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Data-Driven Decision Support for Dairy Producer Selection

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Abstract: This study addresses the challenge of value co-creation in the global dairy supply chain by developing a data-driven decision-support tool for selecting dairy producers. Using data from 201 Brazilian dairy professionals, the research employs Exploratory Factor Analysis (EFA), Confirmatory Factor Analysis (CFA), and regression analysis to identify key selection criteria encompassing economic, production, and social factors. These criteria are integrated into an Analytic Hierarchy Process (AHP) framework to facilitate informed producer selection, promoting sustainable practices and enhancing the dairy industry's competitive advantage.

Keywords: Dairy production; Milk supply chain; Decision-making tool; Resource efficiency; Analytic Hierarchy Process.

1. INTRODUCTION

The Brazilian dairy industry, like many others globally, faces significant challenges in sustainability, efficiency, and maintaining resilient supply chains. Dairy processors increasingly require an objective, data-driven approach to supplier selection to optimise operations and ensure long-term partnerships. Traditional methods, focused on static relationships and equilibrium, are inadequate in today's volatile environment. As Wieland and Durach (2021) highlight, resilience extends beyond bouncing back (engineering resilience) to include adaptation and transformation (social-ecological resilience). This aligns with Johnson et al. (2021), who emphasise combining robustness with resilience to manage disruptions effectively. The proposed AHP-based tool evaluates producers on static and dynamic criteria, fostering robust, resilient, and viable supply chains (Aldrighetti et al., 2024). By enabling adaptability and long-term sustainability, it supports strategic producer selection and value co-creation (Rose et al., 2016), ensuring the dairy industry's competitiveness and resilience in a rapidly changing world. This research seeks to address this gap by developing a decision support tool that incorporates economic, social, and production criteria in the selection process of dairy producers (Iseppi et al., 2022).

The primary objective was to create a Dairy Selection Tool enabling dairy processors to evaluate and select dairy producers objectively based on key criteria. The research focused on integrating systems for decision support and data-driven decision-making approaches, which have become pivotal in improving efficiency and transparency in supply chain management. By employing the Analytic Hierarchy Process (AHP), a technique widely used in decision support systems, this study aims to provide a structured method for determining the most suitable producers based on factors that influence dairies' operational and commercial success (Yang and Lu, 2024).

As reviewed by Roda and Holgado (2024), the state of the art in decision-making methodologies reveals that existing approaches often focus narrowly on technical and economic factors, neglecting critical social and environmental considerations. In the industrial assets domain, decision-making frameworks rely on qualitative assessments or expert judgments, which can introduce biases and lack transparency, leading to inconsistent outcomes. Similarly, in the consumer products domain, while Multi-Criteria Decision-Making (MCDM) methods like the Analytic Hierarchy Process (AHP) are more commonly used, they still tend to prioritise economic and technical criteria, often overlooking broader sustainability goals (Alamerew and Brissaud, 2019). These limitations are further compounded by the challenges of implementing data-driven approaches, which usually require significant technical expertise and infrastructure, making them inaccessible to small and medium-sized enterprises (Roda and Holgado, 2024). These gaps highlight the need for more comprehensive, validated, and accessible decision-making tools that integrate economic, social, and environmental criteria to promote sustainable and resilient supply chains.

The research question guiding this study was: How can a decision support system, using data-driven techniques, be designed to select dairy producers based on production, economic, and social criteria? This question reflects the growing need for more sophisticated and transparent methods of producer selection in the dairy industry. It also highlights the increasing importance of aligning sustainability metrics with supply chain management, as discussed by Pachoud (2024), who notes the critical role of sustainability in maintaining stable and efficient supply chains.

This study breaks new ground by adopting an integrated approach to producer selection in the dairy industry. It goes beyond traditional economic factors like pricing stability and financial incentives, incorporating crucial aspects such as social responsibility and production quality to provide a more

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holistic view of the selection process. This aligns with Gardezi et al. (2024)'s emphasis on a comprehensive approach for resilient and ethical partnerships. This study contributes to both decision support systems and data-driven decision-making in supply chain management by developing a tool that systematically evaluates producers based on these interconnected criteria. Ultimately, it offers valuable insights for dairies seeking to optimise producer selection and achieve long-term business success.

