Journal of Ecohumanism
2025
Volume: 4, No: 4, pp. 462 – 480
ISSN: 2752-6798 (Print) | ISSN 2752-6801 (Online)
https://ecohumanism.co.uk/joe/ecohumanism
DOI: https://doi.org/10.62754/joe.v4i4.6751

# Management of the Production Process of the Colombian Caribbean Coastal Cheese Supply Chain using Lean Manufacturing and Simulation in ProModel

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**Abstract**

*Resource and production yield management in the Colombian Caribbean Coastal Cheese supply chain was carried out through the structuring of a lean manufacturing model and process simulation in Promodel. Production input variables such as raw milk, rennet, salt, equipment, times, processes, and allocations were evaluated in corresponding scenarios. Significant variations in production by department and cheese type were obtained. Scenario 4 stood out due to the increase in production achieved, as well as the improvement in production capacity and demand satisfaction. This model optimized resources and established minimum lead times, improving the efficiency and quality of the final product, and identifying bottlenecks such as milk availability. It was also important to manage its supply to avoid interruptions, providing a comprehensive view for decision-making and effective strategies in the value chain.*

**Keywords:** *Caribbean Coastal Cheese, simulation model, supply chain, ProModel, lean manufacturing.*

## Introduction

This study analyzes data influencing the production of Colombian Caribbean Coastal Cheese using ProModel software simulation and continuous flow lean manufacturing. This study evaluates the effect of variables such as production volume, the amount of milk required and processed, rennet, salt required, pressing times, and the number of baskets of in-process and finished products. Milk inspection time, the amount of rennet and salt required, and the curdling, brining, and pressing processes were also analyzed. This allowed for an evaluation of the effect of these variables on the total production time of Colombian Caribbean Coastal Cheese.

## Theoretical and Conceptual Framework

### Supply Chain

The Supply Chain (SC) is described as a succession of actions that connects customers, institutions, and suppliers through procurement, manufacturing, marketing, and services that facilitate the integration of material, financing, and information flows, so that these can be effectively achieved to fulfill the business foundation, which is the timely delivery of quality goods to a customer, in order to satisfy their needs and expectations (see Figure 1). Therefore, the supply chain can be divided into three basic segments: procurement, manufacturing, and delivery (Morales, Rojas, Hernández, Morales, Rodríguez & Pérez, 2013).

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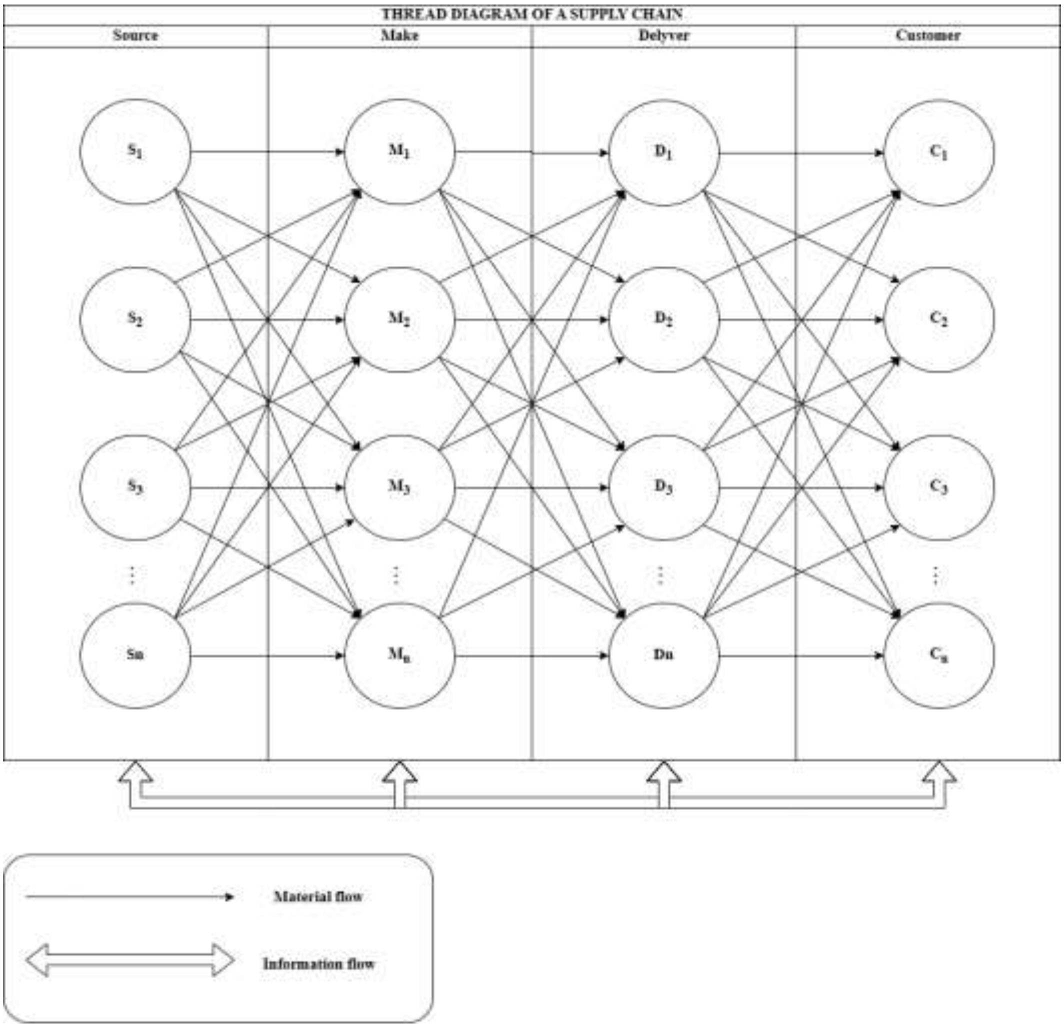
**Figure 1. An approach to the supply chain diagram of the Coastal Cheese Supply Chain**




Source: Authors.

**Simulation ProModel**

The simulation model consists of a set of representations expressed as mathematical, logical, or symbolic relationships between the entities acting in the system. A major advantage of simulation is that once a model is built, it can be used repeatedly to experiment with different alternatives, compare them, and support decisions without requiring significant resources (Ghosh *et al.*, 2000; Morales *et al.*, 2000; Restrepo & Viuche, 2012).

**Types of data required for the simulation model**

The type of information required to simulate a process can vary depending on the type of simulation model used, as simulation models can be deterministic or probabilistic. Deterministic models have no variability in the data, while probabilistic models use random variables and require parameter analysis before running the simulation. They typically use random input variables to simulate variability in the results, and many parameters can be expressed as discrete variables (Calderón & Lario, 2007; Bernal; *et al*, 2015; Causado; *et al*, 2020;).

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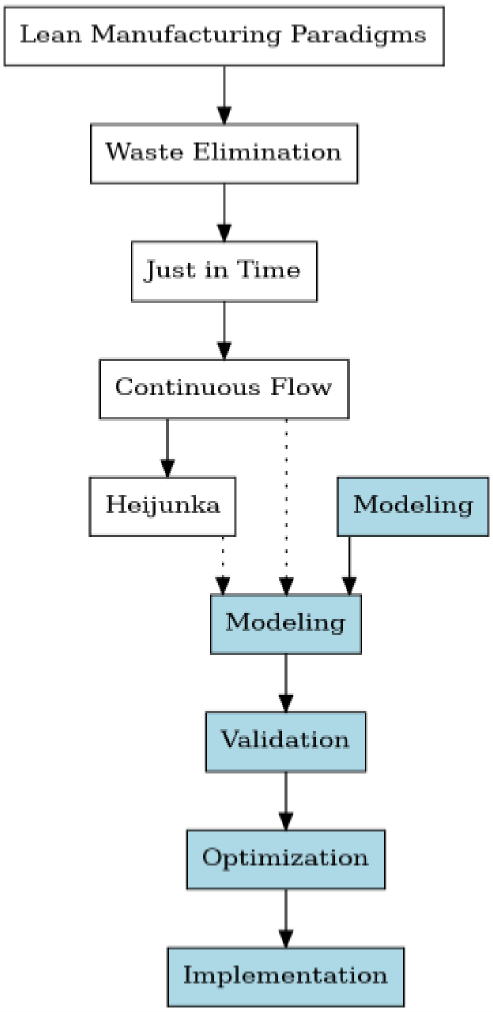
**Lean manufacturing design in the supply chain**

For Morales; *et al* (2000), The design and representation of key elements for creating simulation models of a supply chain are based on the lean manufacturing paradigm. To this end, a simulation tool is used for process evaluation and optimization (see Figure 2). The left column of the conceptual map describes the principles of the lean manufacturing paradigm, including waste elimination, just-in-time, continuous flow, and heijunka. The right column shows the steps in the simulation and optimization process, beginning with modeling, followed by validation and optimization, and finally the implementation of the proposed improvements.

