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Determining Factors for Minimizing Oven Downtime through Controlled Batch Management: A Multineutrosophic Approach with ARAS

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Abstract. This study addresses a critical operational challenge in the baking industry: minimizing oven downtime through effective batch processing control. This study assesses which factors are the most critical contributors to minimizing downtime on batch processing operations to hypothesize efficiencies. But why is this problem? Sadly, much research has been done and found that ineffective resource allocation not only wastes funds but also increases carbon footprint for unnecessary baking, which is ironic since fresh products must drive demand at a low-cost. Furthermore, minimizing downtime allows for the more sustainability-oriented production that today's manufacturers are on the hook for. Therefore, testing new industrial process solutions is warranted. Currently, a lot of scholarly research exists about queuing theory and supply chain feasibility; however, little is known. Many investigations fail to concentrate on baking process optimization with uncertainty and subjectivity of decision-makers as top determinations. Therefore, this study is the first to bridge the gap using multineutrosophic theory and a decision-making tool called Additive Ratio Assessment (ARAS)—a prioritizing assessment tool—which provides nuance to criterion assessments and weighting via incremental rounds with experts rendered neutrosophic. Ultimately the neutrosophic composite-fueled determination of the most critical criteria/test variables includes: batch arrival rate, acceptable batch size and setup time. Ultimately regulating batch processing according to predetermined thresholds vetted against neutrosophic variables decreases downtime significantly without negatively impacting quality control. This project adds to the literature a new methodology that legitimizes ideation for uncertainty-based decision making along with new recommendations for implementation that reduce energy expenditure, new resource allocation and production efficiency takeaways for bakeries that improve their competitive advantage and sustainable quality of life.

Keywords: Batch Management, Downtime, Ovens, Multineutrosophic, ARAS, Efficiency, Sustainability.

1 Introduction

The efficient management of industrial processes, particularly in the food industry, constitutes a fundamental pillar to ensure competitiveness and sustainability in an increasingly demanding global environment. This study focuses on optimizing oven downtime in bakeries through controlled batch management, a critical aspect to reduce operating costs and minimize environmental impact. The relevance of this topic lies in its ability to address practical challenges in food production, where energy efficiency and resource planning are essential to meet the growing demand for fresh products [1], [2]. Recent research highlights that the inactivity of equipment, such as ovens, can significantly increase costs and energy consumption, underscoring the need for innovative approaches to improve production systems [3]. Over the last decades, the food industry has undergone significant transformations driven by technological advances and the adoption of mathematical models to optimize processes. From manual production systems to the integration of tools such as queuing theory, efforts to improve efficiency have been constant [4]. In the context of bakeries, batch management has emerged as a key factor in aligning dough preparation with baking cycles, reducing downtime and optimizing resource use [5]. However, variability in batch arrival and process disruptions remain persistent challenges that require solutions tailored to the stochastic production environment. The problem addressed in this study arises from the need to minimize oven downtime, an aspect that directly affects the productivity and sustainability of bakeries. Despite advances in the application of queuing models, such as MX/G(a, b)/1, few studies have considered the uncertainty inherent in decision-makers' perceptions and the complexity of operational factors [6]. How can key factors that allow reducing oven downtime be identified and prioritized in a context of high variability and ambiguity? This question guides the research, seeking to offer a comprehensive solution that combines analytical rigor with practical applicability.

This paper proposes a novel approach by integrating a multineutrosophic framework with the Additive Ratio Assessment (ARAS) method to assess and classify factors influencing batch management. This approach makes it possible to handle the indeterminacy present in operational decisions, an aspect that traditional models do not effectively address [7]. By considering both technical aspects and the subjective perceptions of experts, the study seeks to generate insights that transcend the limitations of conventional approaches. Historically, process optimization in the food industry has relied on quantitative tools that model workflows and resources. Queuing theory, in particular, has been widely used to analyze production systems with random arrivals and services [8]. However, the application of these tools in bakeries has been limited by the lack of models that incorporate uncertainty into task planning and execution, a challenge that this study directly addresses.

The magnitude of the problem lies in its economic and environmental impact. Idle ovens not only generate additional costs through unnecessary energy consumption but also contribute to the carbon footprint of operations [9]. In an industry where profit margins are slim, the ability to minimize downtime can make the difference between profitability and loss. This study addresses this need by proposing a framework that not only optimizes operations but also promotes sustainable practices. The research question focuses on identifying the determining factors that allow for reduced downtime through controlled batch management. By addressing this issue, the study seeks to contribute to theoretical knowledge in supply chain management and offer practical solutions for the food industry. The combination of a multineutrosophic approach with ARAS represents a significant innovation, allowing for a robust assessment of factors under conditions of uncertainty.

