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APPLICATION ARTICLE

A discrete-event simulation model with a collaborative and lean logistic approach application to a dairy industry

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Abstract
The research introduces a discrete-event simulation model that focuses on implementing a collaborative and lean logistic approach to enhance productivity and competitiveness within a supply chain. The model aims to improve processes in the supply chain by establishing more sustainable methods in production, transportation, and marketing activities. Additionally, a discrete-event simulation model has been created to represent a dairy supply chain and assess performance across various areas such as production activities, transportation, distribution, information systems, and indicators. The model utilizes Arena Simulation Software to depict processes, raw materials, suppliers, manufacturers, resources, products, and customers. It has been developed and validated through statistical comparison with real-world data. Furthermore, the current performance analysis has been computed, and scenarios have been defined to enhance infrastructure utilization, production capacity, collaboration, and lean logistic approaches. The study includes a case study of the dairy industry in Colombia to validate the model. The results indicate that collaborating with suppliers and implementing a new production line have significant benefits in strengthening the dairy sector, leading to improved production planning, the adoption of new technologies, increased incomes, and enhanced competitiveness in the industry.

Keywords Simulation model · Supply chain management · Collaboration · Lean logistics · Dairy industry

1 Introduction

Collaboration between organizations allows for competitive advantages and better environmental, business, and social results [1]. Within a collaborative approach in supply chains, stakeholders can improve market share, growth, and margins.

Extended author information available on the last page of the article

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Collaboration in the supply chain leads to the implementation of strategies to effectivelymanage resources and avoid the bullwhip effect, a low level of service, and increased inventory management costs [2].

Lean logistics is another concept of great importance in developing competitive advantages in supply chains. This approach seeks to minimize waste and non-value activities throughout the supply chain to create more customer value [3–6]. Many companies have implemented lean manufacturing practices to increase productivity and sales, improve quality and lead times, reduce costs, raise capital and stay competitive in the global Marketplace [5, 7], Bhavani, Mishra, et al., 2023; [8, 9].

The design of collaborative and lean logistics strategies along the logistics chain allows for better performance for the members. However, the complexity of the market and the large flow of available information make the use of computerized methods and advanced models a necessity. Simulation is considered the standard method for evaluating the performance of logistics systems due to the inherent capacity to deal with the complexity and randomness of logistics operations. It allows for evaluating and comparing many alternative scenarios and performance predictions and identifying system problems [10, 11].

The integration of the supply chain levels is essential to enhance the competitiveness of milk production. Currently, each member operates independently based on existing regulations and individual interests. However, a practical approach to the supply chain can align the interests of the different stakeholders and lead to strategic planning, value creation, and cost minimization. This approach can result in added customer value and provide comparative advantages that improve the supply chain competitiveness. Additionally, it is essential to strengthen the information system for effective decision-making and supply chain planning. In the Caribbean Region of Colombia, the dairy sector faces significant challenges at a regional level, including noticeable structural deficiencies, a lack of regional and local collaborative culture, low dairy productivity, and minimal technological advancements.

This paper intends to address the research gaps by answering the following questions:

(1) How does developing a logistics management model using collaboration and a lean logistic approach contribute to a supply chain?
(2) How does a discrete event simulation model represent systems' performance and establish improvement scenarios?
(3) What improvement alternatives can be implemented in a dairy sector supply chain considering the collaboration and lean logistics approach?

Therefore, a conceptual management model for the supply chain is proposed, considering lean logistics strategies and a collaborative approach among its members. The model is validated using the supply chain of the dairy sector in the Department of Sucre, Colombia. This sector currently has low added value in agricultural production, focuses on the domestic market, and lags behind other regions in terms of competitiveness due to its structurally low complexity [12, 13]. There is a need for improvement in infrastructure for the dairy herds in this region to enhance the production process and the quality of milk. The transformation in the sector is mainly small family-owned businesses with limited technology and operational capacity [14].

A discrete event simulation model is designed using the Arena simulation tool to validate the conceptual model. The case study of the supply chain of the Dairy Sector of the Department of Sucre, Colombia, is considered. Different scenarios are also evaluated to establish the relationships between the factors of the conceptual model and define strategies that increase the efficiency, productivity, and competitiveness of the dairy industry.

The contributions of this research include:

(1) Develop a conceptual model of the logistics management system using the strategic collaboration and lean logistics approach to promote the development of a supply chain and its competitiveness levels.
(2) Develop a discrete event simulation model that allows for the representation of the supply chain of the dairy industry, including production activities, transportation, distribution, information systems, management indicators, and reverse logistics.
(3) Evaluation of the logistics management system through a discrete event simulation model and evaluation of the supply chain performance based on the improvement scenarios proposed to increase productivity, process efficiency and competitiveness.

The structure of this paper is outlined as follows. Section 2 presents the literature review concerning the collaborative approach and lean manufacturing in supply chains. Section 3 shows the methodological framework to develop a discrete-event simulation model. Section 4 presents the simulation model, system definition, overall project plan, elements, and validation. Section 5 includes the analysis of model performance considering the current status and five scenarios considering lean manufacturing strategies to improve efficiency, productivity, and competitiveness in the supply chain. Finally, Sect. 6 includes the conclusions, recommendations, and future research lines.

2 Literature review

The supply chain (SC) has grown in importance since the early 1990s, although the approach was introduced in the early 1980s. It involves managing the relationships with suppliers and customers in upstream and downstream directions to create more excellent value in the end market at a lower cost to the supply chain. A supply chain comprises suppliers, manufacturers, distributors, and retailers through the manufacturing processes until consumption. In addition, supply chain management involves designing, developing, optimizing, and managing different aspects like material, information, financial flows, and the distribution of finished products. According to Akhtar et al. [15], all these components work together to create an efficient and effective supply chain.

The Discrete Event Simulation (DES) tool is an analytical and predictive tool that can be used to study complex systems. One such complex system is collaborative logistics planning, which involves numerous variables. The challenges of collaboration are analyzed for research. DES can be used to demonstrate the benefits and achievement of collaboration objectives. The results of different scenarios can be studied with simulation models [16]. The main advantage of using a distribution function is that it considers random variables built into the model, such as lead time and demand.

Van Der Vorst et al. [17] created a model to simulate the impact of transportation routes, storage conditions, packaging options, and processing techniques on food product quality. Their research identified areas for improvement, such as reducing waste, enhancing product quality, minimizing environmental impacts, and improving overall operational efficiency.

Several studies have developed simulation models that incorporate collaborative strategies to improve production and logistics processes in supply chains. Hudnurkar & Rathod [18]combined the vendor-managed inventory approach and collaborative planning forecasting to reduce the total inventory cost. Cigolini et al. [19]proposed a simulation model incorporating the production and transportation process, inventory management, order fulfillment, and customer demand in a supply chain. Also, Rabe et al. [16] studied collaborative planning using a discrete-event simulation model to improve food distribution in an urban area. Neagoe et al. [20] developed a simulation model to study the performance of truck queuing, waiting and emissions at a port terminal. Their research studies initiatives to improve the congestion management on trucks and environmental impacts.

González-Reséndiz et al. [21] established a simulation methodology to optimize the distribution processes for a case study in Mexico. The model considers product allocation, inventory levels, and delivery times. Yuan et al. [6] proposed an agent-based simulation model to study the horizontal logistic collaboration approach to examine the impact of information sharing on the Dutch horticultural supply chain. Additionally, Mittal & Krejci [3]studied a hybrid simulation modeling framework, which combines different simulation techniques to analyze and optimize the operations of regional food hubs. This framework considers supply chain logistics, inventory management, transportation, storage, demand forecasting, and decision-making.

Burgos & Ivanov [22] examined the resilience of the food supply chains in Germany during the COVID-19 pandemic. A discrete-event simulation model was developed based on production inventory control, considering demand, lead time, inventory, production, and transportation control. Spiker et al. [23] developed a simulation model representing the vegetable production system as potato, onion, tomato, and eggplant. The simulation model considers market dynamics, distribution systems, and consumer behavior. The simulation model suggests that a simple increase in vegetable production might not necessarily lead to improved food availability in specific contexts, such as India.

Garza-Reyes et al. [24] applied a discrete-event simulation model to examine different scenarios for the optimum line balance for the park homes production industry in the United Kingdom. Also, Atieh et al. [25]developed a hybrid approach that combined discrete-event simulation and value stream mapping to identify bottlenecks in glass fabrication in Jordan. Alzubi et al. [26] implemented a simulation model to identify the bottlenecks in manufacturing processes in the wooden furniture manufacturing industry. Pattanaik [27] proposed a simulation–optimization approach to examine the varying production rates under stochastic and dynamic demand scenarios for the case of a mobile phone manufacturing industry. Moreover, Afy-Shararah & Salonitis [28] created a dynamic and discrete-event simulation model system considering lean manufacturing factors for an aerospace production system. Their research identified overproduction, over-processing, transportation, and inventory as the main types of lean waste.

Abay et al. [29] proposed a simulation model for a collaborative supply chain that integrates the internal and external operations of the supply chain members. Their approach included an inventory control policy and flexible manufacturing strategies to enhance customer service and profits. Abay et al. [30] extended their work by incorporating multi-objective sales and operation planning with uncertain parameters. They applied a simulation model for the Ethiopian automotive industry and expanded collaboration to include suppliers and customers. On the other hand, Miqueo et al. [31] studied the performance of flexible assembly systems under high variability conditions (process and setup time). The simulation model evaluated four scenarios to improve the productivity, lead time, stocks, and production runtime.

Collaboration between supply chain members and lean logistics improves productivity, operational efficiency, process quality, and waste reduction in production and logistics processes. Therefore, the literature review addresses these topics for designing a logistics management model in a supply chain of perishable products to evaluate its performance and establish strategies that improve its productivity and competitiveness. Table 1 presents the discrete-event simulation models incorporating some strategies related to collaborative and lean logistic approaches.