**Figure 2. Design of a simulation model for lean manufacturing**




Source: Adapted from Morales; *et al* (2000).

Furthermore, a hierarchical structure can be observed in the process map, where the logistics simulation and optimization model is the central element and the different phases that comprise, it are grouped into two clusters: the first related to modeling, and the second to the simulation and optimization phases. This structure facilitates understanding and organization of the different steps required to carry out a successful logistics simulation and optimization (see Figure 3).

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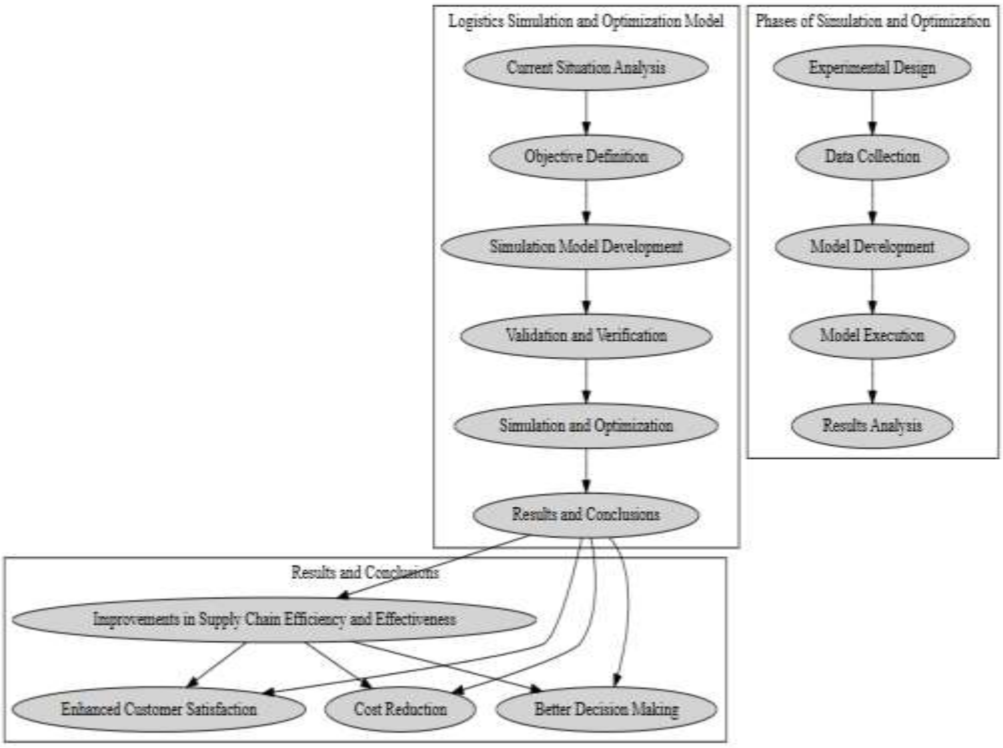
**Figure 3. Phases of the design of a logistics simulation and optimization model**




Source: Adapted from Torres., *et al* (2013).

**Simulation with ProModel**

ProModel is specialized simulation software for evaluating, planning, or redesigning manufacturing, warehousing, distribution, logistics, and transportation processes. This easy-to-use tool allows you to build a computational representation of a company's operations, then evaluate different configuration scenarios and provide the best solution. The animation and graphical results are extremely powerful tools for visualizing and understanding the behavior of a production system (Mondragon et al., 2005; Dunna et al., 2006; Alfonso, 2020).

This simulation software is used by companies around the world to simulate their operations in search of productivity improvements, production optimization, cost reduction, etc., as well as for evaluating ideas and designs for new systems (Bernal, Cock, & Restrepo, 2015, p. 135). In simulation models, ProModel software can be used to develop the basis for production flows, projecting process times, equipment, and facilities in their respective processes (Restrepo & Victoria, 2012).

## Methodology

Logistics is an indispensable part of a supply chain, as it is responsible for coordinating each of the processes, actors, and/or links that comprise it. This includes actions such as defining activities and agreements, ranging from supplying the raw materials necessary for the production of a good or service to marketing and distribution until it reaches the wholesale, retail, and/or final consumer (Causado et al., 2018). Therefore, it is imperative to design a software-based model that allows for optimal improvement or strengthening of supply chain processes, with appropriate information and guidance. This requires a preliminary assessment of the parameters that facilitate modeling and simulation using appropriate data from various sources, whether primary or secondary, for each of the actors and processes in the supply chain of interest (Causado; *et al*, 2019).

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**Model configuration**

When configuring the model processes to be simulated to produce Coastal Caribbean Cheese in Colombia, it is important to consider the information provided by dairy industry experts. According to Arteaga et al. (2020), raw materials, such as milk, lactic acid bacteria cultures, and salt, must be carefully selected and controlled to ensure the quality of the final product. Likewise, Gutiérrez, Quintero, Burbano, & Simancas (2017) emphasize that choosing the right equipment and machinery is essential to optimize the efficiency and consistency of the Queso Costeño (Coastal Caribbean Cheese) production process.

According to research conducted by García, Rodríguez, Contreras, & Jiménez (2019), the production processes for Queso Costeño del Caribe (Caribbean Coastal Cheese), such as unpasteurized milk, coagulation, and molding, must be carried out following specific parameters of time, temperature, and techniques. These parameters may vary depending on the standards established by regulations and best practices in the dairy industry (Pérez, Burgos & Almeida, 2018).

Establishing rigorous quality controls is essential to ensure the consistency and safety of Caribbean Coastal Cheese. According to Ramírez, Mendoza, Torres & Hernández (2021), within this framework, quality control criteria can include acidity, pH, fat content, and sensory evaluation. These criteria ensure that the cheese meets the standards established by the geographic region and consumer preferences (González, López & Delgado, 2019).

Production capacity planning and the time required for each stage of the process can be based on information gathered in the field, as in previous studies conducted in the dairy industry (Hernández, López, Ramírez, & Torres, 2022). Considering market demands and delivery times contributes to establishing an efficient production program (Sánchez, García, Martínez, & Rodríguez, 2021). Furthermore, it is important to evaluate and optimize available resources to avoid bottlenecks and maximize productivity (López, Martínez, Ramírez, & García, 2023).

**Supply Chain Flowchart**

A detailed description of the production processes in the Caribbean Coastal Cheese Supply Chain is shown in the flowchart in Figure 4. It begins with the supplier, who sends the raw milk to the producer. The milk is evaluated to determine if it meets quality standards and, if suitable, is sent to a coagulation tank or stored in a refrigerated tank. In the curdling tank, the rennet required to begin the curdling process is added. Two products are generated: curd and whey. The curd is separated from the whey, and salt is added using brine to the chopped or kneaded cheese. It is then mixed and molded in a press, as appropriate. The distributor maintains adequate storage conditions and transports the cheese until it reaches the final customer.

**Parameter Description**

The parameters used to build the simulation model were based on primary information obtained by the researchers, as well as a priori or secondary sources.

**Simulation Model Data**

Parameters were then defined to facilitate the collection of primary information on the production volume of producers in the departments of Magdalena, La Guajira, and Córdoba in 2022-2023. These parameters included characteristics such as the amount of milk used, the amount of rennet required, the firmness of the cheese, and the type of production process.