The objectives of this research are clear: first, to identify the key factors influencing oven downtime using a multineutrosophic analysis; second, to prioritize these factors using the ARAS method to generate practical recommendations; and third, to validate the proposed approach through a case study in a bakery. These objectives are aligned with the research question and seek to provide a significant contribution to both academia and industry.

2 Materials and methods

MultiNeutrosophic Set

Definition 1. The *Neutrosophic set* N It is characterized by three membership functions [10] , which are the truth membership function T_A, the indeterminacy membership function I_A, and the falsity membership function F_A, where U is the Universe of Discourse and $\forall x\in U$, $T_A(x), I_A(x), F_A(x) \subseteq]{}_A^-0, 1^+[$, and ${}_A^-0 \leq \inf T_A(x) + \inf I_A(x) + \inf F_A(x) \leq \sup T_A(x) + \sup I_A(x) + \sup F_A(x) \leq 3^+$ [10] .

See that by definition , $T_A(x), I_A(x)$, and $F_A(x)$are standard or non-standard real subsets of $]{}_A^-0, 1^+[$and hence, $T_A(x), I_A(x)$and $F_A(x)$can be subintervals of $[0, 1]$. ${}_A^-0$and1^+ belong to the set of hyperreal numbers.

Definition 2. The *single-valued neutrosophic set* (SVNS) A over U is $A = \{< x, T_A(x), I_A(x), F_A(x) > : x\in U\}$, where $T_A: U\to[0, 1]$, $I_A: U\to[0, 1]$and $F_A: U\to[0, 1]$. $0 \leq T_A(x) + I_A(x) + F_A(x) \leq 3$.

SVNN are expressed below:

Given $A_1 = (a_1, b_1, c_1)$ and $A_2 = (a_2, b_2, c_2)$ two SVNN, the sum between A_1 and A_2 is defined as:

$$A_1 \; A_2 = (a_1 + a_2 - a_1 a_2, b_1 b_2, c_1 c_2) \quad (1)$$

Given $A_1 = (a_1, b_1, c_1)$ and $A_2 = (a_2, b_2, c_2)$ two SVNNs, the multiplication between A_1 and A_2 is defined as:

$$A_1 \; A_2 = (a_1 a_2, b_1 + b_2 - b_1 b_2, c_1 + c_2 - c_1 c_2) \quad (2)$$

The product of a positive scalar with a SVNN, A = (a, b, c) is defined as:

$$\lambda A = \left(1 - (1 - a)^{\lambda}, b^{\lambda}, c^{\lambda}\right) \quad (3)$$

The *single-valued neutrosophic number* (SVNN) is symbolized by

$N = (t, i, f)$, such that $0 \le t, i, f \le 1$ and $0 \le t + i + f \le 3$.

Definition 3. The refined neutrosophic set of subsets (SRNS).

Let $\mathcal{U}$ a universe of discourse and a set $R \subset \mathcal{U}$. Then, a refined neutrosophic subset R is defined as follows:

$R = \{x, x(T, I, F), x \in U\}$,where T is refined/divided into p subtruths, $T = \langle T_1, T_2, \dots T_p \rangle, T_j \subseteq [0,1], 1 \le j \le p$; I is refined/divided into r subindeterminacies, $I = \langle I_1, I_2, \dots I_r \rangle, I_k \subseteq [0,1], 1 \le k \le r$,and F is refined /divided into s sub falsehoods, $F = \langle F_1, F_2, \dots F_l \rangle, F_s \subseteq [0,1], 1 \le l \le s$, where $p, r, s \ge 0$are integers, and $p + r + s = n \ge 2$, and at least one of $p, r, s \; is \ge 2$to ensure the existence of refinement (division).

Definition 4 ([11]) **.** The MultiNeutrosophic Set (or MultiNeutrosophic Set Subset SMNS).

