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Manufacturing Engineering Stream

Simulation Based Modeling and Performance Evaluation of a Dairy
Processing Plant: Case Study of Elemtu Milk Industry

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Declaration

I, Dejene Mekonnen Tola, hereby declare that the thesis entitled “Efficiency Analysis and Optimization of Dairy Industry Using Discrete Event Simulation: A Case Study of Elemtu Milk Industry” submitted in partial fulfillment of the requirements for the degree of Master of Science in Manufacturing Engineering at Addis Ababa University is my Own work. Any assistance received and all sources used have been acknowledged in the text and listed in the references section. This thesis has not been submitted for any other degree or diploma in this or any other institution.

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Abstract

The Ethiopian dairy industry plays a critical role in national nutrition and food security, yet its growth is hindered by equipment failures, production bottlenecks, inconsistent capacity utilization, and limited product diversification. Elemtu Milk Industry, a medium-scale processor with a design capacity of 5,000 L/h, has struggled for years with underperformance and low profitability. This study develops a detailed discrete-event simulation (DES) model using Arena 14.0 to analyze the plant's operations and evaluate opportunities for improvement. Two scenarios were examined: the current system and an optimized system integrating preventive maintenance, structured spare-part inventory management, upgraded utilities, automation technologies, and additional processing and packing machinery.

Simulation results show that the optimized scenario substantially enhances production performance. Annual milk throughput increased from 2.41 to 5.19 million liters, yoghurt production rose from 49,370 L to 274,340 L, and butter output expanded from 280 kg to 2,570 kg, supported by additional cream recovered from sour milk. New cream production reached 4,190 L. Cheese and local cheese volumes increased to 2,540 kg and 4,340 kg, respectively. Total packed batches grew from 24,623.8 to 54,795.5 demonstrating a significant expansion in the plant's ability to diversify and scale production.

Operational efficiencies also improved markedly. Utilization of major machines, including the homogenizer, HTST and ESL pasteurizers, cream separator, and refurbished milk and cream packers reached increased by 46% and average downtime of selected machines reduced by 89.8%. The introduction of a cream pasteurizer and vacuum packing machines enabled continuous cream, cheese, and local cheese processing. Preventive maintenance and structured spare-part management reduced overall downtime by 61%, while automated conveyors lowered manual handling time and minimized human contact with finished products. Upgraded utilities, particularly a high-capacity diesel generator and screw air compressor, effectively eliminated power-outage delays and compressed-air shortages.

Economically, the optimized scenario demonstrated strong financial benefits. Total revenue increased from 278.29 million ETB to 625.33 million ETB (a 124% rise), and total profit improved from 19.4 million ETB to 91.23 million ETB, despite higher operational

costs driven by increased production scale and broader product variety. These findings indicate that a coordinated improvement strategy combining maintenance planning, automation, spare-part control, and targeted machinery investments can dramatically enhance throughput, resource utilization, and profitability in small- and medium-scale dairy processing plants.

Keywords: Discrete-Event Simulation, Arena Simulation Software, Milk Processing Plant; Production Optimization, Machine Utilization, Spare Parts Management, Machine Reliability, Financial Performance Analysis

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CHAPTER ONE: INTRODUCTION

1.1 Background of the study

Dairy Processing industry plays a high role in Ethiopia's economy, contributing remarkable contribution to national economic development. According to FAO, 2019 and Tegegne et al., 2021, Ethiopia boasts the largest livestock population in Africa, with about 70 million cattle, yet milk productivity per cow remains far below the global average due to low genetic potential, suboptimal feeding, limited veterinary support, and restricted adoption of modern dairy technologies. This problem has affected the country's ability to meet increasing urban domestic demand for high-quality dairy products. This shows that efficient milk processing is one of the main areas to be given serious attention to ensure food security through production of value-added products such as yogurt, cheese, butter, cream and others.

Both economic and nutritional benefits could be attained from Value-added dairy products. For Example, Yogurt requires control and careful fermentation management and strict temperature control. Others like butter and cream production need efficient separation and churning processes. Cheese making also needs boiling, curdling, molding, and pressing, operations done by experienced and trained operators.

Elemtu Milk Industry is a medium-scale processor in Ethiopia with a design capacity of 5,000 liters per hour. The plant produces pasteurized milk, yogurt, butter, cream, and cheese. However, operations are often below capacity. Pasteurized milk is produced continuously, whereas value-added products are manufactured intermittently due to limited equipment, low automation, and inadequate cold storage. High frequency of machine breakdowns, less spare parts stocking, maintenance strategies which are mainly corrective (reactive) directly affect production efficiencies, resulting in low throughput and poor product quality (Haile & Tadesse, 2020; Aregawi & Melesse, 2022). Similarly, challenges in other East African countries like Kenya and Uganda, Dairy plants face equipment reliability problems, small preventive maintenance practices, and inappropriate process scheduling, all contributing to reduced productivity (Oyango et al., 2021; Mugisha et al., 2022)

In dairy processing industries, multiple factors affect production efficiency. Some of the factors are milk arrival patterns, Resource availability, equipment processing capacity and

processing times. For example, the pasteurization process involves boiling milk to a specific temperature for a given time, followed by rapid cooling. Any delay in upstream or downstream processes can lead to idle equipment, lower throughput, or increased spoilage. Cream separation, cream pasteurization and butter churning also require precise timing to achieve desired fat content and consistency. There are many studies which confirm that Discrete Event Simulation (DES) provides a powerful tool to model such complex, interdependent processes, capturing stochastic behavior and enabling scenario testing without disrupting actual operations (Law & Kelton, 2000; Banks et al., 2010).

DES models system behavior as a sequence of time-dependent events, such as milk arrival, pasteurization, homogenization, cream separation, packaging, and storage. By simulating these events, researchers can analyze production efficiency, machine utilization, downtime, and throughput under varying operational conditions. Studies confirm that this type of simulation approach enables testing of interventions such as preventive maintenance, spare part inventory management, scheduling changes, and partial automation, because this approach minimizes risks and costs compared to physical implementation (Jain & Leong, 2005; Sahoo et al., 2018; Silva et al., 2018). According to Previous Studies, DES can improve throughput by 15–25%, reduce unplanned downtime by 10–20%, and optimize resource allocation in food and dairy processing industries (Tadesse et al., 2020; Oyango et al., 2021; Lee et al., 2017).

In developing countries like Ethiopia, limited practices of preventive maintenance and poor spare part planning are major constraints to operational efficiency. Studies also show that unplanned downtime due to equipment failures interrupts production, increases wastage, and reduces profitability. Integrating preventive maintenance schedules, ensuring spare part availability, and upgrading key equipment are proven strategies to enhance reliability and performance (Gebremariam & Alemu, 2021; Negash & Alemayehu, 2022). DES mainly provides a platform to virtually implement these strategies, enabling evaluation of technical improvements and estimation of their effects before committing financial resources.

This study applies DES to Elemtu Milk Industry to develop a validated simulation model of the current production system and Ideal scenario. The model, in current Scenario identifies bottlenecks, quantifies machine utilization and downtime, and evaluates the effects of operational constraints such as spare part shortages and limited automation. An optimized

(ideal) scenario is then simulated, incorporating preventive maintenance schedules, spare part planning, and partial automation. The comparison between existing and optimized systems quantifies improvements in throughput, reliability, and technical efficiency. This approach provides actionable insights for technical decision-making, supports capacity utilization, and contributes to knowledge on applying DES in dairy processing, particularly in the East African context.

By analyzing Elemtu Milk Industry through DES, this study not only addresses operational inefficiencies but also contributes to the broader understanding of how simulation can guide technical improvements in medium-scale dairy plants. The findings are expected to inform both practitioners and researchers interested in improving dairy processing efficiency in Ethiopia and similar developing regions, highlighting the potential of simulation as a low-risk, high-impact tool for process optimization.

To complement the DES analysis and provide contextual understanding of the system under study, the physical configuration of Elemtu Milk Industry's processing lines is also essential. The spatial arrangement of the pasteurization units, homogenizer, cream separator, packing machines, cold storage rooms, utility systems, and material flow paths directly influences production sequencing, operational efficiency, equipment interaction, and the emergence of bottlenecks. Factors such as distances between processes, accessibility for operators, and the alignment of utility connections (steam, compressed air, chilled water, and electrical systems) play a significant role in determining actual cycle times and the likelihood of delays. A clear visualization of the plant's physical layout therefore supports accurate interpretation of the simulation model, reinforces understanding of interdependencies among units, and provides insight into how workflow constraints shape production outcomes.

The general Flow diagram of Elemtu Milk Industry is presented in Figure 1.1.below

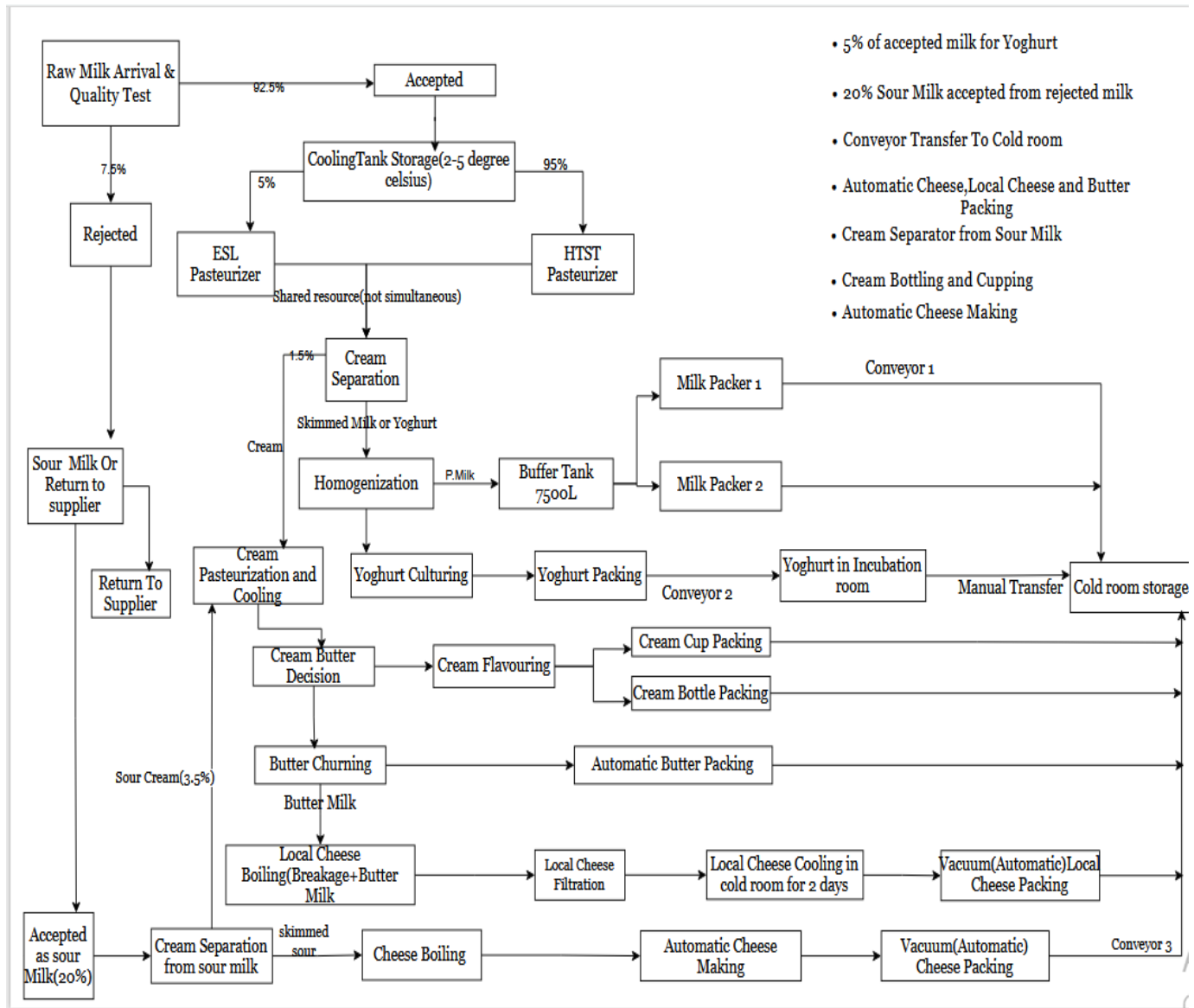


Figure 1.1 Flow Diagram of Elemtu Milk Industry (Ideal)

1.2 Statement of the Problem

The operational challenges faced by Elemtu Milk Industry are supported by a combination of documented production records, Annual reports, utility logs (Generator Run record), and data collected through interviews, questionnaires, and direct observation. To ensure transparency and traceability, all quantitative evidence supporting the problem definition is provided in the appendices.

One of the major Problems is Capacity mismatches between upstream and downstream processing capacities. Main downstream machines like HTST pasteurizer, homogenizer, and

cream separator, are each designed for 5,000 L/h operation (**Appendix VIII**). However, there is only one milk packing machine with a capacity of only 2,500 L/h. As a result, pasteurized milk accumulates downstream, causing extended overtime shifts to pack all processed milk. This practice significantly increases labor costs and energy consumption while reducing overall production efficiency.

According to information from Annual production reports (2015,2016,2017 E.C),the plant operates significantly below its nominal processing capacity of 5,000 liters per hour. As shown in **Appendix VII**, total annual pasteurized milk production was 4,284,874 liters in 2016 E.C. and 4,818,238 liters in 2015 E.C., while yogurt production remained disproportionately low at 83,268 liters and 175,920 liters, respectively. This corresponds to a yogurt allocation of less than 2–4 percent of total processed milk, though yogurt is a higher value-added product. The low yogurt allocation percentage of accepted milk shows that there is limited simultaneous operation capability, frequent packaging interruptions, and dependency on shared utilities rather than market demand constraints (**Appendix IV**).

Daily and hourly milk arrival records also confirm the mismatch between supply variability and processing capability. **Appendix VI** shows significant fluctuations in milk arrival rates within and across operating days which results in periods of overloads followed by idle capacity. These variations disturb production planning and increase dependence on buffer storage. In addition this increases the risk of spoilage during downstream interruptions.

Utility problems also represent a major structural constraint in the current system. Power Outage frequency and power outage duration data presented in **Appendix III** demonstrate repeated outages directly causing unplanned downtimes in pasteurizers, homogenizer, Cream Separator, Boiler and Chiller. Each interruption results in loss of productive time, extended restart delays, packing material loss during restart and high probability of product quality deterioration for in-process milk and yogurt.

