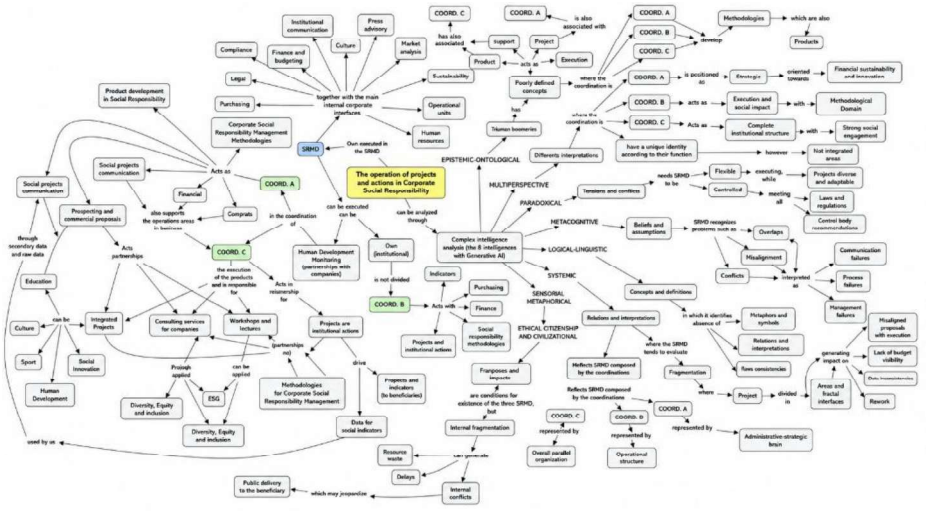
Interaction with GAI, in light of the eight intelligences (Table 1), made it possible to explore investigative hypotheses about the SRMD prior to the interviews. In summary, this interaction revealed: ambiguity in the concepts of "project," "product," "execution," and "support," which were inconsistently associated with the different coordination units (Epistemological-Ontological dimension, cf. Mintzberg [14]); coherent yet non-integrated identities among the three coordination units, which operate as parallel paradigms (Multiperspective, cf. Senge [15]); a permanent structural dilemma between flexibility and control, aggravated by the division of functions among coordination units (Paradoxical, cf. Lawrence and Lorsch [16]); the organization's tendency to interpret structural problems as communication failures (Metacognitive, cf. Argyris and Schön [17]); a lack of clear formalization of roles and decision-making flows (Analytical, cf. PMI [18]); fragmentation of the value flow between prospecting and impact assessment, with a lack of integrated systems (Systemic, cf. Checkland [19]); the metaphor of an "organism with disconnected parts"—Coordination A as the strategic-administrative brain, Coordination C as the operational structure, and Coordination B as a parallel, complete organism (Sensory-Metaphorical, cf. Morgan [20]); and the risk that internal fragmentation may compromise the social impact that constitutes the institutional purpose of the SRMD (Civic and Civilizational Ethics, cf. Sen [21]). These interpretations were treated as hypotheses to be confronted with the interviews and document analysis and were not directly incorporated into the investigation. Based on these procedures, the conceptual map for Phase 1 was developed (Fig. 4).

Additionally, six agents were selected who combine tactical and operational aspects and make it possible to visualize issues both internal and external to management (Table 4). The non-selection of an external agent constituted a limitation of the methodology's application.

Table 4. Selected agents and their relevance. Source: prepared by the authors.

Agent	Dimension represented	Importance
A1: Prospecting and proposals	External/internal interface	Translates institutional demands into projects; senses the expectations of clients and partners.

A2: Human development	Human and symbolic dimension	Captures organizational climate and human impact, aspects that are invisible to formal indicators.
A3: Integrated project leader	Practical integration	Translates methodologies into deliverables; reveals differences between the model and reality.
A4: Project/consulting leader	Integration and interdependencies	Crosses multiple coordination units; occupies the center of the SRMD's interdependencies.
A5: Data/Indicators	Information governance	Connects data, decision-making, and governance; a relevant point of tension within the SRMD.
A6: Management	Strategic integration	Manages institutional paradoxes and decisions under incompleteness; provides cognitive closure for the system.


The operation of projects and actions in Corporate Social Responsibility
SRMD
COORD. A
COORD. B
COORD. C
Complex intelligence analysis (the 8 intelligences with Generative AI)
EPISTEMIC-ONTOLOGICAL
MULTIPERSPECTIVE
PARADOXICAL
METACOGNITIVE
LOGICAL-LINGUISTIC
SYSTEMIC
SENSORIAL
METAPHORICAL
ETHICAL CITIZENSHIP AND CIVILIZATIONAL
Methodologies
Products
Project
Execution
Support
Product
Operational units
Human resources
Purchasing
Finance
Legal
Compliance
Finance and budgeting
Culture
Market analysis
Press advisory
Institutional communication
Product development in Social Responsibility
Corporate Social Responsibility Management Methodologies
Social projects communication
Prospecting and commercial proposals
Acts as partnerships
Education
Culture
Sport
Human Development
Integrated Projects
Social innovation
Consulting services for companies
Workshops and lectures
Diversity, Equity and inclusion
ESG
Methodologies for Corporate Social Responsibility Management
Data for social indicators
Projects are institutional actions
Indicators
Projects and institutional actions
Social responsibility methodologies
Frameworks and linguistic
Internal fragmentation
Resource waste
Delays
Internal conflicts
Public delivery to the beneficiary
Overall parallel organization
Operational structure
Administrative-strategic brain
Rework
Lack of budget visibility
Misaligned proposals with execution
Management failures
Process failures
Communication failures
Conflicts
Misalignment
Overlaps
Control body recommendations
Laws and regulations
Projects diverse and adaptable
Not integrated areas
Strong social engagement
Methodological Domain
Financial sustainability and innovation
Different interpretations
Poorly defined concepts
Tensions and contrast
Beliefs and assumptions
Concepts and definitions
Relations and interpretations
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Areas and fractal interfaces
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Reflects SRMD composed by the coordinations
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Prospects and indicators (to beneficiaries)
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Diversity, Equity and inclusion
Prolongs applied
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Delays
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Public delivery to the beneficiary
which may jeopardize
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Compliance
Finance and budgeting
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Press advisory
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Misalignment
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Process failures
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Misaligned proposals with execution
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Resource waste
Delays
Internal conflicts
Public delivery to the beneficiary
which may jeopardize
Data for social indicators
Methodologies for Corporate Social Responsibility Management
Diversity, Equity and inclusion
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Diversity, Equity and inclusion
Prolongs applied
can be applied
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Prospects and indicators (to beneficiaries)
Projects are institutional actions
Indicators
Projects and institutional actions
Social responsibility methodologies
Purchasing
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Acts with
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Human Development Marketing (partnerships with companies)
Own (institutional)
is not divided
Acts in relationship for
the execution of the projects and is responsible for
Consulting services for companies
Workshops and lectures
Integrated Projects
Social innovation
Human Development
Sport
Culture
Education
Acts partnerships
Prospecting and commercial proposals
Social projects communication
through secondary data and raw data
Social projects communication
Acts as
Financial
Comprats
also supports the operations areas

4.3 Phase 3 – Characterization of Agents' Perspectives

Phase 3 seeks to map the "subjective truths" of each agent—not processes, but their everyday experience of the organization [8]. The process followed three procedures: (a) individual semi-structured interviews, guided by the eight intelligences, addressing routines, difficulties, decision-making criteria, and perceptions of other sectors; (b) translation of the interviews into individual conceptual maps, which were corrected and validated with each agent; and (c) organization of the individual maps into five thematic clusters, aggregated into the Global Thematic Metacognitive Map (Fig. 5), in order to identify structural convergences and divergences. The interview guide was structured around the eight intelligences (for example: "What might your coordination unit be failing to see?" in the Epistemological-Ontological dimension; "What conflicts arise because the areas have different objectives?" in the Multiperspective dimension; "Where does the SRMD simultaneously need autonomy and integration?" in the Paradoxical dimension), without requiring all planned questions to be applied.

The individual maps were consolidated into five thematic clusters: (1) Prospecting and pre-execution of projects; (2) Participant selection process; (3) Performance, monitoring, and evaluation; (4) Social methodologies; and (5) Governance and support activities (Fig. 5). Cluster 1 presents the highest density of relationships, affecting the other clusters; Cluster 5, although having no formally associated agents, emerged transversally, demonstrating its articulating role. Monitoring and evaluation do not appear merely as a final stage, but as a source of learning for continuous adjustments in the other clusters—revealing feedback loops typical of complex systems rather than a linear flow.

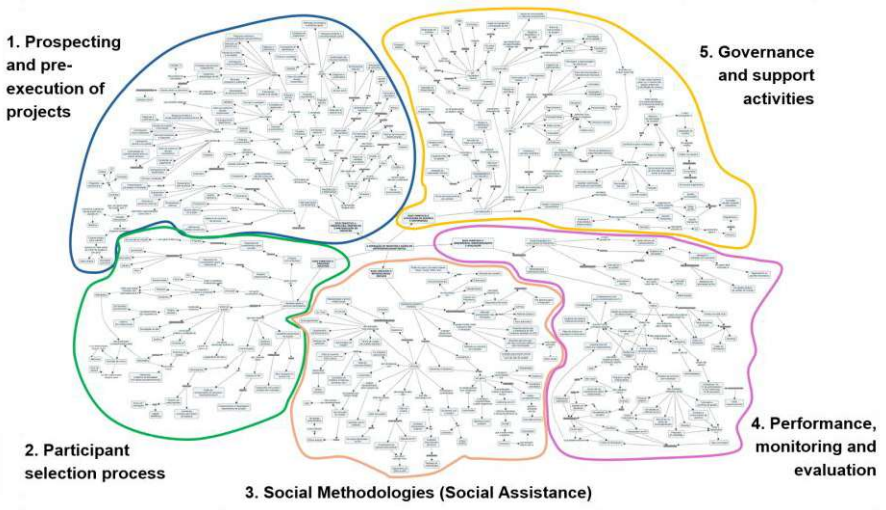

Fig. 5. Global thematic metacognitive map. Source: prepared by the authors.

Each cluster presented relevant convergences alongside structural tensions that recur in different forms (Table 5).

Table 5. Convergences and tensions by thematic cluster. Source: prepared by the authors.

Thematic cluster	Main convergences	Main tensions
1.Prospecting and pre-execution of projects	Expand social impact; align proposals with execution capacity; share good prospecting practices.	Fundraising vs. execution capacity; innovation vs. standardization; speed vs. technical quality; short term vs. sustainability.
2. Participant selection process	Ensure access for priority populations; ensure transparency and legitimacy of processes.	Inclusion vs. technical criteria; scale vs. personalization; agility vs. documentary rigor; equity vs. efficiency.
3. Performance, monitoring, and evaluation	Measure and demonstrate results; support decision-making; strengthen governance.	Control vs. learning; quantitative indicators vs. qualitative impacts; standardization vs. contextualization.
4. Social methodologies	Methodological coherence among coordination units; sharing of good practices.	Standardization vs. territorial adaptation; consistency vs. innovation; formal knowledge vs. practical knowledge.
5. Governance and support activities	Clarity of roles; integration among coordination units; improved information flow.	Autonomy vs. institutional integration; strategy vs. operations; functional specialization vs. cross-functional management.

5 Contribution of the sin to the structuring of organizational knowledge

At the end of Phase 3, the agents had already identified communication failures, overlapping responsibilities, divergent understandings, execution difficulties, and integration problems within the SRMD. The contribution of the SIN was therefore not to generate new empirical facts, but to recursively reinterpret these observations through eight complementary cognitive lenses. Because the study did not include a CHAP²-only comparison, it does not claim that such insights could not have emerged without the SIN. Rather, the case demonstrates that the SIN made previously implicit assumptions, relationships, paradoxes, and implications more explicit and traceable, transforming dispersed perceptions into structured organizational knowledge.

Table 6 summarizes, for each thematic cluster, the main interpretive contribution of the SIN and the organizational knowledge produced.

Table 6. From CHAP² empirical evidence to SIN-mediated organizational knowledge.

Cluster	Evidence produced by agents	SIN lenses and reinterpretation	Knowledge produced

1. Prospecting and pre-execution	Coordination difficulties, overlapping activities, and conflicts regarding proposals.	Analytical, Systemic, Epistemological-Ontological, Paradoxical and Metacognitive: responsibilities and interfaces were differentiated; meanings of "proposal", "product" and "project" were contrasted; conflicts were interpreted as tensions between strategic and operational integration.	The difficulties reflect governance limitations at organizational interfaces rather than isolated operational failures.
2. Participant selection	Need for inclusion, transparency and efficiency, with tensions between criteria and access.	Multiperspective, Systemic, Paradoxical and Civic-Civilizational Ethics: different stakeholder expectations were connected; technical criteria, equity, speed and documentary rigor were treated as coexisting demands.	Participant selection was understood as a strategic governance mechanism linked to institutional mission and social legitimacy.
3. Performance, monitoring and evaluation	Need for indicators, accountability and decision support, with tensions between quantitative and qualitative dimensions.	Analytical, Systemic, Epistemological-Ontological and Metacognitive: performance was differentiated from impact and accountability; information flows were connected to governance and learning.	The challenge is not only producing indicators, but using them as mechanisms of organizational learning and governance.
4. Social methodologies	Need for methodological consistency together with territorial adaptation.	Analytical, Epistemological-Ontological, Paradoxical and Metacognitive: methodology, process and product were differentiated; standardization and adaptation were treated as a structural tension.	Methodological diversity was interpreted as a condition to be governed rather than simply as inconsistency.
5. Governance and support	Role ambiguity, communication problems, integration difficulties and autonomy conflicts.	Systemic, Analytical, Epistemological-Ontological, Paradoxical, Multiperspective, Sensory-Metaphorical and Civic-Civilizational Ethics: interfaces, responsibility gaps, levels of decision, competing rationalities, and institutional implications were connected.	Governance emerged as the articulating mechanism linking strategy, operations, information, resources, and social impact.

The comparison highlights a recurring pattern across the five thematic clusters: the empirical material primarily described what was happening, whereas the SIN provided a structured way of interrogating how and why these observations were connected. A communication failure, for example, was reinterpreted as an interface problem; functional overlap as an organizational-design problem; divergent perceptions as differences in mental models and rationalities; execution difficulties as manifestations of persistent organizational tensions; and fragmentation as a systemic condition with implications for social impact. The eight intelligences therefore operated neither as independent analytical techniques nor as additional sources of empirical evidence, but as coordinated lenses for differentiating and connecting meanings, relationships, tensions, assumptions, and implications.

The findings are consistent with central assumptions of the Problem Structuring Methods (PSM) tradition, particularly the recognition that complex organizational situations involve multiple actors, perspectives, values, and uncertainties and therefore cannot be adequately represented through a single problem formulation [7, 11]. This is also consistent with Soft Systems Methodology, in which different perceptions of a problematic situation are represented to support debate and organizational learning [19], and with SODA (Strategic Options Development and Analysis [22, 23]), in which cognitive mapping is used to represent participants' perspectives and support reflection and shared understanding.

The present findings complement this tradition by introducing an explicit cognitive layer into the problem-structuring process. Rather than using multiple perspectives only as alternative representations of the problematic situation, the SIN recursively interrogates the same empirical material through eight complementary intelligences. In the SRMD case, this made it possible to distinguish conceptual ambiguities, systemic interfaces, mental models, persistent paradoxes, metacognitive assumptions, symbolic patterns, and ethical implications that were distributed across the agents' accounts.

The contribution should therefore be understood as complementary rather than as an alternative to established PSMs. The SIN did not necessarily generate new empirical facts or replace participatory problem representation. Its contribution was to make the cognitive operations used to reinterpret those representations explicit and coordinated, transforming dispersed perceptions into structured organizational knowledge.

Table 7. Role of GAI in the Operationalization of the SIN. Source: prepared by the authors.

Intelligence	Summary of the contribution produced by GAI	Role of GAI in supporting the SIN investigation
Epistemological-Ontological	Questioned the concepts of "project," "product," "execution," and "support," indicating conceptual ambiguities in the organizational structure.	Demonstrated that a significant portion of conflicts does not stem from people, but from the absence of a shared organizational ontology among the coordination units, compromising governance and fostering overlapping responsibilities.
Multiperspective and Theory of Mind	Generated questions exploring how each coordination unit interprets its own role and that of the other units.	Revealed that the observed conflicts result from the coexistence of legitimate yet poorly articulated rationalities, demonstrating that the central challenge lies in integrating perspectives rather than replacing one view with another.
Paradoxical	Identified tensions between control and flexibility, specialization and integration, and strategy and operations.	Made it possible to understand that several problems previously identified as operational failures represent permanent paradoxes arising from the coexistence of a functional structure and project-based execution.
Metacognitive	Questioned the assumptions used by the organization itself to interpret its problems.	Supported the revision of the predominant mental model, shifting the analysis from behavioral factors toward issues related to organizational design and governance mechanisms.

Analytical	Structured responsibilities, categories, processes, and causal relationships, organizing the diagnosis of the SRMD.	Made it possible to decompose the organizational problem into analyzable elements, identifying variables, responsibilities, causal relationships, and decision points that made the organizational structure of the SRMD and its main sources of ambiguity more explicit.
Systemic	Identified information flows, interfaces, and interdependencies among coordination units and processes.	Demonstrated that the main weakness of the SRMD lies not in isolated activities, but in the interfaces among coordination units, highlighting governance as the system's articulating element.
Sensory-Metaphorical	Used organizational metaphors to represent the functioning of the SRMD, exemplifying it as a "fragmented organism."	The metaphors facilitated interpretation of the metacognitive maps, enabling an intuitive understanding of patterns of fragmentation, low integration, and disruption of the value flow among coordination units.
Civic and Civilizational Ethics	Reoriented the investigation toward the impacts of organizational decisions on beneficiaries, partners, and the institutional mission.	Demonstrated that internal conflicts within the SRMD extend beyond administrative issues, directly influencing the institution's capacity to produce social impact, legitimacy, and public value.

Table 8. Analysis of GAI Limitations and Biases during the Operationalization of the SIN. Source: prepared by the authors.

Intelligence	**Limitations of GAI observed during the study**	**Perceived bias in GAI's contribution**
Epistemological-Ontological	GAI responses were based on the hypothesis that a structural problem existed before empirical validation with the agents, initially without considering historical, cultural, and contingent factors.	Tendency toward structural essentialization, interpreting ambiguities primarily as organizational design failures.
Multiperspective and Theory of Mind	The interpretations remained excessively homogeneous, failing to fully capture power relationships, history, and organizational culture, as well as differences in influence among agents.	Tendency to harmonize perspectives, reducing the political conflicts and struggles for legitimacy existing in the actual context.
Paradoxical	Some of the identified conflicts could be reduced through better process definition without necessarily constituting a permanent organizational paradox.	Tendency to overemphasize paradoxes, using them as the primary explanation for problems that also have administrative causes.
Metacognitive	GAI does not perform autonomous metacognition; its reflection depends on the questions formulated and the validation performed by the researcher.	Tendency toward confirmation bias, deepening hypotheses previously suggested in prompts without spontaneously questioning them.
Analytical	Some complex relationships were simplified into excessively linear categories, reducing the dynamic nature of organizational interactions.	Tendency toward premature formalization, privileging logical structures before fully understanding the system.

Systemic	Some suggested relationships corresponded only to occasional operational interactions rather than permanent structural interdependencies.	Tendency toward hyperconnectivity, establishing connections among elements whose systemic influence still required empirical validation.
Sensory-Metaphorical	Metaphors depend on the researcher's interpretation and may excessively simplify complex organizational phenomena.	Tendency to emphasize fragmentation, privileging images of disarticulation and making existing mechanisms of institutional cooperation less visible.
Civic and Civilizational Ethics	Responses adopted broad ethical principles without fully incorporating budgetary, regulatory, and operational constraints present in the organizational reality.	Tendency toward normativity, prioritizing the institutional mission and social impact over concrete management and resource limitations.

