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Web-Based Fuzzy Mamdani System for Adaptive Cost of Production in Culinary MSMEs

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Abstract: Culinary micro, small, and medium enterprises frequently experience financial instability because conventional deterministic costing methods lack the flexibility to handle daily fluctuations in raw material and overhead expenses. This study develops an adaptive Cost of Production model and generates pricing recommendations using a web-based Fuzzy Mamdani decision support system. The research employs an applied quantitative case study design focusing on a single culinary micro-enterprise operating in a volatile local market. The fuzzy engine processes raw material and overhead uncertainties as linguistic inputs using MIN-MAX inference, while treating direct labor as a constant parameter. Centroid defuzzification calculates the final adaptive cost. The results demonstrate that the conventional deterministic cost was Rp27,077, whereas the Fuzzy Mamdani model adjusted this value to Rp27,532. This 1.68 percent increase functions as a calculated risk premium that protects profit margins against minor supply chain volatilities. The system subsequently generated three margin-based pricing tiers. The standard tier with a 30 percent margin demonstrated a 97.74 percent goodness of fit when compared to actual market prices. The primary contribution is the deployment of a lightweight web artifact that removes the technical barriers associated with desktop-based fuzzy simulations. This tool enables non-technical business owners to transition from heuristic guesswork to transparent, data-driven pricing strategies that inherently buffer against operational cost uncertainty.
Keywords: Cost of Production, Fuzzy Mamdani, Decision Support System, Micro-Enterprises, Pricing Strategy, Culinary Industry.

1. INTRODUCTION

Micro, Small, and Medium Enterprises (MSMEs) contribute significantly to the national economy by generating employment and driving local business revenue [1]. The culinary sector represents a highly competitive segment within this ecosystem. Financial stability is essential for these micro and small businesses to maintain profitability. A critical element in setting appropriate product prices is the Cost of Production (HPP), which encompasses raw materials, direct labor, and overhead expenses [2]. However, culinary MSMEs frequently face financial instability due to cost fluctuations. Suppliers often change raw material prices daily based on market availability, and utility expenses vary according to monthly usage. Many MSME entrepreneurs lack formal financial training and rely on simple cost summation or competitor pricing to determine their selling prices [3]. This simplistic approach ignores cost uncertainty and often results in inaccurate pricing, which can lead to reduced profit margins when unaccounted expenses arise.

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Traditional accounting methods, such as Full Costing, rely on deterministic summation [4]. These methods calculate unit costs by adding direct materials, direct labor, and variable overhead, assuming a static cost environment. Consequently, they fail to accommodate daily fluctuations in the quantity, price, or rate of cost elements [Nisa, 2025]. To address cost uncertainty, researchers apply computational intelligence techniques. Fuzzy logic processes ambiguous data using linguistic variables rather than strict binary logic [5]. The Fuzzy Mamdani inference system is particularly suitable for business applications because it models human-like deduction through IF-THEN rules, ultimately producing a crisp conclusion [6]. Prior research has utilized fuzzy inference systems to optimize production quantities and estimate manufacturing costs [7]. Other studies have applied the Fuzzy Sugeno technique for decision-making and production planning [8]. While these intelligent systems perform well, they predominantly focus on structured manufacturing environments rather than micro-level culinary operations.

Despite these advancements, current literature exhibits distinct methodological and practical limitations. Most fuzzy HPP investigations rely on desktop-based software simulations that require technical expertise to operate [4]. Furthermore, existing models primarily target medium-scale manufacturing or focus on production volume optimization rather than unit-level costing for daily pricing decisions [9]. When researchers address MSME costing, they frequently apply the Sugeno method. The Sugeno method generates mathematical functions in the rule consequents, which can be difficult for non-technical business owners to interpret. In contrast, the Mamdani approach uses linguistic fuzzy sets for both inputs and outputs, producing a membership function that is more intuitive and transparent [10]. Currently, there is a lack of practical, web-based Mamdani decision support systems tailored specifically for the volatile cost structures of culinary micro-enterprises.