2. METHODOLOGICAL APPROACH

2.1 Phase 1 - Identification of Selection Criteria

This phase aimed to identify key selection criteria for dairy producers, explicitly focusing on value co-creation, sustainability, and logistical efficiency. The research process was designed to be rigorous and multifaceted, ensuring a comprehensive understanding of the factors influencing producer-dairy relationships. Initially, a thorough literature review was conducted to identify existing criteria for selecting dairy producers, with particular attention to value co-creation, sustainability, and logistical efficiency. This review provided a theoretical foundation for the study and highlighted gaps in the current understanding of producer selection processes.

Following the literature review, a structured questionnaire was developed, incorporating quantitative and qualitative elements to capture the most relevant criteria. Three industry specialists were consulted to ensure the validity and reliability of the instrument. Their feedback was instrumental in refining the questionnaire, ensuring that it accurately reflected the complexities of the dairy industry. A pilot test involving ten representatives from the target population was conducted to validate the questionnaire further and identify potential issues.

Data collection proceeded using the validated questionnaire, administered in-person and online to various industry stakeholders. The resulting data was analysed using R software, a powerful tool for statistical analysis. Exploratory Factor Analysis (EFA) was employed to identify and group key criteria, revealing three main factors: economic, social, and production. Confirmatory Factor Analysis (CFA) was subsequently used to test the validity of these groupings, ensuring that the identified factors were robust and reliable. Regression analysis was further utilised to assess the relationships between different criteria, providing deeper insights into their interconnections.

The empirical results were compared with existing frameworks relating to dairy producer selection to provide a theoretical context. This comparison validated established criteria and identified any new perspectives emerging from the data. Finally, the identified selection criteria were grouped into key dimensions, such as operational efficiency, quality assurance, and relational dynamics, for clarity and ease of interpretation.

2.1.1 Demographic Characteristics of the Sample

The sample was derived from a comprehensive list of experts within the dairy industry, specifically targeting professionals employed in dairy processing companies. This list was compiled through a tailored search on a professional social network, utilising specific keywords to identify relevant individuals. The search yielded the following results: 1,700 profiles using the term "dairy cooperative," 940 with "dairy," 232 with "dairy collection," 45 with "national dairy group," 31 with "UHT milk," 1,300 with "cheese," 442 with "yogurt," 10 with "condensed milk," and 433 with "Minas cheese." In total, 5,133 specialists within the dairy industry were identified and approached. From this initial pool, 237 individuals were selected to receive the questionnaire. Of these, 236 agreed to participate, while one declined. Among the respondents, 201 had direct experience in milk procurement from producers, and only these responses were validated to ensure the data's representativeness of their respective organisations, resulting in a participation rate of 85%.

The respondents are professionals with substantial experience purchasing milk directly from producers across Brazil. The survey yielded 201 valid responses, with the majority of respondents employed by companies with more than 500 employees (45.3%). These companies were categorised as multinational (21.4%), cooperatives (24.9%), small and medium dairies (25.4%), mini plants (0.5%), and national groups (27.9%). The products processed by these companies are diverse, extending beyond pasteurised milk (40.3%) to include UHT milk (46.8%), cheese (67.2%), butter (52.2%), yogurt (41.8%), condensed milk (27.9%), and cream (45.3%).

In terms of their supplier portfolios, the majority of companies reported working with more than 200 milk suppliers (54.4%), with the remaining distribution as follows: 150 to 199 suppliers (6.5%), 100 to 149 suppliers (8.8%), 50 to 99 suppliers (9.5%), and fewer than 50 suppliers (20.7%). Regarding daily milk collection volumes, the distribution was as follows: more than 200,000 liters per day (49.7%), 150,000 to 199,000 liters per day (6.6%), 100,000 to 149,000 liters per day (13.7%), 50,000 to 99,000 liters per day (10.7%), and fewer than 50,000 liters per day (19.3%).