3 Methodology

A new simulation model has been proposed to evaluate the performance of a food supply chain that adopts a collaborative approach and lean manufacturing strategies. The model is statistically equivalent to a real-world system. The research follows a methodological framework of several stages, as shown in Fig. 1. The first stage involves defining the system objective, characterizing the processes, and describing the supply chain.

Estimating parameters and variables (Stage 2) includes data collection and analysis. For this case, raw material entry records, payment methods to suppliers, and delivery of products to final customers were reviewed. The operational data collection was carried out by observing and recording multiple work days in the selected company. Samples were taken over the course of one week, with 8 h of observation each day across all process stages, thus capturing records of time, processing

Table 1 Discrete-event simulation models for collaborative and lean logistic approach with considerations

Authors	Information sharing	Decision synchronization	Incentives	Research and development	Confidence	Resource sharing	Organizational culture	Collaborative communication	Collaboration with suppliers	Collaboration with customer	Collaborative planning	Performance	Environmental uncertainty
Cao et al. [32]	X	X	X	X		X		X					
Hudnurkar and Rathod [18]	X										X		
Cigolini et al. [19]		X							X		X	X	
Rabe et al. [16]	X					X					X		
Atieh et al. [25]						X						X	
Salas-Navarro et al. [2]					X				X	X			
González-Reséndiz et al. [21]		X				X			X	X	X	X	
Yuan et al. [6]	X							X	X		X	X	
Mittal & Krejci [3]	X			X		X						X	
Alzubi et al. [26]	X	X										X	

Table 1 (continued)

Authors	Information sharing	Decision synchronization	Incentives	Research and development	Confidence	Resource sharing	Organizational culture	Collaborative communication	Collaboration with suppliers	Collaboration with customer	Collaborative planning	Performance	Environmental uncertainty
Burgos & Ivanov [22]	X								X		X	X	X
Pattanaik [27]	X	X				X				X			
Martinez & Ahmad [33]	X	X				X						X	
Neagoe et al. [20]	X	X				X					X	X	X
Afy-Shararah & Salonitis [28]	X						X		X			X	
Spiker et al. [23]	X										X	X	X
Abay et al. [29]								X	X	X	X	X	
Miqueo et al. [31]		X			X						X	X	
Abay et al. [30]		X						X	X	X	X	X	
Haddad et al. [34]						X			X		X		X

Table 1 (continued)

Authors	Information sharing	Decision synchronization	Incentives	Research and development	Confidence	Resource sharing	Organizational culture	Collaborative communication	Collaboration with suppliers	Collaboration with customer	Collaborative planning	Performance	Environmental uncertainty
This research	X	X	X	X	X	X	X	X	X	X	X	X	X

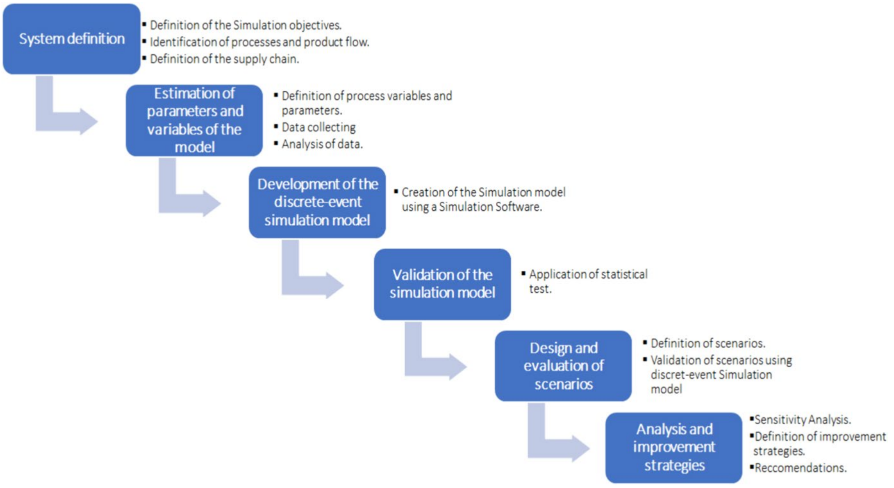

Fig. 1 Methodological framework for developing a discrete-event simulation model with a collaborative approach and lean manufacturing strategies

quantities, work sequences, quantity of finished product, and storage capacities. The analysis of the input data was developed in Stat graphics Centurion XVI by applying goodness-of-fit tests to each data of the supplier, operational data, and process output.

The Arena Simulation Software created a discrete-event simulation model (Stage 3) representing the supply chain and decision-making processes related to raw materials, suppliers, resources, products, and final clients. The model was validated (Stage 4) through performance analysis and statistical tests to represent the real-world system accurately. This stage included reviewing the model's architecture and comparing each stage of the production process with the conceptual model. The performance was verified by ensuring compliance with the specifications and conversions described in the construction of the model. Runs were conducted with different replications for each stage to verify the process and compare the results against actual data. The design and evaluation of scenarios (Stage 5) include defining and validating scenarios using the discrete-event simulation model. Finally, stage 6 presents a sensitivity analysis, definitions of improvement strategies, and recommendations.

4 Discrete-event simulation model

The discrete-event simulation model, which uses a collaborative approach and lean manufacturing, considersexternal and internal factors. This model incorporates variables that affect operations and management performance (See Fig. 2). The external factors include relationships with suppliers, customers and environmental uncertainty. Relationships withsuppliers represent the links required between the environment, suppliers of raw materials, and companies. The

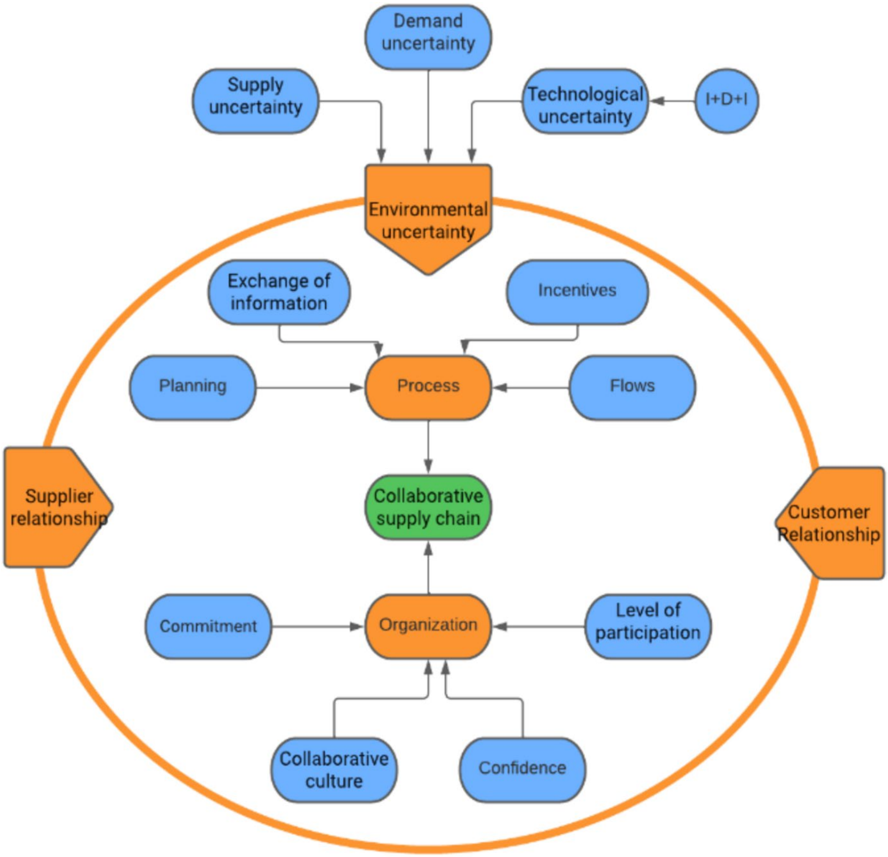

Fig. 2 Conceptual model with a collaborative approach and lean logistics

collaboration strategy generates a competitive advantage by exchanging information and achieving a common objective. The relationship with customers is based on the participation of the offer and supply options to satisfy customer requirements. Environmental uncertainty is considered a key variable in encouraging collaboration among chain actors. This variable allows for evaluating the opportunities to develop relationships and strategic alliances, leading to more significant benefits.

Factors such as information sharing, decision-making synchronization, collaborative communication, uncertainty environment, and collaborative planning are considered in the proposed scenarios to improve the supply chain's current performance.

On the other hand, internal factors include organization and processes. The first involves commitment, trust, level of participation, and collaborative culture, which stimulate and support collaboration among internal groups and between the companies' areas. The second applies integrating processes (flows), planning activities, exchanging information, and aligning objectives to improve performance.

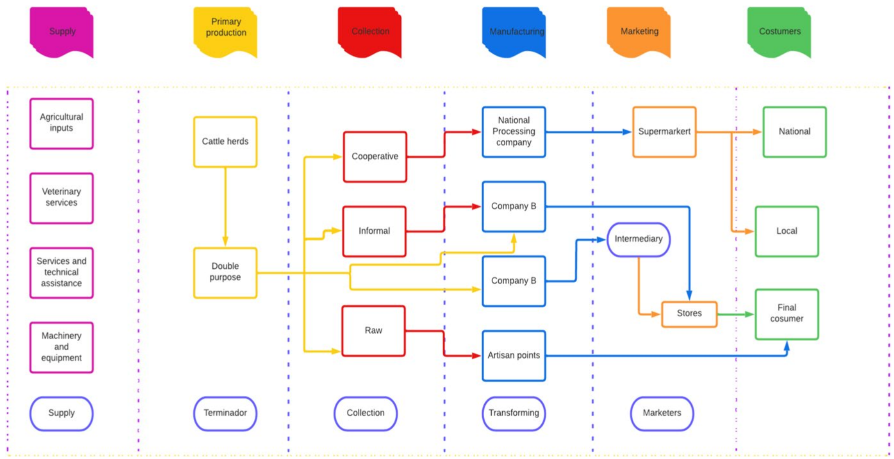

Fig. 3 Supply chain for the dairy industry

Figure 3 illustrates the supply chain for the dairy industry in Sincelejo, Colombia. This supply chain consists of a primary level that includes suppliers (agricultural supplies, veterinary services, technical and assistance services, machinery, and equipment), dairy farms, and milk collection centers (cooperatives and informal economy). The primary production level comprises small, medium, and large cattle herds in the Gal eras municipality. The cattle herds implement a multipurpose animal recording system that supplies raw milk for human consumption and processing. The collection centers include cooperatives and informal vendors buying milk in the primary production centers.