Bridging this gap requires translating complex fuzzy algorithms into accessible digital tools. A web-based platform allows MSME owners to input real-time cost data and receive immediate, uncertainty-adjusted pricing recommendations without installing specialized software [11]. This study applies the Fuzzy Mamdani approach to compute the adaptive Cost of Production for a culinary MSME. The research models raw material and overhead cost uncertainties using MIN-MAX inference and centroid defuzzification, while treating constant labor costs as a deterministic addition post-defuzzification. The primary contribution is the design and implementation of a web-based advisory system. This artifact shifts MSME costing from deterministic summation to an adaptive, linguistically driven approach, generating structured profit margin recommendations that provide a transparent pricing mechanism for micro-enterprises operating in volatile supply chains.

2. METHODOLOGY

Research Design and Context

This study employs an applied quantitative case study design. The research context is UMKM Kopaja, a culinary micro-enterprise operating in a competitive local market. Purposive sampling selected this single case based on its exposure to daily raw material price fluctuations and its operational readiness to adopt web-based decision support tools [1]. The design focuses on translating mathematical fuzzy logic into a practical software artifact for micro-level managerial accounting [11].

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Data Collection and Variables

Primary data collection occurred through semi-structured interviews and financial record extraction in September 2025. The model evaluates two fuzzy input variables: Raw Material Cost and Overhead Cost. The output variable is the Cost of Production (HPP) [2]. Direct Labor Cost remains constant at Rp2,593 per unit across all observed production scenarios. The model excludes labor from the fuzzy inference engine and adds it deterministically to the final defuzzified output [6]. Table 1 defines the universe of discourse, linguistic terms, and curve parameters for the fuzzy variables.

Table 1. Fuzzy Variable Parameters and Linguistic Terms

Variable	Linguistic Term	Curve Type	Parameters (a, b, c) in IDR
Raw Material	Low	Linear Decrease	20,010
	Medium	Triangular	20,010; 21,165; 22,319
	High	Linear Increase	22,319
Overhead	Low	Linear Decrease	3,889
	Medium	Triangular	3,889; 4,074; 4,259
	High	Linear Increase	4,259
Cost of Production	Low	Linear Decrease	26,491
	Medium	Triangular	26,491; 27,831; 29,171
	High	Linear Increase	29,171

Fuzzy Mamdani Model Formulation

The fuzzification process maps crisp input values into linguistic categories using three membership functions based on interpretable linguistic adaptation models [12]. The system applies a linear decrease function for the "Low" category, a triangular function for the "Medium" category, and a linear increase function for the "High" category. Equation (1) defines the general triangular membership function used for the medium category, where a, b and c represent the minimum, peak, and maximum boundaries [7].

$$\mu(x) = \begin{cases} 0 & x \le a \\ \dfrac{x-a}{b-a} & a < x < b \\ 1 & x = b \\ \dfrac{c-x}{c-b} & b < x < c \\ 0 & x \ge c \end{cases} \quad (1)$$

Rule Base Construction

The rule base connects the input variables to the output variable using logical IF-THEN statements. With two inputs and three linguistic terms each, the system generates nine rules based on managerial accounting logic [13]. Higher input costs logically dictate a higher cost of production. Table 2 presents the complete rule base.

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Table 2. Fuzzy Mamdani Rule Base

Rule	IF Raw Material	AND Overhead	THEN Cost of Production
R1	Low	Low	Low
R2	Low	Medium	Low
R3	Low	High	Medium
R4	Medium	Low	Medium
R5	Medium	Medium	Medium
R6	Medium	High	High
R7	High	Low	High
R8	High	Medium	High
R9	High	High	High

Inference and Defuzzification

The inference engine applies the MIN operator to evaluate the antecedent of each rule, following expert judgment-based risk assessment frameworks [14]. Equation (2) calculates the alpha-predicate α_i for the i-th rule, where $\mu_{BB}(x)$ and $\mu_{OH}(y)$ are the membership degrees of the raw material and overhead inputs.