Let $\mathcal{U}$ a universe of discourse and M a subset of it. Then, a MultiNeutrosophic Set is: $M = \{x, x(T_1, T_2, \dots, T_p; I_1, I_2, \dots, I_r; F_1, F_2, \dots, F_s)\}, x \in U$,

where p , r , s are integers $\ge 0, p + r + s = n \ge 2$ and at least one of them $p, r, s \; is \ge 2$,to ensure the existence of multiplicity of at least one neutrosophic component: truth/belonging, indeterminacy or falsity/non-belonging; all subsets$T_1, T_2, \dots, T_p; I_1, I_2, \dots, I_r; F_1, F_2, \dots, F_s \subseteq [0,1]$;

$0 \le \sum_{j=1}^{p} inf \; T_j + \sum_{k=1}^{r} inf \; I_k + \sum_{l=1}^{s} inf \; F_l \le \sum_{j=1}^{p} sup \; T_j + \sum_{k=1}^{r} sup \; I_k + \sum_{l=1}^{s} sup \; F_l \le n.$

No other restrictions apply to these multicomponent. Neutrosophics.

$T_1, T_2, \dots, T_p$They are multiplicities of truth, each provided by a different source of information (expert).

Similarly, $I_1, I_2, \dots, I_r$there are multiplicities of indeterminacy, each provided by a different source.

And $F_1, F_2, \dots, F_s$they are multiplicities of falsehood, each provided by a different source.

The Degree of Multitude (Multimember ship), also called *Mult degree of Truth,* of the element x with respect to the set M are $T_1, T_2, \dots, T_p$.

The Degree of Mult indeterminacy (Mult Neutrality), also called *Multidegree of Indeterminacy,* of the element x with respect to the set M are$I_1, I_2, \dots, I_r$.

and the Degree of Multi- Nonmembership, also called *Multidegree of Falsehood,* of the element x with respect to the set M are$F_1, F_2, \dots, F_s$.

All of these $p + r + s = n \ge 2$are assigned by n sources (experts) that can be:

- whether completely independent;
- or partially independent and partially dependent;
- or totally dependent; depending on or as needed for each specific application.

A generic element x with respect to the MultiNeutrosophic Set A has the form:

$x(T_1, T_2, \dots, T_p;$	$I_1, I_2, \dots, I_r;$	$F_1, F_2, \dots, F_s)$
multi-truth	multi-indeterminacy	multiple falsehood

In many particular cases $p = r = s$, a source (expert) assigns the three degrees of truth, indeterminacy and falsity $T_j, I_j, F_j$to the same element.

Definition 5. Classification of multineutrosophic types of value n of the same form (p, r, s).

$(T_1, T_2, \dots, T_p; I_1, I_2, \dots, I_r; F_1, F_2, \dots, F_s)$, where $p, r, s$are integers ≥ 0, and $p + r + s = n \ge 2$, and at least one of $p, r, s \ge 2$to be sure that it has multiplicity for at least one neutrosophic component (either truth, or indeterminacy, or falsity).

It offers a simpler n classification, but it is more of an approximation. Let's calculate the following.

positivity (4).

$$\frac{\sum_{j=1}^{p} T_j + \sum_{k=1}^{r}(1 - I_k) + \sum_{e=1}^{s}(1 - F_e)}{p + r + s} \tag{4}$$

Average (Truth-Falsehood) (5)

$$\frac{\sum_{j=1}^{p} T_j + \sum_{e=1}^{s}(1 - F_e)}{p + s} \tag{5}$$

truth (6).

$$\frac{\sum_{j=1}^{p} T_j}{p} \tag{6}$$

Definition 6. Classification of tuples n-valued multineutrosophic of different forms (p, r, s).

Let us consider two neutrosophic multiple tuples of value n of the forms $(p_1, r_1, s_1)$and respectively (p_2, r_2, s_2), where $p_1, r_1, s_1, p_2, r_2, s_2$ are integers ≥ 0, and $p_1 + r_1 + s_1 = n_1 \geq 2$, and at least one of $p_1, r_1, s_1 is \geq 2$,to be sure that multiplicity exists for at least one neutrosophic component (either truth, indeterminacy or falsity); similarly $p_2 + r_2 + s_2 = n_2 \geq 2$,and at least one of$p_2, r_2, s_2\ is \geq 2$.

Let's take the following tuples single-value multineutrosophic (SVMNT):

$SVMNT = (T_1, T_2, \dots, T_p; I_1, I_2, \dots, I_r; F_1, F_2, \dots, F_s)$of $(p_1, r_1, s_1) - form$, and

$SVMNT' = (T'_1, T'_2, \dots, T'_p; I'_1, I'_2, \dots, I'_r; F'_1, F'_2, \dots, F'_s)$of $(p_1, r_1, s_1) - form$.