Packaging losses constitute another persistent problem area. Breakage and return data summarized in **Appendix V** indicate 3% of Packed Pasteurized Milk returns to Factory as Breakage mainly due to Milk Packer's inefficiency even though there are other factors like handling problems and damaged crate, frequent machine stoppages, and unstable operating

conditions. The resulting product returns reduce effective sellable product and increase unit production cost, further causes reduction in revenues and profitability.

Cheese and local cheese processing and packing practices represent another critical inefficiency. Although the plant owns a mechanical cheese vat for curd cutting and pressing and Vacuum packer with some facilities to be added, all cheese processing and packing are predominantly performed manually due to low operator experiences and less attentions given for operator training and up upgrading facilities of the machines.. Consequently, cheese handling is conducted directly by hand, increasing labor requirements, extending processing time, and compromising hygienic conditions and shelf life. These limitations have led to low cheese output and poor market acceptance of the products.

Absence of Cream production further illustrates underutilization of installed capacity. Currently, cream separated from milk is collected manually in cream collection tanks and then transferred to a cream boiling tank for butter production. Although the plant is equipped with a batch cream pasteurizer that integrates heating and cooling functions, this unit is non-operational due to mechanical failure. As a result, direct cream pasteurization and packing are not performed, and cream is used exclusively for butter production despite existing facilities for cream processing and packing. This restricts product diversification and reduce revenue opportunities.

In Addition, sour milk acceptance for cheese production is extremely low. We can increase both cheese production, Cream production and Butter production by simply increasing sour milk accepted percentage(sour milk is rejected milk due to quality problem and purchased with lower price).Rejected or sour milk is processed without cream separation, even though it yields higher fat content that could be recovered. Interviews and observations indicate that installing a dedicated cream separator for sour milk could enable recovery of higher cream content (up to approximately 3.5 percent, compared to 1.5 percent from accepted milk), thereby increasing cheese, cream, and butter production simultaneously. The absence of this facility limits utilization of rejected milk and contributes to unnecessary losses.

Several other operational constraints like machine failure frequency, spare-part waiting time, compressed air waiting time, and the extent of manual operation during material transfer and packaging could not be fully quantified using historical records due to the absence of well-

organized data recording culture. To address this limitation, structured operator interviews, questionnaires, and direct on-site observations were conducted. These field-based data sources confirmed frequent unplanned breakdowns, long delays awaiting spare parts, insufficient compressed air capacity, and heavy reliance on manual handling in the existing system. In particular, limited compressed air supply prevents the simultaneous operation of multiple packaging lines, forcing sequential processing even when machines are physically available.

Maintenance practices at Elemtu Milk Industry are mainly corrective. According to interviews with maintenance personnel and some data from maintenance logs shows that maintenance is done only after equipment failure, with minimal preventive maintenance planning. Spare-part shortages further extend downtime durations, causing long spare part waiting times until the spare part is purchased. This situation makes the condition worst if the broken item is not found at local market and to be imported.

In General, according to evidences from production records (Appendices III, IV, VI, and VII) and field-based data collection (interviews, questionnaires, and observations) underperformance of Elemtu Milk Industry is driven by interconnected operational inefficiencies rather than isolated technical faults. Less milk accepting Capacity, high breakage returns, unstable utilities, limited compressed air capacity, Limited Automation and more Manual product handling, Frequent Power outages, spare part stocking problems and reactive maintenance practices collectively constrain production efficiency, product diversification, and financial performance.

Considering the interdependent nature of these constraints, traditional manual planning and decision-making cannot successfully evaluate system-wide impacts or improvement strategies. A systematic analytical approach is therefore required to model the current system, identify bottlenecks, and assess feasible improvement options. Discrete Event Simulation (DES) provides a suitable framework for analyzing such complex, stochastic, multi-product systems without disrupting actual plant operations. That's why this study applied DES to quantify the effects of equipment imbalance, manual operations, maintenance limitations, and process redesign, and to evaluate optimized operational strategies for improving productivity, product diversification, and profitability at Elemtu Milk Industry.

Table 1. 1 Operational and Performance Challenges at Elemtu Milk Industry

No.	Performance Area	Observed Value	Data Source	Implication	Required Improvement
1	Hourly milk arrival rate	911 L/h	2017 E.C. Production Report	Only ~18% of 5,000 L/h capacity utilized	Increase milk intake to $\geq 75\%$ capacity
2	Annual pasteurized milk production	4,284,874 L	2016 Production Report	Low throughput relative to plant capacity	Optimize processing and packing
3	Yogurt production share	1.78% ($\approx 83,000$ L/year)	2016 Production Report	Underutilization of high-value product line	Increase yogurt allocation
4	Cream production	0	2016 Production Report	Lost value-added opportunity	Start cream separation
5	Butter production	5,790 kg/year	2016 Production Report	Below potential due to lack of cream separation	Improve via sour milk utilization
6	Cheese production	2,164 kg/year	2016 Production Report	Limited by low sour milk acceptance	Increase sour milk intake
7	Power interruption	7,925 min/year	Generator Run-Hour Report	Major production stoppages	Eliminate via reliable backup
8	Average annual machine downtime	4,320 min/year	Maintenance Logs, Interviews	Severe productivity loss	Reduce via preventive maintenance
9	Spare part waiting time	10,080 min	Maintenance Records	Extended idle time	Establish spare-part inventory
10	Maintenance strategy	Breakdown only	Interview, Observation	Unpredictable failures	Implement PM system
11	Milk packing capacity	2,700 L/h	Observation	Bottleneck vs processing capacity	Add additional packer
12	Cheese & local cheese packing	Manual	Observation	Slow, labor-intensive	Automate packing
13	Product transfer to cold room	Manual	Observation	Delays, breakage risk	Introduce conveyors
14	Simultaneous operation capability	Not available	Observation	Limits multi-line production	Upgrade compressed air system
15	Annual breakage return	3%	2017 Monthly Records	Direct revenue loss	Reduce to $\leq 1\%$
16	Net annual profit	~ 17 million ETB	2017 Financial Report	Below industry potential	Improve via efficiency gains

1.3 Research Questions

1. How does the existing milk processing system perform in terms of throughput, machine utilization, and downtime, and what are the key bottlenecks identified using the Arena simulation model?
2. How do alternative optimized scenarios incorporating improvements in maintenance practices, spare part availability, packing capacity, product allocation, and material transfer affect the performance of the dairy processing system?
3. Compared to the existing system, what technical improvements are achieved by the best optimized scenario in terms of production output, resource utilization, equipment downtime, and product losses?

1.4 Research Objectives

General Objective:-To analyze and optimize the production efficiency of Elemtu Milk Industry using discrete event simulation.

Specific Objectives

1. **Model and simulate the existing system and identify bottlenecks:-**Develop a discrete-event simulation model of the current Elemtu Milk Industry production system using Arena software. The model captures milk arrival patterns, processing times, machine availability and product flows to establish baseline performance and identify major bottlenecks limiting efficiency.
2. **Model Optimized scenarios and select the best-performing scenario:-**Focuses on developing and simulating three optimized scenarios incorporating improvements such as preventive maintenance, spare part management, Milk Arrival Rate, Product Mix and partial automation. The performance of each scenario is evaluated using simulation outputs to select the most effective optimization strategy.
3. **Compare and analyze existing and optimized system performance and Technical Evaluation:-**Aims to compare key performance indicators of the existing system and the best optimized scenario to quantify technical improvements in throughput, machine utilization, downtime, and overall system efficiency

1.5 Scope of the Study

This study focused mainly on the production operations of Elemtu Milk Industry, mainly about six major product lines: pasteurized milk, yogurt, cream, butter, cheese, and local cheese. These products represent the plant's outputs and capture the full complexity of the dairy processing workflow like cream separation, Pasteurization, Homogenization, packing, and reception operations. The research focused on modeling of these processes using Arena Simulation Software to evaluate system behavior, identify bottlenecks and test alternative operational strategies.

The research includes model development of both the existing and optimized scenarios, including machine behavior, resource addition, spare-part inventory, maintenance practices, utility system performance, and production flows. The simulation result shows machine breakdowns, , processing delays, labor involvement, and spare part availability, allowing for the whole representation of plant operations.

However, certain areas remain outside the direct scope of the study. Upstream milk collection, and milk collection and supplies are excluded, separate data collection methods and broader supply chain modeling required. Similarly, product distribution and market expansion strategies are also beyond the boundary of the simulation. While the study provides economic comparisons between scenarios, a full financial costing analysis including detailed cost benefit evaluation and market forecasting are also excluded. Such financial modeling requires extensive accounting and pricing data, which is recommended for future studies.

The study, in general is designed to examine the internal functioning of the dairy plant, assess its operational efficiency, and propose technically remarkable optimization measures within the limits of available production, maintenance, and spare part data.

1.6 Limitations of the Study

Although the simulation model provided valuable observations into the operational behavior of the dairy processing plant, several limitations should be acknowledged when interpreting the results.

First, the model was developed using the best available operational data and some assumptions. Similar to any simulation study, actual plant performance may differ due to unobserved variability, human behavior, or unexpected operational interruptions. Second, market related factors such as demand fluctuations, price changes, inflation, and competitors' pressures were not added into the model. As a result, the financial outcomes reflect internal operational improvements rather than full market dynamics.

Third, preventive maintenance were modeled under ideal conditions, assuming significant organizational support. In practice, implementation might be affected by workforce unavailability, management commitment, or budget limitations. Finally, the scope of the study was limited to plant operations, while raw milk collection and partially product distribution excluded. These external factors may also influence overall system performance and profitability.

1.7 Significance of the Study

This research contributes to both academic and practical areas, offering observations that benefit industrial researchers, policymakers and other scholars in the field of manufacturing industries. Elemtu Milk Industry, like many other dairy plants in Ethiopia and other developing countries, operates below its design capacity and faces challenges related to equipment reliability, inconsistent workflows and fluctuating production schedules. By using Discrete Event Simulation, the study demonstrates data driven approach to make decision in a sector that typically depends on manual and experience based planning.

The study supports dairy industry managers by providing a detailed, data-driven methodology to evaluate their production systems without interrupting real operations. The ability to test preventive maintenance plans, spare part inventory strategies, impact of automation and compare production policies to offer powerful decision making. For policymakers, the findings of the study contribute to national strategies used to modernize Ethiopia's agro-processing sector. This enhances value addition to products, reduce production losses, and strengthen industrial competitiveness.

From academic point of view, the study is addition to existing literatures on simulation based optimization of dairy processing plants, an area with limited research in developing countries. The study addresses gaps related to machine reliability, spare-part inventory and multi-

product processing areas. The study also demonstrates how simulation can integrate maintenance management, resource utilization, and production system modeling within a single model.

Practically, the research provides Elemtu Milk Industry with evidence-based solutions that can increase throughput, reduce downtime, improve machine utilization and increase production of good value products such as yogurt, cream, and cheese. These improvements have significant improvement in profitability, expand product diversification, and improve customer satisfaction. Strengthening operational performance of local dairy processors supports the broader goal of improving food security through efficient dairy plant development at national level.

1.8 Organization of the Thesis

This thesis is organized into six chapters to provide a logical flow from background to technical analysis and practical recommendations. Chapter One introduces the research topic, explaining background, statement of the problem, objectives, scope, limitation and significance of the study. Chapter Two presents detailed review of relevant literature, including studies on dairy processing systems, DES usage in manufacturing industries, maintenance strategies, inventory management and automation practices. This chapter establishes the conceptual and theoretical foundation for the research.

Chapter Three explains the methodology employed in the study, describing the research design, data collection procedures, modeling approach and data processing, modeling and result analysis tools used. It also outlines how key performance indicators were selected and how both existing and optimized scenarios were developed in the Arena.

Chapter Four presents the detailed simulation models of Base line Scenario and Optimized Scenarios and selecting best Optimized Scenario using Arena process Analyzer.

Chapter Five discusses about Simulation Results Analysis of existing and Optimized Scenarios and improvement Comparisons. It includes Output Analyzer comparisons, scenario analysis, and interpretation of technical and economic findings. The chapter discusses key improvements in throughput, downtime reduction, spare-part management, and resource utilization improvements.

Finally, Chapter Six summarizes the conclusions drawn from the study and provides recommendations for Elemtu Milk Industry and similar dairy processors. It discusses the practical implications of the findings and proposes directions for future research, particularly by integration of financial analysis and production monitoring systems.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Dairy industry plays a remarkable role in food security and economic development, particularly in developing countries where milk and milk products are major sources of nutrition and income. In Ethiopia and across East Africa, dairy processing plants are forced to operate under conditions characterized by fluctuating raw milk supply, strict food safety requirements, limited infrastructure reliability, and growing market demand for diversified dairy products. These challenges place considerable pressure on processing facilities to operate efficiently while maintaining product quality and minimizing losses.

Dairy processing systems are highly complex due to the perishability of raw milk, the multi-stage nature of processing operations, and the need for continuous utilities such as electricity, water, steam, and compressed air. According to previous studies delay or failure at any stage of production can propagate downstream, leading to product spoilage, idle resources, and increased operational costs (Bunte et al., 2011).

According to (Abebe & Worku, 2023; ILRI, 2021), operational inefficiencies are compounded by outdated equipment, frequent machine breakdowns, insufficient preventive maintenance practices, and weak spare-part supply chains in East Africa, including Ethiopia. As a result, installed processing capacities are often underutilized, product diversification is limited, and profitability remains below potential levels in many dairy plants. These challenges point the need for systematic tools that can analyze complex interactions within dairy processing systems and evaluate alternative improvement strategies before physical implementation.

Discrete-event simulation (DES) has emerged as a powerful decision-support tool for analyzing and optimizing complex production systems. DES enables researchers and practitioners to evaluate system performance under varying conditions without disrupting actual operations by modeling system behavior through events such as arrivals, processing, failures, and repairs according to (Banks et al., 2010; Law, 2015) and has been used to assess throughput, identify bottlenecks, evaluate maintenance strategies, and estimate financial performance in dairy processing (Bunte et al., 2011; Franco et al., 2023).

Despite the fact that DES is used in Dairy industry optimization, Most of the previous studies focus on specific process stages or KPI. Modeling of all the integration of all Machine Failure and repair, spare-part inventory, manual vs automated material handling, and financial analysis within a single modeling is found as one of the main gaps of previous studies. Detailed statistical comparison of scenarios also considered in few studies.

I have tried to study previous studies from Ethiopia and east African countries as well as recent global studies on usage of DES in Dairy plants is specific and Food and Manufacturing plants in general. I have also studied about Bottlenecks identification practices in Complex manufacturing environment, Maintenance Management practices, inventory Management, Automation and Hygiene related issues in Industries, Utility related factors as well as financial analysis in manufacturing industries, especially in food and Dairy plants and identified Literature Gaps. These all are presented in next sections

2.2 Dairy Processing Systems and Operational Complexity

2.2.1 Dairy Processing Operations Overview

Raw milk is converted into six products; Pasteurized milk, Yoghurt, Cream, Butter, Cheese and Local Cheese in Dairy plants. Many simultaneous and sequential operations like raw milk reception, Laboratory test for quality, precooling, pumping, cold storing, pasteurization, cream separation, homogenization, packing and etc each operation stage with required processing parameter and standards are some of main processing stages in Dairy processing industries.