$$\alpha_i = \min(\mu_{BB}(x), \mu_{OH}(y)) \qquad (2)$$

The system aggregates the clipped output sets from all active rules using the MAX operator. Equation (3) defines this composition, where $\mu_{sf}[x_i]$ represents the aggregated fuzzy solution set.

$$\mu_{sf}[x_i] = \max(\mu_{sf}[x_i], \mu_{kf}[x_i]) \qquad (3)$$

Finally, the Centroid method defuzzifies the aggregated set into a crisp Cost of Production value z^*. Equation (4) calculates the center of area, where $\mu(z)$ is the aggregated membership function across the domain z [15].

$$z^* = \frac{\int z\mu(z)dz}{\int \mu(z)dz} \qquad (4)$$

System Architecture

The fuzzy model was implemented as a web-based decision support system using HTML and Visual Studio Code. The architecture processes user inputs through sequential fuzzification, inference, and defuzzification modules to generate the final HPP and margin-based pricing recommendations [9]. This implementation aligns with recent web-based fuzzy decision models that prioritize accessibility for non-technical users [16]. Figure 1 illustrates the system architecture and data flow.

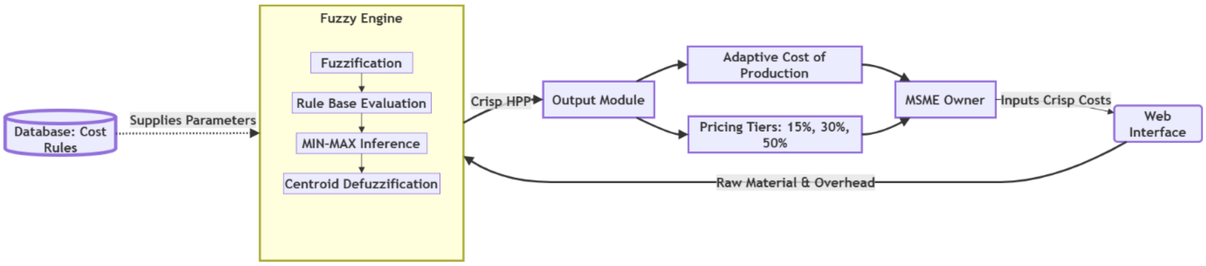

Figure 1. System Architecture and Data Flow for the Web-Based Fuzzy DSS

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Figure 1 illustrates the structural design and data flow of the web-based decision support system. The architecture demonstrates how user inputs for raw material and overhead costs transition through the fuzzification, inference, and defuzzification modules to generate the final adaptive Cost of Production and pricing recommendations.

3. RESULT AND DISCUSSION

Production Cost Data

The fuzzy model is a great method when it comes to evaluating cost fluctuations using a very detailed baseline dataset. The main raw data collection from the UMKM Kopaja unit resulted in three different cost situations (Low, Normal, and High) given market price fluctuation. The Normal cost scenario is the main working baseline that also serves as the main feeder input to the fuzzy inference machine. Table 3 illustrates the Normal cost of raw materials per unit.

Table 3. Normal Raw Material Cost Breakdown per Unit

Item	Purchase Price (IDR)	Yield (Units)	Cost per Unit (IDR)
Coffee Beans	250,000	30	8,333
Hazelnut Syrup	150,000	50	3,000
Palm Sugar	23,000	20	1,150
Creamer	45,000	20	2,250
Ice Cubes	20,000	15	1,333
UHT Milk	22,000	7	3,143
Gallon Water	10,000	50	200
Packaging	500,000	500	1,000
Total			**20,410**

The workers involved in direct labor are the primary human resource for the whole production operation. Since all the workers working on direct labor are being paid a fixed wage each month, the amount of the cost of direct labor stays exactly same for all levels of production that have been observed.