It performs the classic averages of truth (T_a), indeterminacies (I_a) and falsity (F_a), respectively for $SVMNT = (T_a, I_a, F_a)$and the averages of truths (T_a), indeterminacies (I_a) and falsity (F_a) respectively for : $SVMNT = (T'_a, I'_a, F'_a)$. And then applies the Score Functions (), Accuracy () and Certainty (), as for the single-valued neutrosophic set:

Calculate the scoring function (average positivity) (7).

$$S(T_a, I_a, F_a) = \frac{T_a + (1 - I_a) + (1 - F_a)}{3}$$
$$S(T'_a, I'_a, F'_a) = \frac{T'_a + (1 - I'_a) + (1 - F'_a)}{3} \tag{7}$$

i. If $S(T_a, I_a, F_a) \geq S(T'_a, I'_a, F'_a)$then $SVMNT \geq SVMNT'$,

ii. If $S(T_a, I_a, F_a) \leq S(T'_a, I'_a, F'_a)$then $SVMNT \leq SVMNT'$,

iii. And if $S(T_a, I_a, F_a) = S(T'_a, I'_a, F'_a)$then $SVMNT = SVMNT'$, then go to the second step.

Calculate the precision function (difference between truth and falsehood) (8).

$$A(T_a, I_a, F_a) = T_a - F_a$$
$$A(T'_a, I'_a, F'_a) = T'_a - F'_a \tag{8}$$

i. If $A(T_a, I_a, F_a) \geq A(T'_a, I'_a, F'_a)$then $SVMNT \geq SVMNT'$,

ii. If $A(T_a, I_a, F_a) \leq A(T'_a, I'_a, F'_a)$then $SVMNT \leq SVMNT'$,

iii. And if $A(T_a, I_a, F_a) = A(T'_a, I'_a, F'_a)$then $SVMNT = SVMNT'$, then go to the third step.

3. Calculate the certainty (truth) function (9).

$$C(T_a, I_a, F_a) = T_a$$
$$C(T'_a, I'_a, F'_a) = T'_a \tag{9}$$

i. If $C(T_a, I_a, F_a) \geq C(T'_a, I'_a, F'_a)$then $SVMNT \geq SVMNT'$,

ii. If $C(T_a, I_a, F_a) \leq C(T'_a, I'_a, F'_a)$then $SVMNT \leq SVMNT'$,

iii. And if $C(T_a, I_a, F_a) = C(T'_a, I'_a, F'_a)$then $SVMNT = SVMNT'$they are multi-neutrosopically equal, that is $T_a = T_a^{'}, I_a = I_a^{'}, F_a = F_a^{'}$, or their corresponding averages of truth, indeterminacy and falsity are equal.

Definition 7. In cases where some sources carry a greater weight in the evaluation than others, weighted averages are used, indexed as $T_{wa}, I_{ua}, F_{va}$and respectively $T'_{wa}, I'_{ua}, F'_{va}$,. Because sources can be independent or partially independent, the sum of the weights does not necessarily have to equal 1. Therefore:

i. $w_1, w_2, \dots, w_p \in [0,1]$, although the sum $w_1 + w_2 + \dots + w_p$may be $< 1, or\ = 1, or\ > 1$.

ii. $u_1, u_2, \dots, u_p \in [0,1]$, although the sum $u_1 + u_2 + \dots + u_p$may be $< 1, or\ = 1, or\ > 1$.

iii. $v_1, v_2, \dots, v_p \in [0,1]$, although the sum $v_1 + v_2 + \dots + v_p$may be $< 1, or\ = 1, or\ > 1$.

And, similarly, the score, precision, and certainty functions are applied to these weighted averages to rank them.

Multineutrosophic ARAS.

Additive Ratio Assessment (ARAS) method is a multi-criteria decision-making technique that allows the selection of the best option from a set of alternatives [12]. In this case, the study establishes among its objectives a series of strategic guidelines aimed at improving decision-making. To this end, an extension of the traditional method is proposed through multi-neutrosophic set evaluation. Consequently, it is reformulated as the multi-neutrosophic ARAS method to determine the complex relative efficiency of each strategic guideline. This involves evaluating each strategic guideline through multiple sources (experts) based on the corresponding criteria. By integrating multi-neutrosophic set analysis into the ARAS method, the following steps are defined:

Step 1: Identify multiple sources (experts) for the multi-criteria assessment and assign a weight to each expert based on their knowledge (according to Definition 7 in Section 2.1). For this purpose, Saaty 's neutrosophic AHP method is applied (following the procedures referenced in the bibliographic sources [13].

Step 2: Determine the importance weights of each criterion in decision-making for each source (expert).