**Subscript Nomenclature for the Simulation Model**

To determine the coastal cheese production data, data matrices were developed to facilitate the use of the subscript "i" to identify the type of cheese production process and the subscript "j" to define the firmness of the cheese obtained (see Table 1). Additionally, for coastal cheese producers, the subscript "m" was used

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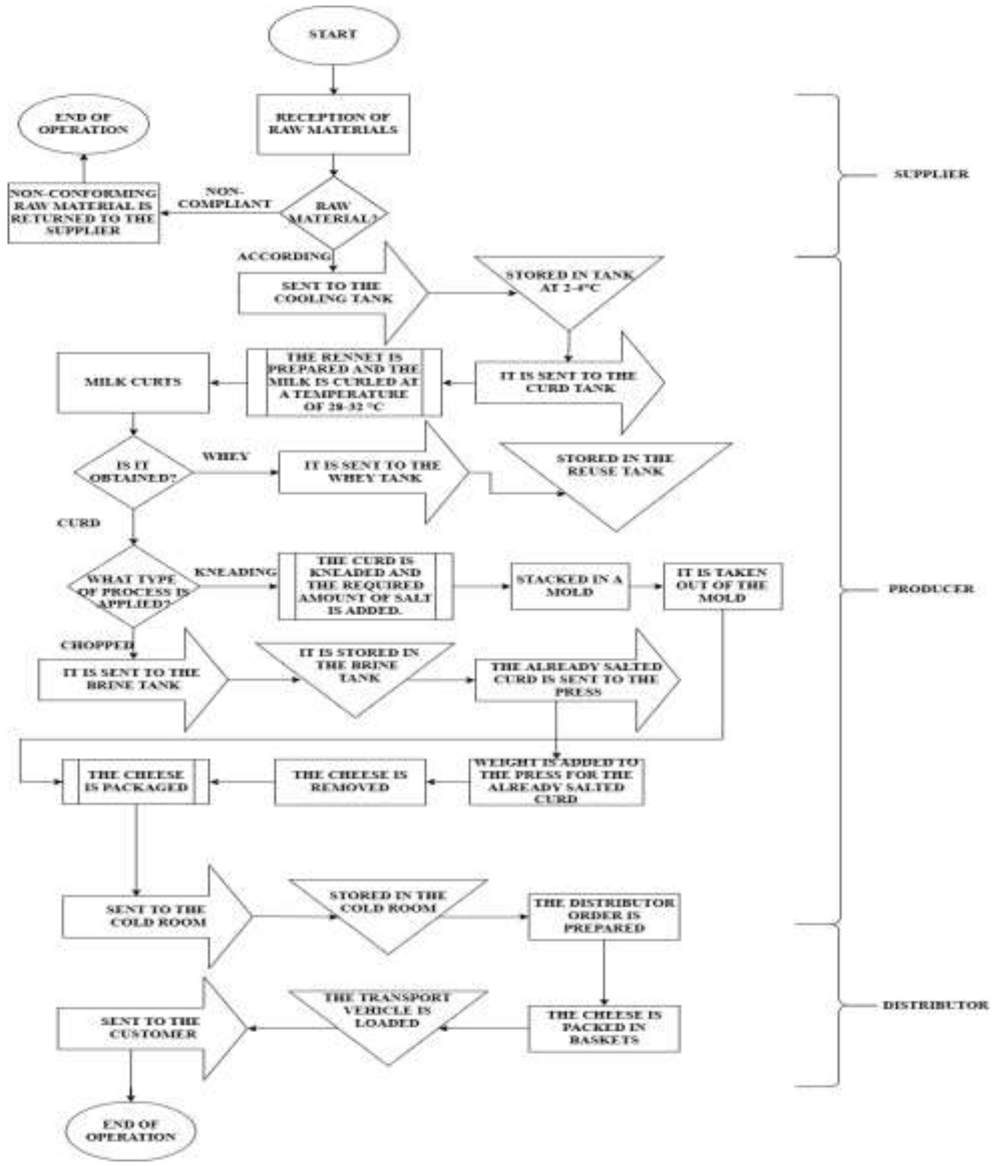
to identify each producer. Information was conveniently collected from a total of 86 coastal cheese producers in the departments of Magdalena, La Guajira, and Córdoba. Data was collected from surveys conducted during the years 2022-2023 for the simulation model in ProModel.

**Figure 4. Approximation of a Flowchart for the Production Process of Caribbean Costeño Cheese in the Supply Chain.**




Source: Authors.

**Table 1. Characteristics of Process Type (i), Cheese (j)**

| Process Type | i | Cheese Type | j |
|---|---|---|---|
| Chopped | 1 | Hard | 1 |
| Kneaded | 2 | Semi-hard | 2 |
| Mixed | 3 | Soft | 3 |
| | | Semi-soft | 4 |

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Source: Authors, based on data from the Costeño cheese project.

**Nomenclature of the parameters associated with the basket requirement for the simulation model**

To determine the number of baskets for the "basket" entity, the quantity of cheese is divided by 30 kilograms of cheese as a standard measure. To determine the number of baskets required to store a given quantity of cheese, equation (1) can be used to perform this calculation.

$$NB_{ijm} = \frac{Q_{ijm}}{30} \tag{1}$$

Where "NBijm" represents the number of baskets required per day of production, per producer, type of process, firmness obtained (u/day); and the quantity of cheese produced Qijm in kg/day.

**Summary of the nomenclature of the parameters associated with the simulation model**

Table 2 below contains detailed information on the parameters associated with the simulation model. This table provides a comprehensive description of the symbols used, the full name, and the corresponding units for each parameter. Its purpose is to provide a clear and concise reference to facilitate the understanding and analysis of the model results.

**Matrix of parameters associated with the simulation model**

The parameters used in the simulation model of the coastal cheese production process were obtained from surveys conducted with producers in different municipalities in the departments of Magdalena, Córdoba, and La Guajira. The surveys are part of the diagnostic study of the Caribbean Coastal Cheese supply chain for the years 2022-2023. Information was collected on various aspects of the process, such as the quantity of milk, the amount of rennet used, pressing time, and transfer times during the production process.

**Table 2. Summary of the Nomenclature Used for the Parameters of the Simulation Model**.

| Símbolo | Nombre | Unidades |
|---|---|---|
| $Q_{ijm}$ | Quantity of cheese produced | $Kg/day$ |
| $AMRP1Q_{ijm}$ | Quantity of milk required to produce 1 kilogram of cheese | $L/Kg$ |
| $AMP_{ijm}$ | Quantity of processed milk | $L$ |
| $ARP1Q_{ijm}$ | Quantity of rennet required to produce 1 kilogram of cheese | $mL/Kg$ |
| $ARU_{ijm}$ | Quantity of rennet used per day | $mL/day$ |
| $SALT_{ijm}$ | Quantity of salt | $Kg/day$ |
| $NB_{ijm}$ | Quantity of baskets required per day | $u/day$ |
| $MIT_{ijm}$ | Milk inspection time | $min$ |
| $\mathrm{MCT}_{ijm}$ | Minimum curdling time | $min$ |
| $PT_{ijm}$ | Pressing time | $min$ |
| $TMMTTC_{ijm}$ | Time to transport milk from the storage tank to the curdling tank | $min$ |
| $TMCTC_{ijm}$ | Time to transport rennet to the curdling tank | $min$ |
| $TMCTS_{ijm}$ | Time to transport curd to the brine tank | $min$ |
| $TMSTS_{ijm}$ | Time to transport salt to the brine tank | $min$ |
| $TMCTP_{ijm}$ | Time to transport cheese to the press | $min$ |
| $TMCCR_{ijm}$ | Time to transport pressed cheese to the cold room | $min$ |
| $TECCRTC_{ijm}$ | Time to label cheese from the cold room before being sent to the transport vehicle | $min$ |

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Source: Authors.