According to (ILRI, 2021) study, in Ethiopia and East Africa, Fluctuation of milk arrival rate results in stochastic behavior of the dairy processing sector which, in other words has direct impact on production scheduling and Resource utilization. After raw milk arrived to the factory is tested for its quality, the accepted milk should be stored under controlled temperature since milk is highly perishable commodity.

Other central processing stages in dairy industry are Pasteurization and Homogenization. Dairy plant pasteurizers are found to be main bottlenecks because there are factors like downtime, capacity problem and other utility related issues like insufficient steam from boiler

according to previous studies.(Bunte et al., 2011; Abebe & Worku, 2023) while multiple product route at cream separation stage require careful and synchronized handling.

Packing operations are also other critical stage in Dairy plants. Manual and semi-automated packing practices are main factors affecting packed product quality, shelf life and hygiene as well as processing time and also increase labor requirement.in addition if there is problem at packing stage all processing before packing like pasteurization, Homogenization and cream separation needs to be stopped because it needs additional buffer storage and extended time (mostly overtime) to complete packing of processed products.

One or more of the following factors causes Operational problems in Dairy plants:

1. **Perishability of Raw Milk:** - Raw milk, as soon as it arrives the plant should be stored under recommended temperature (cooling down to 2-5 degree Celsius) to prevent spoilage and financial loss unlike other manufacturing raw material(Bunte et al., 2011).
2. **Diverse Production:-** Product allocation ratios, priority of production and scheduling of products affect throughput, revenue and profitability of each products since dairy plants use some shared resources to produce multiple product types.
3. **Stochastic Variability:-** According to studies in (Law, 2015),variable behaviors of milk arrival rate, machine failure uptime and downtime, processing times at different processing stages and fluctuation in market demand had caused randomness behavior of dairy plant operations which could not be captured by deterministic tools.
4. **Utility Issues:** - Studies like (Kinyua et al., 2021) indicated that Power outages and other utility related problems are major causes of downtime in Ethiopian and Kenyan dairy plants. This study ensures that uninterrupted availability of electric power, steam water, chilled water, compressed Air and raw water for cleaning are essential for continuous and standard operation of dairy plants

Most of dairy plants operate at low capacity which is less than 60% of its installed capacity due to inconsistent raw milk arrival, short uptime of machine failures and limited product variety according to studies from Ethiopia (Abebe & Worku, 2023).In very similar way, Kenyan and Ugandan studies have confirmed that high downtimes in dairy plants are mainly caused by power interruptions and delayed maintenances. For instance, Packing line failures

accounts for more than 40% of total downtime and pasteurizer failure highly affects throughput during peak supply periods according to Kenyan dairy plant study (Kinyua et al., 2021) and key contributors to post processing losses are found to be limited cold storage and manual product handling according to studies in Uganda (Mugisha et al., 2022).

These all research findings point at the need for system-level analysis tool for successful capturing of interdependencies between production stages, resources, and utilities.

The complexity found in dairy processing plants in different previous studies motivates the use of discrete-event simulation. By modeling the existing production system in Arena, including stochastic milk arrivals, shared resources, and machine availability, the study established a realistic baseline representation of plant performance.

In addition, understanding the sources of the problems to identify bottlenecks that limit throughput and utilization is also what could be achieved by DES method. The literature clearly demonstrates that without dynamic modeling, critical interactions between processes, utilities, and maintenance activities remain hidden, leading to suboptimal decision-making.

2.3 Discrete-Event Simulation in Food and Dairy Industries

2.3.1 Fundamentals of Discrete-Event Simulation

Discrete-event simulation (DES) is a modeling approach in which the state of a system changes at discrete points in time as a result of specific events. Main events in manufacturing and food processing systems are of raw materials' arrival, processing stages, machine failures, repairs, product storage and departures. Studies like (Banks et al., 2010; Law, 2015) confirm that DES is suitable for systems characterized by variability, resource sharing, and complex interactions among processes.

Discrete Event Simulation Approach has capability to represent real-world dairy processing operations and allows incorporation of all stochastic distributions unlike analytical or deterministic models. There are previous studies which ensure that DES is the best approach to enable the estimation of major KPIs like throughput, downtimes and resource utilization with statistical confidence (Rossetti, 2016).

One of the widely used DES software, Arena is known for its modular structure, graphical interface, resource modeling built-in support. The Modules in Arena simulation software like Create, Process, Assign, Decide, Record, etc also allow detailed representation of Production, failure and maintenance logic which makes it suitable for analyzing processing stages and equipment related modeling in manufacturing industries like dairy processing(Law, 2015).

2.3.2 Applications of DES in Food Processing Industries

DES has is highly applied in food processing industries to improve operational efficiency, reduce waste, and support strategic decision-making. Effectiveness of DES in modeling food processing industries like meat processing plants, beverage bottling lines, edible oil industries, and dairy processing plants is discussed by many studies. (Banks et al., 2010; Bunte et al., 2011).

In food processing environments, DES is commonly used to:

- Identify production bottlenecks
- Evaluate alternative layouts and process configurations
- Analyze labor and machine utilization
- Assess the impact of maintenance strategies
- Estimate economic performance under different scenarios

. Their study demonstrated that ignoring machine failures leads to overestimation of throughput and underestimation of operating costs. DES was applied to analyze milk processing operations, pointing the importance of accounting for equipment downtime and sanitation cycles to show that ignoring machine failure leads to overestimation of throughput and underestimation of operating costs (Bunte et al. (2011). Franco et al. (2023) also showed that integrating automation into DES models improved throughput and reduced variability in dairy packaging operations significantly

These findings emphasize the suitability of DES for evaluating both technical and operational improvements in dairy plants.

2.3.3 DES Applications in Dairy Processing

Due to multi-product flows, perishability issues, and high hygiene requirements, dairy plants encounter unique modeling challenges. This is emphasized in previous and recent studies where DES models have been used to analyze Pasteurization capacity, packing efficiency, and cold storage utilization in dairy plants (Bunte et al., 2011; Albisu et al., 2023).

Product mix decisions in dairy plants had also been accessed using DES. Researchers have demonstrated how product diversification can improve profitability and resource utilization by simulating alternative allocations of raw milk to different dairy products (Adekunle et al., 2021).

2.3.4 Regional Studies in East Africa

Application of DES in East African dairy processing is still limited, despite the global adoption. DES applied to edible oil factories in Ethiopia by Abebe and Worku (2023) and showed its capability for similar food processing industries.

DES was also used by Kenyan researchers to analyze dairy processing plants and ensured that inconsistent utility supply and reactive maintenance remarkably reduce effective capacity (Kinyua et al., 2021). These studies confirm the importance of modeling power outages and repair delays to accurately estimate plant performance.

In Uganda also, DES study was conducted on dairy plants and identified manual handling and lack of automation as major contributors to post-processing losses (Mugisha et al., 2022). However, these studies often focused on isolated processes rather than system-wide optimization.

However, most of the regional studies tend to model individual bottlenecks or specific processes, with limited integration of maintenance, automation, and financial analysis.

Although DES has proven effective in dairy processing analysis, several limitations are evident in the existing literature:

- Many studies focus on technical metrics only, such as throughput and utilization, without linking results to financial performance.
- Preventive maintenance and spare-part availability are often omitted or oversimplified.

- Utility systems such as compressed air supply are rarely added to models
- Comparative analysis between existing and optimized scenarios is often qualitative rather than statistical.

These limitations are particularly found in studies conducted in developing countries, where machine reliability and maintenance practices significantly influence system performance.

The reviewed literature strongly supports the methodological choices of this thesis. The documented success of DES in identifying bottlenecks and suggesting process alternatives focuses on identifying inefficiencies in the current system.

Gaps identified in regional DES studies involve simulating an optimized scenario that integrates preventive maintenance, spare-part inventory management, automation, and utility upgrades. By extending DES to include financial performances, this study also responds to the shortcomings noted in previous researches.

Tabel 2. 1 Summary of DES Applications in Dairy and Food Processing

Study	Region	Focus Area	Key Findings	Identified Gaps
Bunte et al. (2011)	Europe	Dairy processing	Downtime strongly affects throughput	Limited financial analysis
Adekunle et al. (2021)	Nigeria	Food packaging	DES improves scheduling	No maintenance modeling
Abebe & Worku (2023)	Ethiopia	Food processing	DES identifies bottlenecks	Partial system coverage
Kinyua et al. (2021)	Kenya	Dairy plants	Utilities cause major downtime	No optimization scenario
Franco et al. (2023)	Global	Dairy automation	Automation boosts throughput	High-level modeling

2.4 Bottleneck Identification and Resource Utilization Analysis

2.4.1 Concept of Bottlenecks in Production Systems

Bottleneck is defined as any resource or process stage whose limited capacity restricts the overall output of a system. Bottlenecks in processing industry are found to determine throughput, influence work-in-process levels, and shape operational performance according to studies by (Goldratt & Cox, 2004). Bottlenecks can shift over time depending on product mix, market demand, machine availability, and utility conditions in complex, multi stage systems like dairy plants.

Traditional methods of bottleneck identification, such as capacity calculations and line balancing, often fail to capture dynamic interactions among system components. According to studies by (Tako & Robinson, 2012), capacity calculations and line balancing methods for bottleneck identification assume deterministic processing times and continuous availability of resources, assumptions that do not usually found in dairy processing environments characterized by stochastic behavior and frequent disruptions

By tracking queue lengths, waiting times, and resource utilization, DES provides a significant framework for identifying bottlenecks by enabling detection of both persistent and transient bottlenecks that might only occur under specific operating conditions (Rossetti, 2016).

2.4.2 Resource Utilization as a Performance Indicator

Resource utilization measures the proportion of time a resource is actively engaged in processing relative to its available time. In dairy plants, key resources include pasteurizers, homogenizers, cream separators, packaging machines, utilities, and labor. High utilization may indicate efficient use of capacity.

According to Banks et al., 2010, sustainable utilization levels for critical processing equipment typically range between 70% and 90%, depending on system flexibility and maintenance practices. Utilization levels below this range often indicate inefficiencies, while levels above it increase the risk of system instability.

Simulation-based utilization analysis allows managers to distinguish between productive utilization and forced idleness caused by upstream or downstream constraints.

2.4.3 Bottlenecks in Dairy Processing Systems

Pasteurization, cream separation, and packaging are identified as common bottlenecks in many studies. Mostly, pasteurizers operate as capacity-constrained equipment due to limited pasteurization capacity and downtime (Bunte et al., 2011) and packaging lines using manual and semi-automatic systems become bottlenecks as a result of low processing speed and high labor dependency (Franco et al., 2023).

In Ethiopian dairy plants, Abebe and Worku (2023) reported that packaging and utility-related interruptions accounted for over 50% of production delays. Similarly, Kenyan studies

found that power outages and compressed air shortages caused frequent stoppages, even when processing equipment was otherwise available

Abebe and Worku (2023) had conducted recent study in Ethiopia and found that packaging and utility interruptions accounted for more than 50% of production delays. Kenyan studies, in similar way, reported that power outages and compressed air shortages caused frequent stoppages, even when processing equipment was still available (Kinyua et al., 2021).

Simulation studies have shown that addressing upstream bottlenecks without resolving downstream constraints often yields limited improvement. For example, increasing pasteurizer capacity without upgrading packaging systems may simply shift congestion downstream.

2.4.4 Regional Case Examples

In Ethiopia, small and medium-scale dairy plants often operate multiple product lines using shared equipment. Abebe and Worku (2023) also reported in their recent study of simulation-based analyses that pasteurizers and packing machines are main bottlenecks, while upstream capacities remain underutilized

Long queues and high labor utilization are found to reduce overall plant throughput despite adequate processing capacity according to Ugandan dairy plant case study (Mugisha et al., 2022) and limited cold storage capacity was identified as bottleneck as recent report from Tanzanian study (Mkenda et al., 2021).

These examples illustrate the importance of system-wide bottleneck identification rather than isolated process analysis.

2.4.5 Bottleneck Shifting and Product Mix Effects

Bottlenecks in dairy plants are influenced by product mix decisions. Production of value added dairy products like yoghurt, butter, cheese, and cream requires different processing routes and resource combinations. Changing the proportion of milk allocated to different products is found to change bottleneck locations and resource utilization according to simulation studies reports (Adekunle et al., 2021).

The literature reviewed in this section focuses on identifying and quantifying major bottlenecks in the process flow. The demonstrated limitations of traditional bottleneck analysis justify the use of DES for dynamic evaluation.

In addition, understanding bottleneck behavior provides the analytical basis which involves developing and simulating an optimized scenario. By identifying resources with limited capacity and underutilized resource, improvements such as equipment refurbishment, automation, and utility upgrades can be evaluated systematically.

2.5 Machine Reliability, Downtime, and Maintenance Strategies

2.5.1 Machine Reliability in Dairy Processing

Machine reliability is defined as the ability of equipment to perform its intended function without failure for a specified period under given operating conditions. Machine reliability, in dairy plant is significantly important because of continuous production requirements, hygiene requirements, and perishable behavior of raw milk. Bunte et al., (2011) clearly demonstrates that equipment failures affect production and lead to product spoilage, quality problem, and high sanitation requirements.

Critical equipment in dairy processing industries like pasteurizers, homogenizer, cream separator, packaging machines, boiler, and air compressors, operate under demanding conditions involving thermal stress and mechanical wear. Studies confirmed that old machinery and inappropriate maintenance practices reduce reliability, in developing countries. (Alrabghi & Tiwari, 2016).

2.5.2 Downtime and Its Operational Impact

Downtime can be classified as planned or unplanned. Planned downtime includes scheduled cleaning, inspections, and preventive maintenance activities, while unplanned downtime results from unexpected equipment failures or utility interruptions. Unplanned downtime is bad event in dairy plants, as it often occurs without warning and milk is highly perishable material and result in spoilage if processing is interrupted at some critical stages. For instance, if yoghurt packing machine is failed at the middle of yoghurt packing the

pasteurized yoghurt milk will immediately spoiled if not packed and sent to incubation room, in maximum of three hours after pasteurization and culture addition.

Recent Ethiopian and Kenyan studies have indicated that unplanned downtime can account for 30–50% of total lost production time in small- and medium-scale dairy plants (Kinyua et al., 2021; Abebe & Worku, 2023). In Ethiopian plants, breakdown maintenance remains the dominant strategy, leading to extended repair times due to delayed fault diagnosis and lack of spare parts.