It should be emphasized that the identified biases do not necessarily represent errors on the part of GAI, but rather characteristics inherent to its operation as a cognitive support tool. Their identification resulted from the critical analysis conducted by comparing the responses produced by AI with organizational documents, interviews with agents, and the metacognitive maps constructed during the application of the CHAP² methodology.

6 Conclusions

This study applied the CHAP² methodology to analyze the SRMD of the organization under study, incorporating Complex Intelligence—operationalized through the SIN and supported by GAI—as a mechanism for expanding investigative capacity. The application made it possible to structure the organizational problem from a systemic perspective, identifying interdependent relationships, patterns of perception, convergences, divergences, and tensions among the coordination units responsible for conducting social responsibility actions, programs, and projects. The thematic clusters demonstrated that a substantial portion of the observed difficulties does not result from isolated failures of individuals or processes, but from characteristics inherent to organizational design, the fragmentation of governance interfaces, and the coexistence of different rationalities.

Among the main results are the identification of conceptual ambiguities related to projects, products, methodologies, governance, and execution; evidence of different mental models among the coordination units; identification of critical organizational interfaces that are not readily visible in traditional analyses; and the explanation of permanent paradoxes—autonomy versus integration, control versus flexibility, strategy versus operations, and functional specialization versus cross-functional project management. These results demonstrate that the observed conflicts largely represent natural manifestations of organizational complexity, requiring permanent governance mechanisms capable of integrating different perspectives without eliminating existing diversity.

The main contribution of the study lies in demonstrating the complementary integration of Complex Intelligence, operationalized through the SIN, with the CHAP² methodology. This integration does not replace the methodological structure of CHAP² or the empirical evidence obtained through interviews and document analysis. Rather, it provides a coordinated cognitive architecture through which such evidence can be revisited from complementary perspectives, making implicit assumptions, epistemological differences, systemic relationships, organizational tensions, and ethical implications more explicit. GAI played a supporting role in formulating investigative questions, exploring preliminary hypotheses, and organizing information, while knowledge production remained under the critical responsibility of the researcher.

From a practical perspective, the results provide support for strengthening SRMD governance, particularly integration among coordination units, definition of responsibilities, and processes of monitoring and organizational learning. It is also noteworthy that Clusters 2 (Participant Selection Process) and 5 (Governance and Support Activities) surprised the agents themselves by revealing complexity and strategic centrality that had previously been insufficiently recognized in everyday activities.

As limitations, the application of the methodology was restricted to the first three phases of CHAP² and therefore did not encompass the complete development of the conceptual and paradoxical models or the implementation of organizational interventions. Thus, the results obtained are understood as part of a problem-structuring process rather than as a definitive solution proposal; moreover, this is a single-case study, and its generalization should be undertaken with caution. For future research, it is recommended that the application of CHAP² be continued through its subsequent phases, that Complex Intelligence and the SIN be further investigated in different organizational contexts, and that comparative research be conducted on the use of the SIN with and without GAI support, in order to empirically assess its contribution to expanding investigative capacity in complex organizational problems. In this way, the study seeks to contribute to the theoretical and methodological advancement of Complex Intelligence as a support mechanism for problem structuring and governance in organizations characterized by high complexity.

References

1. JOHANSEN, B.: Leaders Make the Future: Ten New Leadership Skills for an Uncertain World, 2nd edn. Berrett-Koehler, San Francisco (2012)

2. PLETSCH, C. S.: Fatores contingenciais determinantes para a adoção da inovação gerencial. Sinergia 25(1), 45–58 (2021). doi:10.22410/issn.1982-8713.v25i1a2021.2789

3. MENDONÇA, J. C. et al.: Da volatilidade à fragilidade: como o modelo BANI reconfigura a gestão de projetos e equipes. Rev. Gest. Proj. (GeP) 13(2), 45–63 (2022). doi:10.5585/gep.v13i2.21980

4. SILVA, S. F. P.: Enfoques contingenciais e o processo de mudança estrutural: criação, extinção e aglutinação de áreas nas organizações modernas. Master's thesis, Universidade do Estado de Santa Catarina, Florianópolis (2019)

5. SMITH, W. K.; LEWIS, M. W.: Both/And Thinking: Embracing Creative Tensions to Solve Your Toughest Problems. Harvard Business Review Press, Boston (2022)

6. FRANCO, L. A.; MONTIBELLER, G.: Problem Structuring Methods: developments and future directions. EURO J. Decis. Process. 11, 100034 (2023). doi:10.1016/j.ejdp.2023.100034

7. MINGERS, J.; ROSENHEAD, J.: Problem Structuring Methods in Action. Eur. J. Oper. Res. 279(3), 1003–1013 (2019). doi:10.1016/j.ejor.2019.03.007

8. LINS, M. P. E.; ANTOUN NETTO, S. O.: Estruturação de problemas sociais complexos: teoria da mente, mapas metacognitivos e modelos de apoio à decisão. Interciência, Rio de Janeiro (2018)

9. LINS, M. P. E. et al.: Metacognitive Attitude for Decision Making at a University Hospital. Int. Trans. Oper. Res. 28(6), 3092–3116 (2021). doi:10.1111/itor.12920

10. LINS, M. P. E.: (forthcoming 2026) A desinteligência é artificial? Inteligência híbrida humana e IA, estruturação recursiva de problemas e imunidade cognitiva. Interciência, Rio de Janeiro.

11. SMITH, C. M.; SHAW, D. (2019). The characteristics of problem structuring methods: A literature review. European Journal of Operational Research, 274(2), 403–416. https://doi.org/10.1016/j.ejor.2018.05.003

12. CABRERA, D.; CABRERA, L.: What is Systems Thinking? In: Learning, Design, and Technology: An International Compendium of Theory, Research, Practice and Policy. Springer, Cham (2023)

13. GIL, A. C.: Métodos e técnicas de pesquisa social, 7th edn. Atlas, São Paulo (2022)

14. MINTZBERG, H.: Criando organizações eficazes: estruturas em cinco configurações, 2nd edn. Atlas, São Paulo (2003)

15. SENGE, P. M.: A quinta disciplina: arte e prática da organização que aprende, 27th edn. BestSeller, Rio de Janeiro (2010)

16. LAWRENCE, P. R.; LORSCH, J. W.: Organization and Environment: Managing Differentiation and Integration. Harvard Business School Press, Boston (1967)

17. ARGYRIS, C.; SCHÖN, D. A.: Organizational Learning II: Theory, Method, and Practice. Addison-Wesley, Reading, MA (1996)

18. PROJECT MANAGEMENT INSTITUTE (PMI): Um guia do conhecimento em gerenciamento de projetos (Guia PMBOK), 7th edn. PMI, Newtown Square, PA (2021)

19. CHECKLAND, P.; SCHOLES, J.: Soft Systems Methodology in Action. John Wiley & Sons, Chichester (1999)

20. MORGAN, G.: Imagens da organização, 2nd edn. Atlas, São Paulo (2006)

21. SEN, A.: A ideia de justiça. Companhia das Letras, São Paulo (2011)

22. EDEN, C. (1988). Cognitive mapping. European Journal of Operational Research, 36(1), 1–13.

23. ABUABARA, L.; PAUCAR-CÁCERES, A. (2021). Surveying applications of Strategic Options Development and Analysis (SODA) from 1989 to 2018. European Journal of Operational Research, 292(3), 1051–1065.

Appendix A – GAI-Supported Investigative Protocol

Intelligence	Investigative task submitted to GAI	Expected output	Subsequent validation
Epistemological-Ontological	Identify conceptual ambiguities, assumptions and boundaries in the organizational description	Questions and candidate interpretations	Confrontation with documents and interviews
Multiperspective / Theory of Mind	Explore how different coordination units may interpret their roles and those of other units	Questions concerning alternative perspectives and mental models	Confrontation with agents' accounts
Paradoxical	Identify potentially persistent tensions and competing organizational demands	Candidate paradoxes and investigative questions	Verification against empirical evidence
Metacognitive	Question dominant interpretations and possible attribution biases	Questions about assumptions and mental models	Researcher critical assessment
Analytical	Decompose responsibilities, processes, categories and decision points	Categories, relationships and questions	Documentary and interview evidence
Systemic	Identify interfaces, interdependencies and feedback relationships	Candidate systemic relationships	Validation against maps and evidence
Sensory-Metaphorical	Generate metaphors capable of representing organizational patterns not easily expressed formally	Candidate metaphors	Researcher interpretation
Civic and Civilizational Ethics	Explore implications of organizational arrangements for beneficiaries, mission and social impact	Ethical questions and implications	Confrontation with organizational mission and evidence

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Alocação de Viaturas Policiais por Meio da Integração entre Value-Focused Thinking e FITradeoff: Um Estudo de Caso na Polícia Civil do Rio Grande do Norte

Pedro Henrique Estevo[1], Abel Lameque Silva Damasceno[1], Jamille Pessoa Cavalcanti[1], Antônio Sérgio de Araújo Pereira[1], Jaini Barbosa[1] e Ricardo Pires de Souza[1]

[1]Universidade Federal do Rio Grande do Norte (UFRN), Campus Universitário Lagoa Nova, Natal-RN, Brasil, 59078-970.
phestevo@gmail.com, albellameque2@gmail.com, jamillecavalcanti01@gmail.com, antoniosergio157@gmail.com, jaini.barbosa@ufrn.edu.br, ricardo.pires@ufrn.br

Resumo. Objetivo: a distribuição de recursos na segurança pública constitui um desafio para os gestores, especialmente em cenários de restrição orçamentária e elevada demanda operacional; este trabalho desenvolve um modelo de Apoio Multicritério à Decisão para subsidiar a alocação de cinco novas viaturas entre as dezesseis Delegacias Distritais do Departamento de Polícia da Grande Natal (DPGRAN), no âmbito da Polícia Civil do Rio Grande do Norte. **Metodologia:** utilizou-se a abordagem Value-Focused Thinking (VFT) para a estruturação do problema e a identificação dos objetivos e critérios de avaliação, e o método Flexible and Interactive Tradeoff (FITradeoff) para elicitar as preferências do decisor e ordenar as alternativas, seguido de análise de sensibilidade com variações de ±10% e ±20% nas constantes de escala. **Resultados:** o modelo foi construído com base em cinco critérios — demanda operacional, população atendida, área territorial, produtividade operacional e defasagem da frota — e produziu um ranking completo de prioridade das dezesseis unidades, no qual nenhuma delegacia foi priorizada por um único indicador, mas pelo desempenho conjunto; a análise de sensibilidade indicou índices de robustez iguais ou superiores a 97,21% em todos os cenários. **Originalidade/valor:** o estudo preenche uma lacuna quanto à aplicação integrada de VFT e FITradeoff à distribuição de viaturas na Polícia Civil, oferecendo um processo de decisão mais objetivo, transparente e tecnicamente fundamentado, adaptável a outros problemas de alocação de recursos no setor público.

Palavras-chave: Segurança pública; Apoio multicritério à decisão; FITradeoff; Value-Focused Thinking; Alocação de recursos.

Abstract. Purpose: resource allocation in public security is a challenge for managers, particularly under budget constraints and high operational demand. This paper develops a multi-criteria decision-aid model to support the allocation of five new police vehicles among the sixteen District Police Stations of the Greater Natal Police Department (DPGRAN), within the Civil Police of Rio Grande do Norte, Brazil. **Methodology:** Value-Focused Thinking (VFT) was used to structure the problem and identify the objectives and evaluation criteria, while the Flexible and Interactive Tradeoff (FITradeoff) method was applied to elicit the decision-maker's preferences and rank the alternatives; a sensitivity analysis with ±10% and ±20% variations in the scaling constants was then carried out. **Findings:** the model was built on five criteria — operational demand, population served, territorial area, operational productivity and fleet shortage — and produced a complete priority ranking of the sixteen units, in which no station was prioritized by a single indicator but by joint performance; robustness indices remained at or above 97.21% in every scenario. **Originality/value:** the study addresses a gap concerning the integrated application of VFT and FITradeoff to police vehicle distribution, providing a more objective, transparent and technically grounded decision process that can be adapted to other public-sector resource allocation problems.

Keywords: Public security; Multi-criteria decision aid; FITradeoff; Value-Focused Thinking; Resource allocation.

1 Introdução/Objetivo

A segurança pública constitui uma das principais responsabilidades do Estado e depende da adequada gestão dos recursos disponíveis para garantir a eficiência das atividades policiais. Entre esses recursos, as viaturas desempenham papel fundamental, pois viabilizam o deslocamento das equipes para atendimento de ocorrências, realização de diligências, cumprimento de mandados e demais atividades inerentes à Polícia Judiciária. Entretanto, a limitação orçamentária e a disponibilidade restrita desses veículos tornam sua distribuição um problema complexo de decisão, exigindo critérios técnicos capazes de promover uma alocação eficiente, transparente e alinhada às necessidades operacionais das unidades policiais (Souza, 2006; Gomes e Gomes, 2019).

No âmbito da Polícia Civil do Rio Grande do Norte (PCRN), o Departamento de Polícia da Grande Natal (DPGRAN) é responsável pela distribuição das novas viaturas entre as Delegacias Distritais sob sua jurisdição. Contudo, o quantitativo de veículos disponível é insuficiente para atender todas as unidades, tornando necessária a definição de prioridades para sua alocação. A ausência de um modelo estruturado pode tornar esse processo excessivamente dependente da experiência do gestor, dificultando a justificativa técnica das decisões e a transparência na distribuição dos recursos. Apesar do crescente emprego dos métodos multicritério em problemas de alocação de recursos públicos, observa-se uma lacuna quanto à sua aplicação na distribuição de viaturas policiais no contexto da Polícia Civil, especialmente utilizando de forma integrada as abordagens Value-Focused Thinking (VFT) e Flexible and Interactive Tradeoff (FITradeoff).

Diante desse cenário, este trabalho tem como objetivo desenvolver um modelo multicritério de apoio à decisão para subsidiar a alocação de cinco novas viaturas entre as dezesseis Delegacias Distritais do DPGRAN. Como principal contribuição, o estudo propõe um modelo estruturado e reproduzível, que integra técnicas de estruturação de problemas e de apoio multicritério à decisão em um contexto real de segurança pública, fornecendo uma base técnica e transparente para a priorização das unidades policiais.

1.1 Referencial Teórico

A tomada de decisão no setor público apresenta características distintas da esfera privada, sobretudo pelo volume de atores envolvidos e pela necessidade de conciliar critérios técnicos com conformidade política e social. Souza (2006) destaca que a construção de políticas públicas exige a definição de prioridades em cenários de recursos limitados, competindo aos gestores estabelecer critérios coerentes com os objetivos perseguidos; a ausência de mecanismos de apoio à decisão tende a favorecer escolhas enviesadas. Gomes e Gomes (2019) enfatizam que a utilização de métodos estruturados de apoio à decisão contribui para aumentar a transparência dos processos decisórios, uma vez que os critérios utilizados possuem definições justificáveis, distanciando-se de decisões subjetivas e tendenciosas.

Nesse contexto, os Métodos de Apoio Multicritério à Decisão (MCDA) constituem ferramentas importantes para apoiar gestores na análise e priorização de alternativas, contribuindo para decisões mais estruturadas, transparentes e coerentes com os objetivos estratégicos estabelecidos. Segundo Almeida (2013), o processo de decisão pode ser estruturado em três fases desenvolvidas sequencialmente por refinamentos sucessivos: uma fase preliminar, voltada à compreensão e estruturação do problema (caracterização dos decisores, identificação de objetivos, estabelecimento de critérios, do espaço de ações e da problemática, e identificação de fatores não controlados); uma fase de modelagem de preferências e escolha do método; e uma fase de finalização, correspondente à avaliação das alternativas, à análise de sensibilidade e à recomendação, sendo possível revisar etapas anteriores sempre que necessário.

O método Flexible and Interactive Tradeoff (FITradeoff), desenvolvido por de Almeida et al. (2016), constitui uma evolução dos métodos de agregação de preferências em apoio multicritério à decisão. Fundamentado na Teoria do Valor Multiatributo (MAVT), o FITradeoff possibilita a elicitação das preferências do decisor de forma interativa e flexível, utilizando informações parciais para reduzir o esforço cognitivo durante o processo de decisão. Essas características tornam o método adequado para problemas de ordenação de alternativas, permitindo que as preferências do decisor sejam incorporadas de maneira gradual e consistente ao longo do processo (Frej, 2019), e sua operacionalização é apoiada pelo FITradeoff DSS (de Almeida et al., 2021).

A estruturação do problema, por sua vez, apoia-se no Value-Focused Thinking (VFT), proposto por Keeney (1992) como abordagem baseada na identificação dos valores dos tomadores de decisão. O VFT parte da premissa de que os valores devem orientar todo o processo decisório, distinguindo os objetivos fundamentais, que representam os fins que se deseja alcançar, dos objetivos-meio, que contribuem para o alcance desses fins. A compreensão dos valores antecede a geração de alternativas, permitindo que os

objetivos orientem a construção de soluções mais criativas e reduzindo a tendência de restringir a decisão às opções inicialmente disponíveis (Keeney, 1996).

2 Metodologia

A presente pesquisa caracteriza-se como aplicada, por ter como propósito desenvolver uma solução para um problema prático enfrentado pela PCRN (Gil, 2019). Quanto aos objetivos, possui caráter exploratório, uma vez que busca compreender os fatores que influenciam o processo de distribuição de viaturas e estruturar o problema de decisão. Em relação aos procedimentos técnicos, configura-se como estudo de caso, desenvolvido no DPGRAN e concentrado nas Delegacias Distritais da cidade de Natal, escolhidas por apresentarem características organizacionais semelhantes e estarem subordinadas à mesma diretoria, o que permite uma comparação consistente entre as alternativas. Quanto à abordagem, a pesquisa é quantitativa, pois utiliza indicadores obtidos de dados operacionais das delegacias — boletins de ocorrência, procedimentos instaurados, população atendida, área territorial, efetivo policial e quantidade de viaturas —, empregados na construção da matriz de consequências.

A construção do modelo contou com a participação de especialistas diretamente envolvidos na gestão do DPGRAN. O principal decisor foi o Diretor do Departamento, responsável por apresentar o contexto do problema, os objetivos institucionais e os fatores considerados relevantes na distribuição de viaturas; também participaram servidores que atuam na gestão administrativa do departamento. O trabalho foi conduzido em quatro encontros: (i) estruturação do problema por VFT, com entrevista semiestruturada baseada em roteiro adaptado de Keeney (1992); (ii) validação dos objetivos, definição dos critérios e confirmação das dezesseis Delegacias Distritais como alternativas; (iii) inserção da matriz de consequências no FITradeoff DSS e sessão de elicitação das preferências; e (iv) apresentação e validação dos resultados junto ao decisor e à equipe gestora.

2.1 Estruturação do Problema com Value-Focused Thinking

As entrevistas foram gravadas, transcritas e analisadas por meio da técnica de análise de conteúdo, permitindo a identificação dos objetivos fundamentais e dos objetivos-meio relacionados ao problema. A partir dessa análise foi construída a árvore de objetivos apresentada na Fig. 1, que representa a relação hierárquica entre o objetivo estratégico, os objetivos fundamentais e os objetivos-meio.