Step 3: Construct the decision matrix L_{ij}(see Figure 1), where the element L_{ij}represents each strategic guideline (GE) evaluated by multiple sources (experts (Exp.), according to Definitions 5 and 6 of Section 2.1) based on an identified criterion (C).

$$\begin{bmatrix} l_{11} & l_{12} & \cdots & l_{1j} & \cdots & l_{1n} \\ l_{21} & l_{22} & \cdots & l_{2j} & \cdots & l_{2n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ l_{i1} & l_{i2} & \cdots & l_{ij} & \cdots & l_{in} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ l_{m1} & l_{m2} & \cdots & l_{mj} & \cdots & l_{mn} \end{bmatrix}$$

Figure 1: Decision matrix $L_{ij}$for the ARAS multineutrosophic method.

Step 4: The normalized decision matrix $\bar{L}_{ij}$, considering the beneficial and non-beneficial values, is calculated using equations (10) and (11):

$$\bar{L}_{ij} = \frac{l_{ij}}{\sum_{i=0}^{m} l_{ij}} \quad (10)$$

$$L_{ij} = \frac{1}{l_{ij}^{*}} \quad (11)$$

Step 5: The weighted normalized decision matrix is calculated using equation (12).

$$\hat{L}_{ij} = \bar{L}_{ij} \cdot W_j \quad (12)$$

The weight values $W_j$are determined using the entropy method. Where j $W_j$is the weight of criterion j and j $\bar{L}_{ij}$is the normalized ranking of each criterion.

Step 6: Calculation of the optimization function $S_i$using equation (13).

$$G_i = \sum_{j=1}^{n} \hat{L}_{ij} \quad (13)$$

Where $G_i$is the value of the optimization function of alternative *i*. This calculation has a directly proportional relationship with the process of the values $\hat{L}_{ij}$and weights $W_j$of the investigated criteria and their relative influence on the result [14].

Step 7: Calculating the degree of utility. This degree is determined by comparing the variant under analysis with the best one G_o, according to equation (14).

$$K_i = \frac{G_i}{G_o} \quad (14)$$

Where G_i and G_o are the values of the optimization function. These values range from 0 to 100%, therefore, the alternative with the highest value K_i is the best of the alternatives analyzed [15].

3. Case study

3.1 Impact of Controlled Batch Management on Reducing Oven Downtime.

In the baking industry, operational efficiency depends largely on the ability to minimize oven downtime, a critical factor affecting both productivity and energy consumption. This study focuses on controlled batch management, defined as the dynamic adjustment of dough arrivals to the oven to optimize baking cycles. Key factors evaluated include batch arrival rate (frequency of dough preparation), batch size (number of trays per cycle), preparation time (coordination between mixing and baking), and operational flexibility (ability to adjust parameters in the face of variations). These factors are essential to ensuring continuous production, reducing energy waste, and improving sustainability.

Controlled batch management allows dough preparation to be aligned with baking cycles, avoiding unnecessary interruptions. For example, inadequate batch sizing can result in long wait times or underutilized baking cycles, increasing operating costs . Furthermore, uncertainty in demand and variations in preparation times complicate planning, highlighting the need for approaches that integrate uncertainty into decision-making. This case study addresses these issues by applying a multineutrosophic approach, which captures the subjective perceptions of experts and the inherent variability of the process.

The relevance of this approach lies in its ability to improve decision-making in complex environments. By considering multiple perspectives from experts, such as production managers, process engineers, and furnace operators, multineutral analysis helps identify critical factors that traditional methods might overlook. Furthermore, controlled batch management contributes to sustainability by reducing energy consumption, a crucial aspect in an industry where profit margins are tight.

The case study is carried out in a medium-sized bakery with a daily production of 5,000 bread units. The ovens, capable of processing up to six trays per cycle, face average downtimes of 15 minutes per hour due to mismatches in batch preparation. This scenario serves as a basis for evaluating how controlled batch management can optimize operations, reduce downtime, and improve energy efficiency.

3.2 Strategic Guidelines: Integration of MultiNeutrosophy in Batch Management

The integration of MultiNeutrosophy with the ARAS method allows prioritizing strategies to minimize furnace downtime, taking into account uncertainty and multiple expert perspectives. The proposed strategic guidelines are detailed in Table 1, focusing on optimizing coordination, improving flexibility, and reducing environmental impact.