The questionnaire employed in this study consisted of 18 questions, designed to measure the degree of importance of each item using a five-point Likert scale anchored between "Not at all important" and "Extremely important." Before distribution, the questionnaire underwent a rigorous testing phase involving three dairy sector specialists to assess its clarity and relevance within their professional contexts. This pre-testing phase ensured the questionnaire was comprehensible and pertinent to the target audience.

The sample comprised 201 professionals from Brazil's dairy sector, all with significant experience in milk procurement. Initially, 5,133 potential participants were identified using targeted keywords, and 237 were invited to participate. Of these, 236 consented, with 201 providing valid responses after validation based on their direct experience in milk procurement, resulting in an 85% participation rate.

The organizations represented in the sample were predominantly large, with over 500 employees (45.3%). Respondents came from diverse organizational types, including multinational corporations (21.4%), cooperatives (24.9%), small and medium dairies (25.4%), national groups (27.9%), and mini mills (0.5%). Most companies sourced milk from over 200 suppliers (54.4%), with nearly half (49.7%) collecting more than 200,000 litres daily. Beneficiated products included cheese (67.2%), butter (52.2%), UHT milk (46.8%), and yogurt (41.8%).

The respondents were predominantly managers (65.1%), with supervisors (22.4%) and specialists (15.4%) making up the remaining professional roles. In terms of experience, 77.6% of participants had over five years in the industry, with 38.8% reporting more than ten years of experience. This level of expertise ensured the sample reflected substantial knowledge of milk procurement processes. Additionally, the sample's geographic diversity provided insights from various regions across Brazil, guaranteeing a comprehensive industry perspective.

2.1.2 Exploratory Factor Analysis (EFA)

An EFA was conducted to identify the underlying structure of the selection criteria for dairy producers. The analysis revealed three main factors: economic, social, and production. The factor loadings for each variable are presented in Tables 2, 3, and 4, confirming that the questions related to these factors were strongly correlated with their respective constructs.

Table 1- Factor Loadings for Economic Criterion

Question	Factor Loading	Sub-criterion
1. Is the availability of financing important for the loyalty between producer and dairy?	0.554	Accessibility of financial resources (e.g., interest rates, repayment terms)
3. Is financial incentive (bonuses, prizes, and commissions) important for the loyalty between producer and dairy?	0.586	Type and frequency of financial incentives provided
8. Is price stability important?	0.632	Duration of stable pricing periods
9. Is the price exclusive to your organisation important?	0.726	Competitiveness of exclusive price
10. Is the price in comparison to the required quality important?	0.528	Ratio of price adjustments to quality enhancements
11. Is the price defined by the Council important?	0.649	Transparency and fairness of council-defined pricing mechanisms
12. Is the price compared to the imported substitute vital?	0.533	Impact of international price fluctuations on local pricing

Table 2- Factor Loadings for Social Criterion

Question	Factor Loading	Sub-criterion
2. Is technical assistance substantially promoting the producer's and dairy's loyalty?	0.664	Frequency and quality of technical visits
5. Is the supply contract necessary for the loyalty between producer and dairy?	0.678	Length and flexibility of contract terms
13. Is meeting the delivery deadline important?	0.820	Penalties or rewards associated with meeting delivery schedules
15. Is milk carrier training important?	0.967	Frequency and quality of technical visits

Table 3- Factor Loadings for Production Criterion

Question	Factor Loading	Sub-criterion
4. Is the amount of milk produced important for the loyalty between producer and dairy?	0.510	Consistency in daily milk production levels
6. Is milk quality important for the loyalty between producer and dairy?	0.700	Adherence to quality standards (e.g., fat content, microbiological safety)
14. Is the minimum volume that justifies collection essential?	0.595	Economic viability of collection for different volumes

The Kaiser-Meyer-Olkin (KMO) index was 0.87, indicating that the sample was adequate for factor analysis. Bartlett's Test of Sphericity was significant ($p < 0.001$), confirming the suitability of the correlation matrix for the study

2.1.3 Confirmatory Factor Analysis (CFA)

The fit indices from the confirmatory factor analysis were assessed to evaluate the model's adequacy. The Comparative Fit Index (CFI) was 0.91, and the Tucker-Lewis Index (TLI) was 0.90, indicating a good fit. The Root Mean Square Error of Approximation (RMSEA) was 0.06, suggesting an acceptable model fit. The Chi-Square value was 325.48, with 210 degrees of freedom, and the p-value was less than 0.001, confirming the statistical significance of the model. These indices collectively support the robustness of the three identified dimensions and affirm the model's reliability.