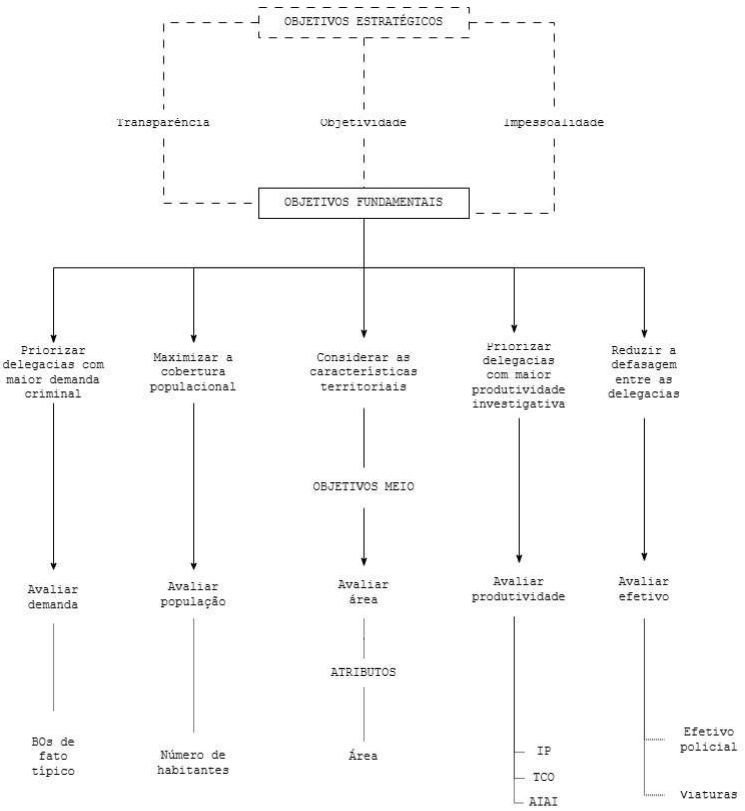

Fig. 1. Árvore de objetivos do problema de alocação de viaturas. Fonte: elaborado pelos autores.

O objetivo estratégico consiste em apoiar a alocação eficiente de cinco novas viaturas entre as Delegacias Distritais do DPGRAN, orientado pelos valores de transparência, objetividade e impessoalidade. A partir desse objetivo foram identificados objetivos fundamentais relacionados à demanda pelos serviços policiais, à população atendida, à área territorial, à produtividade operacional e à defasagem da frota, que serviram de base para a definição dos critérios do modelo multicritério.

2.2 Definição dos Critérios

Os objetivos foram convertidos em critérios mensuráveis, definidos de forma a contemplar diferentes dimensões da necessidade operacional das delegacias. Todos os indicadores foram normalizados pela quantidade de viaturas disponíveis (V) em cada unidade, de modo a expressar a pressão exercida sobre a frota existente, e todos são de maximização: quanto maior o valor, maior a prioridade da unidade para o recebimento de novas viaturas. A Tabela 1 sintetiza os critérios adotados.

Tabela 1. Critérios de avaliação e respectivos indicadores. Fonte: elaborado pelos autores.

Critério	Indicador	Descrição
C1 – Demanda criminal	$I_1 = BO / V$	Razão entre o número de Boletins de Ocorrência de fato típico (BO), que configuram infrações penais e demandam atuação da Polícia Judiciária, e a quantidade de viaturas.
C2 – População atendida	$I_2 = POP / V$	Razão entre a população residente na circunscrição da delegacia e a quantidade de viaturas; representa a demanda potencial por serviços de polícia judiciária.
C3 – Área territorial	$I_3 = AT / V$	Razão entre a área de circunscrição (ha) e a quantidade de viaturas; expressa o esforço de deslocamento exigido da frota.
C4 – Produtividade operacional	$I_4 = (IPP + TCO + IPR + IPF) / V$	Razão entre os procedimentos produzidos — inquéritos por portaria (IPP) e por flagrante (IPF), termos circunstanciados (TCO) e inquéritos remetidos (IPR) — e a quantidade de viaturas.

C5 – Defasagem da frota	$I_5 = E / V$	Razão entre o efetivo policial (E) e a quantidade de viaturas. Segundo o decisor, o cenário ideal é de uma viatura para cada três policiais, admitindo-se até quatro.

Enquanto os critérios C1, C2 e C3 refletem aspectos relacionados à pressão operacional e às características da circunscrição policial, o critério C4 representa a utilização da frota na execução das atividades finalísticas da Polícia Civil, e o critério C5 avalia a adequação entre o efetivo policial e a quantidade de viaturas disponíveis. Em conjunto, os cinco critérios fornecem uma representação abrangente dos fatores que influenciam a alocação de viaturas entre as unidades estudadas.

2.3 Aplicação do FITradeoff

As alternativas do problema correspondem às dezesseis Delegacias Distritais subordinadas ao DPGRAN, sendo cada delegacia considerada uma alternativa de decisão independente. A Tabela 2 apresenta a matriz de consequências utilizada como entrada no método, composta pelos indicadores calculados para cada unidade.

Tabela 2. Matriz de consequências das dezesseis Delegacias Distritais. Fonte: dados da pesquisa.

Alt.	Delegacia Distrital (bairros de circunscrição)	C1	C2	C3	C4	C5
A1	1ª DP (Cidade Alta, Lagoa Seca, Barro Vermelho)	364	9.929	136	52	5
A2	2ª DP (Santos Reis, Praia do Meio, Rocas, Ribeira)	123	4.963	108	40	3
A3	3ª DP (Alecrim)	499	11.427	172	80	5
A4	4ª DP (Mãe Luíza, Petrópolis, Areia Preta, Tirol)	296	10.081	142	52	3
A5	5ª DP (Lagoa Nova, Nova Descoberta)	504	15.499	309	56	5
A6	6ª DP (Lagoa Azul)	278	28.191	584	49	6
A7	7ª DP (Quintas, Bom Pastor, Nordeste)	279	22.975	447	93	9
A8	8ª DP (Cidade da Esperança, Dix-Sept Rosado, Cidade Nova, N. Sra. de Nazaré)	524	29.995	348	127	6
A9	9ª DP (Igapó)	212	11.072	110	33	4
A10	10ª DP (Capim Macio, Candelária)	605	21.342	597	91	8
A11	11ª DP (Planalto, Pitimbu, Guarapes, Cidade Satélite)	465	39.025	1.037	84	6
A12	12ª DP (Potengi, Panatis, Salinas)	364	25.421	916	64	5
A13	13ª DP (Pajuçara, Redinha)	483	36.562	823	85	4
A14	14ª DP (Felipe Camarão)	194	22.517	327	58	4
A15	15ª DP (Ponta Negra, Neópolis)	742	28.620	852	100	7
A16	16ª DP (Nossa Senhora da Apresentação)	397	38.260	512	75	3

Após a inserção da matriz de consequências no FITradeoff DSS, foi realizada uma sessão de elicitação com o decisor. Na etapa de elicitação por decomposição, o sistema apresentou sucessivas comparações entre consequências, permitindo registrar as preferências quanto à importância relativa de cada critério; a ordenação inicial das constantes de escala obtida foi produtividade > defasagem > demanda > população > área. Em seguida foi empregada a etapa de Avaliação Holística, na qual o software realiza comparações diretas entre alternativas, apoiada por recursos de visualização como diagramas de dominância (Hasse), gráficos comparativos e representações tabulares. À medida que novas preferências são informadas, o método reduz progressivamente o conjunto de soluções viáveis até estabelecer uma ordenação consistente das alternativas.

3 Resultados

3.1 Ordenação das Alternativas

A aplicação do FITradeoff permitiu obter a ordenação das dezesseis Delegacias Distritais, considerando simultaneamente os cinco critérios definidos na etapa de estruturação. A Tabela 3 apresenta o ranking gerado pelo FITradeoff DSS, no qual algumas posições concentram mais de uma alternativa, indicando unidades empatadas sob a informação parcial fornecida pelo decisor.

Tabela 3. Ranking das Delegacias Distritais obtido pelo FITradeoff DSS. Fonte: dados da pesquisa.

Posição	Alternativa(s)	Posição	Alternativa(s)
1º	15ª DP	7º	3ª DP; 12ª DP; 6ª DP; 16ª DP; 5ª DP
2º	10ª DP	8º	1ª DP; 14ª DP
3º	8ª DP	9º	4ª DP
4º	11ª DP	10º	9ª DP
5º	7ª DP	11º	2ª DP
6º	13ª DP		

As cinco primeiras posições do ranking, que representam as unidades prioritárias para o recebimento das novas viaturas, foram ocupadas pela 15ª DP (Ponta Negra e Neópolis), 10ª DP (Capim Macio e Candelária), 8ª DP (Cidade da Esperança, Dix-Sept Rosado, Cidade Nova e Nossa Senhora de Nazaré), 11ª DP (Planalto, Pitimbu, Guarapes e Cidade Satélite) e 7ª DP (Quintas, Bom Pastor e Nordeste).

A análise dos indicadores evidencia que a priorização não foi determinada por um único critério, mas pelo desempenho conjunto das alternativas. A 15ª DP apresentou o maior indicador de demanda criminal (742 BOs por viatura), além de valores elevados em produtividade operacional, área territorial e defasagem da frota, fatores que contribuíram para sua classificação em primeiro lugar. A 10ª DP destacou-se pelos elevados indicadores de demanda, produtividade e defasagem, enquanto a 8ª DP apresentou a maior produtividade operacional entre todas as delegacias analisadas (127 procedimentos por viatura). Já a 11ª DP obteve os maiores valores em população e área territorial (39.025 habitantes e 1.037 ha por viatura), evidenciando a elevada demanda potencial e a ampla circunscrição sob sua responsabilidade. Por sua vez, a 7ª DP apresentou o maior indicador de defasagem da frota (nove policiais por viatura), acima, portanto, do parâmetro operacional de três a quatro policiais por viatura informado pelo decisor.

Esses resultados demonstram que o FITradeoff foi capaz de integrar diferentes dimensões da necessidade operacional das Delegacias Distritais, produzindo uma ordenação baseada no desempenho conjunto das alternativas e nas preferências do decisor. Cabe registrar que, na etapa de validação, o ranking obtido, a influência dos critérios e a aderência do modelo à realidade operacional foram discutidos com o decisor e com a equipe gestora do DPGRAN, sendo a ordenação considerada satisfatória.

Merece registro a natureza dos empates observados na Tabela 3, sobretudo na sétima posição, que concentra cinco unidades. Eles não indicam que essas delegacias apresentem desempenho idêntico, mas que a informação parcial fornecida pelo decisor não é suficiente para distingui-las: dentro do espaço de constantes de escala compatível com as preferências declaradas, existem vetores que colocam qualquer uma delas à frente das demais. Essa é uma característica do método, e não uma deficiência do modelo — o FITradeoff interrompe a elicitação assim que a informação acumulada é suficiente para a decisão em questão. Como o problema consiste em distribuir cinco viaturas, e as cinco primeiras posições estão plenamente discriminadas, a indeterminação remanescente nas posições intermediárias não afeta a recomendação. Caso uma remessa futura contemple, por exemplo, oito veículos, bastaria retomar a sessão de elicitação com novas comparações de preferência até desfazer os empates relevantes, sem necessidade de reconstruir o modelo.

3.2 Análise de Sensibilidade

Com o objetivo de avaliar a robustez do modelo proposto, foi realizada uma análise de sensibilidade no software FITradeoff, considerando variações simétricas de ±10% e ±20% em torno das constantes de escala originalmente obtidas na etapa de elicitação. A análise buscou verificar o comportamento da ordenação das

alternativas diante de alterações nas preferências do decisor. O índice de robustez da alternativa (Robustness Index of the Alternative) indica o percentual de estabilidade de cada alternativa diante das variações aplicadas: quanto mais próximo de 100%, maior a robustez da solução.

Na primeira simulação, com variação de ±10%, observou-se elevada estabilidade do modelo: praticamente todas as alternativas apresentaram índices de robustez iguais ou superiores a 98,90%, sendo que a maioria atingiu 100%. A 15ª DP apresentou índice de robustez de 99,99% e a 10ª DP, de 98,90%, evidenciando que pequenas alterações nas preferências do decisor não provocam mudanças relevantes na ordenação. Na segunda simulação, com variação de ±20%, verificou-se comportamento semelhante: mesmo diante de uma alteração mais ampla nas preferências, os índices de robustez permaneceram elevados, variando entre 97,21% e 100%, com a 15ª DP mantendo 99,19% e a 10ª DP apresentando 97,21%, sem alterações significativas na priorização das alternativas.

Os resultados demonstram que o modelo desenvolvido apresenta elevada robustez, uma vez que a ordenação das Delegacias Distritais permaneceu praticamente inalterada mesmo diante de variações nas constantes de escala. Esse comportamento reforça a confiabilidade da solução proposta e indica que a priorização das alternativas não depende de pequenas alterações nas preferências do decisor, conferindo maior segurança à utilização do modelo como instrumento de apoio à distribuição de viaturas no âmbito da Polícia Civil do Rio Grande do Norte.

Convém explicitar, contudo, o alcance dessa robustez. O que os testes de ±10% e ±20% verificam é a estabilidade da ordenação diante de variações nas constantes de escala, isto é, na modelagem de preferências. Eles não avaliam a incerteza dos dados que compõem a matriz de consequências, os quais refletem um recorte temporal específico da operação: o número de boletins de ocorrência, o efetivo lotado e a frota disponível em cada unidade variam ao longo do ano, e alterações expressivas nesses valores podem modificar a ordenação ainda que as preferências do decisor permaneçam idênticas. Isso reforça a recomendação de que o modelo seja reexecutado a cada nova remessa de viaturas, com dados atualizados, em vez de tratado como um resultado permanente.

4 Originalidade/Valor

A contribuição deste trabalho está em demonstrar, em um contexto real de segurança pública, que a integração entre uma abordagem de estruturação de problemas e um método de elicitação por informação parcial produz um resultado que nenhum dos dois entrega isoladamente. O VFT assegurou que os critérios utilizados decorressem dos valores efetivamente manifestados pelo decisor — e não de indicadores já disponíveis nos sistemas do departamento —, enquanto o FITradeoff permitiu ordenar dezesseis alternativas segundo cinco critérios sem exigir do decisor a declaração de pontos exatos de indiferença, tarefa cognitivamente onerosa em ambientes operacionais com pouco tempo disponível para sessões longas de elicitação.

Do ponto de vista prático, o modelo oferece três ganhos ao DPGRAN. Primeiro, objetividade: a prioridade de cada unidade decorre de indicadores auditáveis, normalizados pela frota existente, e não da experiência individual do gestor. Segundo, transparência e impessoalidade — valores explicitados pelo próprio decisor na árvore de objetivos —, uma vez que a documentação dos critérios, das preferências elicitadas e do ranking obtido constitui uma trilha defensável perante as unidades proponentes e os órgãos de controle. Terceiro, reprodutibilidade: o modelo pode ser reexecutado a cada nova remessa de viaturas, bastando atualizar a matriz de consequências, o que o converte em instrumento permanente de gestão baseada em evidências e não em um diagnóstico pontual.

Como limitação, destaca-se que o estudo foi desenvolvido considerando apenas as Delegacias Distritais da cidade de Natal e as preferências de um único decisor, o que restringe a generalização direta dos resultados a outras unidades da PCRN. Ressalta-se ainda que os indicadores refletem um recorte temporal específico da operação, exigindo atualização periódica. Como trabalhos futuros, recomenda-se ampliar o modelo para outras unidades policiais, incorporar novos critérios de avaliação, tratar o problema em contexto de decisão em grupo e realizar comparações com outros métodos de apoio multicritério à decisão. Espera-se que o modelo proposto contribua para o fortalecimento da gestão baseada em evidências na segurança pública, oferecendo aos gestores uma ferramenta capaz de apoiar decisões complexas de forma objetiva, transparente e tecnicamente fundamentada. Registre-se, por fim, que o modelo trata da priorização das unidades e não do dimensionamento ideal da frota: ele indica quais delegacias devem receber os veículos disponíveis, mas não quantos veículos seriam necessários para levar todas as unidades ao parâmetro de uma viatura para cada três

policiais informado pelo decisor. Essa segunda questão, de natureza normativa e orçamentária, constitui um desdobramento natural do trabalho.

Referências

Almeida, A.T. (2013), *Processo de Decisão nas Organizações: Construindo Modelos de Decisão Multicritério*. Atlas, São Paulo.

de Almeida, A.T., Almeida, J.A., Costa, A.P.C.S., Almeida-Filho, A.T. (2016), A new method for elicitation of criteria weights in additive models: flexible and interactive tradeoff. *European Journal of Operational Research*, 250(1), 179-191.

de Almeida, A.T., Frej, E.A., Almeida, J.A., Ribeiro, M.L.S., Roselli, L.R.P., Vieira, M.J.L., Borba, L.B., Santo, P.P.P.E. (2021), *FITradeoff-Web*. Programa de computador, registro BR512021001368-9. INPI, Rio de Janeiro.

Frej, E.A. (2019), *Método multicritério de elicitação por tradeoff interativo e flexível para a problemática de ordenação e para a tomada de decisão em grupo*. Tese (Doutorado em Engenharia de Produção), Universidade Federal de Pernambuco, Recife.

Gil, A.C. (2019), *Métodos e técnicas de pesquisa social*. 7th edn. Atlas, São Paulo.

Gomes, L.F.A.M., Gomes, C.F.S. (2019), *Tomada de Decisão Gerencial: Enfoque Multicritério*. 5th edn. Atlas, São Paulo.

Keeney, R.L. (1992), *Value-Focused Thinking: A Path to Creative Decisionmaking*. Harvard University Press, Cambridge, MA.

Keeney, R.L. (1996), Value-focused thinking: Identifying decision opportunities and creating alternatives. *European Journal of Operational Research*, 92, 537-549.

Souza, C. (2006), Políticas Públicas: uma revisão da literatura. *Sociologias*, 8(16), 20-45.

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A Multicriteria Decision Model to Support State Government Planning for Expanding Professional and Technological Education

Maria Teresa Araújo de Lima[1], Daniel da Silva Oliveira[2], Luciana Hazin Alencar[1]

[1]Federal University of Pernambuco, Av. Acadêmico Hélio Ramos, s/n – Cidade Universitária, Recife – PE, 50740-530, Brazil
[2]State Secretariat of Education of Pernambuco, Av. Afonso Olindense, 1513 – Várzea, Recife – PE, 50810-900, Brazil

maria.talima@ufpe.br, daniel.dsoliveira@adm.educacao.pe.gov.br, alencarlh@insid.org.br

Abstract. The expansion of Professional and Technological Education (PTE) is a fundamental pillar for productive inclusion and regional socioeconomic development in Brazil. This need is reflected in Brazil's National Education Plan (PNE), which sets, among its objectives, increasing access to and retention in professional and technological education, with a goal of expanding technical education to 50% of high school students. To achieve these results, state governments must plan new technical course offerings efficiently and equitably, aligning them with labor-market demands and regional economic development while accounting for each municipality's local reality. However, allocating public resources for expansion faces structural complexities and requires assertive budgetary and operational choices by public administrators. This paper proposes a multicriteria decision model to support the State Government in classifying municipalities within its territory according to the most viable strategy for expanding the state technical network. The analysis integrates criteria that consider municipal population size, local economic profiles, cost, and pre-existing physical infrastructure. As its main outcome, this paper presents a methodological tool to support state public policy design, enabling public managers to implement the most appropriate technical education format for each municipality, promoting regional development and directly contributing to national education targets.

Keywords: Multicriteria Decision Aid; Technical Education; Public Policy; Regional Development

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Early Warning Indicators of Project Failure in PBOs

Maria Helena Lasserre Ferreira[1], Caroline Maria de Miranda Mota[2]

[1]Universidade Federal de Pernambuco (UFPE) & Recife, PE - Brazil
[2]Universidade Federal de Pernambuco (UFPE) & Recife, PE – Brazil

helena.lasserre@ufpe.br, caroline.mota@ufpe.br

Abstract. In Project Based Organizations (PBOs), common in Engineering, Procurement and Construction (EPC) projects, organizational success is a direct function of project success. Senior management must therefore monitor performance and quality indicators under tight resource constraints. Large portfolios, however, suffer in decision capacity: the information available readily identifies the projects whose success is already compromised, but not those whose performance is on its way to failure. This research proposes a process for selecting the Early Warning Indicators that best fit a PBO's needs, applying a hybrid Delphi-DEMATEL approach in a case study of a real Brazilian PBO. The Delphi technique first assesses the company's perception of its KPIs; the DEMATEL (Decision-Making Trial and Evaluation Laboratory) method then identifies interrelations among the consensus indicators. The expected results include an analysis of the organization's KPI structure and interrelationships, and a monitoring framework of Early Warning Indicators fitted to the PBO's needs.