Table 1. Strategic guidelines for controlled batch management

No	Strategic Guideline	Aim	Strategies	Impact
LE1	Optimizing the batch arrival rate	Ensure a continuous flow of dough to the oven adjusted to the baking capacity.	Implement scheduling algorithms based on queue models to adjust preparation frequency. Conduct arrival simulations to anticipate variations in demand.	Reduce downtime by minimizing unnecessary waiting.

No	Strategic Guideline	Aim	Strategies	Impact
LE2	Dynamic batch sizing	Adapt the number of trays per cycle according to the demand and capacity of the oven.	Establish dynamic batch size thresholds through real-time monitoring. Train staff on rapid operational adjustments.	Improves oven utilization and reduces energy consumption.
LE3	Efficient coordination of preparation time	Synchronize dough preparation with baking cycles.	Automate communication between mixing and baking stations. Implement dashboards to monitor times.	Minimizes interruptions due to lack of coordination in preparation .
LE4	Integrating expert judgment into planning	Incorporate the experience of operators and managers to improve decision-making.	Create multidisciplinary committees to evaluate operational parameters. Use structured surveys to capture expert perceptions.	Improves the accuracy of operational decisions under uncertainty.
LE5	Promoting operational flexibility	Increase responsiveness to production variations.	Design protocols for rapid adjustments to production parameters. Train staff in dynamic analysis tools.	Increases resilience to unforeseen changes in demand.
LE6	Reducing environmental impact	Minimize energy consumption through efficient operation.	Implement sensors to monitor energy consumption in real time. Optimize baking cycles to reduce emissions.	Contributes to sustainability and reduces operating costs.
LE7	Continuous improvement through feedback	Ensure constant adaptation of processes through iterative reviews.	Establish regular audits of baking processes. Implement real-time feedback systems.	Promotes continuous optimization and process quality.

3.3 Multineutrosophic ARAS Modeling: Selection of the Strategic Guideline

Step 1: Selecting Multiple Sources (Experts) in the Multi-Criteria Evaluation

To evaluate the strategic guidelines, five experts with experience in baking were selected, as detailed in Table 2. Each expert brings a unique perspective based on their role and knowledge of the process.

Table 2. Multi-source neutrosophic assessment (experts).

Expert	Profession
Exp-1	Production Manager
Exp-2	Process engineer
Exp-3	Senior Furnace Operator
Exp-4	Sustainability Specialist
Exp-5	Operations Analyst

Expert weights were determined using Saaty 's neutrosophic AHP method , considering their experience and contribution to the analysis. Table 3 shows the paired matrix, and Table 4 presents the resulting weights.

Table 3. Paired neutrosophic AHP matrix. +

Fountain	Exp-1	Exp-2	Exp-3	Exp-4	Exp-5
Exp-1	(0.5,0.5,0.5)	(0.7,0.3,0.3)	(0.8,0.2,0.2)	(0.9,0.1,0.1)	(0.6,0.4,0.4)
Exp-2	(0.3,0.7,0.7)	(0.5,0.5,0.5)	(0.6,0.4,0.4)	(0.8,0.2,0.2)	(0.5,0.5,0.5)
Exp-3	(0.2,0.8,0.8)	(0.4,0.6,0.6)	(0.5,0.5,0.5)	(0.7,0.3,0.3)	(0.4,0.6,0.6)
Exp-4	(0.1,0.9,0.9)	(0.2,0.8,0.8)	(0.3,0.7,0.7)	(0.5,0.5,0.5)	(0.3,0.7,0.7)
Exp-5	(0.4,0.6,0.6)	(0.5,0.5,0.5)	(0.6,0.4,0.4)	(0.7,0.3,0.3)	(0.5,0.5,0.5)

Table 4: Analysis of the consistency of the paired matrix. Source: Prepared by the authors.

Fountain	Weight	Approximate eigenvalues
Exp-1	0.30	5.12
Exp-2	0.25	5.08
Exp-3	0.20	5.05
Exp-4	0.15	5.03
Exp-5	0.10	5.01
Eigenvalue = 5.058, CI=0.0145, RC=0.016		

The production manager (Exp-1) and the process engineer (Exp-2) obtained the highest weights (0.30 and 0.25, respectively) due to their direct experience in process planning and optimization.

Step 2: Selection and Evaluation of Criteria for Each Multisource

Five criteria were defined to evaluate the strategic guidelines, detailed below:

- **C1: Impact on downtime**: Measures the guideline's ability to reduce downtime.
- **C2: Energy efficiency**: Evaluates the impact on reducing energy consumption.
- **C3: Operational flexibility**: Determines the ability to adapt to variations in production.
- **C4: Ease of implementation**: Analyzes the practical feasibility of the guideline.
- **C5: Contribution to sustainability**: Values the positive environmental impact.