The transformation level includes processing companies and artisan production centers, which produce processed milk and dairy products. The retailer level includes supermarkets, intermediaries, and neighborhood stores. Finally, the last level of the supply chain comprises the final consumers of dairy products.

4.1 Simulation model

Using a collaborative approach and lean manufacturing, a discrete-event simulation model was proposed to adapt various stages of the simulation methodology from [35] and illustrated by [36], as described below.

4.1.1 System definition

The system definition includes the objectives of the discrete-event simulation model, as follows.

- Objective 1: Identify the general aspects, structure, operation, and production line of the Company under study to determine the production results in each period and analyze the factors that affect them. A characterization survey of

the dairy industry in the Department of Sucre was conducted to obtain general information from the companies. Subsequently, visits to the companies and interviews with the leaders of the production processes were carried out.
- Objective 2: Establish the formative stages for obtaining 'Costeño Cheese' from the Company under study. The production process, input and output data, information systems, methods, variables, and resources were identified for each stage.
- Objective 3: Collect input and output data and information to simulate the current process.
- Objective 4: Simulate the 'Costeño Cheese' production process of the Company understudy to analyze the current scenario.
- Objective 5: Establish simulation scenarios that allow improvementsand evaluate the results based on collaboration and lean manufacturing.

The simulation variables allow decisions to improve current processes. For this case, the collaborative relationships with suppliers and customers, the reduction of environmental uncertainty, and organizational aspects in the collaborative supply chain are considered.The response variables refer to the output data that the model produces. In the scenario being considered, the response variables include the quantity of finished product (Costeño cheese), the amount of by-product (whey), unprocessed milk, and the total sales of the finished product.

4.1.2 Overall project plan

Data processing, analysis, and system modeling tools include MS Excel for data digitization and processing. Statgraphics Centurion XVI was used to analyze the input data for the simulationmodel. Arena Simulation Software developed the current simulation model and the proposed scenarios.

The data collection and analysis included the following activities:

- A description of the Costeño Cheese production process was developed to identify the raw materials, inputs, variables, process parameters, and conversions within the stages, by-products generated, and timelines.
- Raw milk records were obtained, representing the input data (raw material), payment supports per liter of milk from suppliers, and delivery records of the final product to customers. Other data obtained correspond to each stage's resources and the number of operators.

For raw milk entry data, the suppliers were grouped into the routes described by the company: Route 1 (3 suppliers), Route 2 (3 suppliers), Route 3 (6 suppliers), and Route 4 (25 suppliers), as shown in Fig. 4.

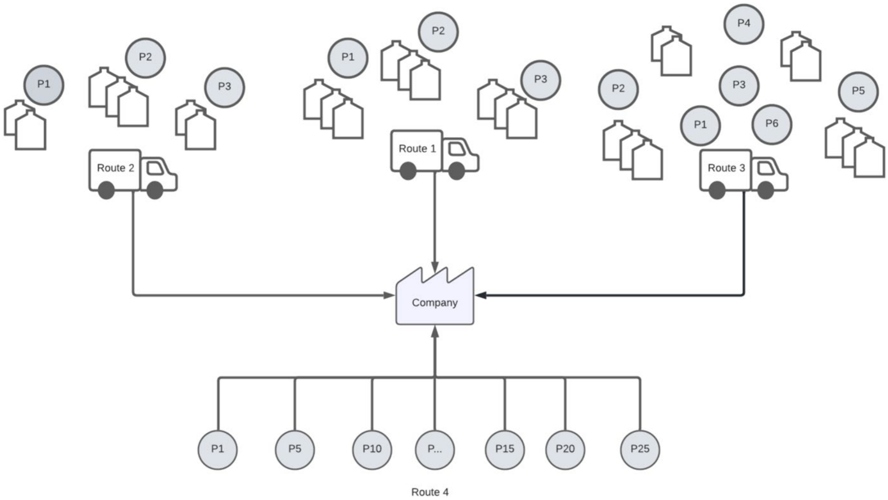

Fig. 4 Route of suppliers of raw milk

- Route 1: Supplier 2 has a constant behavior in its production, so it is presumed that it supplies a fixed number of liters of milk, and the rest of its production is supplied to other processors.
- Route 2: Supplier 3 has a constant behavior in its production, so it is presumed that it supplies a fixed number of liters of milk, and the rest of its production is supplied to other processors.
- Route 3: Suppliers 3 and 4 are the only suppliers with irregular production. The others have a constant regular production.
- Route 4: Due to the constant behavior of the data, few records fit probability distributions. Twenty-one records were eliminated in Suppliers 1 and 2 because they needed to contain sufficient statistical data. The data were assumed to be for a single period.

The data were adjusted by replicating the probability distributions because the supplier set quotas for the companies in the sector with more raw materials where the price was higher.

Table 2 Schedule of the routes and liters of the company

Supplier	Number of suppliers	Milk(L)	Schedule
Route 1	3	341	6:00–7:00 a.m
Route 2	3	237	7:30–9:00 a.m
Route 3	6	240	7: 00–8:30 a.m
Route 4	25	672	9:00–11:00 a.m

4.2 Model construction

The process was developed in stages at a specific time, starting with collecting the raw material. The company has 37 suppliers, and four routes were established at different points in the municipality of Galeras (see Table 2).

Milk collection on routes 1, 2 and 3 is carried out in two company vans. These routes cover 55–60% of the milk to be processed and are cattle herds that have become fixed suppliers. Route 4 supplies 40—45% of the raw material and comprises the cattle herds delivered to the company facilities. The number of suppliers is variable because there is no commitment to deliver raw milk, and it depends on the price per liter of milk the company offers (see Table 2).

When the raw material arrives at the plant, it is deposited in a stainless-steel hop-percontaining a filter (fine canvas) to separate coarse or foreign particles. Subsequently, through a system of pipes, it reaches two vats: one with a capacity of 800 L and the other with 1,200 L (See Fig. 5). The priority in the process is filling vat 1 to begin the transformation stages of raw milk into cheese. The company does not apply heat treatment, temperature adjustment, fat standardization or sodium chloride addition, which are visible in an industrial process.

- *Rennet addition:*The amount of rennet to be used is calculated using a ratio of 10 ml of rennet per 100 L of raw milk, previously diluted in a sample of salted water. This dilution helps activate the input and coagulate the milk. Subsequently, it is added homogeneously to the raw material in vat one or two. The milk is stirred for two minutes to dissolve the rennet.