Keywords: PBOs, EPC Projects, Project Failure, Delphi Method, DEMATEL, Early Warning Indicators, Multi-Criteria Decision Making.

1 Purpose

The construction industry is an important factor in any economy (Al Kulabi and Al Lebban, 2023; Ayyaz *et al.,* 2026). Firms operating in the EPC (Engineering, Procurement and Construction) segment are normally structured as Project Based Organizations (PBOs), in which projects are the core delivery unit and organizational performance is therefore a direct function of project performance. This dependence makes the early detection of underperforming projects a critical management capability.

Deciding which projects should be prioritized in a portfolio where several projects compete for the same resources is an ongoing challenge for PBOs and their decision-makers. The limited resources available (Tavana *et al.,* 2025) and the diversity of parameters for assessing contract performance call for a continuous evaluation of the undertakings in line with the organization's objectives and goals.

Thus, as stated by Larson and Gray (2016), the main purpose of portfolio management is to ensure that the projects comprising it are aligned with the organization's objectives and are properly prioritized, understanding what is strategic for the company and providing information that enables sound business decisions (Keskin, 2019). This task is particularly demanding in PBOs, which behave as complex adaptive systems: highly dynamic, resource-constrained, and shaped by numerous nonlinear dependencies. Consequently, portfolio decisions must be revisited continuously rather than set once (Bocean, 2011; Todorova et al. 2026).

The literature on portfolio and program management is predominantly focused on project evaluation, selection, resource allocation, scheduling and schedule management, strategic alignment, and monitoring (Tuominen and Martinsuo, 2024). In the portfolio and program management environment of a consulting engineering firm, such as in the EPC segment, however, portfolio management is focused on its extension, maintenance, and servicing. Little guidance is nevertheless available on how such a firm should select, among the many indicators it already collects, the reduced set capable of signaling failure before it materializes. For this, assuring project success is critical, and projects whose results are not on track should be identified as early as possible.

By selecting the indicators that are relevant to the organization, it is possible to build an analysis framework, based on productivity and quality parameters, capable of generating the alerts required by the

areas of interest, thus enabling strategic and preventive action and the resolution of potential problem situations before they even occur. It also limits the data overload that can distract decision-making when rapid action is required.To achieve this, a systematic way to reach expert consensus (such as a company's top management) on the identification and validation of the necessary set of Early Warning Indicators, followed by a cause-and-effect exploration of this set can be highly beneficial, which can be achieved by a Delphi-DEMATEL approach (Mabrouk *et al., 2026*). Delphi rounds are a well-established means of building expert consensus on complex or uncertain issues, while DEMATEL is distinguished by its mapping process, which reveals cause-and-effect relationships among interdependent indicators (Hasson *et al.,* 2025; Kayikci *et al.,* 2024; Nguyen *et al., 2026*).

From a strategic standpoint, how can support areas, such as quality management, monitor the results of these projects and assist senior management in identifying those that are already critical for the organization? And, more importantly, how can they identify in advance the projects that are heading towards failure and nonconformity, thereby enabling early and preventive action? Conventional performance monitoring tends to answer the first question but not the second, since it reports results that have already materialized. This research therefore aims to propose a process for selecting such indicators, applying a hybrid Delphi-DEMATEL approach in a real Brazilian PBO.

2 Methodology

The research aims to develop a process for identifying most critical projects (in route to failure) within the context of consulting firms that must manage large portfolios and programs. This structure should contribute to identifying projects whose performance is being compromised, serving as early detectors, and help to predict problems, supporting the implementation of predictive and preventive actions. To carry out this research, applied research are adopted through a case study conducted in a large engineering firm operating in the consulting engineering sector. The flow of activities to be followed can be seen in Figure 1.

A hybrid Delphi–DEMATEL approach with an exploratory purpose is used to select the performance and quality indicators that best identify the projects requiring the greatest attention.

Initially, for the development of Stage 1, a literature review is being carried out on Portfolio and Program Management, Quality Management, Early Warning Indicators and PBOs.

In Stage 2, a semi-structured questionnaire is applied to a panel of experts – the organization's senior leadership. The questionnaire covers the performance and quality indicators and the information used to classify the projects, asking the experts to rate their importance in determining whether a project is critical for the organization, on a 5-point Likert scale. The Delphi study follows the six-step prescription of Belton et al. (2019).

Stage 3 applies the DEMATEL method to assess whether cause-and-effect relationships exist among the consensus indicators. As a multi-criteria decision-making (MCDM) approach based on graph theory and matrix tools, DEMATEL identifies possible correlations between indicators and clarifies their behavior in the final framework, following the steps in Ayyaz et al. (2026).

The DEMATEL questionnaire is administered to the panel, this time using an influence scale. The individual direct-relation matrices yield the average matrix, from which the cause-and-effect diagram is built. Stage 4 defines the final monitoring framework, composed of the selected Early Warning Indicators, which is then presented to the organization and tested by the monitoring teams.

3 Indicator Survey

The assessment of the organization's performance measurement framework was built on two complementary sources. A literature survey of 63 articles on critical success criteria, key performance indicators and multi-criteria prioritization methods identified the indicators most relevant to project management and performance monitoring. In parallel, an exploratory study of the case organization (a Brazilian engineering consultancy) mapped its organizational structure and the 17 performance indicators already in use across quality, productivity and financial results.

The two sets of findings were cross-referenced and structured according to the OKR (Objectives and Key Results) methodology, in which a directional objective is paired with three to five measurable key results scored at the end of a defined cycle. The framework was adopted for two reasons. First, it separates two constructs that the organization had merged: a key performance indicator describes the steady state of an operation and is monitored continuously, whereas a key result expresses the change committed to within a cycle. So, the existing indicator set is not replaced but reinterpreted through it. Second, in project-based organizations overall performance tends to become subordinate to that of the individual project (Backlund and Sundqvist, 2018), and organizational-level performance management systems remain under-represented in this literature (Miterev *et al.,* 2017; Silva and Santos, 2024); OKR, designed to link corporate objectives to operational results, addresses that gap directly.

The indicators were then grouped into one objective per performance dimension – quality, productivity and financial performance – and each was rewritten as key result specified by unit, direction of improvement, and frequency. Because the number of indicators exceeded the three to five key results per objective recommended by practice, each was classified either as primary key result, which scores the cycle, or as a health metric, which is monitored but does not score it. Finally, every indicator was confronted with the reviewed literature and classified by the strength of the support found – direct or analogous. Table 1 presents the ten primary key results and the number of supporting studies found for each; the seven health metrics and the full list of studies are available from the authors on request.

Table 1. OKR Matrix

D	Objective	Key Result	Source Indicator and direction	Unit	Support (n)
Quality	O1 – Deliver projects with demonstrated quality and full conformity to the organization's management system, sustaining client satisfaction.	KR 1.1 – Maintain the average client satisfaction score higher than 75 by the end of the annual cycle.	Client Satisfaction Survey Score (Higher is better)	Score	Direct 11; Analogous 6
		KR 1.2 – Reach more than 95% of deliverables quality control recorded and approved before issue.	Project Quality Control Conformity (Higher is better)	%	Direct 3; Analogous 6
		KR 1.3 – Achieve a rating higher than 80% in 100% of the internal audits of the cycle, with no major nonconformity	Internal Audit Result Rating (Higher is better)	%	Analogous 6
		KR 1.4 – Bring to zero the share of action plans past their due date	Overdue Action Plans (Lower is better)	%	Analogous 4
Productivity	O2 – Increase the productivity and predictability of project execution, delivering on time with efficient use of the planned hours	KR 2.1 – Reduce to lower than 5% the rate of components/deliverables completed after the contractual date	Late Components/Deliverables Rate (Lower is better)	%	Direct 1; Analogous 6
		KR 2.2 – Keep the SPI higher than 95% across 90% of the active products in the portfolio	SPI – Schedule Performance Index (Higher is better)	Index	Direct 2; Analogous 6
		KR 2.3 – Keep the PI above 1.00, delivering the planned scope within the planned hours	PI – Productivity Index (Higher is better)	Index	Direct 1; Analogous 6
Financial Performance	O3 – Secure the profitability and financial health of the project portfolio, converting production into revenue and cash	KR 3.1 – Keep the Direct Cost/GOR ratio under 65% across the project portfolio	Direct Cost/ Gross Operating Revenue (Lower is better)	% of plan	Direct 3; Analogous 5
		KR 3.2 – Reach more than 95% adherence of actual billing to planned billing	Billing (Higher is better)	%	Direct 1; Analogous 2
		KR 3.3 – Reduce WIP to less than 45 days of average billing	WIP – Work executed and not yet	Days	Analogous 6

D	Objective	Key Result	Source Indicator and direction	Unit	Support (n)
			billed (Lower is better)		

4 What would be expected

The general objective of this research is the study of performance and quality indicators for portfolio and program management, aiming to select a sufficient set of indicators that constitutes a set of Early Warning Indicators for "critical" projects. "Critical" projects are those that should be prioritized when allocating the attention of quality management teams and the intervention of senior management.

The expected outcome is a monitoring framework meeting the objectives of the organization under study, together with a replicable process for identifying Early Warning Indicators to support quality and productivity management in large-portfolio environments. The framework should enable continuous analysis of large portfolios and guide the efforts of quality management teams and the strategic action of senior management.

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References

Al Kulabi, A.K., Al Lebban, M.F. (2023), Identifying and Analyzing Failure Factors of Public Construction Projects: A Case Study. AIP Conference Proceedings, 2784, 020021.

Ayyaz, M., Naseem, A., Shahzad, A., Ahmad, Y., Shah, S.T.H. (2026), A Novel Hybrid Approach for Determinants of Construction Projects Failure: An Application of Delphi-DEMATEL Methodology. Results in Engineering, 29, 109057.

Backlund, F., Sundqvist, E. (2018), Continuous improvement: challenges for the project-based organization, IJQRM 35(7), 1306–1320.

Belton, I., Macdonald, A., Wright, G., Hamlin, I. (2019), Improving the Practical Application of the Delphi Method in Group-Based Judgment: A Six-Step Prescription for a Well-Founded and Defensible Process. Technological Forecasting and Social Change, 147, 72-82.

Bocean, C.G. (2011), Project Based Organization – An Integrated Approach. Management & Marketing, 9, 265-273.

Hasson, F., Keeney, S., McKenna, H. (2025), Revisiting the Delphi Technique – Research Thinking and Practice: A Discussion Paper. International Journal of Nursing Studies, 168, 105119.

Kayikci, Y., Gozacan-Chase, N., Rejeb, A. (2024), Blockchain Entrepreneurship Roles for Circular Supply Chain Transition. Business Strategy and the Environment, 33(2), 197-222.

Keskin, F.D. (2019), A Two-Stage Fuzzy Approach for Industry 4.0 Project Portfolio Selection within Criteria and Project Interdependencies Context. Journal of Multi-Criteria Decision Analysis, 27(1-2), 65-83.

Larson, E.W., Gray, C.F. (2016), Gerenciamento de Projetos: O Processo Gerencial. AMGH, Porto Alegre.

Mabrouk, N.B., Mbarek, W., Gamil, Z. (2026), Assessing Logistics Industry Capability Factors for Sustainable Supply Chain Project Management: An Integrated Fuzzy Delphi-DEMATEL Approach. Journal of Project Management, 11(2), 499-510.

Miterev, M., Turner, J.R., Mancini, M. (2017), *The organization design perspective on the project-based organization: a structured review*, IJMPB 10(3), 527–549.

Nguyen, T.T.V., Durda, L., Ključnikov, A. (2026), Micro, Meso and Macro-Barriers to Migrant Entrepreneurship: A Delphi-DEMATEL Approach. Equilibrium. Quarterly Journal of Economics and Economic Policy, 21(2), 743-771.

Silva, R., Santos, G. (2024), Surveying the Academic Literature on the Use of OKR (Objectives and Key Results) – An Update. iSys – Journal of Information Systems, 17, 4:1-4:26.

Tavana, M., Bachari, M.S., Solouki, A., Larni-Fooeik, A., Ghanbari, H. (2025), A Comprehensive Framework for Multi-Aspectual Project Portfolio Resource Allocation and Evaluation. Advanced Engineering Informatics, 68, 103773.

Todorova, A., Kostadinova, I., Ruskova, S., Beloeva, S. (2026), Burnout Risk Management Framework (BRMF) in Project-Based Organizations: Emotional Intelligence Systemic Lever. Systems, 14(2), 210.

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Sectoral Credit Risk Analysis: A Hybrid CRITIC-TOPSIS Approach Using Brazilian Central Bank Data

Abstract. Traditional credit risk management heavily relies on estimating the Probability of Default, often neglecting the magnitude of exposure in sectoral evaluations, a gap that leads univariate models to underestimate tail risk in low-default, capital-intensive corporate portfolios. To address this limitation, this study proposes a hybrid multi-criteria decision-making (MCDM) framework combining the CRITIC and TOPSIS methods to rank the systemic vulnerability of Brazilian economic sectors using open data from the Central Bank of Brazil (BACEN). By objectively weighting criteria variance without expert bias, the model bridges default frequency with capital exposure severity. The findings reveal a paradox: sectors with negligible historical arrears, such as Public Administration and Infrastructure, rank highest in financial vulnerability. This counterintuitive result demonstrates that sectoral risk is primarily driven by capital concentration rather than delay recurrence. The study concludes that decision models that ignore severity tend to underestimate the tail risk of large corporate portfolios.

Keywords: Credit Risk; MCDA; CRITIC-TOPSIS; Sectoral Vulnerability; Systemic Risk.

1 Introduction/Purpose

Credit risk management has consolidated itself as a topic of central relevance for the stability of financial organizations and for a country's economy, as it offers strategies to evaluate, control, and monitor decisions under uncertainty [1]. The scenario of global financial crises, such as the 2007-2008 crisis, highlighted the fragility of banking systems and the ineffectiveness of traditional risk measurement methods in capturing rare but high-impact events, which drove the development of new regulations and more robust evaluation models [2,3].

However, assessing credit quality and the performance of economic sectors faces significant challenges. Frequently, small and medium-sized enterprises (SMEs) and certain sectors in emerging economies lack standardized or audited financial data, which hinders the application of conventional statistical models that rely on strict assumptions [4]. Furthermore, purely financial analysis has proven to be insufficient, requiring the integration of qualitative, social, and environmental criteria for a solvency assessment consistent with contemporary reality [5].

Despite advances in credit scoring techniques, the predominant literature still concentrates its efforts on predicting the frequency of events, that is, the probability of a borrower defaulting. However, for the resilience of the financial system, the severity of the loss in the event of default is as critical as, or more critical than, its frequency. Univariate statistical models tend to classify retail risk as a priority, failing to capture the latent risk in infrastructure or governmental sectors, where default is rare, but the exposure per contract is massive.

This research proposes a multidimensional approach that integrates multiple risk dimensions, such as liquidity, portfolio quality, and concentration, into a single vulnerability index. By using a hybrid methodology, the study removes subjectivity in the assignment of weights, allowing the data structure itself to reveal which financial variables are most discriminating for sectoral risk in the current Brazilian scenario.

MCDM is a branch of operational research that integrates mathematics, management, and economics to solve complex decision-making problems [4]. In finance, decisions rarely seek to satisfy a single objective; they involve a balance between maximizing returns and liquidity while minimizing risks and costs [6]. The literature indicates that the multi-criteria approach offers significant advantages over traditional statistical models, as it does not rely on large historical databases or assumptions of normal distribution of variables, thereby allowing for the incorporation of expert judgments and qualitative factors [3, 5]. Recent bibliometric studies indicate a growing trend in combining different MCDM methods to solve problems related to supplier selection, sustainability, and risk management, with AHP and TOPSIS featuring among the most widely used techniques [7, 8].

Credit risk assessment aims to discriminate between solvent and insolvent borrowers. Although techniques such as logistic regression and neural networks are common, they can present divergent results depending on the performance metrics used [3, 9]. The application of multi-criteria models allows for a more holistic analysis. For example, [10] demonstrated the utility of MCDM methods to evaluate the performance of dominant economic sectors in Mexico, using census data to group sectors according to their level of attractiveness. Furthermore, the inclusion of non-financial criteria, such as management practices, environmental impact, and

reputation, has been fundamental in mitigating information asymmetry, especially in the assessment of SMEs and in markets where accounting records may be limited [4, 12].

Although the vast majority of credit scoring literature focuses on evaluating individual firms or retail clients, assessing entire economic sectors provides a vital macro-prudential perspective. For instance, Leyva [10] successfully applied a multicriteria ranking approach to assess the performance of 89 dominant economic sectors in Mexico, demonstrating that sectoral modeling via MCDM allows policymakers and bank directors to identify systemic bottlenecks. Therefore, the sectoral approach proposed in this study goes beyond individual credit granting; it acts as a macro-prudential tool capable of mitigating financial contagion between sectors and guiding the strategic allocation of economic capital in highly volatile environments.

Developed by Hwang and Yoon in 1981, TOPSIS is based on the concept that the best alternative should have the shortest Euclidean distance from the Positive Ideal Solution (PIS) and the farthest distance from the Negative Ideal Solution (NIS) [3, 11]. The Positive Ideal Solution consists of the best observed, or theoretical, performance values for each criterion, while the Negative is composed of the worst ones. The standard TOPSIS procedure involves:

I. Construction of the normalized decision matrix to eliminate scale differences among the criteria [8];

II. Weighting of the normalized matrix by applying the weights assigned to each criterion;

III. Determination of the ideal solutions;

IV. Calculation of the separation distances of each alternative with respect to these ideal solutions;

V. Calculation of the relative closeness coefficient, which allows for the final ranking of the alternatives [4, 2].

The versatility of TOPSIS is evidenced in various financial applications. [4] developed a credit scoring model for SMEs using a hybrid in conjunction with BWM, concluding that the model outperformed commercial approaches in accuracy and reduction of classification errors. Similarly, [2] used it integrated with other methods to manage credit risk in property investments, highlighting its capacity to synthesize objective financial variables with subjective judgments.

In the context of innovation and sustainability, the method has also been employed to prioritize barriers to green innovation and evaluate the technological capability of companies, proving to be a robust tool for comparative analyses in environments of uncertainty [8, 13]. This flexibility confirms the suitability of the method for the sectoral vulnerability ranking proposed in this study.

The general objective of this study is to apply the Multi-Criteria Decision-Making (MCDM) method Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to rank the credit vulnerability of economic sectors. The specific objectives include: (i) identifying in the literature the financial and non-financial criteria relevant to risk assessment; (ii) modeling the problem using the distance to the ideal solution logic of TOPSIS; and (iii) providing a ranking to assist decision-makers in resource allocation, given that MCDM methods have proven effective in influencing decision-making processes and solving macroeconomic problems [10].

The relevance of the study is justified by the growing importance of MCDM methods in the financial literature, especially after the year 2000, as tools capable of handling conflicting and subjective criteria [7]. The application of such methods provides greater transparency and rationality to financial governance, allowing for adaptation to scenarios of uncertainty and the inclusion of strategic variables that traditional methods neglect [13, 14].

The rest of the article is organized as follows: Section 2 presents the Methodology; Section 3 shows the research results; and finally, Section 4 presents the conclusions.

2 Methodology

The present research is characterized as exploratory and quantitative, based on the application of Multi-Criteria Decision-Making methods for sectoral credit risk modeling. The choice of a multi-criteria approach, rather than traditional statistical models, such as logistic or discriminant regression, is justified by the multidimensional nature of the "financial vulnerability" concept. It is understood, in this proposal, that the risk of an economic sector is not defined solely by its probability of default, but by a vector of characteristics that includes the severity of exposure, the quality of guarantees, and liquidity pressure. The methodological procedure was structured into three sequential stages: (i) Data processing and construction of the decision matrix; (ii) Objective weighting of the criteria via the CRITIC method; and (iii) Ordering of the alternatives (Ranking) through the TOPSIS method.