2.2 Phase 2 - Development of the AHP Tool

Phase 2 addressed the development of a robust decision-making tool. This tool employed the Analytic Hierarchy Process (AHP) to facilitate the selection of dairy producers. This structured approach involved several key steps.

Initially, the problem was clearly defined: the need for a tool capable of selecting dairy producers based on the previously identified criteria, with specific consideration given to sustainability, milk quality, and logistical efficiency. The AHP framework then established a hierarchical structure. This structure positioned the overarching goal—selecting the optimal producer—at the top, followed by the identified selection criteria, with the potential dairy producers themselves represented as alternatives at the base of the hierarchy.

To ascertain the relative importance of each criterion, experts were engaged in pairwise comparisons using a numerical scale. This process generated comparison matrices, capturing the expert judgments. Subsequently, eigenvector estimation was employed to calculate the relative weights of each criterion, providing quantitative support for the decision-making process.

Crucially, the comparisons underwent a consistency check, utilising the Consistency Ratio (CR), to ensure logical accuracy and coherence in the expert judgments. The calculated weights were then aggregated across the hierarchical levels to determine the global priority of each dairy producer alternative. This provided a clear ranking of producers based on their performance across all criteria.

Finally, the results derived from the AHP process underwent rigorous validation using statistical techniques, including Exploratory Factor Analysis (EFA), Confirmatory Factor Analysis (CFA), and regression analysis. This validation process, informed by Hair et al. (2019), aimed to assess the construct validity of the AHP model and evaluate the relationships between the different selection criteria.

2.2.1 Consistency of Judgments

Analysis of the Consistency Ratio (CR) reveals a value close to zero, indicating exceptional consistency in the pairwise comparisons. This is supported by the symmetric comparison matrix based on FDI values, a λ_max of 3 (with three criteria), and a near-zero CI value (6.66×10^{-16}). The extremely low CR value (1.15×10-15) confirms this high consistency, exceeding that of a randomly generated matrix. This result, significantly below the 0.10 threshold, suggests a rigorous AHP process, providing confidence in the derived weights and priorities for decision-making (Yang and Lu, 2024).

2.2.2 Normalized Weight (AHP)

The normalized weight is calculated by normalizing the decision matrix to ensure the sum of weights equals 1 (or 100%) across all criteria, ensuring comparability.

$$\text{Normalised Weight of Criterion } i = \frac{w_i}{\sum_{j=1}^{n} w_j} \quad (1)$$

Where: w_i is the weight for criterion$i$, $\sum_{j=1}^{n} w_j$ is the sum of all weights.

2.2.3 Normalized Factor Loading (AHP)

In AHP, factor loadings are normalised to ensure that each criterion's weight aligns with the comparison matrix.

$$\text{Normalised Factor Loading for Criterion i} = \frac{\mathit{Factor\ Loading\ for\ Criterion\ i}}{\text{Sum of All Factor Loadings}} \quad (2)$$

This normalisation ensures that the sum of all factor loadings equals 1. These findings provide insights into the importance of various factors for dairy processors, guiding their decision-making. Economic and social factors were the most influential, followed by production considerations. These insights are crucial for improving value co-creation and long-term relationships with producers (Ferenhof et al., 2024).