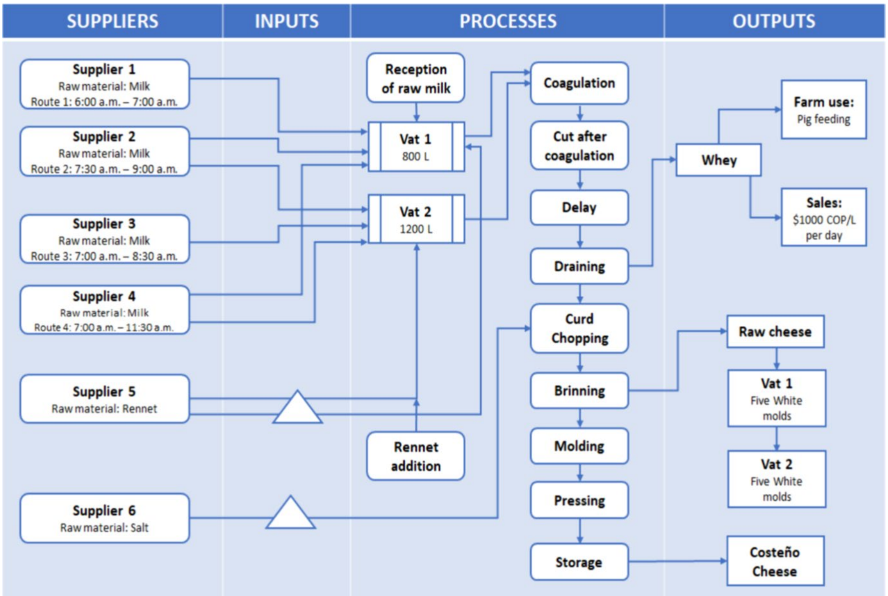

Fig. 5 Diagram of costeño cheese production process

- *Coagulation:*Once the rennet has been added, the raw milk is left to rest for 30 min at room temperature, allowing the milk to solidify into curds with the appearance of white jelly.
- *Cut after coagulation:* Once the curd has a suitable consistency and firmness, it is subjected to several successive cuts with knives made by the operator. The cuts are slow and deep to obtain blocks of curd, increasing the surface area and whey expulsion. This process takes approximately 5 min for each vat.
- *Delay:*For 1 or 2 min, the curd in blocks remains in the vat to continue with the whey output.
- *Draining:* With the help of a basket pressing the curd blocks inside the vats, the operators separate the whey to prevent the curd from acidifying. This operation makes it possible to separate between 70 and 80% of the whey from the curd. Once the process is complete, the blocks of cheese are placed on the chopping table for the next stage. The resulting whey is stored in the vats. For each kilo of resulting curd, 9 L of whey is generated. This stage takes 10 min to execute.
- *Curd Chopping:*The curd blocks on the mincing table are transformed into 5×5 cm cubes and transferred to the brine in 7 min.
- *Brinning:* 50 kg of salt is used daily in the salting processes of the curds obtained. The salt is added to the curd in a ratio of 25 kg for each vatanddistributed evenly when the curd cubes are in the brine tank. Then, it is stirred, and salt is added until the stipulated amounts are consumed. Adding salt slows the production of lactic acid, enhances the aroma, and preserves the cheese and its curing or maturation. The brine is changed every two days. For this purpose, 20 L of water and salt are used in each curd obtained. Due to the amounts of salt used, the company maintains salt storage. Approximately every six months, 13 tons of salt are purchased. The salting process takes 45 min.
- *Molding:* At this stage, the curd is introduced into molds to give it shape. The molds are made of PVC plastic, and there are squares of two types: white and brown. These are previously covered with canvases and filled with curd. As it is introduced, the operators apply pressure to the cheese to share it better. According to the requirements of the final product, salt can be added. Each curd obtained in the vats is used for 10 to 15 min.
- *Pressing:* Once the cheese is covered with canvas, it is pressed to finish shaping the product, allowing the union of the grains and the elimination of whey. For this, aluminum cylinders in the upper part molds are made of PVC plastic, and there are squares of two types: white and brown are used. At the end of the shift, the blocks are turned over to avoid deformation and hard crust. The pressing process lasts for 20 h.
- *Storage:* Once the pressing has elapsed, the cheese molds are stored in the cold room between 4 and 6 °C until delivered to customers every eight days. The company has a cold room with a storage capacity of 8 tons.

Figure 6 shows the process map for the current state of the company. Each process was monitored and inspected for an optimal final product, where time intervals were calculated when the stages of the cheese production process of the company under study were performed. This approach is fundamental for lean manufacturing

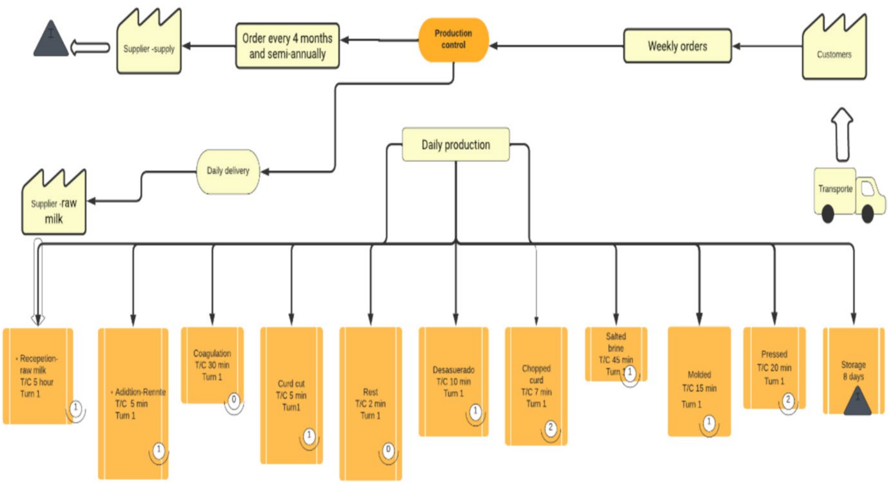

Fig. 6 Map of the process for the current state of the company

research, which allows us to identify the stages and times in which they are developed.

4.3 Model elements

ARENA is the software that will be used to simulate the process. This software allows the complete description of an entity's operations within a system as time

Table 3 Basic module: process

Name	Action	Resources	Units	Minimum	Value	Maximum
Vat 1	Seize delay	2	Minutes			
Vat 2	Seize delay	2	Minutes			
Curd cutting process	Seize delay	2	Minutes		5	
Curd delaying process	Delay	0	Minutes	1		2
Remove excess of whey	Seize delay release	2	Minutes	9		10
Curd chopping process	Seize delay release	3	Minutes	6		7
Brine preparation process	Delay release	1	Minutes	40		45
Brinning process	Seize delay	2	Minutes		1	
Molding process	Seize delay release	2	Minutes	10		15
Pressing process	Delay release	1	Hours		20	
Molding process 2	Seize delay release	2	Minutes	10		15
Press assembly process	Seize delay	2	Minutes		5	
Rennet T1	Seize delay release	1	Minutes		1	
Rennet T2	Seize delay release	1	Minutes		1	
Clean salt tank	Seize delay release	1	Minutes		15	

progresses. Two modules were used to construct the simulation model under study. Table 3 presents information on the basic process modules included in the simulation model. Some process times follow a uniform distribution with minimum and maximum limits.

Table 4 shows the basic modules representing the inputs of the model. Four modules include the routes of milk suppliers, and the others present the rennet and salt inputs. The type of entity, value, units, and entities per arrival are indicated for each module. Also, Table 5 indicates each disposal module's function to obtain the simulation model outputs.

Table 6 includes the basic attribute model the simulation model. These attributes show the data characteristics for raw materials, working in the process, and

Table 4 Basic module: create

Name	Type	Value	Units	Entities per arrival
Route 1	Constant	24	Hours	3
Route 2	Constant	24	Hours	3
Route 3	Constant	24	Hours	6
Route 4	Schedule	24	Hours	1
Rennet Input	Constant	4*30*24	Hours	1
Salt input	Expression	6.5*30*24	Hours	1

Table 5 Basic module: dispose

Name	Function
Dispose 2	Raw material delivery
Dispose 3	Finished product output
Dispose 4	VatWhey 1
Dispose 5	Milk pending processing
Dispose 7	Change brine
Dispose 8	Vat whey 2
Dispose 9	Route counters
Dispose 13	Graphics

Table 6 Basic module: attribute

Name	Rows	Data type	Initial values
Cheese price	12	Float	12 rows
Milk price	12	Float	9 rows
tvertido	4	Float	4 rows
distR4	3	Float	6
distR3	3	Float	12
distR2	3	Float	11
distR1	3	Float	12

Table 7 Basic module: queue

Name	Type
Draining	FIFO
Curd chopping	FIFO
Cut after coagulation	FIFO
Molding process	FIFO
Press assembly Process	FIFO
RennetT1	FIFO
RennetT2	FIFO
CurdChopping2	FIFO
Brinning process	FIFO
Brinning process 2	FIFO
Vat 1	FIFO
Vat 2	FIFO
Clean vat	FIFO
Clean salt tank	FIFO
Molding process	FIFO

finished products. Additionally, Table 7 presents the rule type for each simulation model queue.

The Arena® representation of the current process for obtaining Costeño Cheese of the company under study is seen in Figs. 7, 8, 9 and 10. Figure 7 presents the initial flow diagram, including the arrival of raw material and the rennet addition process. Figure 8 includes the coagulation process to remove excess whey. Figures 9 and 10 show the flow diagram of the processes to obtain the costeño cheese.

4.4 Model validation

The model started with the verification process. Although the conceptual model had to comply with detailed specifications and conversions, the first was done using runs in the simulator. The following verification was performed by an expert in milk transformation and the different stages of the process. Statistical tests were used in the model validation stage. Initially, 1-year runs were developed to graphically determine when the variables of interest began to stabilize within the model to obtain the length of replications for the 42-day simulation. However, a length of 60 days was considered. These were calculated by Eq. (1).

$$n = \frac{\sigma^2 \left(t_{n-1, \frac{\propto}{2}} \right)^2}{K^2} \tag{1}$$

where n represents the number of runs, σ denotes the standard deviation of the pre-sampling, t signifies the t-student distribution statistic, and K denotesthe maximum absolute deviation allowed. The number of runs was calculatedusing the following formula for a value of alpha ∝= 0.05 and a reliability of 95%. Then, a run was