**Matrix of suggested parameters for the simulation model**

Simulating the coastal cheese production process in ProModel allows dairy sector stakeholders to improve efficiency and productivity in the supply chain. It is also a valuable tool for identifying growth opportunities in the regional cheese industry.

n Table 3, the renneting time data were analyzed using ProModel's input analysis tool, yielding the following probability distributions for renneting times in the production of the Caribbean Coastal Cheese: $MCT_{11m}$, $MCT_{12m}$, $MCT_{13m}$, $MCT_{14m}$, $MCT_{21m}$, $MCT_{31m}$, $MCT_{32m}$ and $MCT_{34m}$; which were performed a "Fit all" test to choose their closest probability distribution function with the lowest square error (Sq. Error) value in the "Fit all Summary" output window.

**Table 3. Curdling Time Parameters for Production.**

| Symbol | i | j | Number of Data | KS Test | Sq. Error | Units | Interval | Distribution Type | Parameters |
|---|---|---|---|---|---|---|---|---|---|
| $\text{MCT}_{ijm}$ | 1 | 1 | 13 | * | 0.12 | $min$ | 5-60 | Beta | $\alpha = 10$, $\beta = 1.67$ |
| $MCT_{ijm}$ | 1 | 2 | 7 | * | 0.13 | $min$ | 3-40 | Beta | $\alpha = 0.409$, $\beta = 0.567$ |
| $MCT_{ijm}$ | 1 | 3 | 19 | >0.15 | 0.0068 | $min$ | 1-60 | Weibull | $\alpha = 0.762$, $\beta = 14.1$ |
| $MCT_{ijm}$ | 1 | 4 | 3 | * | 0.131 | $min$ | 3-20 | Triangular | $a = 3$, $m = 10$ y $b = 20$ |
| $MCT_{ijm}$ | 2 | 1 | 7 | * | 0.144 | $min$ | 12-60 | Beta | $a = 0.198$, b= 0.266 |
| $MCT_{ijm}$ | 2 | 2 | 2 | * | ** | $min$ | 1-120 | Exponential | $\lambda = 0.044053$ |
| $MCT_{ijm}$ | 2 | 3 | 2 | * | ** | $min$ | 1-120 | Exponential | $\lambda = 0.044053$ |
| $MCT_{ijm}$ | 2 | 4 | 2 | * | ** | $min$ | 10-30 | Uniform | $a = 10$, b = 30 |
| $MCT_{ijm}$ | 3 | 1 | 6 | * | 0.108 | $min$ | 1-60 | Beta | $a = 0.206$, b= 0.188 |
| $MCT_{ijm}$ | 3 | 2 | 5 | >0.15 | 0.0566 | $min$ | 10-120 | Exponential | $\lambda = 0.022727$ |
| $MCT_{ijm}$ | 3 | 3 | 2 | * | ** | $min$ | 1-120 | Exponential | $\lambda = 0.044053$ |
| $MCT_{ijm}$ | 3 | 4 | 4 | * | 0.202 | $min$ | 40-60 | LogNormal | $\mu_{ln} = 4.61$, $\sigma_{ln} = 16.1$ |

Source: Authors.

* It was not possible to perform the Kolmogorov-Smirnov test because the squared error was considered for evaluating whether the data fit a given probability distribution.

** It was not possible to obtain the squared error value from the Input Analyzer because only 20 to 30 data points were available for analysis, which does not meet the minimum required for the Kolmogorov-Smirnov test. Due to this limitation, the test could not be applied, and the decision was made to assume

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probability distribution functions for the data in question, considering the available information and study conditions.

To obtain the suggested parameters for calculating the time for the movements of raw materials, inputs, work-in-process, and finished product for Caribbean Coastal Cheese, a probability distribution can be assumed. This distribution can follow different types of time, depending on several factors such as the capacity of the transportation systems, the distance between points, and the flow rate, among others (see Table 4).

**Table 4. Movement Time Parameters by Location for Production**

| Símbolo | Proceso | Unidades | Intervalo | Tipo de distribución | Parámetros |
|---|---|---|---|---|---|
| $TMMTM_{ijm}$ | Time to transport milk to the milk storage tank | $min$ | 5-15 | Normal | $\mu$=10, $\sigma$=1.67 |
| $TMCTC_{ijm}$ | Time to transport milk to the curd tank | $min$ | 5-15 | Normal | $\mu = 10, \sigma = 1.67$ |
| $TMCTC_{ijm}$ | Time to transport rennet to the curd tank | $min$ | 5-15 | Exponential | $\lambda$ =0.1 |
| $TMCTS_{ijm}$ | Time to transport curd to the brine tank | $min$ | 5-15 | Normal | $\mu = 10, \sigma = 1.67$ |
| $TMSTS_{ijm}$ | Time to transport salt to the brine tank | $min$ | 5-15 | Uniform | $E(x) =$ 10, $D(x)$ =2.887 |
| $TOCPB_{ijm}$ | Processing time of curd in the brine | $min$ | 30-150 | Normal | $\mu = 90, \sigma = 10$ |
| $TMCTP_{ijm}$ | Time to transport cheese to the press | $min$ | 5-20 | Lognormal | $\mu = 15.869, \sigma = 2.106$ |
| $TMCCR_{ijm}$ | Time to transport pressed cheese to the cold storage | $min$ | 10-30 | Lognormal | $\mu = 26.783, \sigma = 3.049$ |
| $TCCRTC_{ijm}$ | Time to transport cheese from cold storage to the transport vehicle | $min$ | 5-20 | Lognormal | $\mu = 15.869, \sigma = 2.106$ |

Source: Authors.

**Simulation Model Development**

A model of the Caribbean Coastal Cheese supply chain was constructed for each producer based on the determined parameters of milk, rennet, salt, and production time. The model detailed the production process, and the type of firmness obtained throughout the Caribbean Coastal Cheese supply chain. The data used in the simulation model were continuous numerical values, as shown in Figure 5.

**Model Scenarios**

Four different scenarios were applied to simulate the model's behavior in the production of Caribbean Coastal Cheese. The scenarios included: 1. improvements in milk supply, 2. standardization of curdling and pressing times, and 3. the implementation of mandatory milk quality inspection.

Milk quality is critical to public health and food safety in the cheese sector. Furthermore, standardization of the milk curdling process into cheese is crucial to ensuring the quality of the final product.

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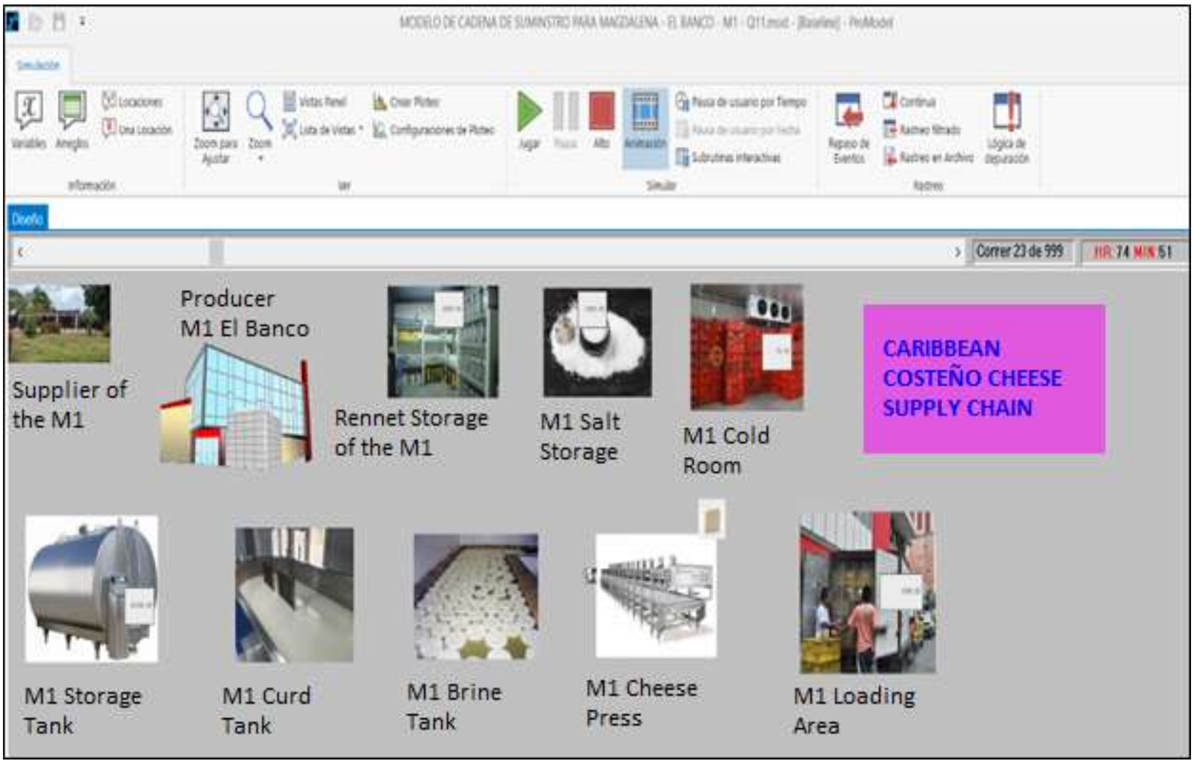
**Figure 5. Simulation Model Design in ProModel for Each Producer by Municipality/Department.**




Source: Authors with project data.