Table 4. Labor Cost Allocation

Monthly Salary (IDR)	Total Menu Items	Working Days	Cost per Unit (IDR)
2,800,000	36	30	2,593

Table 5 details the Normal overhead cost breakdown. Overhead includes indirect operational expenses required to sustain daily production

Item	Monthly Cost (IDR)	Working Days	Menu Items	Cost per Unit (IDR)
Rent	3,500,000	30	36	3,241
Electricity	400,000	30	36	370
Equipment Maintenance	200,000	30	36	185
Gas	300,000	30	36	278
Total				**4,074**

Baseline Conventional Cost of Production

The deterministic baseline relies on simple summation. Applying the Normal scenario data produces the conventional Cost of Production (HPP). The conventional HPP is Rp27,077. This static value assumes fixed operational conditions and ignores daily supply chain volatility.

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$$HPP = 20410 + 2593 + 4074 = 27077 \qquad (5)$$

Fuzzification Process

The fuzzification unit of the system transforms the numerical values like Raw Material = 20,410 and Overhead = 4,074 (which are the crisp inputs) into linguistic categories (as the system works with words) after matching the values with the membership functions of respective terms in Table 1. Raw Material membership chart is shown in Figure 2.

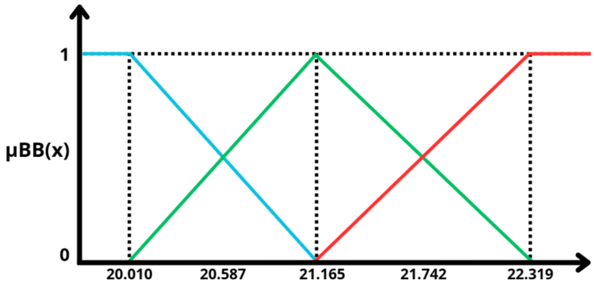

Figure 2. Raw Material Membership Functions and Fuzzification Degrees

Figure 2 displays the triangular and linear membership functions used to map crisp raw material costs into linguistic variables. The graph highlights the specific intersection points where the normal input value of Rp20,410 yields a membership degree of 0.654 for the low category and 0.346 for the medium category. The Raw Material input of 20,410 intersects the "Low" and "Medium" sets. Equation (6) calculates the membership degree for the "Low" set using the linear decrease function.

$$\mu_{low}(20410) = \frac{21165 - 20410}{21165 - 20010} = \frac{755}{1155} = 0,654 \qquad (6)$$

Equation (7) calculates the membership degree for the "Medium" set using the left side of the triangular function.

$$\mu_{medium}(20410) = \frac{20410 - 20010}{21165 - 20010} = \frac{400}{1155} = 0,346 \qquad (7)$$

Figure 3 illustrates the Overhead membership curves. The crisp input of 4,074 aligns exactly with the peak of the "Medium" triangular function.

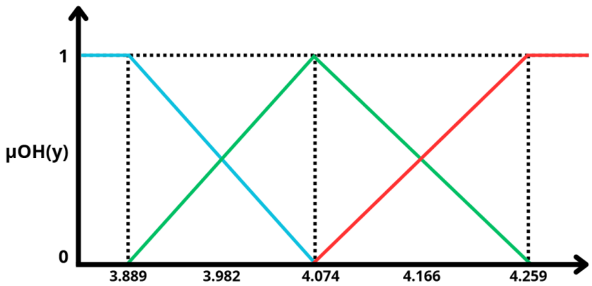

Figure 3. Overhead Membership Functions and Fuzzification Degrees

Figure 3 presents the membership curves for the overhead cost variable using linear decrease, triangular, and linear increase functions. The visual mapping confirms that the crisp input value of Rp4,074 aligns perfectly with the peak of the medium linguistic set and results in a maximum membership degree of 1.0. Equation (8) confirms the membership

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degree for the Overhead "Medium" set, as the "Low" and "High" Overhead sets yield a membership degree of 0.