2.1. Data Source and Variable Definition

Primary data were extracted from the open database of the Central Bank of Brazil (BACEN), specifically from the Credit Information System (SCR). The time frame refers to the period of 2025, covering the active portfolio of Legal Entities (PJ) segmented by the National Classification of Economic Activities (CNAE). The data processing and calculations that will be presented below were performed using the Python programming language. For the construction of the Decision Matrix X, where Xij represents the performance of sector i in criterion j, five indicators were defined that capture different dimensions of credit risk. A maximization direction was adopted for all criteria, where higher values indicate greater vulnerability. To operationalize the model, five evaluation criteria based on the SCR financial indicators were defined, as detailed in Table 1.

The font sizes are given in Table 1.

Table 1. Credit Risk Evaluation Criteria

Criterion (Cj)	Financial Indicator	Theoretical Justification of Risk	Direction
C1: Default Rate	Default Portfolio / Active Portfolio	Materialization of credit risk (Frequency).	Maximize
C2: Quality	Problematic Asset / Active Portfolio	Deterioration of asset quality before default.	Maximize
C3: Immediate Risk	Overdue Portfolio / Active Portfolio	Short-term solvency difficulty and liquidity stress.	Maximize
C4: Cash Pressure	Maturity < 90 days / Total to Mature	Refinancing risk (Rollover Risk).	Maximize
C5: Average Ticket	Active Portfolio / No. of Operations	Concentration risk and capital impact (Severity).	Maximize

2.2. Criteria Weighting: CRITIC Method

The literature frequently utilizes subjective methods like the Analytic Hierarchy Process (AHP) or the Best-Worst Method (BWM) to elicit criteria weights through expert panels [2, 4]. However, when dealing with large-scale open government data, such as those from the Central Bank, relying on expert judgments can introduce cognitive biases and operational delays. The choice of the CRITIC method is thus justified by the strictly quantitative nature of the accounting data employed [15] . By extracting the weights directly from the variance and correlation of the data, the CRITIC method allows the weighting to reflect the intrinsic amount of information, valuing criteria that present greater discrimination power, high standard deviation, and low redundancy among the sectors.

To prevent these scale differences from distorting the subsequent statistical calculation, the original matrix underwent a prior algorithmic standardization step. As emphasized by [2], the choice of the mathematical normalization technique can significantly alter the final ranking in TOPSIS applications. In this study, Min-Max normalization was specifically chosen to preserve the extreme distances between retail and infrastructure sectors. This ensures that the colossal values of the Average Ticket criterion are not mathematically flattened, maintaining the true magnitude of the capital exposure in the subsequent statistical calculations. Considering that all criteria defined in this study have a maximization direction (as per Table 1), the normalized element xij is obtained through the following equation:

$$x'_{ij} = \frac{x_{ij} - min_i(x_{ij})}{max_i\ (x_{ij})} \quad \textbf{(1)}$$

x_{ij} represents the original performance value of sector i in the criteria j, while $min_i(x_{ij})\ and\ max_i(x_{ij})$ represent, respectively, the best and worst performance observed for that criterion across the entire analyzed sectoral sample.

From this standardized matrix, the CRITIC method extracts the weights based on two fundamental statistical premises of informational content: Contrast: Measured by the standard deviation. Criteria with greater variability among the sectors provide more information for the ranking. Conflict: Measured by the correlation. Highly correlated criteria contain redundant information and should have their weights attenuated. The amount of information contained in criterion j, denoted by Cj, is calculated through the equation:

$$Cj = \sigma_j \sum_{k=1}^{n} (1 - r_{jk}) \quad (2)$$

In equation (2), the standard deviation of the normalized values of criterion *j*, and *rjk* is the Pearson linear correlation coefficient between criteria. The term (1 - *rjk*) represents the conflict measure created by criterion j in relation to the others. Finally, the objective weight Wj is obtained by normalization of *Cj*:

$$W_j = \frac{C_J}{\sum_{J=1}^{n} C_j} \quad (3)$$

In equation (3), Wj is the final relative weight of the criterion, ensuring that the sum of all weights in the model is exactly equal to 1.

2.3. Ordering of Alternatives: TOPSIS Method

For the processing of the ranking, the central premise is that the best alternative, the most vulnerable sector in this context, must have the shortest geometric distance from the Positive Ideal Solution and the farthest distance from the Negative Ideal Solution. The operationalization of the method begins with the elimination of measurement unit dimensions through vector normalization, followed by the weighting of the criteria. The vector-normalized element n_{ij} and the respective weighted decision matrix element v_{ij} are defined by the following equations, executed sequentially:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum x_{ij}^2}} \quad (4)$$

$$v_{ij} = r_{ij} \times W_j \quad (5)$$

Where n_{ij} is the normalized value in the vector matrix for sector i in criterion j, and v_{ij} is the final weighted value, resulting from the dot product between the normalized value n_{ij} and the weight Wj, previously extracted via the CRITIC method.

From the weighted normalized matrix V, the theoretical ideal scenarios are determined. The Positive Ideal Solution (A^+) is composed of the highest observed performance values, while the Negative Ideal Solution (A^+) is composed of the lowest. Given that all five modeling criteria assume the direction of financial risk maximization, the ideal vectors are defined as:

$$A^+ = \{v_1^+, v_2^+, \ldots, v_n^+\}, \text{ where } v_j^+ = max_i(v_{ij}) \quad (6)$$

$$A^- = \{v_1^-, v_2^i, \ldots, v_n^-\}, \text{ where } v_j^- = min_i(v_{ij}) \quad (7)$$

The vector A^+ represents the hypothetical scenario of maximum vulnerability, highest credit risk, and the vector A^- represents the scenario of resilience and minimum systemic risk. The Euclidean distances of each economic sector *i* in relation to these two ideal scenarios are calculated using L2 norms:

$$D_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2} \quad (8)$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \quad (9)$$

D_i^+ is the separation distance of sector *i* to the extreme risk profile, and D_i^- is the separation distance to the minimum risk profile.

Finally, the ranking of alternatives is determined by calculating the relative closeness coefficient CC_i, given by:

$$CC_i = \frac{D_i^-}{D_i^+ + D_i^-}, \quad 0 \leq CC_i \leq 1 \quad (10)$$

The vulnerability coefficient CC_i is bounded within the interval [0, 1]. Economic sectors that present CC_i values closer to 1 indicate a strong adherence to the system's maximum risk profile A^+, configuring themselves as the alternatives that should be prioritized in sectoral risk monitoring and portfolio restriction processes.

3 Findings

3.1. Analysis of the Weight Importance Structure

The analysis of the obtained weights demonstrates that the model's weighting is sensitive to the intrinsic variance of financial data. As observed in Figure 1, there is an overwhelming predominance of the Average Ticket criterion in the final index composition, with approx. value 0.3868. From an economic standpoint, this is due to the high dispersion of exposure values in active portfolios, which range from pulverized microcredits to infrastructure financing on a billion-dollar scale. The low correlation of this criterion with traditional default rates reinforces the thesis that, in the Brazilian scenario, the magnitude of the operation, and not just the recurrence of delay, is the variable that most discriminates sectoral risk. The statistical method, by identifying this variability, prioritizes concentration risk as a fundamental component for the balance sheet stability of financial institutions, reducing subjectivity in risk governance.

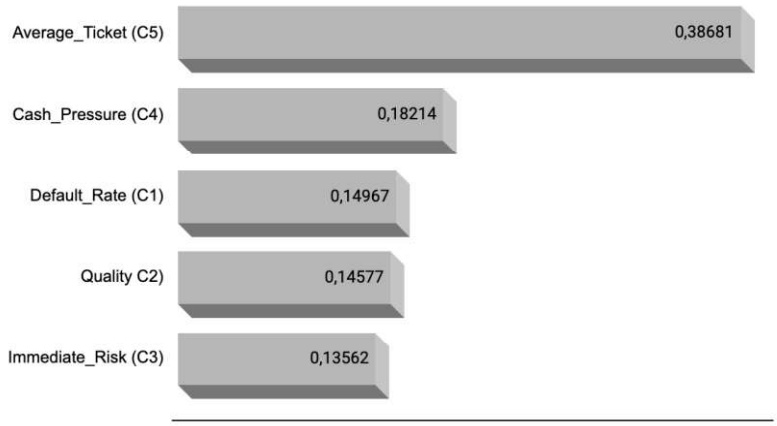

Fig. 1. The relative weights of the five credit risk evaluation criteria extracted via the CRITIC method (horizontal bars), demonstrating the predominance of the Average Ticket criterion (top bar) over the others. This shows a figure consisting of a horizontal bar chart ranking the criteria by their objective weights.

3.2. The Low Default Paradox: Structural Discussion

The ranking presented in Table 2 highlights a counterintuitive pattern: systemic vulnerability is associated with severity, and not necessarily with the frequency of default. The Public Administration, Defense, and Social Security sector occupies the first position in the ranking, CCi ≡0.6102, a phenomenon termed in this study as The Low Default Paradox.

Table 2. Top 10 Sectors of Highest Multicriteria Risk

Sector	C1	C2	C3	C4	C5	Score	Ranking
Public administration, defense, and social security	0.0002	0.0016	0.0002	0.0332	18,844,477.05	0.6102	1
Electricity and gas	0.0027	0.0257	0.0026	0.0334	16,559,725.46	0.5816	2
Domestic services	0.1251	0.1892	0.0993	0.3419	1,988.76	0.3484	3
International organizations	0.0001	0.1568	0.0003	0.7216	45,570.54	0.2748	4
Accommodation and food	0.0817	0.1323	0.0492	0.2070	21,310.28	0.2354	5
Professional, scientific, and technical activities	0.0523	0.1033	0.0335	0.2395	33,656.68	0.1838	6
Other service activities	0.0572	0.0904	0.0371	0.1913	13,921.66	0.1802	7
Trade; repair of motor vehicles and motorcycles	0.0478	0.0882	0.0300	0.2833	46,070.53	0.1785	8
Education	0.0429	0.0836	0.0243	0.1705	30,076.00	0.1442	9
Arts, entertainment, and recreation	0.0359	0.1033	0.0207	0.1705	41,816.68	0.1440	10

Although the Public Administration sector presents historically irrelevant default rates, $C_1 \equiv 0.0002$, the average exposure per operation, which exceeds R$ 18 million, places it at an extremely high tail-risk level. The MCDM model correctly captured that, for bank solvency, a default event in this sector would not merely be an operational setback but an event of systemic decapitalization. Conversely, sectors located in the intermediate positions of the ranking, such as Domestic Services, with Score approx. 0.3484, present default rates above 12%, but due to the low Average Ticket, they configure an actuarial risk that is easy to price and recurrently provision for, thus being less critical to the institution's overall liquidity.

3.3. Comparison: Pulverized Risk vs. Concentrated Risk

The divergence between the traditional statistical approach and the hybrid model becomes evident when visualizing the dispersion between Frequency and Severity.

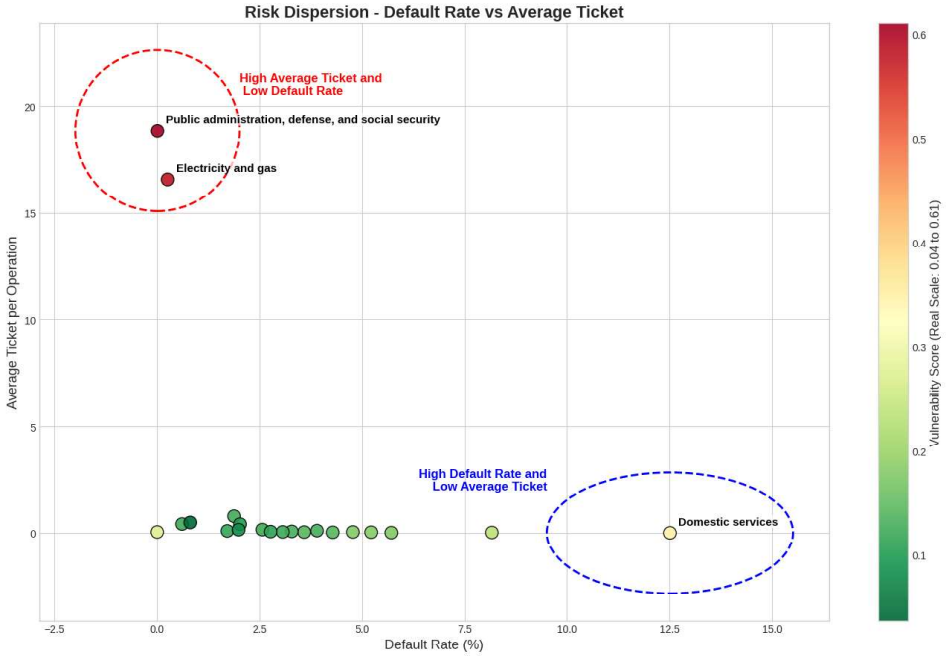

Fig. 2. The risk dispersion between the default rate (x-axis) and the average ticket per operation (y-axis) for the analyzed economic sectors. The chart highlights the contrast between capital-intensive wholesale sectors (upper left cluster) and highly pulverized retail sectors (lower right cluster), with the overall vulnerability score indicated by a color gradient (color bar on the right). This shows a figure consisting of a scatter plot with annotated data points and dashed clustering boundaries.

Figure 2 demonstrates the clear separation of two diametrically opposed risk regimes. On the lower right axis (the retail cluster), the risk dynamic is governed by the Law of Large Numbers. In these portfolios, default events are independent, and idiosyncratic risk is diluted by the pulverization of contracts. The high default rate is offset by the low individual magnitude, requiring less structural regulatory capital effort.

Conversely, the upper left quadrant isolates capital-intensive sectors, notably Electricity and Gas and Public Administration. In these wholesale markets, the Law of Large Numbers fails because the portfolio comprises a few borrowers with colossal financial volumes. The TOPSIS model demonstrated its accuracy by heavily penalizing these sectors: when weighting the magnitude, the algorithm shifted the focus from daily default risk to ruin risk. This proves that managing corporate credit portfolios cannot treat diversification simplistically; concentration in a few high-ticket sectors nullifies the benefits of pulverization and demands a governance model based on extreme shock mitigation.

3.4 Sensitivity and Analysis of the Model

In the MCDA literature, the validation of a decision-making model requires conducting a sensitivity analysis. This procedure is fundamental to ensure that the generated recommendations are not mere mathematical artifacts derived from the initial weighting, but rather consistent and stable reflections of the data structure [13, 4]. In order to assess the stability of the obtained sectoral ranking and, consequently, the proposed model was subjected to mathematical stress tests.

To this end, an isolated criteria weight perturbation approach, One-At-a-Time, was adopted. The procedure consisted of altering the weight of a single criterion at a time by margins of ±10%. To preserve the mathematical integrity of the TOPSIS model, immediately after the perturbation of the target criterion, the weights of the other four remaining criteria underwent an automatic proportional readjustment, ensuring that the global sum of the weights remained strictly equal to 1 [12]. This cycle of perturbation and renormalization was repeated independently for all criteria, and the decision matrix was reprocessed for each scenario to obtain new relative closeness coefficients (CCi).

The comparison of the simulations with the original ranking revealed that the ordering structure possesses

a remarkable resilience to variations in the parameters. Even in scenarios where the importance of arrears frequency was artificially increased with the consequent proportional reduction in severity, the top of the ranking remained unchanged. The Public administration, defense, and social security and Electricity and gas sectors retained their isolated leadership in the degree of vulnerability.

This behavior attests to the statistical robustness of the finding. The magnitude of the structural risk, anchored in the extremely high capital exposure in these wholesale sectors, demonstrated sufficient mathematical strength to stabilize the model against uncertainties in the weightings. Therefore, it is confirmed that excessive dependence on portfolios with massive concentration constitutes, in fact, the main systemic vulnerability of sectoral credit, validating the analytical effectiveness of the hybrid CRITIC-TOPSIS approach.

4 Conclusions

Sectoral credit risk assessment is a complex analytical task that requires moving beyond traditional metrics of probability of default. This study fulfilled its objective by developing and applying a hybrid CRITIC-TOPSIS model to rank the vulnerability of Brazilian economic sectors using real data from the Central Bank.

The results yield three main conclusions. First, financial vulnerability is a multidimensional construct, and the imperfect correlation between past defaults and future exposure reinforces the need to monitor liquidity and financial concentration indicators simultaneously.

Second, the Public Administration and Infrastructure sectors were identified as the greatest sources of latent risk within the system. The historical payment stability of these sectors disguises a structural fragility characterized by an extremely high concentration of capital. In terms of portfolio management, this implies that exposure limits to these sectors must be strictly enforced, not due to the statistical chance of default, but because of the system's inability to financially absorb such an event.

Third, the methodology proved that the frequency of default is not synonymous with severity. Sectors with high default rates but low average tickets present an actuarial risk that is easy to price and provision for, whereas sectors with low default rates and high average tickets carry a business model that demands a greater allocation of economic capital.

From a regulatory standpoint, these findings offer insights for the financial regulators operating under the updated Basel III framework [16]. Developed by the Basel Committee on Banking Supervision, Basel III establishes international regulatory standards designed to strengthen financial stability by requiring banking institutions to maintain adequate capital buffers against credit, market, and operational shocks. Standard Pillar 1 regulatory capital requirements rely heavily on Risk-Weighted Assets derived from historical Probability of Default. Because capital-intensive sectors, such as Public Administration and Electricity & Gas, exhibit near-zero default rates, conventional models assign them low capital surcharges. However, the hybrid multicriteria model demonstrates that massive exposure concentration creates severe tail-risk events that Pillar 1 metrics overlook. Consequently, regulatory organs, such as BACEN, could adopt hybrid MCDM vulnerability metrics as a macro-prudential supervisory tool under Pillar 2, Supervisory Review Process [17]. This pillar allows monetary supervisors to evaluate risks not fully captured by standardized formulas, specifically portfolio concentration and extreme shock scenarios, and mandate institution-specific capital add-ons. By integrating sectoral severity metrics into concentration risk buffers and stress-testing protocols, regulatory authorities can enforce sector-specific capital add-ons for high-ticket corporate portfolios, ensuring that financial institutions hold adequate economic capital against low-frequency, high-severity systemic shocks.

Despite its contributions, this research presents limitations that pave the way for future studies. First, the proposed evaluation matrix relies exclusively on quantitative data. Modern credit risk literature emphasizes that purely financial analysis has proven insufficient, requiring the integration of qualitative, social, and environmental (ESG) criteria for a coherent solvency assessment [5]. Sectors identified at the top of the vulnerability ranking, such as "Electricity and gas", possess intrinsic socio-environmental risks that, if measured, could further refine the model [4]. Second, the study is limited by its cross-sectional design. Credit markets operate in dynamic environments where decision models are prone to performance degradation over time, a phenomenon known as dataset shift or drift [14].

For future investigations, it is recommended to overcome these limitations by implementing a continuous longitudinal framework, allowing for the periodic rebalancing of criteria weights as new economic data are consolidated. Furthermore, the integration of Fuzzy set theory into the modeling is strongly suggested. Considering that a significant portion of the credit market comprises Small and Medium-sized Enterprises (SMEs)—often subject to limited accounting records and high information asymmetry—, hybridizing TOPSIS

with Fuzzy logic will provide the appropriate mathematical treatment to handle the imprecision, uncertainty, and vagueness inherent to these data during economic stress scenarios [11, 12].