Curdling milk into cheese involves separating it into a solid part (curd) and a liquid part (whey) using a coagulant (Beckett, 2015). The curd is then cut, salted, and pressed to obtain cheese; in some cases, it is aged for a period of up to a week to achieve a dry, hard cheese, which can be used as grated cheese in the baking industry. These processes can vary depending on several factors, such as the type of milk, the coagulant used, the size of the cut, and the pressing and ripening times. These variations affect the flavor, aroma, texture, color, and shape of Queso Costeño del Caribe (Beckett, 2015). Therefore, it is essential to standardize the process of curdling milk into cheese to ensure it meets the necessary quality and identity requirements.

After simulating the first scenario in ProModel, data was collected, and statistical parameters of the simulated processes were obtained. The objective was to achieve greater control and improve the supply chain for Queso Costeño del Caribe. As a result, scenario 1 will determine the need to implement a more rigorous process for incoming milk inspection (see Table 5). The pressing time for chopped and mixed Queso Costeño del Caribe was also standardized (see Table 6).

**Table 5. Parameters of Milk Inspection Time and Minimum Coagulation Time for the Production Process of Costeño Cheese from the Caribbean.**

| Symbol | Units | Interval | Distribution Type | Parameters |
|---|---|---|---|---|
| $MIT_{ijm}$ | $min$ | 4.38-34.51 | Normal | $\mu = 19.445, \sigma = 5.02$ |
| $TMMTTC_{ijm}$ | $min$ | 31.93-52.25 | Normal | $\mu = 42.09, \sigma = 3.39$ |

Source: Authors with project data.

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**Table 6. Pressing Time Parameters for the Different Types of Costeño Cheese Produced in the Caribbean.**

| Symbol | i | j | Units | Interval | Distribution Type | Parameters |
|---|---|---|---|---|---|---|
| $PT_{ijm}$ | 1 | 1 | $min$ | 380-1415.62 | Normal | $\mu = 897.81, \sigma = 172.60$ |
| $PT_{ijm}$ | 1 | 2 | $min$ | 30-1416.39 | Normal | $\mu = 723.195, \sigma = 231.06$ |
| $PT_{ijm}$ | 1 | 3 | $min$ | 24-1199.89 | Normal | $\mu = 611.94, \sigma = 195.98$ |
| $PT_{ijm}$ | 1 | 4 | $min$ | 150-480 | Normal | $\mu = 315, \sigma = 55$ |
| $PT_{ijm}$ | 3 | 1 | $min$ | 60-1413.26 | Normal | $\mu = 736.63, \sigma = 225.54$ |
| $PT_{ijm}$ | 3 | 2 | $min$ | 35-240 | Normal | $\mu = 137.5, \sigma = 34.17$ |
| $PT_{ijm}$ | 3 | 3 | $min$ | 60-180 | Normal | $\mu = 180, \sigma = 20$ |
| $PT_{ijm}$ | 3 | 4 | $min$ | 40-60 | Normal | $\mu = 50, \sigma = 3.33$ |

Source: Authors with project data.

The fourth scenario of the simulation combined the results of the second and third scenarios, proposing a better diet and quality supplements, resulting in a 19.24% increase in milk production. This will allow for a supply of higher-quality milk to increase cheese production. Furthermore, curdling and pressing times were standardized, and mandatory milk inspection was implemented. The standardization of processing times also improved the efficiency of Caribbean Coastal Cheese production. In summary, the fourth scenario demonstrated that these actions have a positive impact on cheese production and quality by implementing improvements in the milk and cheese production process.

### Replicas and Simulation Time

The simulation time of 168 hours is equivalent to a full week, with 999 model replications performed to obtain more accurate and representative results of the system's behavior in different situations. These replications allow for a larger and more diverse sample of possible outcomes, which increases the reliability and validity of the results obtained.

## Results

Four key scenarios were applied from the simulation model to strategically analyze which mechanisms favor the Caribbean Coastal Cheese production chain. These data include: $Q_{ijm}$, $AMP_{ijm}$, $ARU_{ijm}$, $SALT_{ijm}$, $NB_{ijm}$, $MIT_{ijm}$, $TMCTS_{ijm}$, $MCT_{ijm}$, $TMSTS_{ijm}$, $TOCPB_{ijm}$ y $PT_{ijm}$ from the simulation of scenarios 1, 2, 3 and 4.

### Inspection Time

Figure 6 presents information on the $MIT_{ijm}$ v Estimated required for of Caribbean Coastal Cheese in Magdalena, La Guajira and Córdoba

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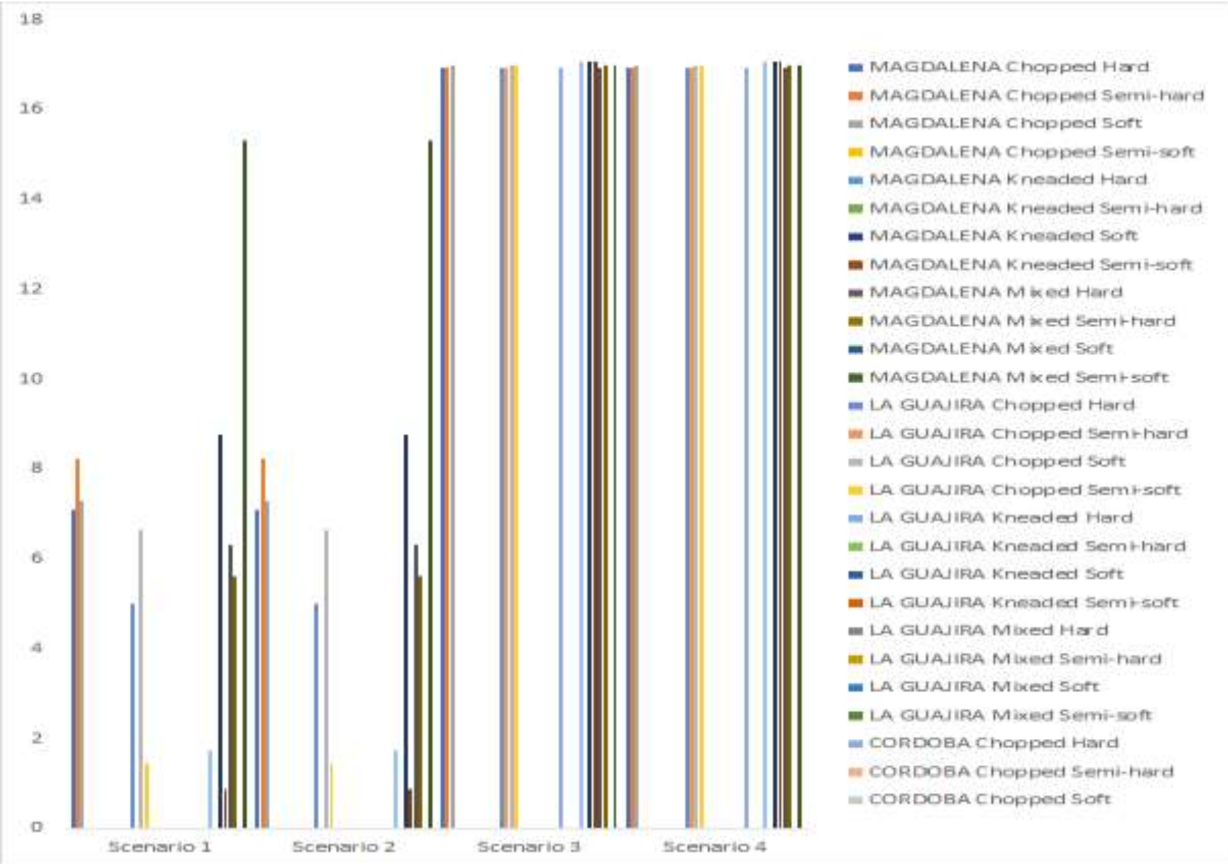
**Figure 6. Comparison of Estimated $\mathbf{MIT_{ijm}}$ of Caribbean Costeño Cheese in Scenarios 1, 2, 3, and 4**.