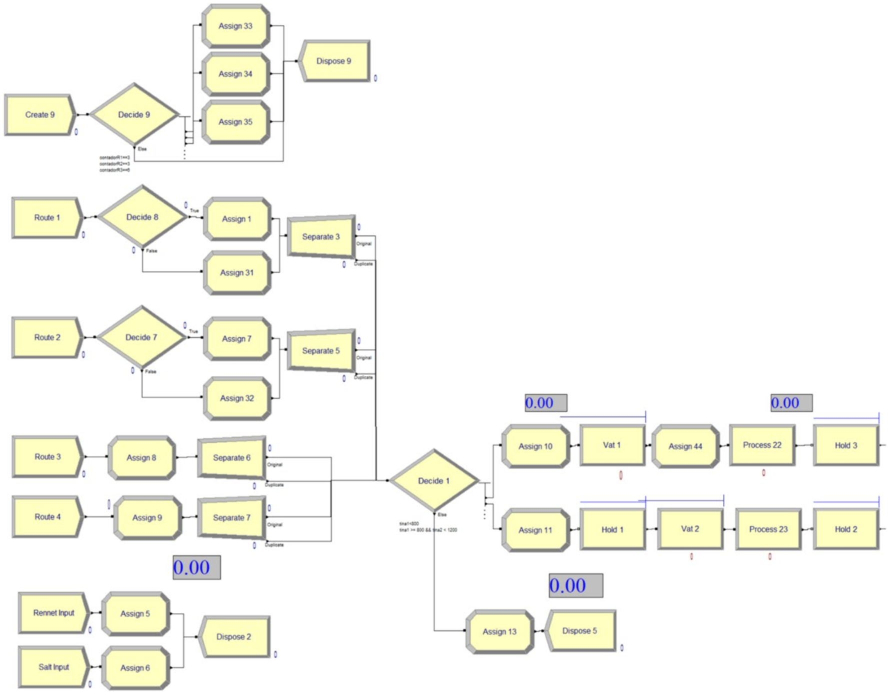

Fig. 7 Flow diagram using an arena simulation modelling of a dairy industry

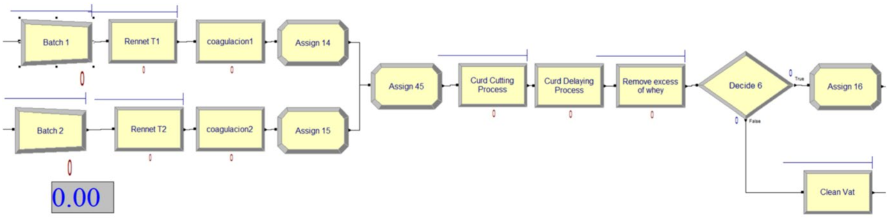

Fig. 8 Flow diagram using an arena simulation modelling of a dairy industry

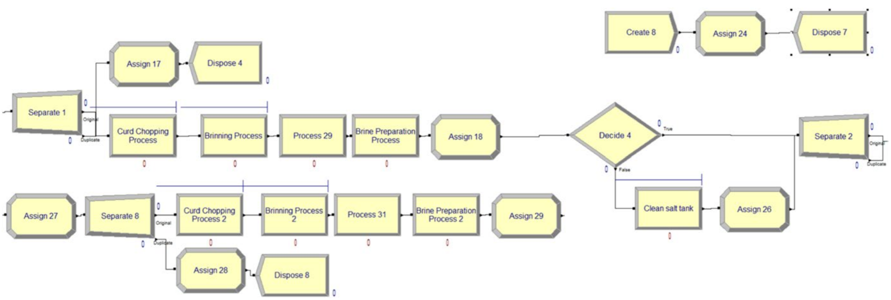

Fig. 9 Flow diagram using an arena simulation modelling of a dairy industry

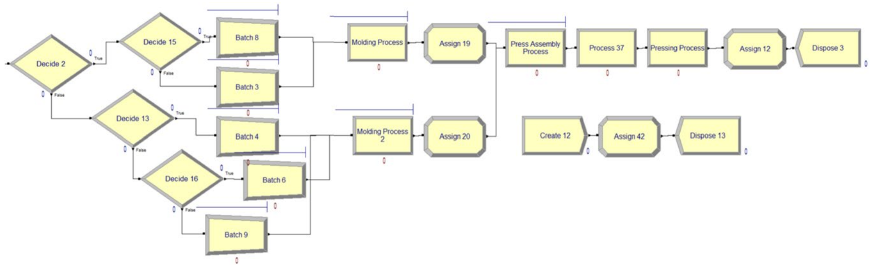

Fig. 10 Flow diagram using an arena simulation modelling of a dairy industry

Table 8 Number of runs for the simulation model

Replications	Milk in process (L)	Milk purchase cost (COP$)	Costeño cheese (Kg)	Income from cheese sales (COP$)
1	84,988	72,240,000	11,983	83,883,000
2	56,019	47,616,000	7,885.7	55,200,000
3	58,935	50,095,000	8,288.1	58,017,000
4	1,018,800	86,599,000	14,365	100,560,000
5	120,000	102,000,000	16,920	118,440,000
6	82,678	70,276,000	11,657	13,500,000
7	45,562	38,728,000	6,312.4	44,187,000
8	76,980	65,535,000	10,854	65,433,000
9	120,000	102,000,000	16,920	118,440,000
10	106,810	598,780,000	15,059	105,420,000
μ	177,077	123,386,900	12,024	76,308,000
σ	296,885.754	168,434,103	3,768.926	34,830,123
K	168,345	95,078,620	3,033	29,040,600
n	18,446	18,613	9,156	8,531

developed to validate the performance model using the actual data from the source system (see Table 8).

The hypothesis test was developed as a second stage to validate the performance of the model between the current system data and the data obtained via simulation. The variable "Costeño cheese" was selected (see Table 9). This variable was established as a null and alternative hypothesis.

$$H_0 : u = \text{Dailycoste n ocheeseproductionisleesthan200kg}$$

$$H_1 : u \neq \text{Dailycoste n ocheeseproductionisgreaterthan 200kg}$$

Table 9 Average quantities of Costeño cheese for 19 replicates in 60 days of production

Replications	Costeño cheese	Replications	Costeño cheese
1	189	13	253
2	124	14	144
3	133	15	256
4	222	16	130
5	256	17	256
6	187	18	256
7	99	19	142
8	170	Average	195.13
9	256	Deviation	56.927
10	231	Minium	99
11	150	Maximum	256
12	256		

The preceding data indicate the production of “Costeño cheese” by simulating the current process for the company over 19 replicates, revealing that, on average, 195.13 kg of cheese can be generated daily. The obtained data deviates, on average, by 56.927 kg from the mean of the variables. Also, when obtaining cheese, there is a probability of obtaining a minimum of 99 kg in one production day or a maximum of 256 kg.

Table 10 shows the current production data and the simulation results. The results show relative values between the actual production averages and those obtained via simulation, with a difference of 1.13 kg. Regarding the minimum values, the actual production data maintains 24.24 kg more than the simulated data, while the maximum values are lower in a proportion of 9.08 kg.

At a 95% confidence levelwith $\sigma = 5\%$, considering a standardized normal distribution, where a value of $t = 1.96$ was established. The t-collection of the samples resulted in $t = 0.084$, which does not exceed the established $t - value$, thus accepting the null hypothesis. Based on the hypothesis, it can be affirmed thatthe value of the supply analyzed as a sample is correct because it produces less than 200 kgper day. The simulated model is valid, confirmed by the Z value within the confidence level.

Table 10 Current data vs. simulated data

Item	Current data	Simulated data
Mean	194	195.13
Standard deviation	39.0	56.93
Minimum value	123.67	99.43
Maximum value	247.07	256.15

5 Scenario analysis

The process was verified and validated. Then, planning and evaluating scenarios for process improvements were developed in the Arena® simulator version 14.0 on a personal computer equipped with an Intel (R) Core (TM) i7-7700U processor (CPU @ 3.60 GHz; 3.60 GHz; 64-bit operating system; 16.00 GB of RAM).These were evaluated based on the averages of the variables in each replication.

5.1 Current status

The company has a processing capacity of 2000 L of raw milk per day and 8 tons to store "costeño cheese". However, despite these characteristics, the company should increase its capacity to process all the raw milk it receives. In the analysis period, of 125,408 L of raw milk, only 29% still needs to be unprocessed, thus decreasing production plans. Regarding the demand, the company has a weekly request for 6 tons of costeño cheese, represented by six clients. For 60 days, equivalent to 8.6 weeks of production, the company must deliver 51.6 tons of costeño cheese. However, the results show a production of only 12,578 kilos, equivalent to 12.6tons, 24.38% of the total demand (see Table 11).

According to the situation report (EVA, 2017), the average daily production of raw milk in the Municipality of Galeras in 2017 was 37,434 L. However, considering the company's raw material input database, it only received 1,605 L per day for the same year, representing 4.28% of the municipality's production.

Milk Price: Regarding the price paid per liter, when comparing with the statistics from the National Federation of Cattlemen and DANE on milk prices at the farm level, the company pays an average price in the municipality of Galeras that is COP$112 lower than the national average[37].

Whey generated: 70% of the whey produced is used to feed pigs, generating no income for the company. 10% is given to people who come to the facilities in exchange for the milk sold, and the remaining whey is sold at a rate of 20 L for COP$1,000.The quantities and the costs associated with the production of "costeño cheese" are presented in Table 12.

Based on the simulation results, several scenarios are suggested to enhance the utilization of the current infrastructure, production capacity, and the principles of collaboration and lean logistics to increase revenue and streamline processes.

Table 11 Results of the current status

Variable	Average
Milk in process	89,259L
Raw milk	36,149L
Purchase of milk	COP$75,870,316
Costeño cheese	12,578 kg
Income from cheese sales	COP$88,046,421
Whey generated	120,500L

Table 12 Costs of costeño cheeseproduction

Items	Quantity	Value	Purchase frequency
Rennet	10 L	COP$360,000	Everyfourmonths
Salt	13 ton	COP$3,500,000	Half-yearly
Labor cost 1	2	COP$300,000	Monthly
Labor cost 2	2	COP$150,000	Monthly
Utilities	3	COP$1,300,000	Monthly
Transportation	3	COP$60,000	Daily

5.2 Scenario 1:use the capacity of vat 1 to process raw milk

The company registers the amount of raw milk, which impacts daily cheese production. The process map has identified all the actions that add and do not add value to the production of Costeño cheese (see Fig. 6). One noticeable issue is the waste of milk in vat one after obtaining the initial whey and the use of 6.93 h of an 8-h workday. It is proposed to utilize the vat's capacity again to process the remaining liters of milk, which would involve an additional 800 L. The information from the herds is crucial in this scenario to determine the exact number of liters of milk awaiting processing.

The employees can only process the quantities stored in the two vats. Once the draining process begins for cleaning, the vats must be prepared for use again. Raw milk is received at 11 a.m. After this time, it is impossible to receive it as the transformation process has already started, and both vats are occupied. This approach is feasible if the whey generated in Vat 1 is sent to a temporary storage tank, making the whey available for the farm or the herds arriving at the company. After 45 min of the process, there is already whey in the vat, which can be transferred. It allows for improving the company's internal processes and adequately using equipment and human resources. Figure 11 shows the representation in Arena® of using the capacity of Vat #1 while maintaining its initial design.

Other parameters for this scenario for the current scenario include:

- Amount of whey for sale: Of the total whey generated, 40% is available for sale, 40% will be sent to feed pigs, and 20% will be delivered as an incentive to cattle herds for their sale of milk (see Table 13).
- The sale price of whey is maintained at COP$50, as this price has attracted customers in the past.