Simulation-based analyses in Banks et al., (2010) emphasize that ignorance of downtime in production planning causes too high throughput estimates and underestimation of operational costs.

2.5.3 Maintenance Strategies in Manufacturing Systems

Maintenance strategies in manufacturing industries can be broadly categorized into corrective (breakdown) maintenance, preventive maintenance (PM), and predictive maintenance. Corrective maintenance involves repairing equipment only after failure, while PM schedules maintenance activities at planned intervals to reduce the probability of failure (Alrabghi & Tiwari, 2016).

2.5.4 Regional Maintenance Practices

Maintenance practices are mainly reactive in East African dairy plants. This is due to the fact that there is limited technical capacity of equipment, poor spare part inventory control, and budget related problems. Maintenance teams in manufacturing industries mainly depend on temporary fixes according to reports from Ethiopian and Kenyan studies reports (Abebe & Worku, 2023; Kinyua et al., 2021).

Lack of preventive maintenance planning are found to be main factor for high downtime in packing and utility machines, particularly air compressors and generators as reported from Ugandan studies (Mugisha et al., 2022). These issues underscore the importance of incorporating maintenance strategies into operational analysis.

2.5.5 Modeling Reliability and Maintenance in DES

DES allows modeling of machine failures, repair times, and maintenance schedules. Different failure distribution functions can be used to represent time between failures, while repair time distributions capture variability in maintenance activities (Law, 2015).

Incorporating preventive maintenance and spare-part availability has been shown to significantly reduce unplanned downtime and improve throughput stability from dairy processing simulations (Doostparast et al., 2014). Arena provides built-in facility for failure modeling, enabling realistic representation of equipment reliability behavior.

The literature reviewed in this section focuses on developing an optimized scenario integrating preventive maintenance and spare-part management. By modeling reliability and maintenance in the simulation, this study evaluates the impact of maintenance strategies on downtime, throughput, and machine utilization.

Additionally, reduced downtime contributes to improved financial performance, which assesses technical and financial improvements.

This section evaluates preventive maintenance scheduling, refurbished equipment, and spare parts inventory management within an optimized simulation scenario.

2.6 Spare-Part Inventory Management in Process Industries

2.6.1 Importance of Spare-Part Availability

Spare-part availability is a critical determinant of maintenance effectiveness and equipment availability in process industries. Even when skilled maintenance personnel are available, the absence of critical spare parts can extend downtime significantly, resulting in lost production and increased operational costs. Delayed repairs affect entire production system in dairy processing plants, because continuous operation is required to prevent raw milk spoilage (Doostparast et al., 2014).

Critical spare parts such as seals, bearings, sensors, and spare kits for critical special machines are essential for maintenance of pasteurizers, homogenizers, cream separators, packaging machines, boilers, and compressors. Failure to maintain adequate inventories of these components often leads to prolonged machine downtimes.

2.6.2 Challenges of Spare-Part Management in Developing Countries

Spare part supply chains are characterized by long lead times, high import costs, and limited local suppliers in many developing countries like Ethiopia, Kenya, Uganda and Tanzania. This results in operation of dairy plants with minimal spare part inventories, depending on emergency purchasing when failure occurs (Abebe & Worku, 2023).

2.6.3 Spare-Part Inventory Policies

According to previous studies on spare part management strategies by fixing reorder points and periodic inventory checks, criticality is mainly analyzed to classify spare parts based on their impact on system performance and downtime risk (Alrabghi & Tiwari, 2016).

Even though simulation studies have emphasized that giving priority for critical spare parts and aligning inventory policies with maintenance schedules can significantly reduce downtime and maintenance costs, the true impacts of this approach is seen only when integrated into system-level operational models (Doostparast et al., 2014).

2.6.4 Integration of Spare-Part Management into DES

DES enables explicit modeling of spare-part availability and its effect on repair times. According to (Law, 2015), modeling approach of keeping stock levels of critical spare parts enable to capture realistic maintenance behavior.

Other very recent study on dairy processing plant also ensures that if spare-part inventory logic is added in dairy plant optimization model, it can reduce optimistic bias in performance estimates and provide more reliable evaluations of maintenance strategies (Franco et al., 2023).

2.6.5 Regional Evidence

Recent studies of Ethiopian dairy plants ensure that extended downtime is occurred due to limited stocks of spare parts for packing machines and pasteurizers which are not found in local markets (Abebe & Worku, 2023) while Kenyan studies report delays utility machines' repairs due to limited spare parts at local markets (Kinyua et al., 2021).

These findings point at the need of modeling spare-part inventory as an integral component of system optimization.

This section involves developing an optimized scenario by integrating spare part inventory management. By adding spare part inventory within the simulation model, the study evaluates its impact on downtime, machine utilization, and throughput.

Reduced downtime resulting from improved spare-part management also contributes to better financial performance.

Tabel 2. 2 Impacts of Spare-Part Availability on Maintenance Performance

Spare-Part Status	Repair Delay	Operational Impact
In stock	Minimal	Quick recovery
Delayed supply	Extended	Prolonged downtime
No inventory	Severe	Production loss

(Sources: Doostparast et al., 2014; Abebe & Worku, 2023)

2.7 Automation, Hygiene, and Product Quality in Dairy Processing Systems

2.7.1 Role of Automation in Dairy Processing

Automated processing and material handling systems plays significant role in improving efficiency by reducing process variability, minimizing manual handling, improving product quality, and enabling higher throughput of better quality products with lower labor requirement. This is also emphasized in previous dairy plant studies that automation is mainly applied in milk transfer, pasteurization, packaging and cold room handling (Walstra et al., 2006). This issue is also discussed in very recent studies to ensure that automation is used in plants handling multiple product types, such as pasteurized milk, yogurt, butter, cream, and cheese, where frequent changeovers and hygiene requirements increase operational complexity (Kumar et al., 2021).

2.7.2 Automation and Hygiene Compliance

Hygiene is a critical requirement in dairy processing due to the high perishability of milk and the risk of microbial contamination. There is high risk of contamination when there is manual handling during packaging and product transfer to cold room. Previous studies had improved this truth by suggesting that automation significantly reduces human contact with products,

thereby improving compliance with food and safety standards such as HACCP and ISO 22000 (Tamime, 2018).

Studies also ensure that if manual cheese and butter packing is replaced with vacuum packing machines, contamination incidents are significantly reduced and shelf life could be improved by 20–40% (Bunte et al., 2011). Automated conveyors and transfer systems further reduce exposure time between processing and cold storage, preserving product quality.

2.7.3 Impact of Automation on Throughput and Downtime

Automated processing and material handling eliminates delay, reduces labor, and reduce time by reducing waiting time between process stages. This is confirmed, by previous studies to result in smoother flow, higher throughput, and limited bottlenecks, mainly at interface between packaging and storage (Law & Kelton, 2015).

Other recent simulation-based studies also ensure that even partial automation can yield considerable performance improvements when applied at critical bottlenecks such as packaging and post-processing handling (Franco et al., 2023).

2.7.4 Regional Evidence on Automation Adoption

According to studies on East African dairy processing plants, specifically Ethiopian and Kenyan studies ensure that many dairy plants still rely on manual filling, sealing, and product transfer, resulting in inconsistent product output and high rejection rates (Abebe & Worku, 2023; Kinyua et al., 2021). This is due to the fact that automation adoption to dairy industries is still limited due to high capital costs.

Recent studies in Kenya and Tanzania, however, show that investments in medium-scale dairy plants, mainly automation of packaging and cold room transfer, can improve without full plant automation (Mashauri et al., 2022).

This section evaluates automation interventions such as vacuum packing machines, automated conveyors to cold rooms, and improved cream and milk packaging lines. Improved hygiene and reduced handling time directly contribute to higher throughput and lower rejection rates.

Tabel 2. 3: Effects of Automation on Dairy Plant Performance

Automation Area	Operational Effect	Quality Impact
Automated packaging	Reduced cycle time	Consistent filling
Vacuum packing	Faster sealing	Extended shelf life
Product conveyors	Reduced waiting	Lower contamination

(Sources: Tamime, 2018; Kumar et al., 2021; Abebe & Worku, 2023)

2.8 Energy Reliability and Utility Systems in Dairy Plants

2.8.1 Importance of Reliable Utilities

Interruptions in utilities like electricity, steam, compressed air, and chilled water can affect production, reduce product quality and increase waste since dairy processing plants depend on this utilities.

2.8.2 Power Outages and Production Loss

Unreliable grid power is one of the main factors leading to frequent production interruption in many developing countries. Recent studies of Ethiopian dairy plants show that frequent power outages interrupts pasteurization and packaging processes, which results in unplanned downtime and milk spoilage (Abebe & Worku, 2023).

According to recent studies from Uganda and Tanzania, power interruptions account for up to 15–25% of total downtime in food processing plants (Mugisha et al., 2022; Mashauri et al., 2022).

2.8.3 Role of Backup Generators

Diesel generators are widely used as backup power sources in dairy plants, while insufficient generator capacity significantly limits simultaneous operation of critical processing stages, forcing partial shutdowns. According to (Kinyua et al., 2021), Upgrading generator capacity enables continuous operation of pasteurizers, packaging machines, compressors, and cold rooms during outages. Other Simulation studies also show that having adequate backup power capacity highly reduces downtime and stabilizes throughput in power-constrained environments (Law, 2015).

2.8.4 Compressed Air Systems

This section addresses utility-related bottlenecks. In Elemtu milk industry, Compressed air is essential for different operations like actuating pneumatic valves, controlling packaging operations, and other control systems. Old and limited capacity piston compressors often create bottlenecks due to limited capacity and pressure fluctuations. Previous studies ensure that Screw air compressors provide continuous airflow and allow simultaneous operation of multiple machines, reducing waiting time and idle periods (Arabghi & Tiwari, 2016). The optimized scenario includes a screw air compressor to reduce downtime, improve machine utilization, and ensure stable operation.

Table 2. 4 Utility-Related Downtime Sources

Utility Failure	Impact on Production
Power outage	Line stoppage
Low generator capacity	Partial shutdown
Air shortage	Packaging delays
Chiller failure	Quality degradation

(Sources: Kinyua et al., 2021; Abebe & Worku, 2023)

2.9 Human Factors, Labor Utilization, and Operational Efficiency

2.9.1 Role of Human Labor in Dairy Processing

Human labor is still main component of dairy processing operations, particularly in developing countries where automation levels are limited where there is labor involvement in milk reception, quality inspection, packaging, cleaning, and product transfer. Salmon et al.,(2017) shown in his studies that human involvement provides flexibility and reliability on manual operations increases variability, contamination risk, and processing time.

2.9.2 Labor-Related Bottlenecks

Manual packaging and product handling often create bottlenecks due to limited labor availability, fatigue, and inconsistent work pace. It is emphasized in previous studies that manual packaging lines operate at 40–60% efficiency compared to automated systems (Kumar et al., 2021).

In Ethiopian dairy plants, labor-related delays are frequently compounded by poor ergonomic conditions and lack of standardized work procedures (Abebe & Worku, 2023).

2.9.3 Automation and Human–Machine Interaction

Even though automation does not fully eliminate labor involvement in processing and material handling in manufacturing industries, direct handling is changed to monitoring and control. This shift from manual to automated packaging and transfer is found to reduce repetitive tasks, allow workers to focus on control and maintenance activities which results in improvement of both productivity and workplace safety (Tamime, 2018).

Franco et al.,(2023) also indicate that partial automation often yields higher returns than full automation when capital resources are limited and human-machine interaction is properly designed.

2.9.4 Modeling Human Resources in DES

Human resources could be modeled as constrained resource in DES. Law and Kelton confirm that DES models can evaluate labor utilization and enable to suggest addition or reduction of employee by incorporating labor schedules and task assignments(Law & Kelton, 2015).

This section supports that labor utilization, automation, and reduction of manual handling are explicitly modeled and evaluated in both existing and optimized scenarios.

2.10 Financial Performance Evaluation in Simulation Studies

2.10.1 Importance of Financial Modeling

Even though technical improvements are found to be achieved in simulation studies, financial performance evaluation is key parameter to ensure whether recommended investments in maintenance, automation, and utilities are economically confirmed. This requires integrating main financial indicators like revenue, cost, profit and return on investment (Kaplan & Norton, 2001).

2.10.2 Cost Components in Dairy Processing

The main costs modeled in dairy plant simulation are raw milk price, labor, and packing material, maintenance, and transportation costs. According to previous studies, even though Preventive Maintenance introduction increases maintenance and spare parts' costs, these increased maintenance costs are eliminated by reduced downtime and waste(Alrabghi & Tiwari, 2016).

2.10.3 Revenue and Profit Modeling in DES

The approach from recent studies of integrating financial variables into simulation models for computing revenue and profit enables direct comparison of alternative system configuration (Cavalieri et al., 2020).

Simulation-based financial analysis is particularly valuable in multi-product dairy plants, where different products contribute unevenly to revenue and profit.

This section involves comparing financial performance between existing and optimized scenarios and evaluating the economic impact of technical improvements.

2.11 Synthesis of Literature and Link to Research Objectives

The reviewed literatures confirm that dairy processing systems are complex, stochastic, and affected by maintenance policies, utility related issues, labor utilization and product mix decisions. While discrete-event simulation is widely recognized as a suitable tool for analyzing such systems, existing studies rarely integrate technical, operational, and financial dimensions in a single modeling framework.

This study extends previous research by combining:

- Detailed process modeling
- Maintenance and spare parts integration
- Automation and hygiene improvement
- Utility reliability enhancement
- Product diversification analysis
- Comprehensive financial evaluation

This integrated approach directly addresses all stated research objectives and responds to the specific challenges faced by Ethiopian dairy processing industries.

2.12 Research Gaps Identified from the Literature

Despite vast global research on dairy processing plants and the wide application of discrete-event simulation in food industries, critical gaps still remain, particularly in the developing countries and East African dairy plants.

First, although discrete-event simulation has been widely applied to analyze throughput, bottlenecks, and resource utilization in dairy and food processing industries, most existing studies focus mainly on technical performance evaluations. The integration of preventive maintenance policies, spare-part inventory management, and equipment reliability within a single model remains limited, especially for dairy processing plants.

Second, utility reliability, including power supply, compressed air availability, and backup generation capacity, is rarely included in existing simulation studies. Utility issue is significant for developing countries' cases, where utility interruptions are a major contributor to downtime, production losses, and quality degradation.

Third, while automation has been shown to improve hygiene, throughput, and consistency, few studies evaluate selective or partial automation strategies for medium-scale dairy plants with limited capital resources. Most existing research either assumes high automation levels or treats automation impacts smaller.