3. RESULTS

3.1 Selection Tool Implementation

The economic criterion is pivotal in the producer-dairy relationship, as financial factors such as price, financing, and contracts directly influence decision-making. Accessibility of financial resources (Question 1) enables producers to invest in better practices, while the type and frequency of monetary incentives (Question 3) foster loyalty. Price stability (Question 8), measured by the duration of stable pricing periods, ensures predictability, and exclusive pricing (Question 9), evaluated for competitiveness, supports long-term planning. Price adjustments aligned with quality enhancements (Question 10) ensure fair compensation, while council-defined pricing (Question 11) promotes transparency and fairness. Additionally, the impact of international price fluctuations on local pricing (Question 12) is critical for retaining producers in a competitive global market.

The social criterion focuses on the quality of interactions, including the frequency and quality of technical visits (Question 2), which enhance production and reinforce loyalty. Well-structured supply contracts (Question 5), evaluated for length and flexibility, provide legal and operational security, ensuring mutual expectations are met. Adherence to delivery deadlines (Question 13), with associated penalties or rewards, builds trust and efficiency, while proper training for milk carriers (Question 15) improves handling and transportation standards.

The production criterion emphasises milk quantity and quality. Consistency in daily production levels (Question 4) ensures operational efficiency, while adherence to quality standards (Question 6) meets industry and consumer expectations. The minimum volume required for milk collection (Question 14), assessed for economic viability, is crucial for logistical and financial sustainability, as insufficient volumes may jeopardise the partnership. These criteria create a balanced framework for selecting producers, ensuring stability, efficiency, and mutual benefit.

3.2 Dairy Selection Tool Development

Figure 1: Dairy selection tool concept

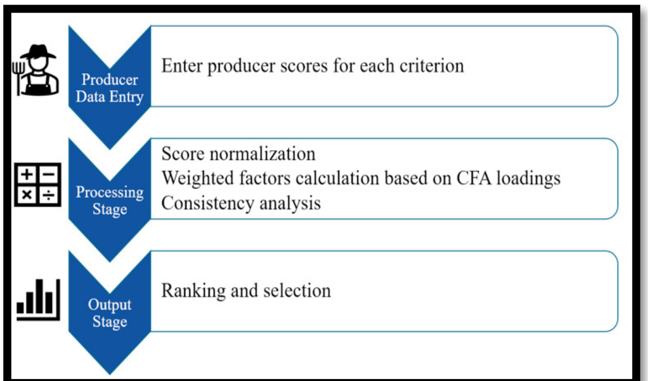

Figure 1. Overview of the dairy selection tool's conceptual design

Figure 2: Dairy selection tool view

This research presents a decision-making tool that uses the Analytic Hierarchy Process (AHP) to facilitate the robust and transparent selection of dairy producers. It addresses the industry's need for structured producer evaluation, considering economic, social, and production factors. This tool enables a holistic assessment and promotes sustainable supply chain practices.

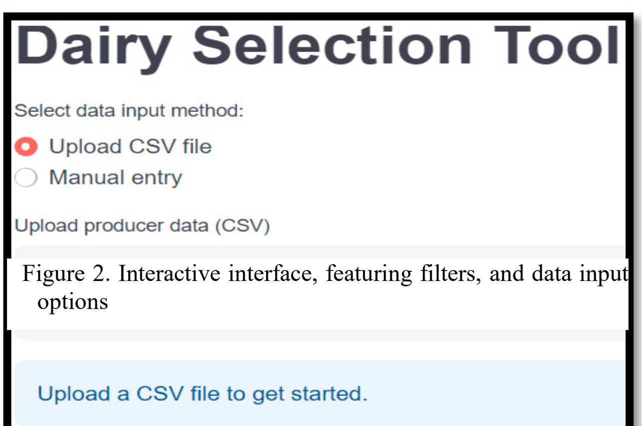

Figure 2. Interactive interface, featuring filters, and data input options

The tool follows a transparent workflow. Users input producer data, which is evaluated against predefined sub-criteria weighted through Confirmatory Factor Analysis (CFA). This ensures the scoring system accurately reflects the relative importance of each sub-criterion, aligning with industry priorities.

A key feature is incorporating a consistency check, which is fundamental to AHP methodology. Based on the Consistency Ratio (CR), this check ensures logical coherence in the pairwise comparisons. By maintaining a CR below the acceptable threshold (typically < 0.10), the tool guarantees the reliability and transparency of the evaluation process.