5.3 Scenario 2:establish collaboration ties with cattle herds and use the capacity of vat 1

Scenario 2 involves developing and establishing a collaborative approach with cattle herds by creating a cooperative. It allows a joint effort to overcome the limitations

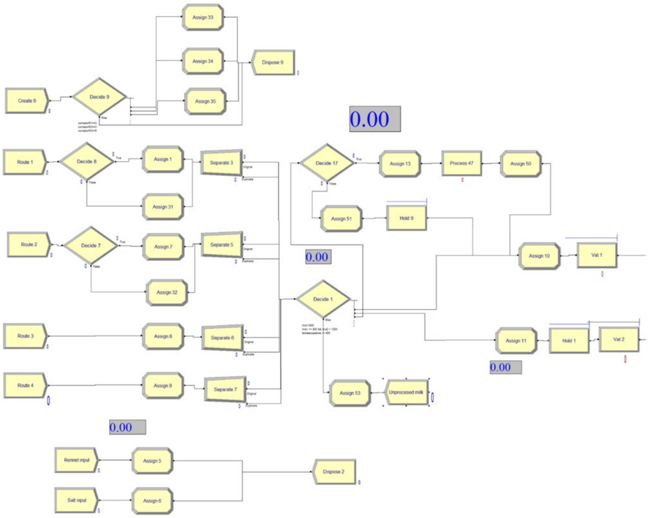

Fig. 11 Diagram of the simulation model in Arena® using the capacity of the Vat 1

Table 13 Results of current status vs. scenario 1

Variable	Current status	Scenario 1
Processed milk	89,259L	89,750 L
Purchase of milk	COP$75,870,316	COP$76,286,737
Costeño cheese produced	12,578 kg	12,646 kg
Income from cheese sales	COP$88,046,421	COP$88,527,105
Whey generated	120,500L	121,162L
Whey for farm use	84,350L	48,465L
Whey for sale	24,100L	48,465L
Whey to distribute	12,050L	24,232L
Income from whey sales	COP$1,205,002	COP$2,423,240

Table 14 Number of liters of milk by supplier

Supplier	Milk (L)
Route 1	600
Route 2	600
Route 3	500
Route 4	1100
Total	2,800

within the dairy sector. This scenario defines a fixed amount of raw milk for each route to be delivered to the company daily to establish a daily production plan and guarantee the availability of this raw material, as shown in Table 14. Scenario 1 uses

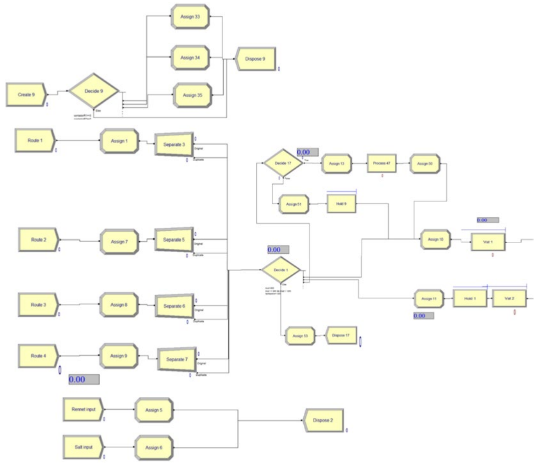

Fig. 12 Representation in Arena® of a collaborative approach and the use of the capacity of Vat 1

the capacity of VAT 1 again to process the new amounts of milk to enter as part of the use of physical and operational resources. Figure 12 shows the Arena® representation of this scenario, where the other processes maintain their initial design.

Table 15 shows the results comparing the current status with scenario 2. In scenario 2, there is an increase in the percentage of whey to be provided to cattle herds for milk sales, going from 20 to 30%. This increase serves as an incentive for a collaborative approach within the supply chain. In this scenario, suppliers are expected to adjust to the production plan, make commitments to deliver specific quantities of milk, and implement economies of scale to reduce costs. Manufacturers share the production plan with suppliers, provide information on product demand or sales forecasts, and enhance the scheduling for raw milk reception.

The manufacturer should consider establishing collaborative relationships with state entities to facilitate the acquisition of a storage tank through the Cooperative. This will allow the pending liters of milk to be stored and processed as needed, especially when cheese production increases.

Table 15 Results of current status vs. scenario 2

Variable	Current status	Scenario 2
Processed milk	89,259L	168,000L
Purchase of milk	COP$75,870,316	COP$142,800,000
"Costeño cheese" produced	12,578 kg	23,599 kg
Income from cheese sales	COP$88,046,421	COP$165,194,737
Whey generated	120,500L	226,800L
Whey for farm use	84,350L	68,040L
Whey for sale	24,100L	90,720L
Whey to distribute	12,050L	68,040L
Income from whey sales	COP$1,205,002	COP$4,536,000

The ANOVA test comparing the variable of interest (ripe cheese) with the liters of milk in the current and two scenarios indicates a statistically significant difference in the average ripeness of the cheese between different levels of milk, with a 95% confidence level, as shown in Table 16. It suggests a relationship between the liters of milk and the quantities of mature cheese that can be obtained.

5.4 Scenario 3: inclusion of a new production line

This scenario incorporates a new production line for processing the whey generated in the production process. According to research and production data from companies in the sector, the following stages must be developed to obtain cottage cheese from whey, as shown in Fig. 13. The stages of the process are described below:

- Rennet addition: The first stage involves adding rennet in the ratio of 65 ml of rennet for every 2500 L of whey previously diluted in a sample of this by-product. Then, it is added and stirred for two minutes to dissolve the rennet.
- Heating 1: The whey is heated to 30 °C for 30 min to activate the rennet and detachthe proteins present.
- Heating 2: A second heating is developed at 90 °C for 15 min to eliminate any-heat-resistant microorganisms generated in the production of serum.
- Protein collection: Once the proteins in the whey have been precipitated, they are extracted using a cloth. Canvases are used for 20 min in this process stage. From 2500 L of whey, 90 L of cottage cheese were extracted, along with whey as a co-product.
- Cooling: Once the cottage cheese is obtained, it is stored at 2 to 4 °C for 20 min.
- Homogenization: The cottage cheese mixture is developed using paddles and manual agitation for approximately 30 min to achieve a homogeneous appearance.
- Packaging: The cottage cheese is packed in transparent plastic bags, each holding 1 L. This activity can take an average of 20 min.
- Storage: Finally, the cottage cheese is transported to the cold room until it is ready for sale.

This scenario is proposed for thecurrent situation. Figure 14 presents the process for obtaining serum in Arena®.The other processes maintain their initial design. Some considerations for this scenario include:

Table 16 ANOVA for Costeño Cheese per liter of milk from Scenario 2

Source	Sum of squares	GI	Mean square	*F-Ratio*	*P-Value*
Between groups	1.42927E9	15	9.52848E7	6421.06	0.0000
Within groups	326,467.0	22	14,839.4		
Total	1.4296E9	37			