Source: Authors with Project Data.

In Scenario 1, inspection times in Magdalena are 7.09 minutes for hard cheese and 8.22 minutes for semi-hard cheese. In La Guajira, 5.00 minutes of inspection are required for hard cheese, and no inspection is required for semi-hard cheese. In Córdoba, no inspection is performed for hard cheese. In Scenario 2, inspection times are the same as in Scenario 1. In Scenario 3, inspection times vary. In Magdalena, 16.94 minutes of inspection are required for hard, semi-hard, and soft cheese. In La Guajira, 16.94 minutes of inspection are required for hard and semi-hard cheese, and 16.97 minutes for soft and semi-soft cheese. In Córdoba, 16.94 minutes of inspection are required for hard and semi-hard cheese. In Scenario 4, inspection times are the same as in Scenario 3.

**Milk curdling time**

Figure 7 presents information on the required $MCT_{ijm}$ Estimated for of Caribbean Coastal Cheese in Magdalena, La Guajira and Córdoba.

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Volume: 4, No: 4, pp. 462 – 480
ISSN: 2752-6798 (Print) | ISSN 2752-6801 (Online)
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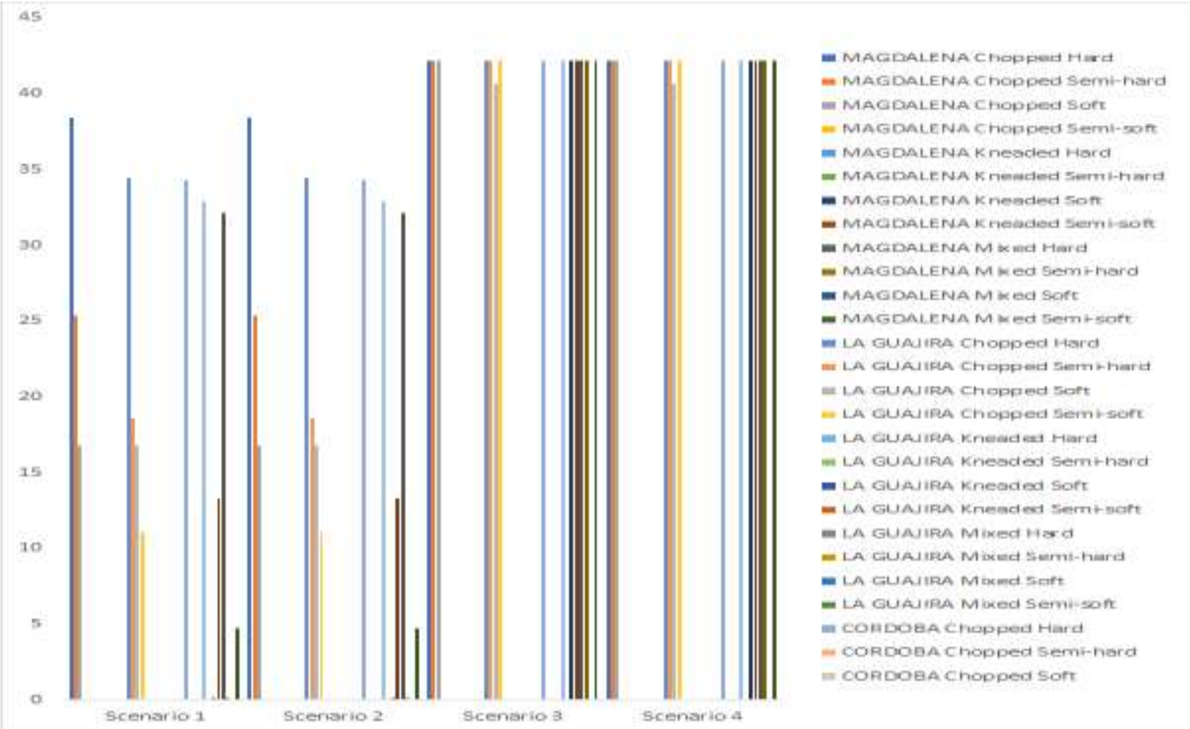
DOI: https://doi.org/10.62754/joe.v4i4.6751

**Figure 7. Comparison of Estimated $\mathbf{MCT_{ijm}}$ of Caribbean Costeño Cheese in Scenarios 1, 2, 3, and 4.**




Source: Authors with Project Data.

In Scenario 1, setting times vary between 39.37 minutes and 56.68 minutes in Magdalena, and between 28.53 minutes and 52.53 minutes in La Guajira. In Córdoba, 47.44 minutes of setting are required. In Scenario 2, setting times are identical to those in Scenario 1. In Scenario 3, setting times vary between 71.24 minutes and 71.27 minutes in Magdalena, between 69.94 minutes and 71.29 minutes in La Guajira, and are 71.27 minutes in Córdoba. In Scenario 4, the minimum setting times are identical to those in Scenario 3 in all three departments.

### 4.1 Tiempo de espera sal para la preparación de la salmuera

Figure 8 presents information about the $TMSTS_{ijm}$ Estimated for of Caribbean Coastal Cheese in Magdalena, La Guajira and Córdoba.

In Scenario 1, Magdalena requires 56.68 minutes of curdling time for hard cheese, 47.87 minutes for semi-hard cheese, and 39.37 minutes for soft cheese, while La Guajira requires 52.53 minutes for hard cheese, 33.73 minutes for semi-hard cheese, 38.70 minutes for soft cheese, and 28.53 minutes for semi-soft cheese. In Córdoba, curdling times are 47.44 minutes for hard and semi-hard cheese. In Scenario 2, the times are identical to those in Scenario 1, and in Scenario 3, 71.27 minutes of curdling time are required in Magdalena for all cheese types, while in La Guajira, 71.27 minutes are required for hard and semi-hard cheese, 69.94 minutes for soft cheese, and 71.29 minutes for semi-soft cheese. Córdoba requires 71.27 minutes of curdling for hard and semi-hard cheese in Scenarios 3 and 4