The weights of the criteria were calculated using the entropy method, as shown in Table 5.

Table 5. Multineutrosophic evaluation of each criterion.

Criterion	({T1,T2,T3},{I1,I2},{F1,F2,F3})	(T_a,I_a,F_a)	Weight	Score (S)
C1	({0.8,0.7,0.9},{0.2,0.1},{0.3,0.4,0.2})	(0.80,0.15,0.30)	0.30	0.78
C2	({0.7,0.6,0.8},{0.3,0.2},{0.4,0.5,0.3})	(0.70,0.25,0.40)	0.25	0.68
C3	({0.6,0.5,0.7},{0.4,0.3},{0.5,0.6,0.4})	(0.60,0.35,0.50)	0.20	0.58
C4	({0.5,0.4,0.6},{0.5,0.4},{0.6,0.7,0.5})	(0.50,0.45,0.60)	0.15	0.48
C5	({0.6,0.5,0.7},{0.3,0.2},{0.4,0.5,0.3})	(0.60,0.25,0.40)	0.10	0.65

Criterion C1 (impact on downtime) was given the highest weight (0.30), followed by C2 (energy efficiency, 0.25), reflecting its importance in furnace optimization.

Step 3 to 7: Calculation of the Gi Optimization Function

The multineutrosophic decision matrix L_{ij} was constructed by evaluating each strategic guideline according to the defined criteria. All evaluations were classified as beneficial. Table 6 presents an extract of the matrix, and Table 7 shows the results of the optimization function Gi.

Table 6. Extract from the multi-neutrosophic ARAS decision matrix.

Directive	Criterio C1 (Ta, Ia, Fa)	Score (S)	Criterion C2 (Ta, Ia, Fa)	Score (S)	...
LE1	(0.75,0.20,0.30)	0.75	(0.70,0.25,0.35)	0.70	...
LE2	(0.65,0.30,0.40)	0.65	(0.60,0.35,0.45)	0.60	...
LE3	(0.80,0.15,0.25)	0.80	(0.75,0.20,0.30)	0.75	...
LE4	(0.70,0.25,0.35)	0.70	(0.65,0.30,0.40)	0.65	...
LE5	(0.60,0.35,0.45)	0.60	(0.55,0.40,0.50)	0.55	...
LE6	(0.85,0.10,0.20)	0.85	(0.80,0.15,0.25)	0.80	...
LE7	(0.65,0.30,0.40)	0.65	(0.60,0.35,0.45)	0.60	...

Table 7. Optimization function Gi and utility degree Ki.

Directive	C1	C2	C3	C4	C5	Gi	Ki (%)
LE1	0.045	0.035	0.030	0.020	0.015	0.145	72.50
LE2	0.039	0.030	0.025	0.018	0.012	0.124	62.00
LE3	0.048	0.038	0.032	0.022	0.016	0.156	78.00
LE4	0.042	0.033	0.028	0.019	0.014	0.136	68.00
LE5	0.036	0.028	0.023	0.016	0.011	0.114	57.00
LE6	0.051	0.040	0.034	0.024	0.017	0.166	83.00
LE7	0.039	0.030	0.025	0.018	0.012	0.124	62.00
G0						0.200	100.00