Fourth, existing regional studies in Ethiopia and neighboring east African countries only analyze isolated processes or single bottlenecks, rather than adding system level, integrated modeling technique that captures interactions among processing stages, maintenance activities, labor, utilities, and product mix decisions.

Fifth, financial performance evaluation is often limited or excluded in dairy plant simulation studies. Many studies report improvements in throughput or utilization without connecting these technical gains to revenue, cost, and profitability. This limits the practical decision-making value of such studies for industry managers and policy makers.

Finally, there are also gaps of simulation-based research to address product diversification and value addition in dairy processing plants, particularly for plants with multiple products such as pasteurized milk, yogurt, butter, cream, and cheese within shared resources.

These gaps indicate the need for an integrated simulation approach that simultaneously considers operational, technical, maintenance, utility, labor, and financial issues of dairy processing systems.

Table 2. 5 Summary of Key Literature and Identified Gaps Relevant to the Current Study

S.N	Year	Author(s)	Title	Identified Gap Relevant to This Study
1	2009	Van der Vorst et al.	Simulation modeling for food supply chain redesign	Focuses on supply chain redesign; does not model internal dairy plant operations, machine failures, or maintenance strategies.
2	2010	Banks et al.	Discrete-event system simulation	Provides methodology only; no application to dairy processing or developing-country contexts.
3	2011	Bunte et al.	Improving dairy chain performance through process optimization	Emphasizes value chain efficiency; lacks detailed plant-level DES modeling and maintenance analysis.
4	2014	Seifu & Doluschitz	Dairy value chain challenges in Dire Dawa	Descriptive analysis only; no simulation, no evaluation of equipment utilization or downtime.
5	2016	Rossetti	Simulation modeling and Arena	Tool-focused; no sector-specific application to dairy processing plants.
6	2017	FAO	Maintenance systems for the dairy plant	Provides guidelines; lacks quantitative evaluation using simulation.
7	2017	Huijps et al.	Bio-economic modeling of mastitis in Ethiopian dairy farms	Farm-level focus; does not address processing plant efficiency or post-harvest operations.
8	2018	Tamime	Dairy processing and quality assurance	Technical processing focus; no operational optimization or simulation-based analysis.
9	2019	FAO	Dairy development in Ethiopia	Macro-level policy perspective; no plant-level operational modeling.
10	2020	Cavaliere et al.	Simulation-based maintenance and spare parts policies	Maintenance-focused but not applied to dairy plants or integrated with production throughput.
11	2020	Haile & Tadesse	Efficiency of Ethiopian dairy processors	Identifies inefficiencies but lacks quantitative DES modeling and optimization scenarios.
12	2021	Getabalew et al.	Dairy value chain integration in Ethiopia	System-level analysis; ignores equipment reliability and processing bottlenecks.
13	2021	Kumar et al.	Simulation-based dairy	Supply-chain oriented; internal

			supply chain analysis	processing dynamics not modeled in detail.
14	2021	Kinyua et al.	DES in food packaging industries in Kenya	Packaging-focused; excludes upstream dairy processing and maintenance integration.
15	2021	Oyango et al.	Productivity of dairy processors in Kenya	Empirical analysis only; no simulation or scenario testing.
16	2022	Aregawi & Melesse	Production inefficiencies in Ethiopian dairies	Identifies problems but does not propose or test optimization strategies.
17	2022	Mugisha et al.	Dairy processing challenges in Uganda	Qualitative assessment; no modeling of machine downtime or throughput.
18	2023	Abebe & Worku	DES in edible oil factories in Ethiopia	Non-dairy context; maintenance and product diversification not addressed.
19	2023	Materials Today Proceedings	Reliability analysis in dairy industry	Reliability-focused; lacks integration with production flow and financial performance.
20	2023	Innocenti et al.	Workforce stress in East African dairy suppliers	Human factor focus; ignores technical and operational system performance.
21	2024	Feyisa et al.	Milk safety practices in Ethiopia	Food safety focus; no processing system modeling or throughput analysis.
22	2024	Nyokabi et al.	Food safety adoption in dairy systems	Policy and adoption focus; no operational or simulation-based evaluation.
23	2024	Kilima et al.	Sustainability standards in East African milk chains	Regulatory perspective; lacks plant-level operational optimization.
24	2024	Wolkaro et al.	Yoghurt quality in Addis Ababa	Product quality analysis; does not assess production efficiency or system dynamics.
25	2025	Frontiers in Animal Science	Precision dairy farming in Africa	Farm-level technologies; processing plant automation not addressed.

2.13 Relevance and Contribution of the Current Study

The current study addresses the identified gaps by developing a comprehensive discrete-event simulation model of a medium-scale Ethiopian dairy processing plant with a design capacity of 5,000 L/h.

Unlike most previous studies, this research:

- Models the existing system and an optimized scenario using real operational data

- Integrates preventive maintenance scheduling, machine reliability, and spare-part inventory models into single simulation
- Incorporates utility reliability like electric power and compressed air supply
- Introduces partial automation some critical bottlenecks such as packaging and product transfer
- Enables simulation outputs to include financial performance indicators, such as revenue, cost and profit
- Discusses product diversification under shared resources.

By integrating technical, operational, and financial analysis within a single model, the study provides a realistic evaluation of improvement strategies for dairy processing plants in Ethiopia and similar developing countries. The findings can be utilized by plant managers, policymakers, and researchers to improve efficiency, reliability, and profitability without depending on unrealistic assumptions or pure theoretical models.

CHAPTER THREE: RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction

This chapter presents the research design and methodology used to analyze and improve the operational efficiency of Elemtu Milk Industry using discrete event simulation (DES). The chapter describes the overall research approach, data collection procedures, simulation modeling and data processing tools used, key modeling assumptions, and result analysis techniques applied in the study.

Simulation based study is very suitable for complex manufacturing industries such as dairy processing plants, where multiple products, shared resources, and stochastic events occur dynamically. Studies in simulation textbooks improve that representation of time dependent system behavior like machine failures, maintenance processes , and variable production flows are achieved by Discrete event simulation, allowing alternative operating scenarios to be evaluated without interrupting actual plant operations (Law & Kelton, 2000; Banks et al., 2010).

3.2 Research Design

This study adopts a quantitative, simulation-based research design to examine the operational behavior of a medium-scale dairy processing plant. The research design is structured to support measurement of system performance and to enable comparison between the existing operational setup and proposed improvement scenarios.

A discrete event simulation (DES) approach is selected due to the stochastic, dynamic, and interdependent nature of the plant. Key system parameters such as raw milk arrivals, processing times, equipment availability, utility interruptions, and maintenance practices experience randomness and time dependent behavior. These stochastic behaviors limit the usage of analytical methods for reliable system evaluation. DES provides the capability to represent such variability and to observe its cumulative impact on system performance.

The research design ensures the use of **computer based simulation experimentation** as a support tool for decision making. Recorded and unrecorded (Questionnaire, Interviews and

on site observation) data collected from the case study plant are processed using Microsoft excel and translated into probability distributions using Arena input analyzer to capture real system variability. These inputs are then used to simulate system behavior under repeated replications, allowing statistically valid estimation of key performance indicators such as throughput, resource utilization, equipment downtime, and overall profitability.

To ensure reliability of results of both existing and optimized scenarios, the study incorporates **statistical output analysis techniques**. Output statistical values and graphical representations obtained from simulation are analyzed using confidence interval estimation, histogram analysis, and paired comparison methods. In particular, paired-t tests are employed to compare the existing and optimized scenarios under identical conditions, enabling direct assessment of performance improvements attributable to system changes rather than random variation.

The research design is mainly structured to support **scenario-based evaluation**, where alternative improvement strategies can be tested without affecting actual plant operations. This approach reduces implementation risk and cost while providing quantitative justification for managerial decisions.

Even though the research is executed on specific dairy processing plant, the adopted research design is generalizable to similar medium-scale food and dairy processing industries. The methodology provides a systematic approach for diagnosing operational inefficiencies, evaluating improvement strategies, and supporting data driven decision making before physical implementation.

3.3 Problem Formulation and Simulation Objectives

This study addressed the challenge of low utilization of installed processing capacity in a 5,000 L/h milk processing plant caused by unplanned equipment failures, maintenance delays, limited spare part availability, and inefficient material handling. These issues affect different processes such as pasteurization, homogenization, cream separation, and packaging, leading to reduced throughput and unstable production schedules.

To address these challenges, the simulation study is structured around three objectives. First, a baseline discrete-event simulation model is developed to represent the existing production

system using observed operational logic, failure behavior, and resource constraints. Second, a set of optimized scenarios are modeled by modifying maintenance policies, spare part availability, equipment condition, and selected automation of some processing stages. Third, the performance of the optimized scenarios is evaluated relative to the baseline model using critical KPIs like throughput, machine utilization, downtime, and breakage returns

Several modeling assumptions are applied to maintain focus on internal plant efficiency. External supply related factors such as milk quality rejection rates are kept constant, while internal operational variables such as maintenance strategy, product allocation, and material handling are adjusted differently within the optimized scenarios. This approach ensures fair and controlled comparison between scenarios and supports objective evaluation of improvement strategies.

3.4 Data Collection Strategy

3.4.1 Data Sources and Types

One full year of operational, production, maintenance and financial data was collected from Elemtu Milk Industry. Data sources included production records, maintenance logs, inventory reports, direct observations, and interviews with plant personnel. Critical variables included are milk arrival patterns, processing times, equipment downtime, repair durations, labor involvement, and product yields.

3.4.2 Sample Size Determination and Data Period Justification

The study population consisted of 35 operational and support personnel. Given the finite population size, the Yamane (1967) formula was applied at a 95% confidence level, resulting in a required sample size of approximately 32 respondents. Accordingly, a near census sampling approach was adopted.

One year historical data period was selected to capture seasonal variation in milk supply, production demand, and equipment performance. The simulation run length was also aligned with this one year period to ensure consistency between real system data and simulated outputs.

3.5 Data Analysis and Input Modeling Framework

3.5.1 Preliminary Data Processing and Descriptive Analysis

Collected data were cleaned, organized, and summarized before starting simulation modeling. Different analyses were conducted to identify variability, outliers, and data consistency. Microsoft Excel was used for preprocessing and computation of summary statistics. These steps ensured that input data were suitable for stochastic modeling.

3.5.2 Input Modeling Approach for Simulation

Stochastic input parameters such as milk arrival interval rates, processing times, equipment failure frequency and repair durations were modeled using probability distributions derived from historical data. Distribution fitting were performed within the Arena input analyzer to ensure realistic representation of system variability. Detailed distribution parameters are presented in Chapter Four.

3.6 Simulation Model Development in Arena

The discrete-event simulation model was developed using Arena 14 Simulation Software to represent the operation of the milk processing plant. Entities represent milk batches entering the system, while attributes track product type, batch size and processing route. Resources represent processing equipment, labor and utilities.

Performance indicators were embedded within the model to record throughput, utilization, downtime, waiting times, and product output. Detailed performance results are reported in Chapter Five.

3.7 Model Verification and Validation

Model verification and validation were conducted using multiple complementary methods. Logical verification ensured that entity flow, resource allocation, and failure behavior followed the intended system logic. Face validation was conducted with plant engineers and supervisors to confirm realism.

Historical production data were used to validate baseline model outputs. Multiple replications were executed to account for stochastic variability, and statistical confidence intervals were examined to confirm result stability. Arena's internal analysis features supported controlled experimentation and output validation.

3.8. Simulation Result Analysis

Simulation experimentation and output validation were conducted using Arena's process Analyzer (PAN) and Output Analyzer (OA). These tools were employed to ensure statistically reliable comparison between the existing and optimized production scenarios and to validate that observed performance differences were not due to random simulation variability.

The Process Analyzer was also used to design controlled simulation experiments by defining key control variables and systematically varying them across scenarios while maintaining identical model logic. Control variables are annual milk arrival rates, milk rejection percentages, and allocation of milk to yoghurt production, number of packaging machines, preventive maintenance schedules, spare part availability, level of automation in material handling, and utility availability. Ten replications were executed for each experimental model to capture stochastic variability in milk arrivals, processing times, and equipment failures.

Response variables monitored during experimentation included total throughput, product-specific output quantities, machine utilization, downtime duration, spare-part waiting time, total operating cost, total revenue, and profit. PAN enabled efficient comparison of scenarios by automating replication runs and recording performance metrics in a structured format, thereby supporting objective evaluation of alternative system selections.

The Output Analyzer was used to perform statistical analysis and validation of simulation outputs. Paired-t confidence interval procedures at a 95 percent confidence level were applied to compare corresponding performance measures between the existing and optimized scenarios. This approach was selected because both scenarios were simulated under identical experimental conditions, allowing direct statistical comparison. Output variability, confidence interval half-widths, and replication consistency were examined to verify that the number of replications was sufficient and that simulation results were statistically stable. The

combined use of PAN and OA strengthened and ensured that conclusions drawn from the simulation were statistically remarkable.

Table 3. 1 Summary of Data Analysis and Simulation Tools Used in the Study

Tool	Primary Purpose	Type of Analysis	Stage of Use
Microsoft Excel	Data cleaning, preprocessing, and descriptive analysis	Descriptive statistics, data validation, visualization	Pre-modeling
Arena Input Analyzer	Statistical fitting of stochastic inputs	Probability distribution fitting and goodness-of-fit testing	Pre-modeling
Arena Simulation Model	Representation of production system logic	Discrete-event simulation of material and resource flows	Modeling
Arena Process Analyzer (PAN)	Scenario experimentation and comparison	Controlled simulation experiments and sensitivity analysis	Experimentation
Arena Output Analyzer (OA)	Statistical validation of simulation outputs	Confidence intervals and hypothesis testing	Post-simulation

3.9 Ethical Considerations

Ethical considerations were observed throughout the research to protect participants, safeguard organizational data, and ensure the integrity of the study. Data collection at Elemtu Milk Industry was conducted with transparency, professionalism and respect for all involved personnel. Plant staff participating in interviews, or observations were informed about the objectives of the study, the intended use of collected data, and the voluntary nature of their participation. Informed consent was obtained prior to data collection, and participants were assured that their responses would be treated confidentially and used for academic research purposes.

Sensitive operational and business information, including production volumes, machine performance records, and financial data, was handled with strict confidentiality. Access to such information was limited to the research process, and no data were disclosed to unauthorized parties. Data collection and observation activities were designed to avoid any interruption of plant operations or interference with production activities.

The simulation based analysis conducted using Arena software had no ethical risk, as it relied exclusively on historical operational data and virtual modeling of the production system. No experimental interventions were performed on the actual plant. By evaluating improvement alternatives through simulation, the study avoided any potential negative impact on equipment, personnel, or production continuity.