Journal of Ecohumanism
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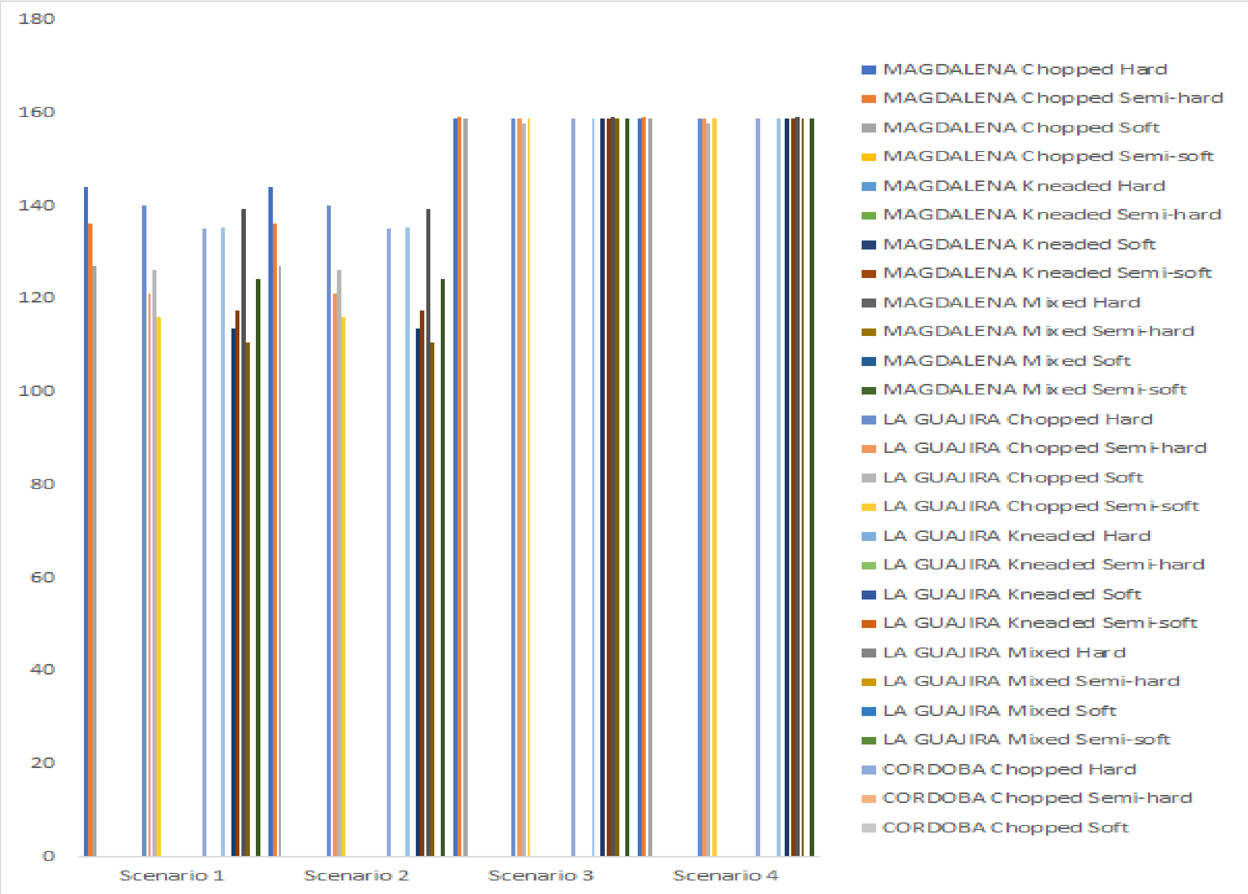
**Figure 8. Comparison of Estimated $\mathbf{TMSTS_{ijm}}$ of Caribbean Costeño Cheese in Scenarios 1, 2, 3, and 4.**




Source: Authors with Project Data

**Tiempo de espera de la cuajada en el tanque de la salmuera**

Figure 9 presents information about the $TOCPB_{ijm}$ Estimated for of Caribbean Coastal Cheese in Magdalena, La Guajira and Córdoba.

In Scenario 1, the estimated wait time in Magdalena is approximately 99.924 minutes for hard cheese, 99.982 minutes for semi-hard cheese, and 99.94 minutes for soft cheese. In La Guajira, the wait times are approximately 100.1285714 minutes for hard cheese, 99.825 minutes for semi-hard cheese, 99.91 minutes for soft cheese, and 100.0166667 minutes for semi-soft cheese. In Córdoba, the wait time is approximately 100.04 minutes for hard and semi-hard cheese. On the other hand, in Scenario 3, the wait time is estimated to be approximately 158.91 minutes for hard and semi-hard cheese in Magdalena, and 158.93 minutes for soft cheese. In La Guajira, wait times are approximately 158.91 minutes for hard cheese, 157.6152941 minutes for soft cheese, and 158.89 minutes for semi-soft cheese. In Córdoba, the wait time is approximately 158.91 minutes for hard and semi-hard cheese.

ISSN: 2752-6798 (Print) | ISSN 2752-6801 (Online)
https://ecohumanism.co.uk/joe/ecohumanism
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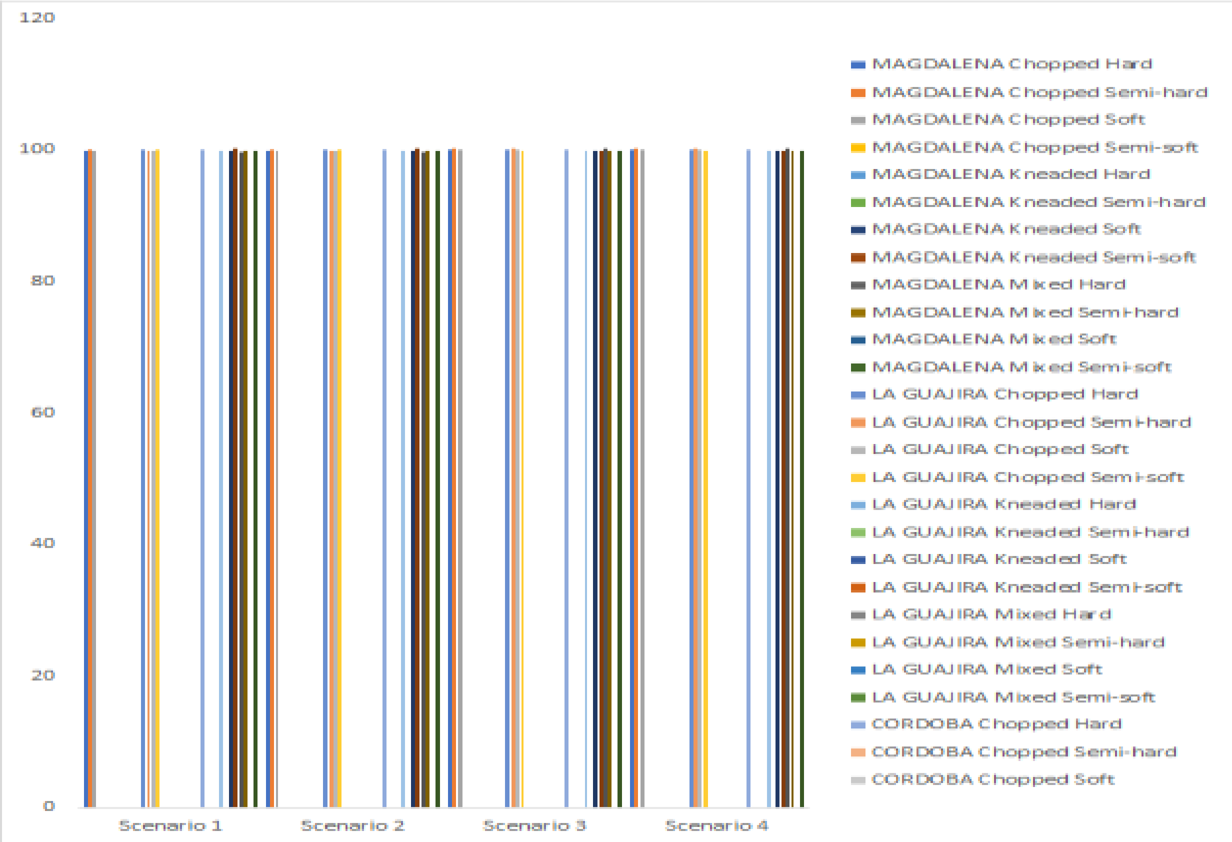
**Figure 9. Comparison of Estimated $\mathbf{TOCPB_{ijm}}$ of Caribbean Costeño Cheese in Scenarios 1, 2, 3, and 4.**




Source: Authors with Project Data.

**Tiempo de prensado**

Figure 10 presents information about the $PT_{ijm}$ Estimated for of Caribbean Coastal Cheese in Magdalena, La Guajira and Córdoba.