References

1. Yoshiura, L.J.M., Martins, C.L., Costa, A.P.C.S., Santos-Neto, J.B.S.: A multicriteria decision model for risk management maturity evaluation. Pesquisa Operacional 43, e270186 (2023).
2. Locurcio, M., Tajani, F., Morano, P., Anelli, D., Manganelli, B.: Credit Risk Management of Property Investments through Multi-Criteria Indicators. Risks 9(6), 106 (2021).
3. García, V., Sánchez, J.S., Marqués, A.I.: Synergetic Application of Multi-Criteria Decision-Making Models to Credit Granting Decision Problems. Applied Sciences 9(23), 5052 (2019).
4. Roy, P.K., Shaw, K.: A multicriteria credit scoring model for SMEs using AHP and TOPSIS. Financial Innovation 7, 77 (2021).
5. Serrano-Cinca, C., Gutiérrez-Nieto, B., Reyes, N.M.: A Social and Environmental Approach to Microfinance Credit Scoring. Manuscript Accepted (2015).
6. Steuer, R.E., Na, P.: Multiple criteria decision making combined with finance: A categorized bibliographic study. European Journal of Operational Research 150(3), 496–515 (2003).
7. Kaya, N.: Multi-Criteria Decision Making Methods (MCDM): A bibliometric analysis (1974-2024). Journal of Business, Economics and Finance (JBEF) 13(2), 55–67 (2024).
8. Rodríguez-Carrillo, M.L., Pérez-Domínguez, L., Romero-López, R., Luviano-Cruz, D., León-Castro, E.: A systematic literature review on the use of multicriteria decision making methods for small and medium-sized enterprises innovation assessment. Frontiers in Artificial Intelligence 8, 1605756 (2025).
9. Černevičienė, J., Kabašinskas, A.: Review of Multi-Criteria Decision-Making Methods in Finance Using Explainable Artificial Intelligence. Frontiers in Artificial Intelligence 5, 827584 (2022).
10. Leyva López, J.C., Solano Noriega, J.J., León Santiesteban, M.: An application of a multicriteria ranking approach to assessing the performance of the dominant Mexican economic sectors. Pesquisa Operacional 44, e283126 (2024).
11. Oliveira Filho, D.M., Almeida Filho, A.T., Ferreira, L., Righi, M.B., Borenstein, D.: Fuzzy-Based Decision Support System for Private Banking. Pesquisa Operacional 43, e264857 (2023).
12. Akbulut, O.Y.: Assessing the environmental sustainability performance of the banking sector: A novel integrated grey Multi-Criteria Decision-Making (MCDM) approach. International Journal of Knowledge and Innovation Studies 2(4), 239–258 (2024).
13. Kayed, S., Alhawwatma, Z., Morshed, A., Khrais, L.T.: Strategic Foresight for FinTech Governance: A Scenario-Based MCDA Approach for Kuwait. MDPI (2026).
14. Ziemba, P., Becker, J., Becker, A., Radomska-Zalas, A.: Framework for multi-criteria assessment of classification models for the purposes of credit scoring. Journal of Big Data 10, 94 (2023).
15. Diakoulaki, D., Mavrotas, G., Papayannakis, L.: Determining objective weights in multiple criteria problems: The Critic Method. Computers and Operations Research. 22 (7), 763–770 (1995).
16. Basel Committee on Banking Supervision (BCBS): Basel III: Finalising post-crisis reforms. Bank for International Settlements (BIS), Basel (2017).
17. Central Bank of Brazil (BACEN): Resolution CMN nº 4.958 (2021).

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Recife-PE, Brazil

A DECISION SUPPORT MODEL FOR RANKING HIGH-VOLTAGE EQUIPMENTS FOR TRANSMISSION SUBSTATIONS

Heitor Souza Vilela[1], Luciana Hazin Alencar[2]

[1]Federal University of Pernambuco, Recife, Pernambuco, Brazil
[2] Federal University of Pernambuco, Recife, Pernambuco, Brazil
Heitor.vilela@ufpe.br, Alencarlh@insid.org.br

Abstract. The selection of high-voltage equipment for power transmission substations involves multiple conflicting technical, economic, operational, environmental, and regulatory criteria. Engineering decisions regarding the selection of circuit breakers, disconnectors, instrument transformers, surge arresters, and alternative equipment configurations require a structured process capable of comparing competing alternatives in a consistent, transparent, and justifiable manner. However, there remains a lack of decision models that systematically organize the application of multicriteria ranking methods to support this decision-making process. This research proposes a decision support model to structure the application of Multi-Criteria Decision Aid (MCDA) ranking methods for high-voltage equipment selection problems. he model defines a structured workflow for screening feasible alternatives, ensuring consistency in the evaluation process and improving the traceability of engineering decisions throughout the selection procedure. By integrating decision criteria, decision-maker preferences, and alternative performance into a unified decision structure, the model provides a robust basis for ranking competing solutions and supporting well-founded engineering recommendations. The expected outcome is a transparent, consistent, traceable, and reproducible decision-making process capable of improving the quality of engineering evaluations through the systematic comparison, classification, and ranking of high-voltage equipment alternatives.

Keywords: Multi-Criteria Decision Aid (MCDA); Ranking Methods; High-Voltage Equipment Selection; power transmission substations

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Production Engineering and the New Industry Brazil (NIB): a systemic diagnosis through the CHAP² method and the 8 Intelligences Model

Rafael da Costa Jahara[1][0000-0002-3681-9662], Marcos Estellita Lins[2] [0000-0003-1980-0764]

[1] COENP-NI/CEFET-RJ | PEP/COPPE/UFRJ
[2] PEP/COPPE/UFRJ | CCET/UNIRIO

rafael.jahara@cefet-rj.br, estellita@pep.ufrj.br

Abstract. This paper presents a systemic diagnosis of the alignment between undergraduate Production Engineering (PE) programs in Brazil and the strategic missions of the New Industry Brazil (NIB). The research employs a multimethodological Problem Structuring approach based on Phase I of the Complex Holographic Assessment of Paradoxical Problems (CHAP²) method, integrated with the Systemic Investigation Network (SIN) and the 8 Intelligences Model, operating in critical interface with Generative Artificial Intelligence (GAI). Drawing on official e-MEC registry data (977 active programs) and ENADE performance metrics, combined with cognitive mapping from domain experts, the findings reveal a stark structural polarization: while private institutions supply 95% of student capacity, public universities concentrate 85% of top-tier performance (ENADE score 5). Furthermore, while curricula have readily integrated Mission 4 (Digital Transformation), significant pedagogical and infrastructural bottlenecks hinder adherence to missions concerning decarbonization, bioeconomy, and healthcare. The study demonstrates the necessity of advancing from an Industry 4.0 efficiency-driven model toward a Society 5.0 paradigm, anchoring engineering education in civic ethics, paradoxical inquiry, and national socioeconomic sovereignty.

Keywords: Production Engineering, New Industry Brazil, CHAP², 8 Intelligences Model.

1 Introduction

The New Industry Brazil (NIB), launched in January 2024 by the Brazilian Federal Government, is consolidated as the country's new industrial policy, establishing critical goals to enhance national industrial development up to 2033. The policy is spearheaded by the Ministry of Development, Industry, Commerce, and Services (MDIC) and forecasts financial investments in the order of R$ 300 billion by 2026 [5].

The NIB is structured around six main missions and four strategic axes. Mission-oriented policies establish that instead of the State subsidizing isolated sectors or handpicking specific companies, it should set bold goals aimed at solving major societal challenges, such as climate change and public health, thereby fostering cross-sectoral innovation [30]. The NIB's missions range from decarbonization to digital transformation and the bioeconomy. Meanwhile, the strategic axes focus on expanding the productive capacity of national industries, innovation, digitalization, export expansion, and greener [6].

With the transition to Industry 4.0 and the directives set by the NIB, higher education in Production Engineering (PE) demands a reassessment to ensure its effectiveness in addressing emerging technological and sustainability requirements. Due to its systemic nature, PE plays a role in qualifying professionals capable of integrating the physical and digital domains, fostering industrial competitiveness and national sovereignty in Brazil. Within this context, this research investigates whether undergraduate degree programs and Higher Education Institutions (HEIs) have curricula that are genuinely aligned with the demands of a more productive, digital, sustainable, and sovereign national industry.

This work is part of doctoral research aimed at developing a multimethodology to evaluate the effectiveness of undergraduate PE programs in Brazil, grounded in the pillars and missions of the NIB. Its primary deliverable is a representative nationwide diagnosis, identifying whether HEIs are effectively preparing the workforce required for the modernization and transformation of Brazil's industrial base, particularly considering challenges surrounding digitalization, energy transitions, and national sovereignty.

The methodological framework employs the Complex Holographic Assessment of Paradoxical Problems (CHAP²) problem-structuring method, developed at the Alberto Luiz Coimbra Institute for Graduate Studies

and Research in Engineering (COPPE) of the Federal University of Rio de Janeiro (UFRJ). CHAP² focuses on paradoxical dimensions and integrates qualitative and quantitative methods to support decision-making in complex social contexts [24]. To broaden the modeling scope and understand the problem systemically, the research employs the Systemic Investigation Network (SIN) and the 8 Intelligences Model proposed by Lins [25]. This framework establishes an epistemology of responsible decision-making regarding the evaluation of PE programs in connection with Brazilian industrial policy. The integration between SIN and the 8 Intelligences is applied notably at the interface with Generative Artificial Intelligence (GAI).

The innovation and main scientific contribution of this study lie in three aspects. The first one is related to the empirical novelty, because it provides the first nationwide diagnostic assessment analyzing the alignment between Brazilian undergraduate Production Engineering education and the strategic missions of the New Industry Brazil (NIB). The second contribution lies in the methodological innovation, which pioneeringly integrates Phase I of the CHAP² problem-structuring method with the Systemic Investigation Network (SIN) and the 8 Intelligences Model acting in a critical human-AI collaborative loop. The third one is the epistemic shift because it advances engineering education research beyond traditional Industry 4.0 productivity metrics toward a Society 5.0 paradigm grounded in civic ethics, paradoxical inquiry, and national sovereignty.

2 Theoretical Background

2.1 New Industry Brazil (NIB)

Brazil has undergone an early and accelerated deindustrialization process since the 1980s. The current bottlenecks restricting the competitiveness of its productive sector are deeply rooted in a combination of macroeconomic choices, global dynamics, and internal structural problems, causing the country to lose economic complexity across its productive matrix [8]

In response to this stagnation, the Brazilian Federal Government formulated the New Industry Brazil (NIB), establishing six missions focused on agro-industry, healthcare, infrastructure, digital transformation, bioeconomy/energy transition, and defense [6]. The mission-oriented policy framework was conceptualized by Mazzucato [30]. Hitner & Castro [17] emphasize that, unlike top-down policies of the past, the NIB Action Plan gained strong democratic legitimacy because it was drafted within the National Council for Industrial Development (CNDI), engaging civil society entities, business leaders, and labor representatives in a participatory process.

The NIB is based on three core premises, according to Brazil [6]: (i) The key to Brazil's sustainable development lies in strengthening national industry; (ii) Since the 1980s, the country has faced an early and accelerated deindustrialization process; (iii) National exports are heavily concentrated in low-technological-complexity products.

The strategy is founded on four axes: productivity (modernization), digital innovation (new technologies), foreign trade/exports, and green industry (decarbonization) [6], alongside six strategic missions targeting 2033 goals [5]:

1. Sustainable and digital agro-industrial chains: increase agro-industry's share in agricultural GDP and supply domestic machinery and equipment for family farming;
2. Resilient economic-industrial healthcare complex: meet 70% of national demands for pharmaceuticals, vaccines, and medical devices through domestic production, strengthening the Unified Health System (UHS);
3. Sustainable infrastructure, sanitation, housing, and mobility: reduce commuting time by 20% and increase national manufacturing shares in sustainable public transport supply chains;
4. Digital transformation of industry: digitalize 90% of Brazilian industrial companies and triple domestic manufacturing shares in advanced technology sectors;
5. Bioeconomy, decarbonization, and energy transition: cut industrial carbon emissions per unit of industrial GDP value added by 30% and expand biofuel participation in the national transport matrix;
6. Technologies of interest to national defense and sovereignty: achieve 50% autonomy in the domestic production of critical defense technologies.

For this policy to succeed, State operational practices must transform. Mazzucato [31] recommends three structural shifts in Brazil: redesigning public procurement to shape new markets (leveraging the purchasing power of UHS, por example), strategically coordinating state-owned enterprises, such as Petrobras and the Brazilian Development Bank (BNDES), beyond short-term profits, and consolidating a Public Digital Infrastructure (PDI) founded on public values.

In practice, the financing of this transformation is underway through the “More Production Plan” (MPP). Hamatsu & Souza [16] document the massive mobilization by the Financier of Studies and Projects (FINEP) and the Ministry of Science, Technology, and Innovation (MCTI) in allocating non-reimbursable economic subsidies for high-risk energy transition projects (electromobility, green hydrogen, carbon capture). BNDES has also shifted its priorities: Dunham et al. [7] show that 88.3% of the bank's innovation resources in 2023–2024 were directed toward high-technological-density projects. Sectorally, this translates into strengthening the Healthcare Economic-Industrial Complex (CEIS) to decrease external dependence, financing electric vertical takeoff and landing aircraft (eVTOLs), decarbonizing steelmaking (green steel), and supporting sustainable data center infrastructure for Artificial Intelligence demands [9, 15, 42].

The core tenet of the NIB is neo-industrialization linked to environmental sustainability. In urban mobility, Marques et al [28] argue that bus decarbonization should not rely exclusively on battery-electric vehicles but also leverage competitive domestic advantages such as hybrid models running on biofuels and biomethane. However, transitioning to a green economy introduces intricate social and operational challenges.

2.2 Production Engineering in Brazil

The undergraduate Production Engineering (PE) degree in Brazil began in 1959 at the University of São Paulo (USP), under a Mechanical Engineering emphasis led by Professor Ruy Aguiar da Silva Leme. Its early success, marked by the immediate absorption of graduates into multinational corporations, led to the creation of the Department of Production Engineering at the Polytechnic School in 1963 [22, 37]. Subsequently, demand for production engineers surged, driven by the expanding automotive hub in Greater ABC region and along the Rio–São Paulo axis. The arrival of electronic computing in corporate environments consolidated these professionals’ strategic roles in computer programming and systems analysis due to their holistic and systemic outlook.

During the military regime, particularly under the Castelo Branco administration, incentives for capital markets and investment banks fostered the recruitment of production engineers, prized for their strong quantitative and economic-financial foundations. In 1965, Petrobras institutionalized Operational Research (OR) by forming an internal study group for practical applications. Over time, the engineer's versatility was recognized across diverse industries, establishing PE as a strategic asset for organizational competitiveness [37].

In this context, new undergraduate Production Engineering programs emerged across various Brazilian states. In the state of Minas Gerais, the Federal University of Minas Gerais (UFMG) established its program in 1971 with a Mechanical emphasis. In Rio de Janeiro, the Pontifical Catholic University of Rio de Janeiro (PUC-Rio) created its degree in 1962, offering emphases in Civil, Electrical, and Mechanical/Metallurgical Engineering, followed in the same year by the Federal University of Rio de Janeiro (UFRJ) with a Mechanical emphasis. In the state of São Paulo, following the pioneering initiative at the University of São Paulo (USP) in 1959, the Federal University of São Carlos (UFSCar) launched its program in 1976 with a Mechanical emphasis. In Santa Catarina, the Federal University of Santa Catarina (UFSC) founded its course in 1979 featuring Civil, Electrical, and Mechanical emphases, whereas in Rio Grande do Sul, the University of Caxias do Sul (UCS) created its program in 1981 with Mechanical and Chemical emphases [37].

The Brazilian Association of Production Engineering [1], adopting definitions from the Institute of Industrial and Systems Engineers (IISE), defines: "Production Engineering is concerned with the design, installation, operation, improvement, and maintenance of integrated production systems of goods and services, involving people, materials, technology, information, and energy. It is also responsible for specifying, predicting, and evaluating the results obtained from these systems for society and the environment, drawing upon specialized knowledge in mathematics, physics, humanities, and social sciences, together with the principles and methods of engineering analysis and design". Furthermore, ABEPRO [1] outlines ten knowledge areas within PE, presented in the Table 1.

Table 1. Knowledge areas within PE

Knowledge Area	Summary definition
1. Operations and Production Process Engineering.	Design, operation, and improvement of systems that create and deliver the primary products (goods or services) of the enterprise.
2. Supply Chain and Logistics.	Techniques and operational considerations regarding transportation, material handling, inventory control, and storage of supplies and finished goods.
3. Operational Research (OR).	Resolution of real-world decision-making problems through mathematical and structured modeling.

4. Quality Engineering.	Planning, design, and control of quality management systems and continuous improvement.
5. Product Engineering.	Tools, processes, organizational design, decision-making, and execution involved in new product development activities
6.Organizational Engineering.	The body of knowledge focused on strategic, structural, and cultural management of organizations.
7. Economic Engineering.	Formulation, estimation, and evaluation of economic outcomes to evaluate alternatives in decision-making.
8.Work Engineering.	Deals with the technology and management of the machine–environment–human–organization interface.
9. Sustainability Engineering.	Planning the efficient use of natural resources, waste/effluent treatment and disposal, and implementing environmental management and social responsibility systems.
10. Production Engineering Education.	The ecosystem of higher education in engineering and related fields, using a systemic approach encompassing educational management in all its facets.

According to official data from the National Registry of Higher Education Courses and Institutions (e-MEC Registry) of the Ministry of Education (MEC), there are currently 977 active undergraduate PE programs in Brazil. Their distribution by administrative category is shown in the Table 2.

Table 2. Number of programs and authorized students seats

Administrative category	Number of programs	%	Authorized student seats	%
Special	2	0,20%	220	0,03%
Private (For-Profit)	475	48,62%	456.321	62,43%
Private (Non-Profit)	333	34,08%	239.062	32,70%
Public (State)	38	3,89%	2.684	0,37%
Public (Federal)	104	10,64%	8.111	1,11%
Public (Municipal)	7	0,72%	950	0,13%
Unclassified	18	1,84%	23.640	3,23%
	977	100,00%	730.988	100,00%

The private sector accounts for the overwhelming majority of course offerings and authorized seats. While private institutions represent roughly 83% of degree programs and 95% of authorized seats, public higher education offers 16% of programs and around 1% of total capacity. When crossing administrative categories with performance in the National Exam for the Assessment of Student Performance (ENADE 2023), the polarization becomes clear, as presented in the Table 3.

Table 3. ENADE score by administrative category of PE programs

Administrative category	Score 1	Score 2	Score 3	Score 4	Score 5	No score
Special	0,00%	0,00%	0,42%	0,00%	0,00%	2,07%
Private (For-Profit)	61,54%	63,24%	43,51%	22,32%	3,57%	70,83%
Private (Non-Profit)	38,46%	33,51%	41,00%	27,68%	10,71%	25%
Public (State)	0,00%	2,16%	3,35%	10,71%	14,29%	0%
Public (Federal)	0,00%	0,54%	10,88%	36,61%	71,43%	2,08%
Public (Municipal)	0,00%	0,54%	0,84%	2,68%	0,00%	0%
Unclassified	0,00%	0,00%	0,00%	0,00%	0,00%	0%
	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%

The data reveals a stark quality-versus-quantity polarization. While the private sector dominates quantitatively (83% of programs and 95% of seats), its academic excellence is disproportionately low, comprising only 14% of top-tier grades (ENADE score 5). Conversely, the public sector, despite holding only 5% of student seats, concentrates 85% of high-excellence programs (ENADE score 5). Overall, 44.7%

of all programs score at or below level 3, and 56.2% score up to level 4. Unrated programs ("No score") stem from procedural factors such as recent evaluation cycles or administrative pendencies.

2.3 Operational Research (OR), Multimethodology and the CHAP² Method

OR originated during World War II, and its success prompted its adoption across industry and organizations to optimize resource allocation. While traditional "hard" OR drove substantial analytical advances, it proved limited in capturing the full nuance of real-world social problems, giving rise to "Soft OR" [2, 19, 24, 33].

Rosenhead [38] defines Soft OR through Problem Structuring Methods (PSMs). PSMs are predominantly qualitative approaches that use visual mapping tools—especially knowledge maps—and stakeholder engagement to generate structured representations of reality and formulate actionable improvements [32, 34]. As real-world complexities grew, combining multiple qualitative and quantitative methods became necessary, originating Multimethodology—an approach suited for socio-technical contexts like healthcare and education [20, 26].