$$\mu_{medium}(4074) = 0 \qquad (8)$$

Inference and Rule Evaluation

The inference engine applies the MIN operator to the rule base (Table 2; Equation 2) to compute the strength with which a rule supports the conclusion. As shown in Equation 9, only the rules that refer to the presence of "Low" Or "Medium" Raw Material with "Medium" Overhead activate. For Rule 2 the calculation of the matching level is the subject of Equation 9.

$$\alpha_2 = \min(\mu_{BB\_low}, \mu_{OH\_medium}) = \min(0.654, 1) = 0.654 \qquad (9)$$

Rule 5 (IF Raw Material is Medium AND Overhead is Medium THEN HPP is Medium) produces an alpha-value of $\min(0.346, 1) = 0.346$. Other rules produce a zero value. Figure 4 represents HPP output membership functions. While Figure 5 demonstrates the MIN clipping process for the active rules.

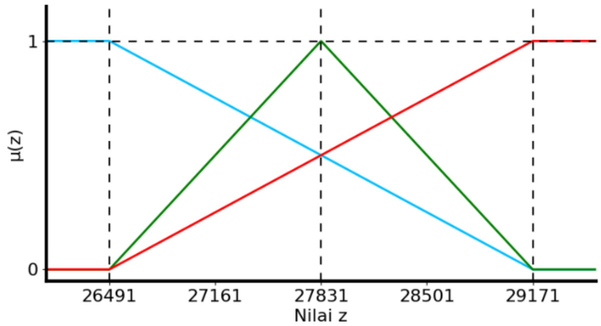

Figure 4. Cost of Production Membership Functions

Figure 4 defines the output variable boundaries for the Cost of Production using three distinct linguistic sets. The graph establishes the mathematical limits for the low, medium, and high-cost categories based on the minimum, normal, and maximum production scenarios.

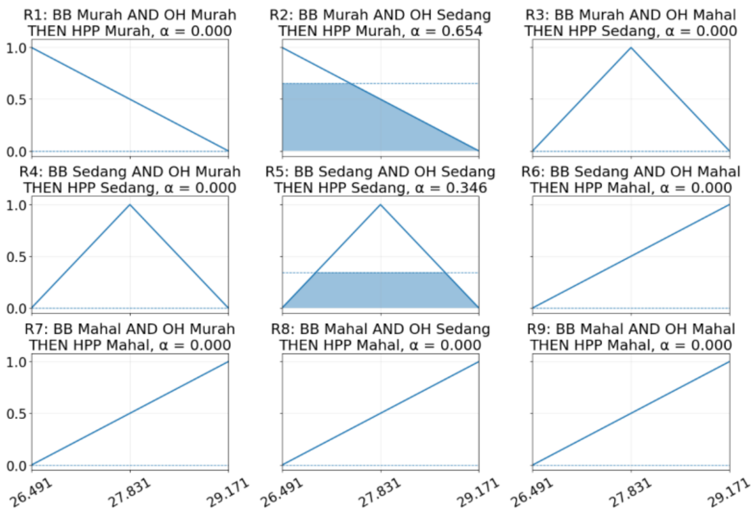

Figure 5. Rule Evaluation and MIN Clipping Process

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Figure 5 visualizes the MIN implication method applied to the active fuzzy rules. The diagram shows how the alpha-predicate values of 0.654 and 0.346 truncate the low and medium output membership functions.

Aggregation and Defuzzification

In this case, the clipped output sets are aggregated with the MAX operator (Equation 3). The alpha level corresponding to the highest membership degree in the Low HPP set is 0.654 whereas the one for Medium HPP set is 0.346. Figure 6 illustrates the fuzzy solution space resulting from aggregation.