The tool outputs a ranked list of dairy producers, providing actionable insights for supply chain managers to identify and select producers who efficiently meet their requirements. The user-friendly interface, incorporating data visualisation tools, ensures accessibility for various stakeholders.

This research delivers a practical and robust decision-making tool for the dairy industry. By integrating AHP methodology, CFA-derived weights, and a user-friendly interface, the tool promotes informed decision-making, strengthens supply chain relationships, and contributes to the sector's long-term sustainability. The Dairy Selection Tool is available for public use at https://dairy-selection-tool.streamlit.app/.

4. DISCUSSION

The findings provide significant insights into the complexities of selecting dairy producers within the Brazilian dairy industry, focusing on efficiency. The integration of the EFA and CFA methodology, as adapted from Metaxas et al. (2016), identified key selection criteria—economic, social, and production factors—that drive effective decision-making. This study aligns with their findings while offering a more nuanced perspective by incorporating often-overlooked social and output factors, reinforcing the importance of a holistic approach in fostering effective partnerships between dairies and producers.

Economic performance emerged as a crucial driver, reflecting the need for financial stability and predictability in the dairy supply chain. As Pachoud (2024) highlighted, economic incentives such as bonuses and pricing agreements are pivotal in maintaining producer loyalty. The study demonstrates that exclusive pricing agreements and favourable terms can reduce costs for dairies, enhancing overall efficiency. Assessing producers' reliability in meeting delivery deadlines further ensures operational continuity, supporting the work of Rose et al. (2016) on the role of economic factors in stable supplier relationships.

Production factors, such as milk quality standards and minimum collection volumes, were also critical. The results confirm Gardezi et al. (2024)'s emphasis on aligning production metrics with strategic priorities. By incorporating quality-related factors, the Dairy Selection Tool ensures the prioritisation of producers to meet high standards, balancing quality and volume to optimise processing capacity and meet market demand.

Though traditional models did not address the social dimension, it was essential. Focusing on labour conditions, community engagement, and ethical practices, this research mirrors Iseppi et al. (2022)'s call for a broader view of selection criteria. Social factors foster trust and collaboration, and the tool captures these dynamics, selecting producers who meet economic and production criteria while positively contributing to their communities.

The frequency of reapplying the Dairy Selection Tool should ensure its continued relevance. Drawing on Wieland and Durach (2021) and Johnson et al. (2021), the tool should evolve with changing conditions, addressing disruptions and industry shifts. For long-term goals, reapplying every 3 to 5 years, as suggested by Aldrighetti et al. (2024), is recommended, with flexibility for ad-hoc use in response to significant changes.

In conclusion, this study advances the understanding of dairy producer selection by integrating economic, social, and production factors into a cohesive decision-making framework. Aligning with Metaxas et al. (2016), Pachoud (2024), Rose et al. (2016), Gardezi et al. (2024), and Iseppi et al. (2022), it underscores the importance of a holistic approach. Recommendations for periodic reapplication, informed by Wieland and Durach (2021), Johnson et al. (2021), and Aldrighetti et al. (2024), ensure adaptability to evolving industry needs, enhancing operational efficiency and fostering long-term resilience.

5. CONCLUSIONS

The Dairy Selection Tool offers a comprehensive framework for selecting dairy producers based on economic, production, and social criteria. It addresses challenges in financial viability, production standards, and labour practices, promoting resilient and efficient supply chains. The tool provides researchers a resource for studying supply chain dynamics, offering data-driven insights into optimisation and best practices.

Applied outcomes include improved producer selection, operational efficiency, and transparency. The tool aligns producers with financial goals, quality requirements, and ethical standards, fostering socially responsible and economically stable supply chains. Future developments could incorporate environmental impact factors, predictive analytics, consumer preferences, refined producer selection to meet evolving market demands, and sustainability goals. Ultimately, the Dairy Selection Tool enhances decision-making, operational efficiency, and social responsibility in the dairy industry, with ongoing advancements ensuring its continued relevance and impact.

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