In Scenario 1, the estimated pressing time in Magdalena is approximately 144.19 minutes for hard cheese, 136.26 minutes for semi-hard cheese, and 126.93 minutes for soft cheese. In La Guajira, the pressing times are approximately 140.23 minutes for hard cheese, 121.18 minutes for semi-hard cheese, 126.23 minutes for soft cheese, and 116.14 minutes for semi-soft cheese. In Córdoba, the pressing time is approximately 135.07 minutes for hard and semi-hard cheese. On the other hand, in Scenario 3, the estimated pressing time is approximately 158.91 minutes for hard and semi-hard cheese in Magdalena, and 158.93 minutes for soft cheese. In La Guajira, pressing times are approximately 158.91 minutes for hard cheese, 157.62 minutes for soft cheese, and 158.89 minutes for semi-soft cheese. In Córdoba, the pressing time is approximately 158.91 minutes for hard and semi-hard cheese.

Journal of Ecohumanism
2025
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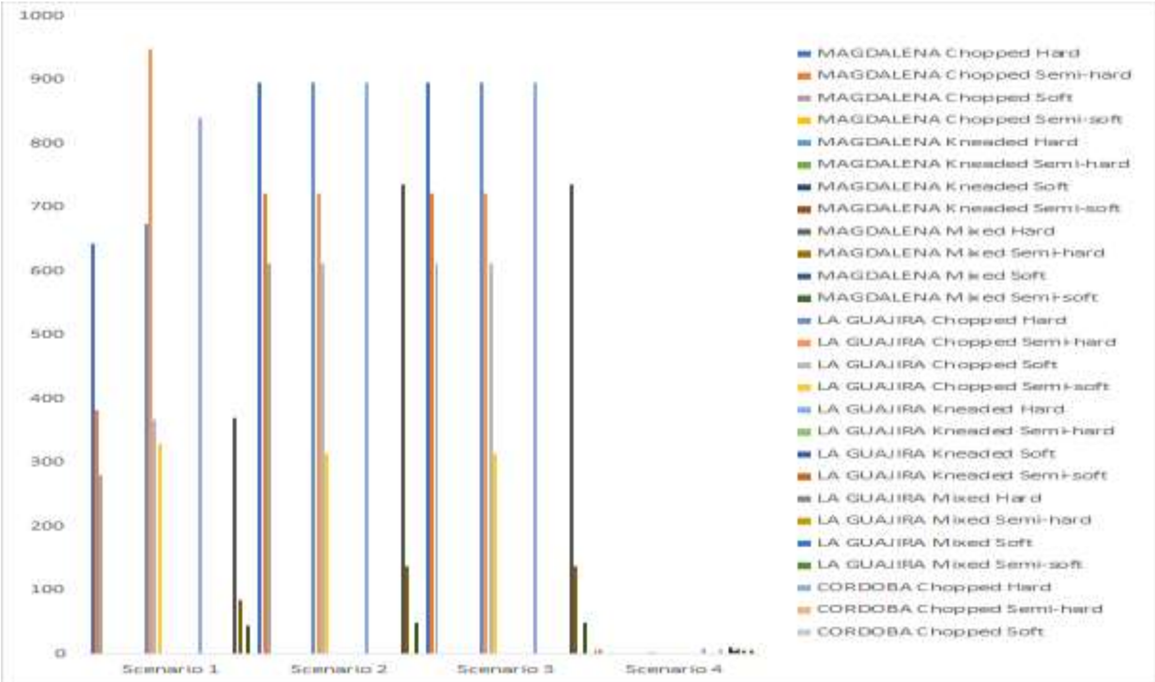
**Figure 10. Comparison of Estimated $PT_{ijm}$ of Caribbean Costeño Cheese in Scenarios 1, 2, 3, and 4.**




Source: Authors with Project Data.

## Discussion

The most favorable scenario in terms of Caribbean Coastal Cheese production is observed in Scenario 4. This scenario shows a significant increase in cheese production compared to the previous scenarios. Magdalena stands out as the department with the highest production, followed by La Guajira and Córdoba. In Scenario 4, a considerable increase in hard and semi-hard cheese production is observed in Magdalena. This indicates greater production capacity and a positive response to market demand. Furthermore, La Guajira experiences an increase in soft cheese production, demonstrating a diversification in the cheese supply in this department. Córdoba also sees an increase in hard, semi-hard, and semi-soft cheese production compared to the previous scenarios.

It is important to note that the most favorable scenario may vary depending on the specific criteria and established goals. In this case, considering total cheese production and the diversity of cheese types produced, Scenario 4 shows a higher yield compared to the other scenarios. However, a detailed analysis of costs, profitability, and other relevant factors is essential to fully assess the feasibility and success of each scenario. Furthermore, the need to implement more rigorous processes for the inspection of fresh and raw milk, as well as standardized minimum times for milk curdling and pressing, was identified. This is essential to ensure the quality of the final product and meet the minimum quality standards demanded by consumers. Processing times vary in each scenario, with Scenarios 1 and 2 presenting the shortest times and Scenarios 3 and 4 requiring longer times to improve cheese quality.

In future simulation models, it is recommended to include associative variables that allow for a better analysis and understanding of the factors and effects that contribute to the productive improvement of the Caribbean Coastal Cheese supply chain. This will facilitate decision-making and the implementation of strategies that drive growth and efficiency in the production of this traditional and emblematic product of the region. This will facilitate decision-making and the implementation of strategies to drive growth and efficiency in the production of this traditional and emblematic product of the Caribbean region of Colombia.

## Conclusion

In conclusion, the analysis of the different production scenarios for Caribbean Coastal Cheese in the departments of Magdalena, La Guajira, and Córdoba has provided a comprehensive view of the supply chain and its implications. Comparing the scenarios reveals variations in cheese production in each department, as well as in the types of cheese produced and the processes used.

An increase in cheese production is observed as we move from one scenario to another. Magdalena remains the department with the highest production in most scenarios, followed by La Guajira and Córdoba. However, each scenario presents particularities in cheese production in each department. Some scenarios show a decrease in the production of certain types of cheese, while others show significant increases.

The type of process used also influences cheese production. Hard cheese, especially that produced using the chopped process, shows the highest production in all scenarios and departments. On the other hand, kneaded and soft cheeses are produced in smaller quantities compared to hard and semi-hard cheeses. This may indicate a lower relative demand for these types of cheeses or a market preference for hard cheese.

The amount of milk required varies depending on the type of cheese and the process used. Hard cheese typically requires a higher amount of milk compared to other types of cheese. The scenarios show fluctuations in the amount of milk required for cheese production in each department. Increases and decreases are observed depending on the scenario and type of cheese.

Furthermore, the model has also contributed to improving the finished product. By simulating different production processes and associated variables, standardized minimum curdling and pressing times have been established for each type of cheese.

Regarding the resources used, the model has made it possible to optimize key resources such as milk, rennet, salt, and baskets. By simulating different scenarios, the optimal amount of each resource required to achieve the desired cheese production volumes has been identified. This helps avoid unnecessary waste and ensures efficient use of available resources.

### Acknowledgments

This article is part of the project "Strengthening the Productive and Commercial Capacity of the Coastal Cheese Supply Chain in the Subregions of the Colombian Caribbean, Departments of Magdalena, Córdoba, and La Guajira," with BPIN code 2020000100116 - General Royalties System (SGR). We would like to thank in advance the Ministry of Science, Technology, and Innovation (Minciencias), the National Planning Department (DNP), the SGR, the Universities of Magdalena, Córdoba, and La Guajira; and, especially, the stakeholders in the coastal cheese supply chain of the Colombian Caribbean.

### Contribution of The Authors

Edwin Causado Rodriguez worked on the methodological process of analysis Contribution: writing - first draft writing - review and editing. Andres Mauricio Peñalosa Fernandez contributed: writing - first draft writing - review and editing; and Jorge Luis OyolaMendoza contributed: writing - first draft writing - review and editing. The three authors contributed to the interpretation of the results and to the preparation and writing of the document.

### Conflict of Interest

The authors declare that there is no conflict of interest in relation to the publication of this manuscript. Additionally, ethical aspects, including plagiarism, informed consent, data fabrication and/or falsehood, duplicate, and redundant publication were observed and verified by the authors.

Journal of Ecohumanism
2025
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**Journal of Ecohumanism**
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