Data processed in software Statgraphics® Centurion XVI

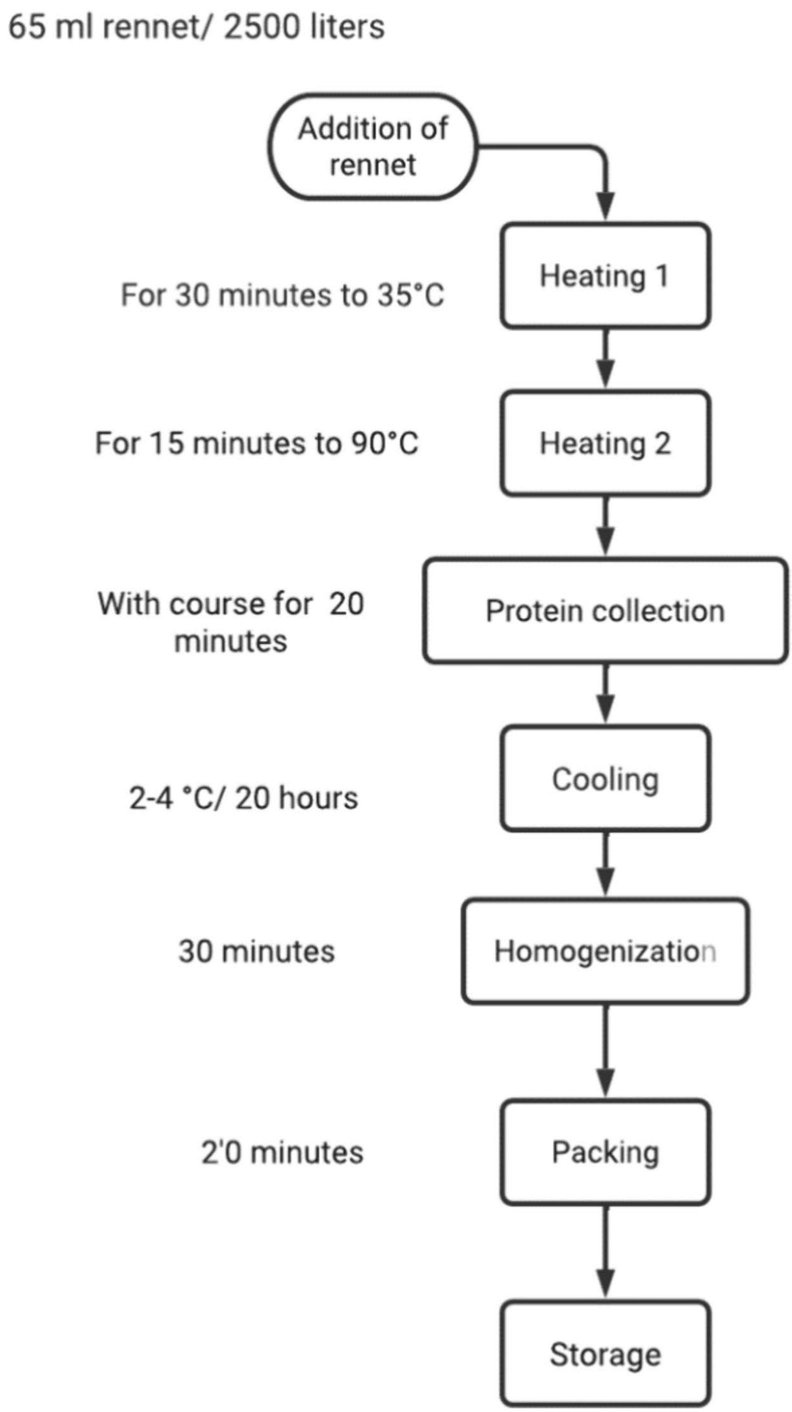

Fig. 13 Diagram of the whey brewing process

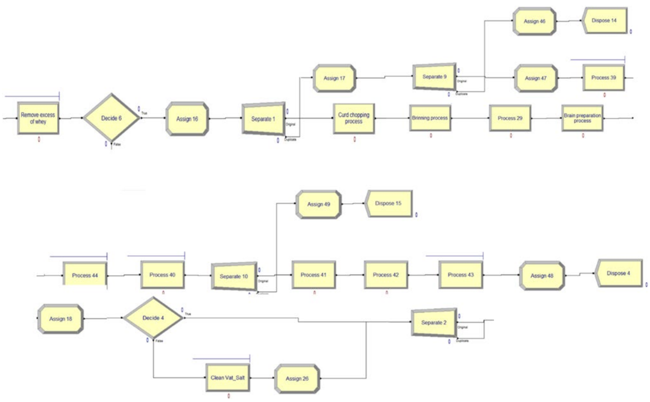

Fig. 14 Representation in ARENA® of the process of obtaining whey

- Whey 1: Of the quantities generated, 10% will be used for feeding pigs, 20% will be sold for COP$50 per liter, and 70% for whey production.
- Whey 2: 70% is destined for sale at COP$50 per liter, and the remaining amount will be used as an incentive for cattle herds.
- Value of whey: The final price is set at COP$3,000 per liter.

Table 17 shows the results obtained by the simulation model for current status and scenario 3. This analysis includes adding a new production line for the sub-product Whey, generating 3038 L of serum. The new product is priced at COP$3,000 and

Table 17 Results of current status vs. scenario 3

Variable	Current status	Scenario 3
Processed milk	89,259L	89,779L
Purchase of milk ()	COP$75,870,316	COP$76,311,842
"Costeño cheese" produced (Kg)	12,578 kg	12,651 kg
Income from cheese sales	COP$88.046.421	COP$88,556,211
Whey generated	120,500L	121,201L
Whey for farm use	84.350L	12,120L
Whey for sale	24,100L	24,240L
Whey to distribute	12,050L	
Income from whey sales	COP$1,205,002	COP$1,212,009
Wheyto serum		84,840L
Serum		3,038L
Income from serum sales		COP$9,114,626
Whey 2		81,786L
Whey 2 for sale		57,250L
Whey 2 to distribute		24,536L
Income from whey two sales		COP$2,862,507

brings in revenues of approximately COP$2,862,507. The Lean Logistic approach was used to make use of the whey by-product.

The ANOVA test is not applicable in this scenario because it applies the Lean Manufacturing approach using a by-product derived from the company's current production line. Additionally, the current scenario lacks serum production values as it does not utilize a process currently employed by the company.

5.5 Scenario 4: apply scenario 1 and include a new production line

This scenario seeks to represent the increase in milk and whey production to identify the income the company would obtain by improving its production and increasing its product portfolio. The parameters considered are:

- Whey 1: 10% is used for pig feed, 20% is available for sale at $50 per liter, and 70% is allocated for whey production.
- Whey 2: 70% is destined for sale for COP$50 per liter. The rest is an incentive for cattle herds.
- Serum Value: Price remains constant at COP$3,000 per liter.
- Table 18 shows the results obtained by the simulation model for current status and scenario 4.

Using an ANOVA test to compare the serum variable and the amount of milk in scenarios 3 and 4, the P-value of the F-test was less than 0.05. This indicates a

Table 18 Results of current status vs. scenario 4

Variable	Current status	Scenario4
Processed milk	89,259L	89,750L
Purchase of milk	COP$75,870,316	COP$76.286.737
"Costeño cheese" produced	12.578 kg	12,646 kg
Income from cheese sales	COP$88,046,421	COP$88,527,105
Whey generated	120,500L	121,162L
Whey for farm use	84,350L	12,116L
Whey for sale	24,100L	24,232L
Whey to distribute	12,050L	
Income from whey sales	COP$1,205,002	COP$1,211,620
Whey to serum		84,813L
Serum		3,040L
Income from serum sales (COP$)		COP$9,121,205
Whey 2		81,760L
Whey 2 for sale		57,232L
Whey 2 to distribute		24,528L
Income from whey 2 sales		COP$2,861,594

Table 19 ANOVA test for whey per liter of milk

Source	Sum of Squares	DF	Mean Square	F-Ratio	P-Value
Between groups	3.19769E7	22	1.4535E6	5094.03	0.0000
Within groups	4280.0	15	285.333		
Total	3.19812E7	37			

Data processed in software Statgraphics® Centurion XVI

statistically significant difference between the mean serum levels at different milk quantities, with a confidence level of 95.0%, as shown in Table 19. These results demonstrate a relationship between the serum variable and the quantity of milk in the simulated scenarios, suggesting that the milk quantity factor impacts the resulting whey quantities.

5.6 Scenario 5: apply Scenario 2. Include a production line

This scenario contemplates fixed amounts of milk per route due to collaborative relationships with cattle herds, using the capacity of the vat1 and including whey production.

The following aspects are considered:

- Whey 1: 10% of the whey is assigned for feeding pigs, 20% is for sale for $50 per liter, and 70% is destined for whey production.
- Whey 2: 70% of the whey is destined for sale for COP$50 per liter and the restservesas an incentive for cattle herds.
- Serum value: maintains its price at $3,000 per liter.

Table 20 shows the results obtained by the simulation model for current status and scenario 5.

An ANOVA test comparing the serum levels and the amount of milk in scenarios 3 and 5 indicates that the P-value of the F-test is below 0.05. This suggests a significant difference between the average serum levels at different milk quantities, with a 95% confidence level, as shown in Table 21. The significance in the mean differences between the variables underscores the relationship between milk quantity and serum levels. There are distinct effects on serum production between scenarios 3 and 5.

5.7 Sensitivity analysis

A cost–benefit analysis calculates the pre-tax profits of different options using data from specific variables for each scenario (see Table 22). The production costs for the current scenario (see Appendix A: Tables 24, 25, 26 and 27) are categorized based on information provided by the company, which includes costs by area and are then projected over a 60-day study period.

Table 20 Results of current status vs. scenario 5

Variable	Actual	Scenario 5
Processed milk	89,259L	168,000L
Purchase of milk	COP$75,870,316	COP$142,800,000
"Costeño cheese" produced	12,578 kg	23,599 kg
Income from cheese sales	COP$88,046,421	COP$165,194,737
Whey generated	120,500L	226,800L
Whey for farm use	84,350L	22,680L
Whey for sale	24,100L	45,360L
Whey to distribute	12,050L	
Income from whey sales	COP$1,205,002	COP$2,268,000
Wheyto serum		158,760L
Serum		5,715L
Income from serum sales		COP$16,948,421
Whey 2		153,045L
Whey 2 for sale		107,131L
Whey 2 to distribute		45,913L
Income from whey 2 sales		COP$5,356,562

Table 21 ANOVA test for whey per liter of milk

Source	Sum of squares	DF	Mean square	F-ratio	P-value
Between groups	8.38527E7	14	5.98948E6	32,186.44	0.0000
Within groups	4280.0	23	186.087		
Total	8.38569E7	37			

Data processed in software Statgraphics® centurion XVI

The milk prices were provided by the simulator, along with the costs of inputs for cheese manufacturing. Company data indicated a consumption of 25 kg of salt, which translates to 50 kg daily. In scenarios 2 and 5, filling the vat three times would result in a daily consumption of 75 kg. Regarding fixed costs, there is a 4% increase in energy consumption due to installing a kettle, which costs COP$19,000,000. This cost is recoverable over time due to implementing a new production line for a by-product. This would significantly improve the industrialization of processes, increasing production to meet demand and providing the company with stability and income to recoup the investment made. Shipping costs are not reflected as they are collected by customers based on the company's assumptions, as shown in Table 22.