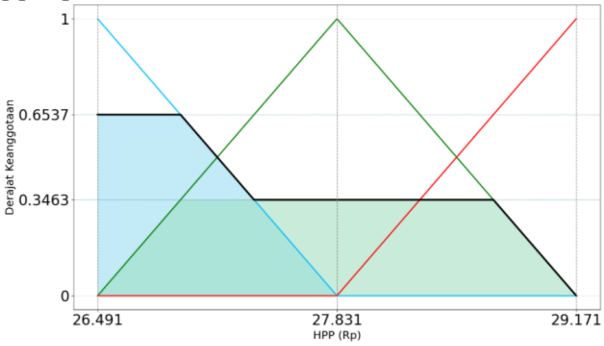

Figure 6. Output Aggregation using MAX Composition

Figure 6 depicts the unified fuzzy solution space generated by combining the clipped output sets. The shaded region represents the maximum membership values across all activated rules and merges the truncated low and medium functions into a single continuous polygon. The Centroid method calculates the final crisp output. The aggregated area divides into four distinct geometric regions based on the intersection points of the clipped functions as

$$t_1 = 27,418.28$$
$$t_2 = 26,954.64$$
$$t_3 = 28,707.36$$

Table 5. Centroid Defuzzification Area and Moment Calculations

Region	Geometric Shape	Area A_i	Moment M_i
1	Rectangle (Low HPP)	606.44	16,346,402.07
2	Trapezoid (Low to Medium HPP)	238.14	6,576,330.30
3	Rectangle (Medium HPP)	303.22	8,571,796.59
4	Triangle (Medium to High HPP)	80.21	2,315,005.45
Total		**1,228.01**	**33,809,534.41**

Substituting the totals into Equation (4) yields the final defuzzified HPP.

$$z^* = \frac{33,809,534.41}{1,228.01} = 27,531.95 \approx 27,532$$

The Fuzzy Mamdani model outputs an adaptive HPP of Rp27,532. This represents a 1.68% increase (Rp455) over the conventional deterministic calculation.

Pricing Strategy Recommendations

The system applies standard culinary profit margins to the defuzzified HPP to generate pricing tiers. Table 6 details these recommendations.

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Table 6. Margin-Based Pricing Recommendation

Pricing Strategy	Profit Margin	Recommended Price (IDR)	Market Position
Economy	15%	31,662	Market penetration
Standard	30%	35,792	Stable baseline
Premium	50%	41,298	Exclusive positioning

The Standard pricing tier (Rp35,792) is very close to the price actually paid by the MSME, with a goodness of fit of 97.74%. The difference of only 2.0%, shows that not only the mathematical model, but also the fuzzy model, accurately reflect the current market situation and cost uncertainty.

Web System Implementation

A light-weight web browser application of the interface that contains the mathematical description of the process. The system leaves out the fixed labor costs at the interface of computation to minimize the computing burden. Users only need to key in the raw materials and overhead data and the program would handle fuzzy operations on its own: fuzzification inference defuzzification. Figure 7 depicts the user interaction workflow and processing logic of the system.