Generally, ethical principles guided at all stages of the research, from data collection to analysis and reporting. These principles ensured respect for participant rights, protection of confidential information, and credibility of the research outcomes.

3.10. Results Dissemination Strategy

The results dissemination strategy defines how the outcomes of the simulation study will be communicated to relevant academic and industrial stakeholders. The purpose of dissemination is to ensure that the knowledge generated from the research is accessible, interpretable, and usable for decision making and further study.

Research findings will be documented primarily through the Master's thesis, which presents the simulation methodology, model development process, scenario analysis framework, and comparative performance evaluation. Results will be communicated using structured tables, charts, and simulation output reports generated from Arena software to support clear interpretation of system behavior and performance measures.

Academic dissemination will include presentations to academic supervisors and examiners, and potential submission of selected findings to peer reviewed journals or conferences related to industrial engineering, simulation modeling, and food processing systems. This ensures that the methodological contribution of applying discrete event simulation to a medium scale dairy processing plant is shared with the wider research community.

In addition to academic dissemination, the study results will be communicated to the management and technical staff of Elemtu Milk Industry through presentations, technical reports, and model demonstrations. The validated simulation model may be used as a decision-support tool to evaluate operational policies, maintenance strategies, and resource allocation alternatives. This approach supports evidence based planning without disrupting ongoing production.

In general, the documentation of modeling procedures, assumptions, and scenario modeling enables the study to serve as a reference for other dairy processing plants facing similar operational challenges. Dissemination of the research outcomes supports broader adoption of simulation-based analysis for operational improvement within the dairy processing sector.

CHAPTER FOUR: SYSTEM MODELING AND SIMULATION

4.1 Introduction

This chapter presents the development of a simulation model for Elemtu Milk Industry using Arena 14.0 software. The primary objective is to create a digital representation of the plant's operations that accurately captures milk reception, processing at different stages, machine utilization, maintenance practices, Spare part inventory management and labor involvements. By establishing this model, the study provides a foundation for analyzing the system's behavior under existing operational conditions and for modeling optimized scenarios.

The modeling process emphasizes the stochastic nature of the plant, including irregular milk arrivals, variable processing times, equipment breakdowns, and manual handling delays. Building this simulation model enables identification of operational bottlenecks, resource constraints, and workflow inefficiencies. These observations form the technical basis for subsequent scenario evaluation and optimization, which are presented in Chapter 5.

4.2 Simulation Approach

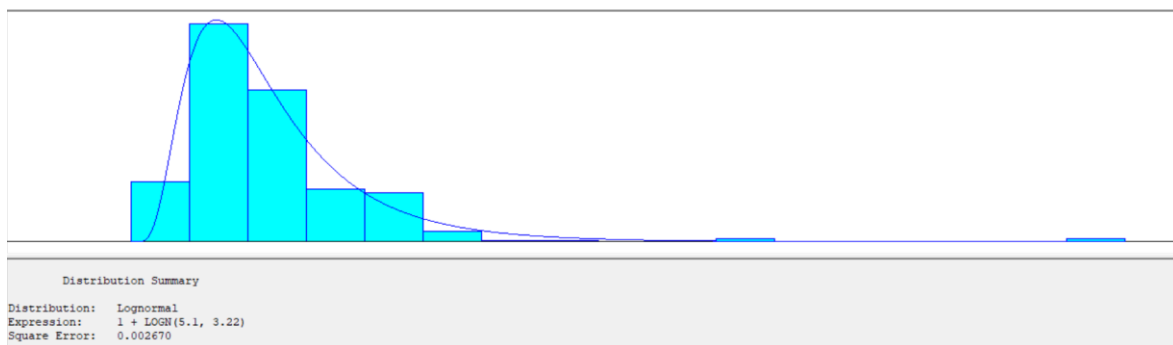
Arena 14.0 was chosen for its ability to model complex, stochastic production systems with multiple interconnected and shared resources. Discrete Event Simulation (DES) captures variability in milk supply, fluctuating production demand, machine failures, and maintenance activities, making it suitable for the dairy processing plant.

Operational data were preprocessed in Microsoft Excel to ensure consistency and reliability. Key inputs included milk batch arrivals, processing times, machine uptime and downtime, batch yields, and maintenance records.

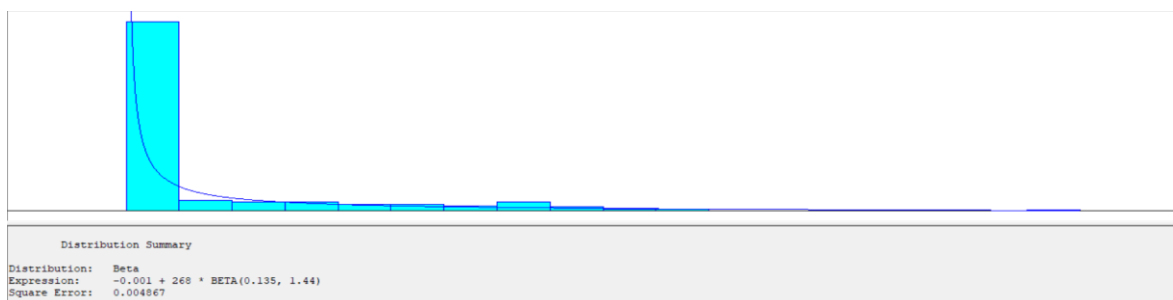
Arena Input Analyzer was then applied to fit probability distributions to operational variables, ensuring realistic representation of plant variability.

- **Milk arrivals:** In the existing scenario, inter arrival times followed a shifted Lognormal distribution, $T = 1 + \text{LOGN}(5.1, 3.22)$ min, reflecting irregular supply from smallholders (~27,000 batches/year). In optimized scenarios, arrivals were modeled as exponential with a mean of 2.92 min (~164 batches/day), supporting smoother production flow.

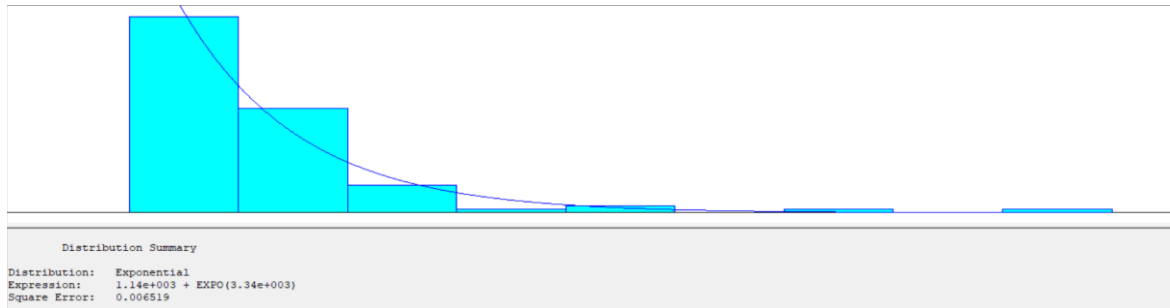
- **Utility interruptions:** Power outage durations were modeled using a Beta distribution, $\text{Duration} = -0.001 + 268 * \text{BETA}(0.135, 1.44)$, with inter-outage times following a shifted exponential, $1140 + \text{EXPO}(3348)$ min, capturing stochastic disruptions.
- **Product allocations:** Yogurt production percentage followed a Weibull distribution, $\text{Yoghurt \%} = -0.001 + \text{WEIB}(0.039, 0.229)$, averaging 2% of accepted milk. Milk rejection percentages followed a Beta distribution, $\text{Rejection \%} = -0.001 + 140 * \text{BETA}(0.127, 2.25)$, averaging 7.5% in both scenarios.
- **Equipment failures:** Machine uptime and repair durations were fitted with shifted Weibull, Gamma, or Exponential distributions based on historical maintenance records. Spare-part delays were included to capture downtime. In optimized scenarios, preventive maintenance, sufficient spare parts, and refurbished machines were assumed to reduce downtime and improve throughput.



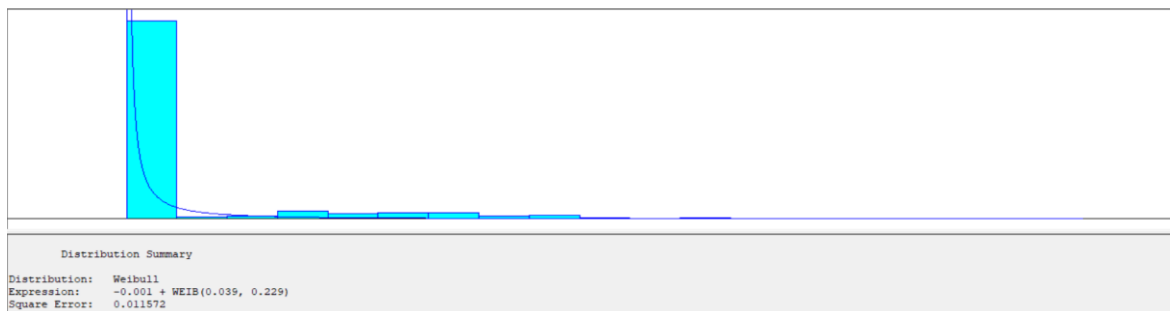
a) Milk Inter arrival time distribution function (Existing)



b) Power Interruption duration distribution function (Existing)



c) Power Interruption Frequency distribution function (Existing)



d) Yoghurt Allocation Percentage distribution function (Existing)

Fig.4. 1 Distribution Function of selected Parameters Using Input Analyzer

4.3 Modeling of the Existing Scenario

The existing system model represents the current operational conditions at Elemtu Milk Industry. Milk batches were generated according to probabilistic inter-arrival distributions reflecting historical variability. Machines like pasteurizers, homogenizers, milk packers, cheese vats, and butter churners, etc were defined as constrained resources with failure logic based on historical mean-time-between-failure and mean-time-to-repair distributions. Preventive maintenance was not included, ensuring that breakdowns occurred dynamically, while repair times were extended by spare part waiting delays.

Labor resources were modeled to reflect manual handling tasks such as batch transfer, packaging and material movement between process stages. The plant's product allocation was represented by routing entities according to observed production practices, with yogurt, sour milk, and cream flows following historical proportions.

The model's process flow is mirror of production sequence on the shop floor: milk reception, quality testing, precooling, cooling storage, pasteurization, homogenization, cream

separation, buffer storage, yoghurt culturing, cream boiling, cheese boiling, local cheese boiling, and packaging. By capturing both machine and labor constraints within this flow, the model experiences operational delays, queues, and bottlenecks without incorporating output performance metrics, which are analyzed separately in Chapter 5.

4.3.1 Production Line Modeling – Existing Scenario

The existing production system of the 5,000 L/h milk processing plant was modeled using Arena 14.0 to represent actual operational conditions, including manual handling, older machinery, and breakdown based maintenance practices. I have structured the simulation to capture the flow of milk batches, product specific processing, resource constraints, and human labor involvement, allowing a realistic evaluation of plant performance and identification of bottlenecks.

One batch is assigned to be 100L for liquid milk state (both for raw material and product) and 100kg for solid products like butter, cheese and local cheese. According to historical data from quality control department, average acceptance percentage of milk arrived to the factory is 92.5% and rejection is 7.5%. Accepted milk was allocated to different products, reflecting the observed production mix: pasteurized milk was stored and packed directly; yoghurt production utilized only 2% of accepted milk and stays in incubation room for 3-4 hours just after packing, while cream was either packed or sent to manual butter production. Sour milk and buttermilk were processed into cheese and local cheese using separate vats, with minimal allocation in the baseline scenario.

All major resources including pasteurizers, homogenizer, cream separator, and product packers were modeled with single-unit capacities and failure profiles based on historical maintenance data. Labor resources were explicitly modeled to reflect manual handling tasks such as transferring milk, operating packers, and managing cheese production. The simulation captured operational delays, long cycle times, and queue formation caused by limited resources and human workload.

I have incorporated the processing times for each station as probability distributions derived from observed operations and interviews with specific machine operators, reflecting variability due to machine conditions and operator performance. By building the model and running simulation for one year period to indicate actual plant behavior, I have visualized

system inefficiencies, low throughput, high downtime, and underutilized resources, which provided a quantitative baseline for later optimization scenarios.

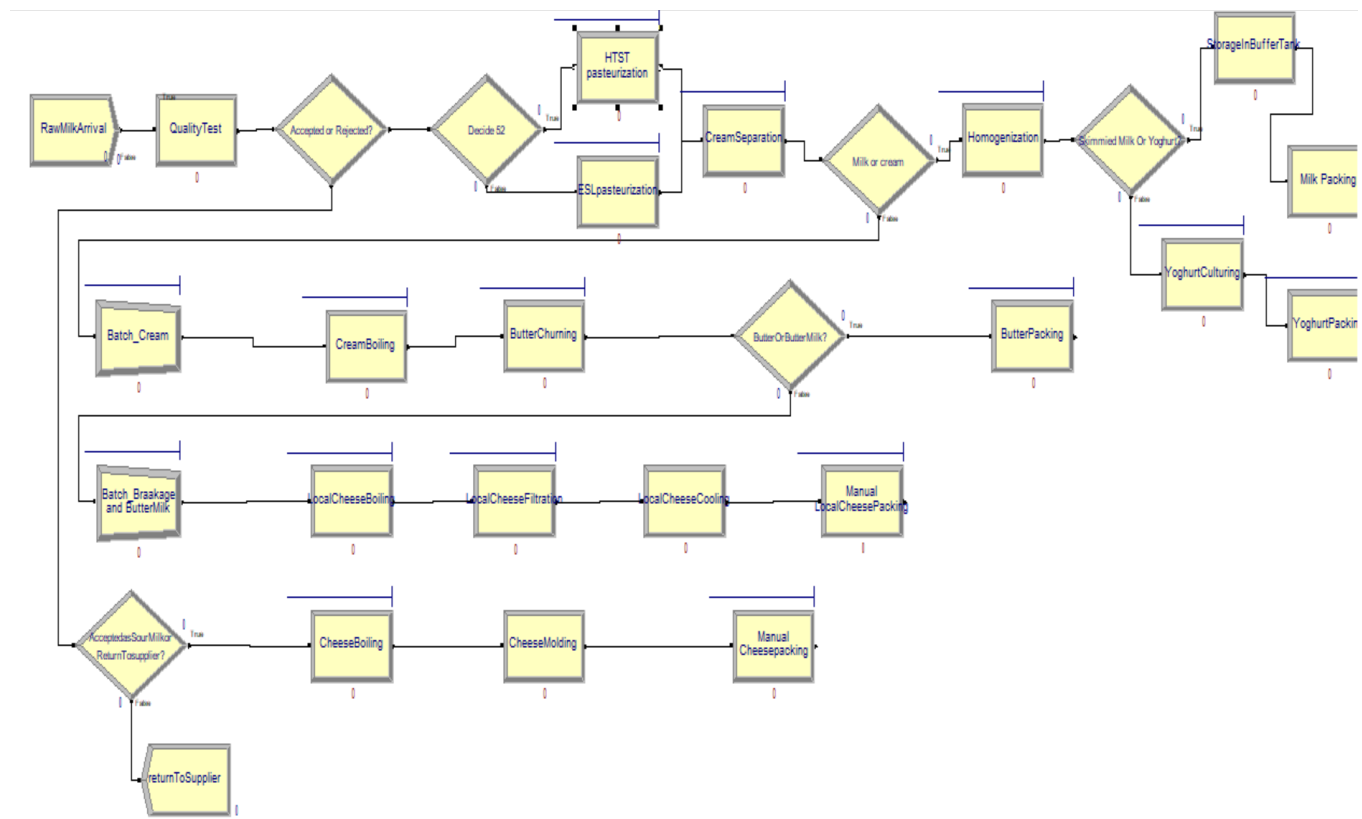


Fig.4. 2 Production Line Model-Existing Scenario (Image Modified to capture screenshot)

4.3.2 Machine Breakdown and Downtime Modeling – Existing Scenario

In the existing scenario, machine reliability was a major constraint on production at the Elemtu Milk Processing Plant. Frequent equipment failures arose from the absence of preventive maintenance, aging machinery, and limited availability of spare parts. To capture these, critical machines including pasteurizers, homogenizers, cream separators, and packing lines were assigned failure and repair characteristics derived from historical plant data.