Among PSMs, the Complex Holographic Assessment of Paradoxical Problems (CHAP²) stands out as a multimethodological method tailored for complex social environments [24]. Rather than enforcing premature consensus (which can obscure legitimate, structural tensions), CHAP² emphasizes conflicting, paradoxical aspects inherent to complex systems. It builds on the Theory of Mind (ToM) by modeling how individuals interpret other agents' behaviors, intents, and mental models [23].

The CHAP² method is developed over six sequential phases, and its implementation should not be hierarchical, i.e., by order of a local authority. Its development should involve raising awareness, consciousness, and understanding among the agents involved regarding the method and the principles on which it is based [12, 21, 24]. The method's execution is based on the construction of conceptual, cognitive, and metacognitive maps for the transcription and reproduction of knowledge. The conceptual map aims to define, explain, and conceptualize, with a purely explanatory, neutral character, free from opinions and ambiguities. The metacognitive type, defined by Lins & Cabral [27], is used as a differentiation from the cognitive type, used to "support the knowledge of individuals or organizations regarding systems that identify and contain themselves." The development of CHAP² occurs according to the steps described in Table 4.

Table 4. CHAP² phases

Phase	Description
1. Characterization of the real system and relevant stakeholders**.**	Builds an initial understanding of the problem and its context via preliminary interviews, literature reviews, official databases, or AI. Privileged stakeholders are selected to form the "Dialogical Group" (DG).
2. Training and qualifying the dialogical group**.**	The DG receives structured training on the methodology, concepts, and objectives.
3. Characterization of the cognitive structure of the participants**.**	DG members are interviewed individually to generate cognitive maps, which are validated by their sources and consolidated into master metacognitive thematic maps.
4. Workshop for the elaboration of conceptual and paradoxical models**.**	DG members work in sub-groups to analyze the thematic maps, identifying priorities and strategic actions to address mapped challenges.
5. Formal modeling	The CHAP² facilitator links the DG's qualitative solutions and priorities with formal quantitative tools and Production Engineering techniques.
6. Intervention using Key Performance Indicators	Feasible actions are deployed to transform the system, establishing performance indicators to monitor systemic gains over time.

2.4 The 8 Intelligences Model and the Systemic Investigation Network (SIN)

The scientific definition of human intelligence has evolved significantly. In the early 20th century, intelligence was framed as a measurable, unitary trait restricted to logical-discursive and mathematical-abstract skills (e.g., Spearman's g factor, Binet, and Piaget's logical-structural models) [25].

Complexity sciences challenged this reductionism. Varela et al. [41] introduced embodied cognition, asserting that intelligence is rooted in bodily, situated experience rather than isolated internal computation. Hutchins [18] showed that cognition is socially distributed, while Bateson [4] and Maturana & Varela [29]

highlighted systemic patterns and autopoiesis. Multi-dimensional paradigms gained prominence through Gardner's [13] Multiple Intelligences and Sternberg's [40] Triarchic and Adaptive Intelligence theories. Synthesizing this progression, Morin's [35] Complex Thought posits that genuine intelligence must navigate uncertainty, contradiction, and systemic interdependence.

With Artificial Intelligence (AI) excelling in analytical complexity (processing large-scale data and predefined optimization problems), developing human Complex Intelligence is crucial for formulating novel problems and intervening ethically. Lins [25] conceptualizes eight interdependent dimensions, presented on Table 5.

Table 5. Definition of the 8 intelligences

	Intelligence	Description	Avoided risk
1.	Logical-Linguistic (Analytical)	Formulates rigorous arguments, structures propositions, interprets texts, and conducts deductive/inductive reasoning.	Ambiguity
2.	Systemic	Identifies structural relationships, multi-loop feedbacks, and non-linear dynamics.	Reductionism
3.	Multi-perspective & Theory of Mind	Understands diverse cognitive, emotional, and cultural perspectives of different stakeholders.	Algorithmic Monologue / Epistemic Monoculture
4.	Paradoxical	Integrates seemingly contradictory tensions without reducing them prematurely, using paradox as an engine of synthesis.	Theoretical Dogmatism
5.	Epistemic-Ontological	Questions ontological assumptions, scientific paradigms, and navigates the inevitable gap between mental models and factual reality.	Illusion of Completeness
6.	Sensory-Metaphorical	Leverages bodily, emotional, and cognitive metaphors grounded in practical experience.	Detached Abstraction
7.	Civic and Civilizational Ethics	Defines the purpose and beneficiaries of actions, serving as an ethical safeguard against algorithmic or market-driven reductionism.	Illusory Neutrality
8.	Metacognitive	Reflects upon one's own thinking processes, enabling communities to interrogate how their interpretations are constructed.	Cognitive Alienation

These eight intelligences share five overarching macro-structural attributes [25]:

1. Purpose-driven context adaptability: adaptability anchored in core values such as quality of life, equity, and sustainability [40];
2. Deliberate uncertainty management: treating uncertainty not as an error, but as an irreducible, structural dimension of reality (inspired by Gödel [14]);
3. Metacognitive self-reference: the ability of a system to monitor and regulate its internal processes, detect biases, and revise beliefs [10, 11].
4. Holistic synthesis: re-integrating body, emotion, reason, and ethics;
5. Meaning-oriented intentionality: grounding decisions in existential meaning, intergenerational responsibility, and the common good.

The integration of AI with the Systemic Investigation Network (SIN) and the 8 Intelligences transforms human-machine interaction from a purely transactional modality (simple prompt-and-response) into a collaborative, critical inquiry loop [25]. While AI provides high-speed analytical power, it struggles with ill-structured real-world problems. In the SIN framework, AI acts as a "heuristic provocateur" and an "amplified mirror," while human complex intelligence directs problem formulation, epistemic critique, and civilizational purpose.

3 Methodology

This study constitutes the foundational diagnostic stage of a doctoral research project initiated in March 2026 within the Production Engineering Program (PEP) at COPPE/UFRJ. Methodologically, it is classified as applied, exploratory-descriptive, and socio-technical, adopting a multimethodological Problem Structuring framework based on Phase I of the CHAP² method. Furthermore, this study draws on two distinct levels of

evidence. First, a nationwide quantitative dataset, with 977 courses, constructed from official e-MEC and ENADE 2023 metrics, to address a census-level overview of institutional capacity, administrative framework, and academic performance. Second, a qualitative investigation based on cognitive mapping with three senior domain experts, to provide deeper insights into faculty perceptions, pedagogical bottlenecks, and day-to-day operational realities. The operationalization of Phase I was executed through three articulated investigative vectors:

1. Empirical and regulatory diagnosis: nationwide data collection covering all 977 active undergraduate PE programs registered in the Ministry of Education's e-MEC database, cross-referenced with performance results from the 2023 National Exam for the Assessment of Student Performance (ENADE) to map institutional capacity, administrative dependency, and geographic distribution;
2. Epistemic Exploration via SIN and 8 Intelligences: Generative Artificial Intelligence (Google Gemini) was integrated into the Systemic Investigation Network (SIN) framework to generate multi-dimensional heuristic inquiries across all eight intelligence dimensions (Table 6) [25]. Rather than automating analysis, AI acted as an "epistemic mirror" and heuristic provocateur, subjected to human critical filtering to prevent algorithmic monologue and reductionism;
3. Cognitive Mapping with privileged stakeholders: semi-structured interviews (average duration of 60 minutes) were conducted with three senior PE professors from public universities in southeastern Brazil, experienced in program management and research. The interviews explored curricular dynamics, infrastructure, and policy integration. Audio recordings of the interviews were transcribed and directly mapped using CmapTools software, strictly preserving the participants' natural language to ensure authentic knowledge representation. Each map was then submitted back to its respective author for formal validation. This member checking step was essential to ensure that the experts' ideas, systemic nuances, and operational perceptions were accurately captured and faithfully represented by the researchers.

4. Application of the first phase of CHAP²

This section describes the activities and results obtained during the execution of the activities that make up the method.

4.1 Phase I - Characterization of the real system and relevant stakeholders.

Phase I of CHAP² provides a preliminary diagnosis of the selected problem and the complex system in which it is embedded. Accordingly, this stage comprised a literature review on the topics of NIB, Production Engineering, Multimethodology, the CHAP² Method, the Systemic Investigation Network (SIN), and the 8 Intelligences Model.

To broaden exploration through the SIN framework, Google's Gemini AI tool was used to formulate questions associated with the 8 Intelligences defined by Lins [25]. The objective was to ensure comprehensiveness, given the complexity and significance of the study. The prompt submitted was: "Formulate questions based on the 8 Intelligences model regarding the topic: Multimethodology for evaluating the efficiency of undergraduate Production Engineering programs in Brazil from the perspective of the New Industry Brazil (NIB)". From this command, the tool returned the framework presented in Table 6.

Table 6. The 8 Intelligences Model applied to the research problem

Intelligence dimension	Exploratory research questions	Targeted risk mitigated
Logical-Linguistic (Analytical)	How does the proposed multimethodology define and mathematically integrate the different concepts of "efficiency" (technical, allocative, and social) in the context of the NIB? What foundational assumptions structure the choice of each method within the multimethodological framework?	Ambiguity in terminology definitions and inconsistency in method integration.
Systemic	In what ways does the multimethodology capture feedback loops between academic training and the development of NIB priority industrial chains? How does the model assess the systemic impact of a program's efficiency on the regional innovation ecosystem?	Reductionism stemming from analyzing programs as entities isolated from their industrial environment.

Multi-perspective & Theory of Mind	How does the multimethodology incorporate the divergent views of program coordinators, regulatory agencies, and industrial leaders regarding what constitutes "value" in Production Engineering? Which alternative pedagogical paradigms (humanist, technicist) are considered in the evaluation?	Algorithmic monologue and epistemic monoculture in program evaluation.
Paradoxical	How does the multimethodology address the tension between productivist efficiency (focus on performance indicators) and the broad academic resilience required for NIB transitions (adaptation, resistance, crises, and transitions)? Is it possible for a program to be efficient in throughput metrics yet inefficient in generating long-term social impact?	Theoretical dogmatism that overlooks the inherent contradictions between education and industry.
Epistemic-Ontological	Which dimensions of engineering education reality in Brazil remain "invisible" or unmodelable by the chosen multimethodology? Where might the combination of methods create an illusion that the phenomenon of efficiency has been fully understood?	Illusion of scientific completeness and lack of epistemic humility.
Sensory-Emotional / Metaphorical	What metaphors represent the models of "efficiency" underpinning engineering education in Brazil today (e.g., a "diploma mill" versus an "innovation cradle")? How can quantitative multimethodological results be translated into imagery or narratives that foster a meaningful connection with society?	Abstraction detached from the practical and sensory reality of the programs.
Civic & Civilizational Ethics	Does the application of this evaluation multimethodology widen or reduce inequalities among programs across different regions of Brazil? How can findings be democratically utilized to guide public policies for industrial and educational promotion?	Illusory neutrality that ignores the social ramifications of academic ranking.
Metacognitive	When using multiple methods and potentially AI to process data, am I preserving intellectual autonomy over the final interpretations? What does the selection of this multimethodology reveal about my own limitations and biases as a researcher in Production Engineering?	Cognitive alienation and blind dependency on automated tools.

It is evident that the SIN introduced dimensions not initially considered, uncovering aspects that could have remained ignored or unknown but are essential given the complexity and relevance of the topic. Additionally, Phase I incorporated an initial system characterization from the perspectives of privileged agents invited to participate in the study. These three agents are Production Engineering professors working in public institutions in the southeastern region. Finally, synthesizing information from the literature review, SIN, the 8 Intelligences Model, and agent perspectives allowed the construction of conceptual maps regarding the research problem and its operational context (Figures 1 and 2).

The maps indicate that Brazilian PE education has incorporated the digitalization paradigm and, consequently, NIB Mission 4 (Digital Transformation), reinforced through coursework in programming languages and Operations Research. Furthermore, programs are expected to bridge the market and regional/national development. A consensus exists among consulted professors that programs must train professionals capable of working on real-world projects and solving industrial chain bottlenecks; simultaneously, programs must maintain a generalist profile to provide students with a holistic understanding of the profession.

Conversely, profound regional inequalities persist. While some programs exhibit strong integration with local industry, high employability, competitive salaries, and active international exchange programs, others serve lower-income student profiles who must balance work and evening studies. In the latter, the focus centers on empowering students as agents of personal and socioeconomic transformation through higher education.

Moreover, physical contradictions are evident: state-of-the-art facilities with advanced software coexist alongside institutions lacking basic library resources and physical laboratory spaces. Consequently, certain programs organically advance NIB missions (e.g., developing projects in nanotechnology, circular economy, and discrete manufacturing), whereas in others, mission adherence is fragmented, relying on individual faculty interest rather than structured curricular policies. Although Production Engineering carries strong

technological appeal (Industry 4.0/Digitalization) within its conceptual matrix, implementation remains constrained by resource disparities.

These structural and pedagogical contradictions observed across Brazilian PE programs reflect a deeper civilizational and epistemological mismatch. As argued by Lins [25], contemporary educational systems largely remain anchored in paradigms inherited from the Second Industrial Revolution, shaped by mechanistic-Cartesian and market-competitive logic that dissociates technical knowledge from complex human reality. This dynamic produces what the author, drawing on Bauman [3], identifies as a structural and 'liquid' dissonance between education and societal needs. In the context of Brazilian PE, while curricula have readily absorbed technical tools aligned with Industry 4.0 and market productivity, they often fail to cultivate the humanist, axiological mindset necessary for the transition toward "Society 5.0" [5].

As Lins [25] highlights, whereas the Industry 4.0 paradigm is primarily driven by economic efficiency and technological throughput, a Society 5.0 orientation prioritizes human flourishing, equity, and sustainability [36, 39]. Bridging this divide requires mobilizing Civic and Civilizational Ethics alongside Paradoxical Intelligence, ensuring that higher education does not merely deliver technocentric training, but actively fosters transformative capabilities capable of steering the missions of the New Industry Brazil (NIB) toward broad societal well-being.

Comparing the inquiries raised by SIN, the 8 Intelligences, and the conceptual maps makes it possible to establish their direct relationship. Table 7 details which intelligences were activated during Phase I of CHAP².

Table 7. Intelligences activated in Phase I of CHAP²

Aspect / Intelligence Dimension	Core question raised by SIN	Empirical Synthesis from Phase I Mapping
Reality concealment and regional disparities (Epistemic-Ontological & Public Ethics)	SIN questioned which dimensions of educational reality remain "invisible" behind the illusion of metric completeness, and whether the evaluation widens or reduces regional inequalities.	The map directly addresses these questions by exposing what conventional metrics obscure: severe infrastructure gaps and regional socioeconomic contrasts that cannot be captured by purely quantitative indicators.
Tension between curricular matrix and NIB missions (Paradoxical Intelligence)	SIN asked how to manage the tension between productivist efficiency (metric focus) and the academic capacity required for NIB transitions, including whether a program can perform well in indicators but lack social impact.	There is consensus around "productivist efficiency," where Mission 4 (Digital Transformation) is easily absorbed by generalist curricula. However, social impact remains hindered because programs struggle to integrate topics such as bioeconomy or healthcare due to curricular rigidity and lack of faculty preparation.
Integration with productive chains (Systemic Intelligence)	SIN asked how the multimethodology captures feedback loops between academic training and NIB priority productive chains.	The conceptual map shows that systemic feedback operates partially. Brazilian PE mitigated reductionism by absorbing digitalization, yet systemic integration with regional innovation ecosystems remains incomplete and heavily skewed toward services and traditional transformation industries.
Mapping divergent perspectives (Multi-perspective Intelligence)	SIN questioned how the multimethodology incorporates divergent views regarding what constitutes "value" in Production Engineering.	Rather than forcing an artificial consensus that suppresses complexity, CHAP² establishes dual models—one for consensus and one for paradoxes—to address systemic contradictions, such as divergent faculty profiles and institutional engagement levels.