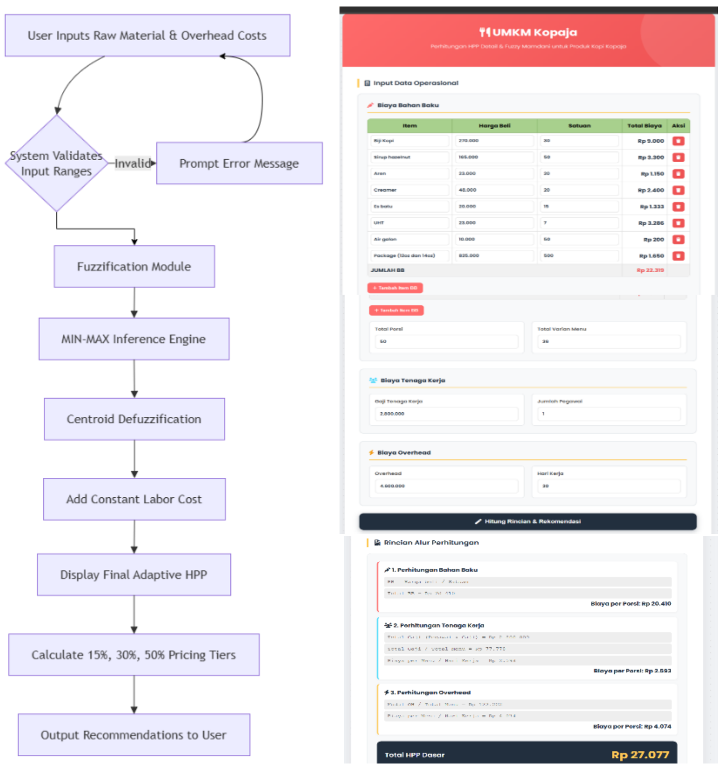

Figure 7. Web System Interaction and Processing Workflow

Figure 7 outlines the sequential user interaction and backend processing logic of the deployed web application. The flowchart details the validation of input ranges, the automated execution of the fuzzy inference sequence, and the final presentation of the adaptive Cost of Production alongside margin-based pricing tiers.

Discussion

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The 1.68% adjustment generated by the Fuzzy Mamdani model functions as a calculated risk premium. Conventional accounting averages costs, which exposes MSMEs to margin erosion when minor, unrecorded overhead or raw material variations occur. The fuzzy inference engine captures overlapping cost scenarios and balances these areas using MIN-MAX composition and centroid defuzzification, yielding a value that buffers against supply chain fluctuations. These findings contrast with deterministic Full Costing models documented in earlier MSME studies [17]. Full Costing allocates fixed overhead rigidly without considering daily operational variances. The results also diverge from Fuzzy Sugeno implementations [8]. While the Sugeno model computes outputs efficiently using linear mathematical functions in the rule consequents, it lacks the linguistic transparency required by non-technical MSME owners. The Mamdani approach maps linguistic inputs directly to corresponding rules, providing a clear explanation of the reasoning behind the pricing decision.

The practical implication is that MSMEs can transition from heuristic pricing to data-driven decision-making. The web artifact removes the technical barriers associated with desktop-based simulations, allowing non-technical users to access immediate margin analytics without advanced mathematical qualifications [11]. Embedding the fuzzy engine in a standard web browser eliminates the need for software installation and specialized expertise. This study exhibits specific boundaries. The research relies on a single case study, limiting the external validity of the 1.68% risk premium across different culinary sub-sectors. The model treats labor as a constant, which restricts the fuzzy engine to two dimensions. The current web implementation requires manual data entry and lacks integration with external supplier databases. Future research must integrate real-time market application programming interfaces to update fuzzy membership boundaries dynamically. Subsequent studies should evaluate the computational efficiency of the Sugeno method across multi-product menus and conduct longitudinal field tests to measure the actual profitability improvements of micro-enterprises using fuzzy pricing versus conventional accounting.

4. CONCLUSION

This work highlights, through the application of the Fuzzy Mamdani method, the possibility of having a systematic, flexible method which will do away with the rigid traditional deterministic costing of culinary micro-enterprises. By incorporating uncertainties of raw material and overheads with MIN-MAX inference and centroid defuzzification, the web-based decision support system developed gives a means to translate volatile cost conditions into the Cost of Production adjusted for risk. This flexible method gives a risk-based premium that helps to ensure the protection of the profit margins against the daily fluctuations in the supply chain.

The authors acknowledge the research is limited in that it has been based upon a one-case model study and besides labor cost has been treated as a constant thereby leaving out the fuzzy inference engine from being three-dimensional. The present web-based application calls for the user to input data manually and at the same time lacks an interface with suppliers' information systems outside. Researchers of the future should include the use of real-time market Application Programming Interfaces in the development which would serve the purpose of the dynamic updates of the fuzzy membership bounds. Other studies might as well assess the Sugeno method for computational performance under multi-product menu settings and do so with the help of field research over a number of years to find out real profit growths for micro-enterprises that adopt fuzzy pricing relative to conventional accounting.

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