The results should be compared with the cost of acquiring a kettle for whey processing. While this involves a significant investment, approximately COP$19,000,000, it can be recovered over time through increased production and sales. This would lead to stability, increased profits, and offset the initial investment. Table 23 displays the results for each scenario studied, highlighting the significant expected benefits. The main advantage lies in reusing VAT 1 to increase

Table 22 Results by scenarios for variables of interest

Variables	Current	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Milk in process(L)	89,259	89,750	168,000	89,779	89,750	168,000
Milk price(COP$)	75,870,316	76,286,737	142,800,000	76,311,842	76,286,737	142,800,000
Costeño cheese (Kg)	12,578	12,646	23,599	12,651	12,646	23,599
Sale cheese (COP$)	88,046,421	88,527,105	165,194,737	88,556,211	88,527,105	165,194,737
Whey generated (L)	120,500	121,162	226,800	121,201	121,162	226,800
% Property(L)	84,350	48,465	68,040	12,120	12,116	22,680
% Sale(L)	24,100	48,465	90,720	24,240	24,232	45,360
% Delivery(L)	12,050	24,232	68,040			
Sale of Whey(COP$)	1,205,002	2,423,240	4,536,000	1,212,009	1,211,620	2,268,000
Whey (L)				84,840	84,813	158,760
Serum				3038	3040	5715
Sale serum (COP$)				9,114,626	9,121,205	16,948,421
Whey 2				81,786	81.760	153.045
% Sale (L)				57,250	57,232	107,131
%Delivery(L)				24,536	24,528	45,913
Sale of Whey2 (COP$)				2,862.507	2,861,594	5,356,562
Supplies						
Rennet(ml)	8925,91	8974,98	16,800	8977,87	8974,98	16,800
Value of rennet (COP$)	321,333	323,099	604,800	323,203	323,099	604,800
Salt(Kg)	3,000	3,000	7,500	3000	3000	7500
Value of salt(COP$)	807,692	807,692	2,019,231	807,692	807,692	2,019,231
Total of supplies(COP$)	1,129,025	1,130,792	2,624,031	1,130.,895	1,130,792	2,624,031

production capacity for a single production line. It would result in a higher percentage of whey for the collaborators, as outlined in scenario 2. The focus of the two production lines is maximizing production by utilizing the whey by-product and establishing partnerships between collaborators, as indicated in Scenario 5. Both scenarios primarily benefit the relationships with the collaborators and contribute to the company's growth by boosting production and generating new revenues for enhancements in the manufacturing plant. It also ensures the procurement of raw materials, specifically raw milk. Figure 12 compares sales, costs, and pre-tax profits across the proposed scenarios.

In Fig. 15, the current status of the company case study exhibits varying degrees of variability: 24.85% in scenario 1, 233.97% in scenario 2, and 213.71% in scenario 3. Scenario 4 shows a variability of 213.73%, and scenario 5 exhibits 602.7% variability. These findings suggest that scenarios with no relationship with associates are less beneficial to the business, while scenarios that involve collaboration provide the most significant benefits.

Table 23 Income statement (COP$)

Scenarios	Current	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Sales						
Revenues from cheese sales	88,046,421	88,527,105	165,194,737	88,556,211	88,527,105	165,194,737
Revenues from whey sales	1,205,002	2,423,240	4,536,000	1,212,009	1,211,620	2,268,000
Revenues from serum sales				9,114,626	9,121,205	16,948,421
Revenues from whey 2 sales				2,862,507	2,861,594	5,356,562
Total Revenues	89,251,423	90,950,345	169,730,737	101,745,353	101,721,525	189,767,720
(−) Sales cost	0	0	0	0	0	0
(−) Production cost						
Milk purchase cost	75,870,316	76,286,737	142,800,000	76,311,842	76,286,737	142,800,000
Raw material purchase cost	1,129,025	1,130,792	2,624,031	1,130,895	1,130,792	2,624,031
Labor cost	900,000	900,000	900,000	900,000	900,000	900,000
Utility cost	6,200,000	6,200,000	6,200,000	7,240,000	7,240,000	7,240,000
Profit before tax	5,152,082	6,432,817	17,206,706	16,162,616	16,163,997	36,203,690

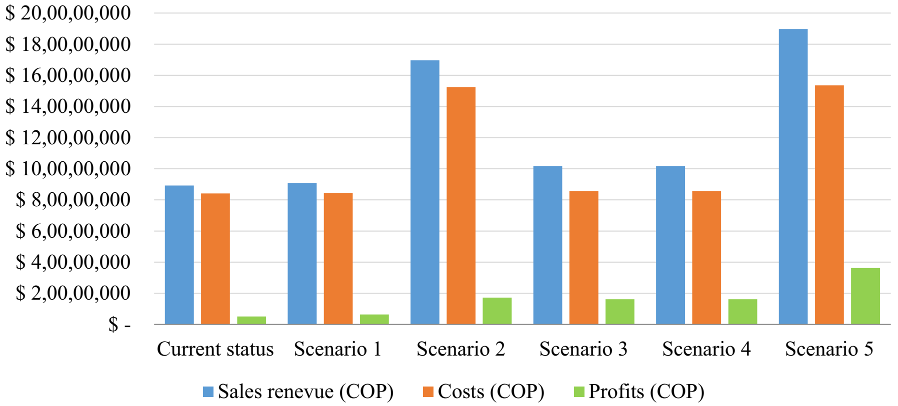

Fig. 15 Comparison of current status sales revenues, cost and profits and proposed scenarios

The capacity utilization of Vat 1 demonstrated an increase in productivity, resulting in a significant increase of 800 L in milk processing. This increase will lead to cheese production, utilizing Vat 1 during the draining and salting processes. Therefore, it is necessary to train the staff to study the feasibility of utilizing the VAT's drainage system and to improve plant distribution.

The dairy industry in Colombia faces significant challenges, and the simulation that has been developed is of the most significant importance. It has highlighted the importance of collaboration between suppliers and manufacturers for industry improvements.

The case study highlights the need for a robust company structure and challenges in its relationships with partners. Improving this will boost productivity and contribute to the economic well-being of partners, ensuring sustainability. Strengthening trust between producers and processors and adding value to by-products can enhance benefits for partners and cattle herds, benefiting the dairy industry.

6 Conclusion

In conclusion, this study contributes significantly to the literature on discrete-event simulation models in many ways. Firstly, a new logistic management model is proposed, which considers lean logistic strategies and a collaborative approach to improve the productivity and competitiveness of the supply chain. Secondly, the research presents a discrete-event model to validate and evaluate the performance of the dairy supply chain. The study evaluates the dairy industry in Colombia to understand its current status and suggests strategies to improve the efficiency and productivity of the supply chain. This research also includes a new strategy to establish collaborative planning processes between suppliers and manufacturers of Costeño cheese. The aim is to create a new line of dairy products using whey generated in the cheese production process.

Analyzing research and requirements has enabled the identification of conceptual collaboration models with more than three factors. These factors include relationships with suppliers, information exchange, joint planning, alignment of incentives, synchronization of decisions, trust, and customer relations. This conceptual model addresses the main actors in the chain with collaboration scenarios and obtains productivity improvements for the activities in the dairy chain. The research proposes a discrete-event model considering collaboration and lean logistics strategies in a dairy industry supply chain. The model analyzed and described essential factors at the agri-food level. This strategy was considered to obtain greater productivity in the sector.

A simulation model was developed to evaluate the conceptual model. The simulation model uses advanced models to evaluate the performance of different scenarios and identify system problems. Implementing this approach would enable the dairy industry to bolster its position in the departmental economy. It reveals structural flaws, a lack of collaborative culture, minimal technological capabilities, and low productivity that can be improved. This would make the industry more competitive, increasing productivity and economic gains.

6.1 Managerial implications

Collaboration is essential in the dairy industry. Establishing strategies that focus on teamwork to increase productivity, efficiency, effectiveness, and competitiveness is crucial. The simulation model results confirm that collaborating with suppliers and implementing a new production line can provide significant benefits. The dairy industry can improve its income and competitiveness by strengthening production planning and adopting new technologies.

The simulation results of the model concerning the dairy industry in Sucre, Colombia, confirm that implementing collaboration with suppliers and improving internal processes provide significant expected benefits for all actors in the supply chain. This approach allows the negotiation of the interests of the different actors, development of collaborative production planning with suppliers, increased technological levels, and improvement of income to enhance the industry's competitiveness.

It is important to establish training programs that involve all stakeholders in the industry. These programs should concentrate on important areas such as production, transportation, collection, and processing of high-quality raw milk. Technical training is crucial for improving quality standards and gaining advantages at each stage of the supply chain through cooperative relationships among its participants.

6.2 Future research lines

In terms of future research, it would be worthwhile to incorporate other collaboration environments between suppliers into the simulation model. This could involve assessing production costs and examining how these relationships affect the number of suppliers and purchase volumes. It is also important to consider other lean logistics techniques since dairy production processes involve sequential stages. By examining and analyzing these process operations, we can lay the groundwork for achieving high productivity levels, quality, and safety.

Several lines of research have been suggested for the dairy industry. These include utilizing by-products and waste, creating productive supply chains, and enhancing and establishing new production methods. It is also crucial to assess levels of competitiveness, form clusters, advance agricultural technology, and facilitate technology transfer. In addition, future research could involve comparing the results of the supply chain activity planning optimization model with the improvement scenarios validated using the simulation model.

Appendix A. Parameters values of production costs of case study

See Tables 24, 25, 26 and 27.

Table 24 Raw material costs to obtain Costeño cheese

Item	Quantity	Value (COP$)	Purchase Frequency	Bimonthly cost (COP$)
Rennet	10 L	360,000	Every four months	180,000
Salt	13 Ton	3,500,000	Biannual	1,166,667
Total				1,346,667

Table 25 Labor costs to obtain Costeño cheese

Item	Quantity	Value (COP$)	Purchase Frequency	Bimonthly cost (COP$)
Labor cost 1	2	30,.000	Monthly	600,000
Labor cost 2	2	150,000	Monthly	300,000
Total labor cost				900,000

Table 26 Indirect production costs to obtain Costeño cheese

Item	Quantity	Value (COP$)	Purchase Frequency	Bimonthly cost (COP$)
Utility cost	3	1,300,000	Mensual	2,600,000
Transportation cost	3	60,000	Diario	3,600,000
Total indirect production Cost				6,200,000

Table 27 Raw material costs to obtain Costeño cheese for 60 days

Item	Units	Quantity	Value (COP$)	Purchase frequency	Bimonthly cost (COP$)	Value per unit (COP$)
Cuajo	Liters	10	360,000	Every four months	180,000	36 *
Sal	Tons	13	3,500,000	Biannual	1,166,667	269,23 **
Total			1,346,667			

* Value per mL of rennet

*Value per kg of salt

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Declarations

Conflict of interest We do hereby declare that we do not have competing interests with other Works.

Ethical approval The study is not funded by any agency. The authors declare that there is no conflict of interest with other works regarding the publication of this paper. This article contains no studies with human participants or animals performed by any author.

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