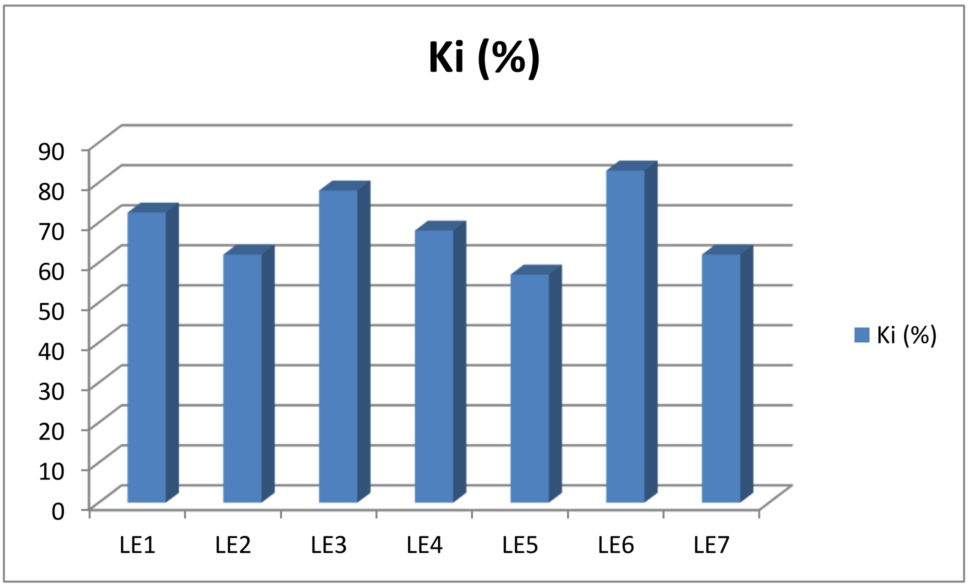

Figure 2: Degree of utility Ki. Source: Prepared by the authors.

3.4 Analysis of Results and Recommendations

The multineutrosophic ARAS method identified that strategic guidelines LE6 (reducing environmental impact) and LE3 (efficient coordination of preparation time) obtained the highest degrees of usefulness (83% and 78%, respectively). These guidelines stand out for their ability to reduce downtime and improve energy efficiency, aligning with sustainability and productivity goals. LE6, focused on minimizing energy consumption through optimized baking cycles, directly addresses the need to reduce the carbon footprint, a critical aspect in the food industry. LE3, meanwhile, addresses the lack of coordination between dough preparation and baking, a common problem that generates significant downtime.

LE1 (batch arrival rate optimization) also showed strong performance (72.50%), suggesting that adjusting the frequency of dough preparation is key to maintaining continuous flow. In contrast, LE5 (promoting operational flexibility) achieved the lowest degree of usefulness (57%), possibly due to the difficulty of implementing rapid changes in resource-constrained environments. These results underscore the importance of prioritizing strategies that combine practical feasibility with a direct impact on operational efficiency.

The integration of MultiNeutrosophy allowed experts' uncertainty and subjective perceptions to be captured, providing a more robust assessment than traditional methods. For example, variability in opinions regarding ease of implementation (C4) was effectively managed through multineutrosophic analysis, ensuring that decisions reflected a balanced consensus.

Recommendations:

1. **Implement LE6 as a priority**: Install energy consumption sensors and optimize baking cycles to reduce downtime and emissions. This can be achieved by scheduling batches based on projected demand.
2. **Strengthen LE3 through automation**: Develop automated communication systems between preparation and baking stations to synchronize processes, reducing wait times.
3. **Train staff in LE1**: Train operators in the use of scheduling algorithms to adjust batch arrival rates, improving coordination with oven capacity.
4. **Continuous monitoring**: Establish a system of regular audits and real-time feedback (LE7) to identify deviations and dynamically adjust operating parameters.
5. **Invest in sustainable technology**: Adopt technologies such as energy-efficient furnaces to complement strategic guidelines and maximize environmental benefits.

These results and recommendations can be integrated into the bakery's operational strategy, promoting more efficient, sustainable, and competitive production in a dynamic environment.

4. Conclusion

This study reveals that controlled batch management, analyzed using a multineutrosophic approach and the ARAS method, identifies key factors for significantly reducing oven downtime in bakeries. The findings highlight the importance of optimizing baking cycles and synchronizing dough preparation with oven operation. This approach addresses uncertainty in operational decisions, providing a robust solution for production environments with high variability. In practical terms, the results offer tangible benefits for the food industry. Adopting strategies such as improving energy efficiency and operational coordination can generate considerable savings and reduce environmental impact. These solutions are particularly relevant for medium- and small-sized bakeries, where efficient resource management is crucial to maintaining competitiveness and responding to the demand for fresh products while promoting sustainability. This research makes a significant contribution by introducing an innovative methodological framework that integrates Multineutrosophic with the ARAS method. This approach enriches supply chain management by offering a practical tool for managing ambiguity in decision-making. By incorporating multiple expert perspectives, the study advances knowledge on industrial process optimization in complex and dynamic contexts.

However, the study is not without limitations. Subjectivity in expert assessments can introduce variability, and the analysis focused on a specific bakery, which could limit the applicability of the results. Furthermore, the implementation of advanced technologies could face economic constraints in resource-limited settings. For future research, we recommend exploring the use of artificial intelligence, such as machine learning algorithms, to predict demand patterns and optimize batch management in real time. It would also be valuable to validate the approach in various industrial contexts and analyze external factors, such as energy costs. The evolution of optimization methods and the integration of emerging technologies will be essential to achieve more efficient and sustainable production processes.

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