Using Arena’s failure spreadsheet, machine breakdowns were modeled y, reflecting the mean time between failures (MTBF) and repair durations for each unit. Repair processes were represented with the same failure spreadsheet based on mean time to repair (MTTR), with additional delays incorporated due to unavailability of spare parts. When a machine failed, the corresponding production processes were interrupted, leading to queue formation and reduced throughput. Parallel production lines, such as multiple milk packers, operated at partial capacity when only some machines were functional.

Variation in the uptimes of failures and repair durations was included to reflect realistic operational conditions. This modeling approach quantified the impact of unplanned downtime on production flow, bottleneck formation, and equipment utilization, providing a foundation for the optimized scenarios where preventive maintenance, improved spare part availability, and enhanced operational efficiency were implemented to address the limitations observed in the existing system.

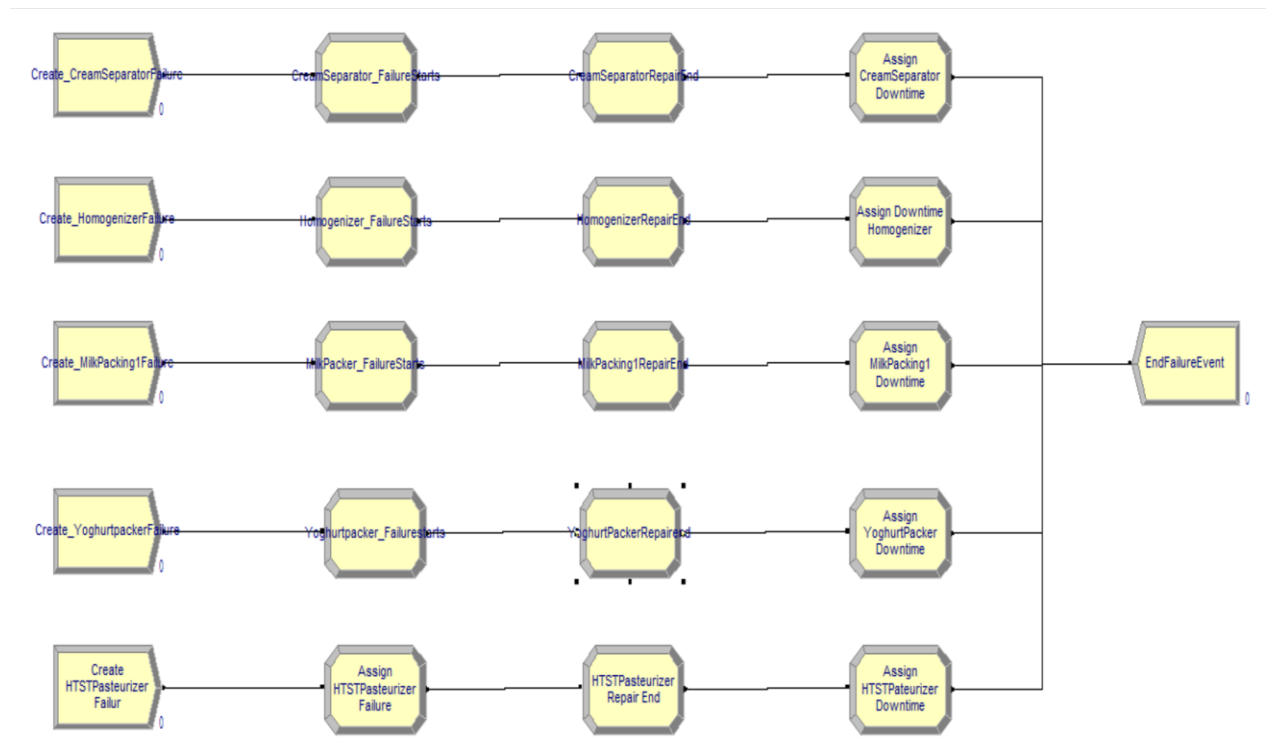


Fig.4. 3 Machine Failure, Repair and Downtime Model-Existing Scenario

4.3.3 Financial Modeling – Existing Scenario

I have developed financial model within Arena for the existing scenario to capture the economic performance of Elemtu Milk Industry under current operational conditions. The model integrates all major revenue and cost components across all product lines, including pasteurized milk, yogurt, butter, cream, cheese, and local cheese, providing a baseline for comparison with optimized scenarios.

Revenue for each product was calculated by multiplying the batch selling price by the simulated annual production volume, and total plant revenue was obtained by summing the contributions from all products. Because product pricing was held constant across scenarios, any differences in total revenue directly reflected variations in production performance,

which in the existing system were constrained by machine downtime, inefficient workflows, and limited throughput.

Profit was also simulated at both the product and plant levels. Product level profit was calculated as revenue minus directly attributable costs, while total profit considered all operating expenses, including labor, raw materials, packaging, transportation, maintenance, utilities, and depreciation. I have also included detailed cost modeling for batch production (raw milk, packaging, and labor), transport (fuel, driver wages, and sales personnel), maintenance (daily maintenance and breakdown repairs) and equipment depreciation, ensuring a complete representation of operating costs.

All financial variables were filled in variable spreadsheet and updated in the model using Arena Assign modules. This approach allows tracking revenue, costs, and profiting throughout the simulation. It also enables to quantify the economic impact of operational inefficiencies, machine breakdowns, and underutilized resources, producing a realistic baseline against which the improvements from optimized scenarios could be measured. By integrating production and financial performance within the simulation, I was able to link operational bottlenecks directly to economic consequences, providing actionable insights for decision-making and investment prioritization.

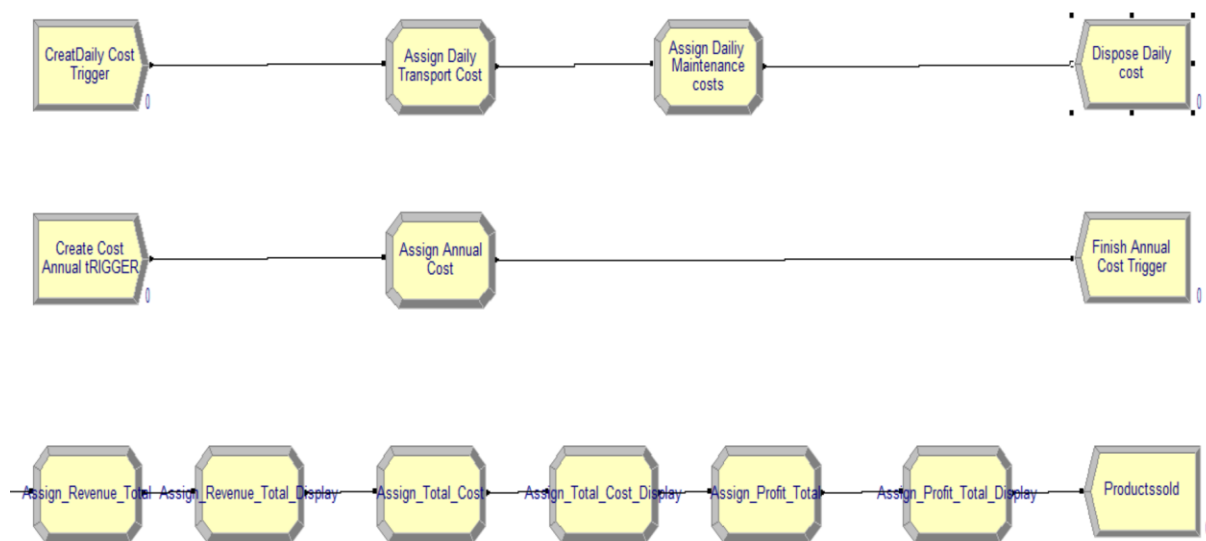


Fig.4. 4 Financial Model (Both Scenarios)

4.3.4 Simulation Run Setup

To capture the stochastic variability found in milk arrivals, machine failures, and processing times, the simulation was run with ten replications. This number balances statistical reliability with computational efficiency, as preliminary tests indicated that additional replications provided minimal improvement in confidence intervals for key outputs such as throughput, downtime, and resource utilization, while substantially increasing run time.

The simulation covers a full operational year (525,605 minutes) to reflect daily, weekly, and seasonal variations in supply, demand, and maintenance, ensuring that performance metrics represent realistic operational conditions rather than short term fluctuations. Time was measured in minutes to accurately model short duration events, including batch arrivals, processing times, and repairs, allowing detailed capture of queues and precise resource utilization. No warm-up period was applied, as the system is assumed to operate continuously and initial conditions also reflect typical plant operations, making KPI measurements measured from the start.

Throughout each replication, KPIs such as throughput, machine downtime, labor utilization, spare-part availability, and financial performance were recorded and exported for statistical analysis and scenario comparison. This setup ensures that differences observed between the existing and optimized scenarios are due to operational improvements rather than random variation.

4.3.5 Model Verification and Validation

4.3.5.1 Model Verification

I have carried out model verification to ensure that the simulation was correctly implemented according to the conceptual design. Verification confirmed that the logical structure, process flows, resource definitions, and event sequencing in Arena accurately represented the intended system.

I have also performed step-by-step tracing, animation review, and logic checking within Arena to identify and correct errors in entity flows, queue logic, resource allocation, and event triggers. Conceptual verification also performed reviewing all process modules including milk reception, cold storage, HTST and ESL pasteurization, homogenization, cream separation, product specific processing (milk packing, yogurt fermentation, butter and cream production, cheese and local cheese processing) and packaging to ensure whether the simulation matches real world operational sequences.

Simulation runs were conducted to confirm conservation of material flow, absence of infinite queues, correct activation of breakdown and repair logic, and proper interaction between machines, labor, and utilities. This step ensured the model was internally consistent and technically correct.

4.3.5.2 Model Validation

Model validation evaluates whether the simulation accurately represents the real world dairy processing system, ensuring that the “right system” is being modeled. Validation assesses the realism of the outputs by comparing them with historical production and financial data. In this study, both face validation and quantitative validation techniques were applied.

1. Face Validation Using Expert Review

Face validation was conducted through structured review sessions with plant engineers, supervisors, and experienced operators. The experts checked whether the modeled process flows, machine behaviors, manual handling operations, and production scheduling realistically represented daily plant operations. Both scenarios were reviewed: the existing scenario, reflecting manual transfers, reactive maintenance, and spare-part shortages, and the

optimized scenario, representing automated transfers, preventive maintenance, and adequate spare-part availability. The reviewers confirmed that processing sequences, downtime patterns, and operational constraints in the model reflected actual plant behavior, ensuring the model's validation.

2. Validation Using Quantitative and Statistical Measures

Quantitative validation was performed by comparing annual simulated outputs from the existing scenario with one year of actual production data to ensure alignment with real operational performance. Key performance indicators were evaluated using the percentage error formula:

$$\text{Percentage Error (\%)} = \left| \frac{\text{Simulated Output} - \text{Actual Output}}{\text{Actual Output}} \right| * 100$$

The percentage error between the simulation outputs and the actual company data was used as the primary criterion for validating the discrete-event simulation model. In simulation studies of complex, stochastic production systems, exact numerical agreement is neither realistic nor required. According to Law (2015), validation should focus on whether the model outputs are sufficiently close to real system data for selected KPI, rather than on exact matching, and percentage differences within a reasonable tolerance range are considered acceptable.

Errors of **5% or less** indicate excellent agreement and suggest that the model structure, input distributions, and process logic accurately represent the real system, leading to strong model validation. Its explained by Banks et al., (2010, pp. 396–399) that Percentage errors of **5–10%** are interpreted as very good agreement, reflecting minor deviations caused by stochastic variability and simplifying assumptions, while still indicating a validated model. For large-scale industrial systems involving human operations, equipment failures, and uncertain inputs, percentage errors in the **10–15% range** are generally considered acceptable and conditionally validated, particularly when the model is intended for comparative analysis and scenario evaluation rather than precise forecasting, according to report by Sargent, (2013).

Robinson(2014) also demonstrated that Percentage errors exceeding **15%** indicate weak agreement and suggest that important system behaviors may be missing or inadequately

modeled, requiring further refinement of assumptions, logic, or input data before the model can be considered reliable.

Table 4. 1 General Rule of Percentage Error

Percentage Error	Interpretation	Validation Status
≤ 5%	Excellent agreement	Strongly validated
5–10%	Very good agreement	Validated
10–15%	Acceptable for complex systems	Conditionally validated
> 15%	Weak agreement	Requires model refinement

Source: Banks et al., 2010

Quantitative model validation was conducted using percentage error analysis for selected key performance indicators. Pasteurized milk revenue was chosen due to its dominant share in total production and stable operating characteristics, while total annual revenue was selected as significant performance measure.

Pasteurized Milk Revenue Validation

- Actual pasteurized milk revenue (2017 E.C): **279.19 Million ETB**
- Simulated pasteurized milk revenue (existing model): **270.00 Million ETB**

$$\text{Percentage Error (\%)} = \left| \frac{270 - 279.19}{279.19} \right| * 100 = 3.28\%$$

Total Annual Revenue Validation

- Actual total annual revenue (2017 E.C): **293.87 Million ETB**
- Simulated total annual revenue (existing model): **278.2871 Million ETB**

$$\text{Percentage Error (\%)} = \left| \frac{278.2871 - 293.87}{293.87} \right| * 100 = 5.3\%$$

The percentage errors for pasteurized milk revenue (3.28%) and total annual revenue (5.3%) fall within accepted validation range for discrete-event simulation models according to (Banks et al., 2010). For low volume products such as cheese, butter, and yogurt, absolute differences are small but percentage deviations can be misleading; therefore, these were assessed using qualitative comparison.