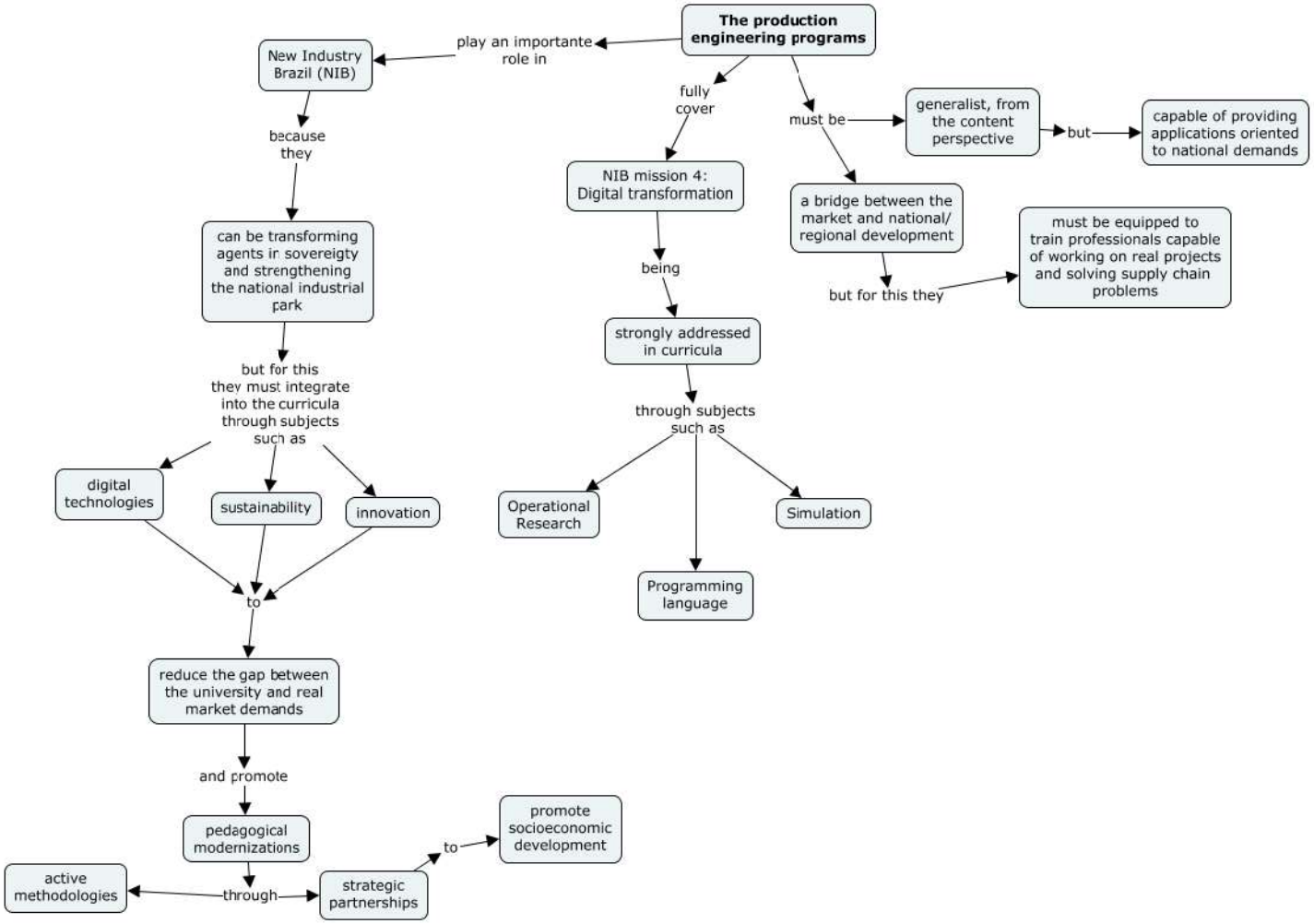

Figure 1. Phase 1 concept map

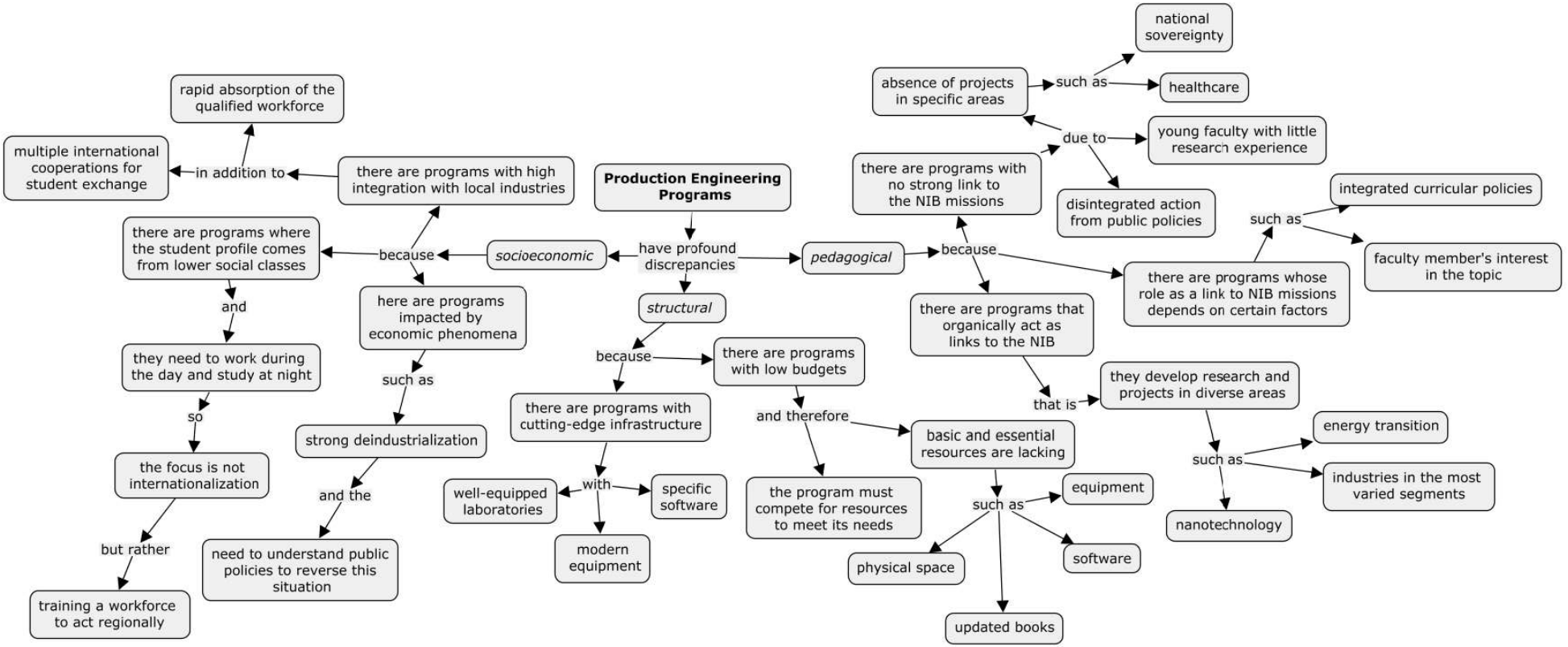

Figure 2. Phase 1 concept map

4.2 Discussion

The combination of macro-level quantitative metrics, like ENADE score, and qualitative cognitive mapping reveals a complex educational landscape. While the e-MEC database proves that the private sector holds 95% of student enrollment capacity, ENADE metrics demonstrate that top-tier academic quality (Score 5) is concentrated (85%) in public universities. The qualitative maps complement this finding by explaining why this structural divide occurs. Professors from public institutions highlight that while their programs possess research infrastructure and qualified faculty capable of organically connecting with NIB missions (e.g., energy transition, nanotechnology), they face severe budgetary constraints and public policy fragmentation. Conversely, widespread private offerings often focus on high-throughput, low-cost operations, which readily absorb digital programming tools (Mission 4) but lack the laboratory infrastructure and research capabilities required for complex missions like healthcare resilience (Mission 2) or industrial decarbonization (Mission 5).

The activation of the 8 Intelligences Model, particularly Civic Ethics and Paradoxical Intelligence, demonstrates that Brazilian PE education remains heavily influenced by Second Industrial Revolution paradigms, prioritizing technical efficiency and immediate market demand. Moving toward NIB targets demands an axiological leap to a Society 5.0 paradigm, where engineering capabilities are directed toward human flourishing, environmental sustainability, and national sovereignty.

As an exploratory Phase I diagnosis within ongoing doctoral research, this study acknowledges specific limitations. While quantitative data is census-based, the cognitive maps reflect the perspectives of three senior experts located in southeastern Brazil. While representative of public research universities, future research phases must expand the Dialogical Group across different regions (North, Northeast, Center-West) and institutional types (private for-profit and community colleges).

5. Conclusions

Production Engineering (PE) is a foundational vector for the realization of the New Industry Brazil (NIB). By applying Phase I of the CHAP² method articulated with SIN and the 8 Intelligences Model, this paper delivered a critical preliminary diagnosis of the Brazilian PE educational landscape.

The empirical and conceptual synthesis uncovers a fundamental paradox because while the private educational sector has democratized access in quantitative terms, excellence remains overwhelmingly concentrated in public institutions. Moreover, current curricular structures reveal an epistemic anchoring in market-driven paradigms of the Second Industrial Revolution, prioritizing narrow digital/computational competencies (NIB Mission 4) suggesting, based on experts' perspectives, that many current curricular structures face significant pedagogical and infrastructure constraints to fully address complex socio-environmental challenges such as industrial decarbonization, healthcare resilience, and bioeconomy. Aligning engineering education with national reindustrialization demands an axiological leap from an Industry 4.0 productivity mindset to a Society 5.0 paradigm, wherein technology is subordinated to human capabilities, equity, and sustainable sovereignty.

The scientific, social, and political impacts of this research provide actionable guidelines for curricular updating by Core Faculty Teams and empirical evidence for public policymakers to formulate transversal industrial-educational strategies. As next steps within this ongoing doctoral research, subsequent stages will deploy the remaining phases of the CHAP² framework, engaging a nationwide Dialogical Group to build consensus and paradoxical metacognitive models, followed by formal modeling to quantify the systemic alignment of Brazilian PE programs with NIB targets.

6. AI usage declaration

In compliance with scientific integrity standards and CNPq regulations, the authors declare that Generative Artificial Intelligence (GAI) tools were utilized during the development of this research.

Methodological and Heuristic Inquiry: GAI was integrated into the Systemic Investigation Network (SIN) framework during Phase I of CHAP² to assist in formulating multi-dimensional exploratory questions across the 8 Intelligences Model, acting as an epistemic mirror and heuristic provocateur.

Intellectual autonomy and responsibility: all AI-generated prompts, heuristic questions, and text suggestions were rigorously filtered, evaluated, and validated by the human authors. Theoretical conception, data

collection, analytical modeling, qualitative interpretation, and conclusions were entirely conducted by the authors, who accept full responsibility for the manuscript's content and integrity.
Tools used: Google Gemini and NotebookLM (Gemini Notebook).
Model versions: Platform versions active on August 19, 2026.

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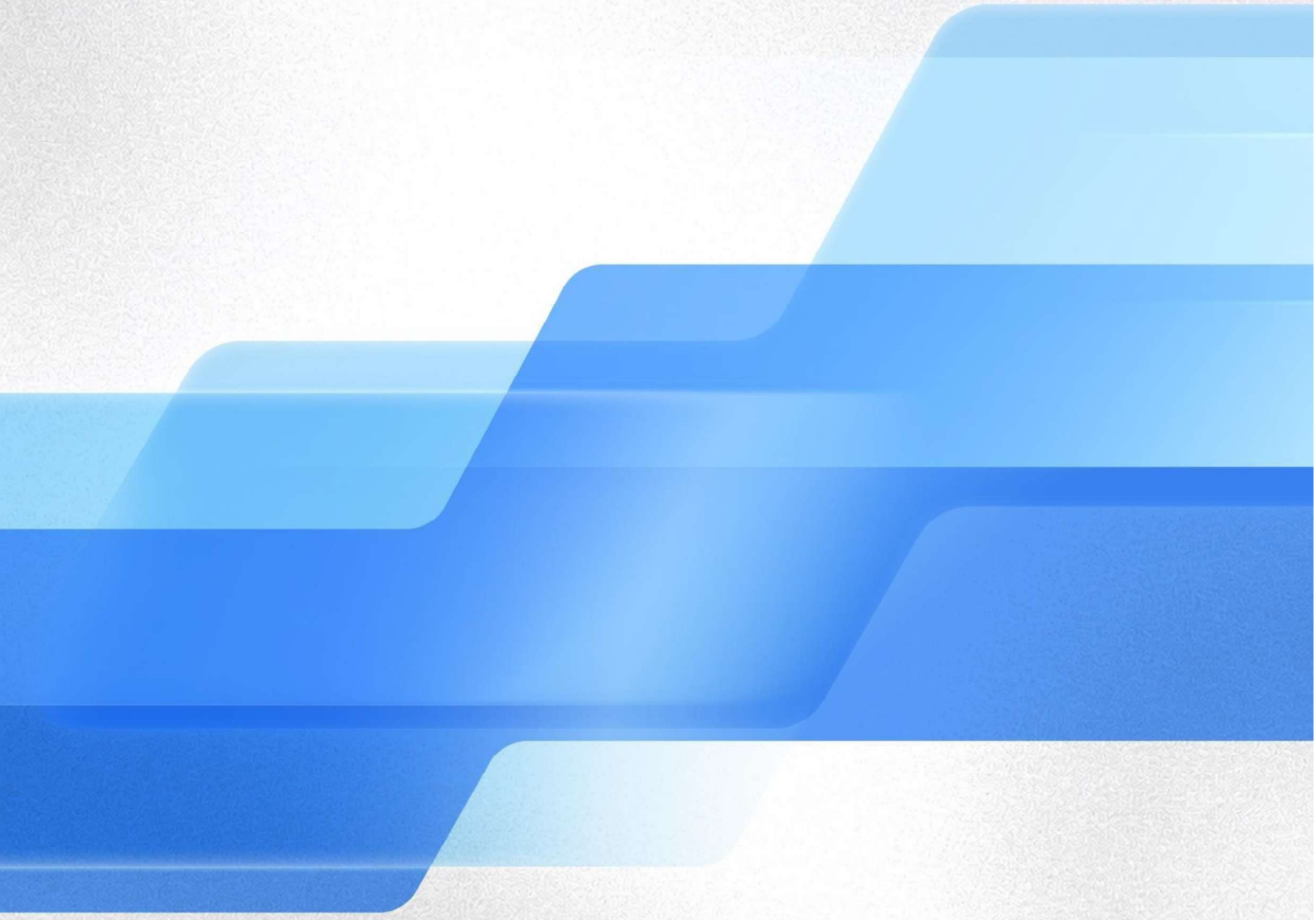
Referências

[1] ABEPRO (2024), Áreas de Conhecimento da Engenharia de Produção. ABEPRO, Rio de Janeiro.
[2] Ackermann, F. (2012), Problem structuring methods 'in the Dock': Arguing the case for Soft OR. European Journal of Operational Research, 219(3), 652–658.
[3] Bauman, Z. (2013), *Sobre a Educação e a Juventude*. Translated by C. A. Medeiros. Zahar, Rio de Janeiro. (Or original in English: Bauman, Z. (2012), *On Education: Conversations with Riccardo Mazzeo*. Polity Press, Cambridge).
[4] Bateson, G. (1972), Steps to an Ecology of Mind. University of Chicago Press, Chicago.
[5] Brazil (2024), Nova Indústria Brasil: Plano de Ação para a Neoindustrialização 2024-2026. Ministério do Desenvolvimento, Indústria, Comércio e Serviços (MDIC), Brasília. http://www.gov.br/fazenda/pt-br/acesso-a-informacao/acoes-e-programas/transformacao-ecologica/programas-em-destaque/nova-industria-brasil. (last accessed on 18 May 2026).
[6] Brazil (2025), Nova Indústria Brasil – Forte, Transformadora e Sustentável: Diretrizes Estratégicas e Acompanhamento. Conselho Nacional de Desenvolvimento Industrial (CNDI), MDIC, Brasília. (last accessed on 18 May 2026).
[7] Dunham, F.B., Abreu, I.B.L., Neves, M.S., Pieroni, J.P., Marcato, M.B. (2025), Densidade tecnológica no contexto da nova política industrial. BNDES Setorial, 31(60), 49–79.
[8] Feijó, C. (2024), Transformação Produtiva e Nova Indústria Brasil (NIB). Revista Tempo do Mundo, 36, 57–75.
[9] Fernandes, P.D., Mesquita, P.P.D., Miranda, A.R., Oliveira, L., Mendes, R.J.M., Gallo, A., Lira, B.H. (2025), Descarbonização na indústria siderúrgica: oportunidade para agregar valor e aumentar a competitividade. BNDES Setorial, 31(60), 207–253.
[10] Flavell, J.H. (1979), Metacognition and cognitive monitoring: A new area of cognitive-developmental inquiry. American Psychologist, 34(10), 906–911.
[11] Fleming, S.M., Dolan, R.J., Frith, C.D. (2012), Metacognition: computation, biology and function. Philosophical Transactions of the Royal Society B: Biological Sciences, 367(1594), 1280–1286.
[12] Fontes, K.L. (2017), Uma Avaliação da Logística da Rede de Suprimentos Aplicada à Saúde: Estudo de Caso do Hospital Universitário Clementino Fraga Filho. Master's dissertation, Programa de Engenharia de Produção, COPPE, Universidade Federal do Rio de Janeiro, Rio de Janeiro.
[13] Gardner, H. (1983), Frames of Mind: The Theory of Multiple Intelligences. Basic Books, New York.
[14] Gödel, K. (1992), On formally undecidable propositions of Principia Mathematica and related systems. Translated by B. Meltzer. Dover Publications, New York. (Original work published in 1931).
[15] Gomes, S.B.V., Baran, R., Vital, M.H.F., Araujo, B.C. (2025), Novo mercado de mobilidade aérea urbana: desenvolvimentos recentes e desafios para os eVTOLs e para o BNDES-Parte 1. BNDES Setorial, 31(60), 255–294.
[16] Hamatsu, N.K., Souza, E.R. (2024), Transição energética, Nova Indústria Brasil e o papel do Ministério da Ciência e Tecnologia e da Finep. Revista Princípios, 170.
[17] Hitner, V., Castro, A.C. (2024), O Processo de Formulação da Nova Indústria Brasil (NIB): política orientada por missões e participação social no desenho do Plano de Ação da NIB. Revista Tempo do Mundo, 36, 29–56.
[18] Hutchins, E. (1995), Cognition in the Wild. MIT Press, Cambridge.
[19] Jahara, R.C., Lins, M.P.E. (2020), Multimetodologia para intervenção e melhoria em uma Oficina Ortopédica. In: Anais do XL Encontro Nacional de Engenharia de Produção (ENEGEP 2020), pp. 1–13. ABEPRO, Foz do Iguaçu.
[20] Jahara, R.C., Lins, M.P.E. (2023), Multimethodology for diagnosis and intervention in a prosthetics and orthotics factory in Brazil. International Transactions in Operational Research, 30(2), 619–639.
[21] Laricchia, C.R., Addor, F., Lins, M.E. (2018), Cooperativa de produtos da Reforma Agrária. In: Lins, M.P.E., Antoun Netto, S.O. (eds.), Estruturação de Problemas Sociais Complexos: Teoria da Mente, Mapas Metacognitivos e Modelos de Apoio à Decisão, pp. 282–302. Interciência, Rio de Janeiro.

[22] Leme, R.A.S. (1983), A História da Engenharia de Produção no Brasil. In: Anais do III Encontro Nacional de Engenharia de Produção (ENEGEP 1983). ABEPRO, São Paulo.
[23] Lins, M.E., Antoun Netto, S.O., Fontes, K.L., Laricchia, C.R., Cabral, L.M. (2023), Metacognitive attitude for decision making at a university hospital. International Transactions in Operational Research, 30(3), 1366–1386.
[24] Lins, M.P.E. (2018), Avaliação Complexa Holográfica de Problemas Paradoxais (CHAP²). In: Lins, M.P.E., Antoun Netto, S.O. (eds.), Estruturação de Problemas Sociais Complexos: Teoria da Mente, Mapas Metacognitivos e Modelos de Apoio à Decisão, pp. 130–134. Interciência, Rio de Janeiro.
[25] Lins, M.P.E. (2026), A desinteligência é artificial? – Inteligência híbrida humana e IA, estruturação recursiva de problemas e imunidade cognitiva. Interciência, Rio de Janeiro. (In press).
[26] Lins, M.P.E., Antoun Netto, S.O., Lobo, M.S.C. (2019), Multimethodology applied to the evaluation of Healthcare in Brazilian municipalities. Health Care Management Science, 22(2), 197–214.
[27] Lins, M.P.E., Cabral, L.M.E.S.P. (2018), Representação do Conhecimento: Mapas Metacognitivos. In: Lins, M.P.E., Antoun Netto, S.O. (eds.), Estruturação de Problemas Sociais Complexos: Teoria da Mente, Mapas Metacognitivos e Modelos de Apoio à Decisão, pp. 10–20. Interciência, Rio de Janeiro.
[28] Marques, P.H.M., Souza, F.O., Maher Junior, J.P., Dantas, L.I.S. (2025), Descarbonização dos ônibus: oportunidades além dos veículos a bateria. BNDES Setorial, 31(60), 119–165.
[29] Maturana, H.R., Varela, F.J. (1997), The Tree of Knowledge: The Biological Roots of Human Understanding. Shambhala, Boston.
[30] Mazzucato, M. (2014), O Estado Empreendedor: Desmascarando o mito do setor público vs. setor privado. Translated by E. Serapicos. Portfolio-Penguin, São Paulo.
[31] Mazzucato, M. (2025), Transformação do Estado no Brasil: Desenhando compras públicas, empresas estatais e infraestrutura pública digital orientadas por missões para promover o crescimento sustentável e inclusivo. Policy Report, UCL Institute for Innovation and Public Purpose (IIPP), London.
[32] Midgley, G., Cavana, R.Y., Brocklesby, J., Foote, J.L., Wood, D.R.R., Ahuriri-Driscoll, A. (2013), Towards a new framework for evaluating systemic problem structuring methods. European Journal of Operational Research, 229(1), 143–154.
[33] Mingers, J. (2006), Realising Systems Thinking: Knowledge and Action in Management Science. Springer, New York.
[34] Mingers, J., Brocklesby, J. (1997), Multimethodology: Towards a framework for mixing methodologies. Omega, 25(5), 489–509.
[35] Morin, E. (2005), Introdução ao Pensamento Complexo. 4th edn. Sulina, Porto Alegre.
[36] Nussbaum, M.C. (2011), *Creating Capabilities: The Human Development Approach*. Harvard University Press, Cambridge.
[37] Piratelli, C.L. (2005), A Engenharia de Produção no Brasil. In: Anais do XXXIII Congresso Brasileiro de Ensino de Engenharia (COBENGE 2005), pp. 1–15. ABENGE, Campina Grande.
[38] Rosenhead, J. (ed.) (1989), Rational Analysis for a Problematic World: Problem Structuring Methods for Complexity, Uncertainty and Conflict. John Wiley & Sons, Chichester.
[39] Sen, A. (1999), *Development as Freedom*. Oxford University Press, Oxford.
[40] Sternberg, R.J. (2019), A Theory of Adaptive Intelligence and Its Relation to General Intelligence. Journal of Intelligence, 7(4), 23.
[41] Varela, F.J., Thompson, E., Rosch, E. (1991), The Embodied Mind: Cognitive Science and Human Experience. MIT Press, Cambridge.
[42]Viana, M.E.F., Scheidegger, O.F.C.R. (2025), Infraestrutura computacional para a era da IA: desafios, políticas e oportunidades em data centers no Brasil. BNDES Setorial, 31(60), 167–205.



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