Item	Company Report	Simulation	Percentage
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	(2017 E.C)	Model	Difference
Pasteurized Milk Revenue (Million ETB)	279.19	270.00	3.3%
Total Revenue (Million ETB)	293	278	5.1%
Total Profit (Million ETB)	17	19	11.8%

The percentage error between the simulation outputs and the actual company data was used for validating the developed discrete event simulation model. This approach is widely accepted for complex industrial systems where perfect agreement is neither realistic nor expected.

3. Statistical Validation Using Confidence Interval Analysis

Statistical stability of the simulation outputs was evaluated using classical confidence interval analysis generated in Arena Output Analyzer. This approach is widely used in discrete event simulation studies to test whether the number of replications is sufficient and whether random variation has a meaningful effect on key performance indicators.

For the packed milk batches KPI, the simulation produced a mean annual output of 2.41×10^4 batches based on 10 independent replications with standard deviation of 70.2 batches, indicating low variation across replications. At the 95% confidence level, the calculated confidence interval half-width was 50.2 batches, meaning that the true mean annual packed milk production lies within the interval:

$$24,100 \pm 50.2 \text{ batches}$$

The precision of simulation output estimates was evaluated by expressing the confidence interval half-width as a percentage of the estimated mean. This is common practice in discrete event simulation studies to assess the statistical reliability of performance measures according to Law (2015) and Kelton et al., (2015).

$$\text{Relative variation} = \frac{50.2}{24100} * 100 = 0.21\%$$

A small relative variation indicates that the simulation outputs exhibit low stochastic variability across replications and that the estimated mean is statistically precise. According to standard simulation modeling and analysis in Banks et al., (2010) and Law (2015), confidence interval precision is typically interpreted using the following qualitative guidelines:

- **Less than 1% of the mean** indicates excellent statistical stability and highly reliable output estimates
- **Between 1% and 5%** is generally acceptable for most engineering and operational decision-making studies
- **Between 5% and 10%** is considered marginal and may require additional replications or further model refinement
- **Greater than 10%** suggests unstable results, where conclusions drawn from the simulation may be unreliable

Since the relative variation for annual packed milk batches is approximately **0.2%**, which is well below the 1%, the simulation output can be considered statistically stable and suitable for performance evaluation and scenario comparison.

Similarly, Statistical stability of the total profit output was evaluated using classical confidence interval analysis generated in Arena Output Analyzer. The analysis was based on ten independent replications of the existing system model at a 95% confidence level. The mean simulated total annual profit was **49.3 million ETB**, with a standard deviation of **0.195 million ETB**. The corresponding 95% confidence interval half-width was **0.14 million ETB**, indicating a narrow confidence band around the estimated mean.

$$\text{Relative variation (\%)} = \frac{0.14}{49.3} * 100 = 0.28\%$$

This relative variation of approximately **0.28%** is well below the commonly accepted **1% value** for excellent statistical stability in discrete-event simulation studies. The minimum and maximum profit values across replications, ranging from **48.9 to 49.5 million ETB**, further confirm that stochastic variability between runs is minimal and that no unstable or extreme outcomes occurred.

Table 4. 2 Confidence Intervals of Packed Milk Batches and Profit Total

KPI	Average	Standard Deviation	95% CI Half-Width	Minimum	Maximum	Replications
Packed Milk Batches	2.41×10^4	70.2	± 50.2	2.40×10^4	2.42×10^4	10
Total Profit (million ETB)	49.3	0.195	± 0.14	48.9	49.5	10

These results demonstrate that the simulated total profit is statistically precise, reliable, and suitable for use in model validation and comparative analysis of optimization scenarios. The narrow confidence interval confirms that the number of replications used is sufficient to estimate long run financial performance and that random variation has a negligible influence on the reported profit outcomes.

Conclusion on Model Validation

Based on comprehensive face validation, quantitative comparison with historical production and financial data and statistical stability assessment using confidence interval analysis, the existing simulation model is considered valid and reliable for further analysis. Face validation confirmed that the modeled process flows, machine behaviors, and operational constraints accurately reflect real plant operations. Quantitative validation demonstrated close agreement between simulated and actual outputs, with percentage errors for key financial indicators falling within acceptable limits for discrete-event simulation models.

The confidence interval analysis further confirmed the statistical stability of the simulation outputs, showing low variability across replications and sufficient precision in estimating long-run performance measures. Narrow confidence intervals for selected key performance indicators indicate consistent system behavior and reinforce confidence in the robustness of the model results.

In general, the validated simulation model of existing system reliably captures the real world behavior of Elemtu Milk Industry’s production system and provides a good baseline for evaluating optimized scenarios aimed at improving throughput, reducing downtime, enhancing resource utilization, and improving financial performance.

4.4. Modeling of the Optimized Scenarios

The optimized scenarios were developed to reduce the operational problems identified in the existing system and to improve overall plant performance at Elemtu Milk Industry. Rather than restructuring the plant, the fundamental flow of milk reception, pasteurization, homogenization, cream separation, packaging, and storage was preserved to maintain methodological consistency. Differences between scenarios were introduced through operational parameters, resource allocation, maintenance policies, and product routing strategies. This approach ensured that improvements in throughput, utilization, and financial performance could be contributed directly to the implemented changes, rather than to structural modifications in the model.

Three optimized scenarios were constructed, each representing different milk arrival rate, machine availability, preventive maintenance frequency, and product allocation strategy. The scenarios were modeled to show practical managerial interventions and to allow systematic evaluation of their impact on production efficiency and profitability. In all scenarios, milk arrival is in batches of 100 liters, with 92.5% passing quality inspection, while small percentage of rejected milk was accepted as sour milk and the rest be returned to supplier. Scenario specific variables, such as the proportion of milk allocated to yoghurt production, the acceptance rate of sour milk for cheese production, the number of milk packers, planned operating times of critical equipment and preventive maintenance schedules were implemented using Arena's Variable spreadsheet and added to the models through Assign modules. This allowed a single simulation model structure to represent multiple operational configurations efficiently.

Each scenario reflected a specific operational philosophy. Adjustments to the number of milk packers and their planned operating times directly affected downstream processes and throughput, while preventive maintenance frequency reduced the occurrence of breakdowns without introducing excessive planned downtime. Product allocation percentages were also changed to increase yoghurt production from the intermittent schedule observed in the baseline system to a consistent 5% of accepted milk, and sour milk utilization was increased to 20% of rejected milk. These changes improved raw material utilization, balanced product mix, and enhanced revenue generation. The combined effect of these operational

modifications influenced key performance measures including throughput, equipment utilization, downtime, queuing, and financial outcomes.

4.4.1. Selection of the Best Optimized Scenario Using Process Analyzer (PAN)

After developing and validating the baseline simulation model, multiple optimized scenarios were formulated to evaluate alternative operational improvement strategies for the Elemtu Milk Industry. These scenarios are modeled with different combinations of production controls, maintenance policies, automation levels, and resource configurations. The Arena Process Analyzer (PAN) was employed to systematically compare these modeled scenarios under identical stochastic conditions and to support selection of the best performing optimized scenario based on multiple technical and financial performance measures.

PAN was selected for this purpose because it enables controlled experimentation by varying key control variables and observing their combined impact on multiple output responses. Unlike Output Analyzer, which focuses on statistical comparison of finalized scenarios, PAN is specifically designed for scenario screening and selection. It allows decision makers to understand how changes in controllable factors influence system performance and to identify best scenario that maximizes benefits while minimizing negative KPIs like downtime and breakage returns.

In the first PAN experiment, production and quality related control variables were analyzed. These included maximum daily milk arrival, inter-arrival time, yoghurt production allocation percentage, sour milk acceptance rate, and packing breakage percentage. The responses variables are packed milk batches, packed yoghurt, packed cream, packed cheese, packed local cheese, and butter production volumes, total annual profit, and breakage return.

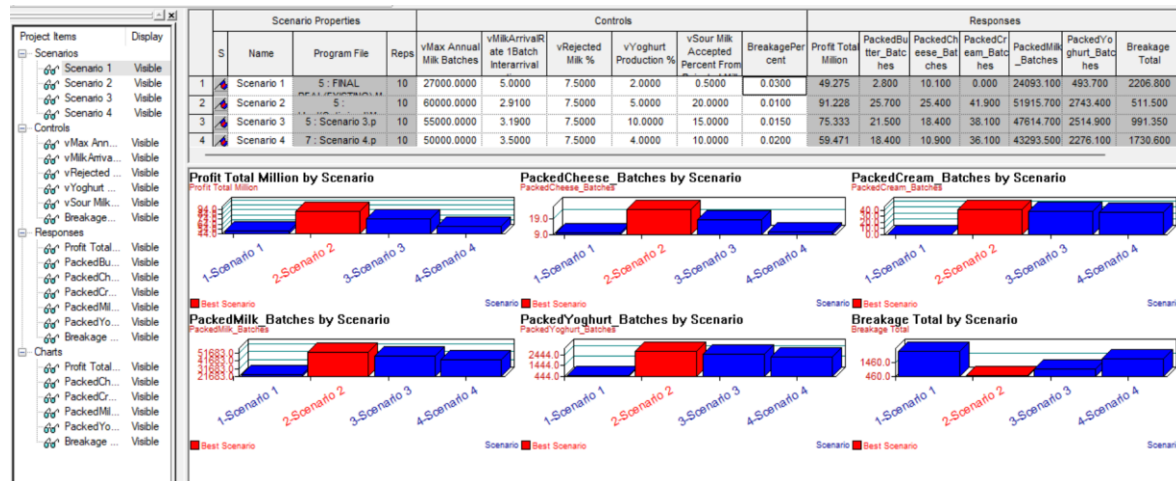


Fig.4. 5 PAN Analysis Milk Arrival, Yoghurt Production percentage and sour Milk Acceptance Control on Product Throughput and Profit

The results show that Scenario 2 consistently achieved higher packed milk output and total profit while maintaining low breakage returns. Increased milk availability and improved allocation to yoghurt and sour milk processing enhanced overall throughput and total profit. Other scenarios either underutilized available capacity or increased breakage losses, reducing their overall effectiveness.

The second PAN experiment focused on maintenance and machine reliability related controls like number of preventive maintenance days, planned production run duration and spare part stock availability. The corresponding responses variables are machine utilization and downtime for critical equipment such as pasteurizers, homogenizers, and packing machines.



Fig.4. 6 PAN Analysis of PM and Spare part inventory Control on Downtimes and resource utilization

Scenario 2 achieved high resource utilization levels while reducing unplanned downtime. The introduction of preventive maintenance and spare part stocking stabilized machine performance and prevented frequent stoppages observed in the baseline and other optimized scenarios. This balance between availability and utilization was not consistently achieved in other scenarios.

The third PAN experiment checked how automation and material handling-related controls, including the introduction of conveyors, the number of milk, vacuum, and cream packers, the use of a mechanical cheese vat with automatic molding and curd cutting, and addition of manual cream separator control responses like transfer time to cold storage, packing time, etc.

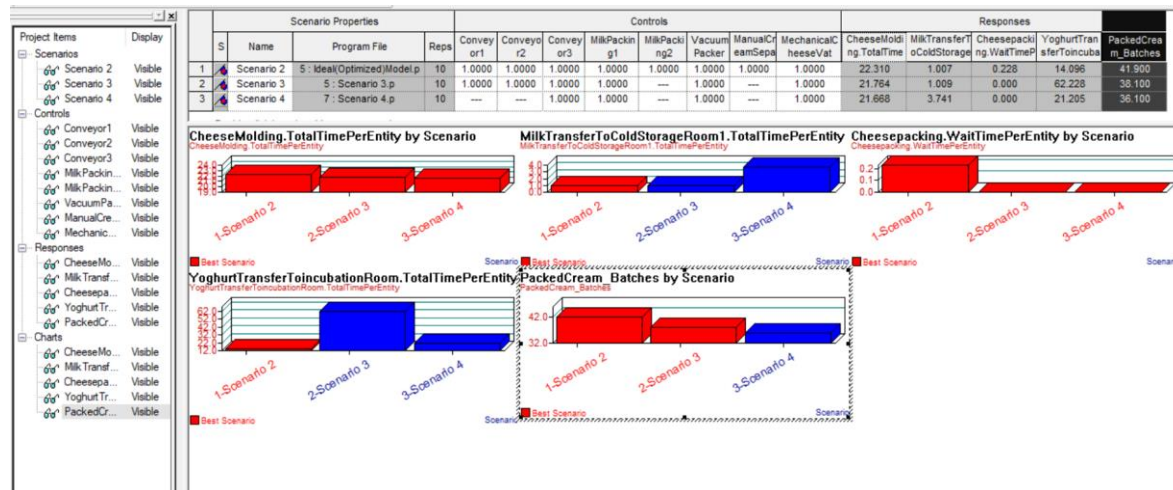


Fig.4. 7 PAN Analysis of partial Automation on Processing time and throughput

The results from PAN Analysis indicate that Scenario 2 significantly reduced internal transfer and processing delays by eliminating manual bottlenecks and improving synchronization between processing and packing operations. Although automation increased capital budget, the resulting reductions in waiting time and handling losses translated into high operational efficiency and higher throughput.

Based on the combined evidence from the PAN graphical analyses and the consolidated KPI comparison table, Scenario 2 was selected as the best optimized scenario for the Elemtu Milk Industry. It offers the most balanced improvement by increasing throughput, stabilizing machine performance, reducing operational losses, and maximizing profit without introducing operational risk. Consequently, Scenario 2 was selected for detailed statistical validation using Arena Output Analyzer in the subsequent section.

4.4.3. Production Line Modeling of the Selected Best Optimized Scenario

The selected optimized production line was modeled in Arena 14.0 to represent a high-efficiency 5,000 L/h dairy processing plant operating under improved maintenance, utility reliability, automation, and resource availability conditions. Milk arrives stochastically in batches of 100 L and undergoes quality screening upon arrival. On average, 92.5% of incoming milk is accepted and transferred to dump tanks, while rejected milk is returned to suppliers except, partially accepted as sour milk (20%) for cheese production. Accepted milk

is pumped into three 10,000 L storage tanks and cooled to 4 °C before being routed to next processes.

Milk is allocated either to HTST pasteurizers for pasteurized milk production or ESL pasteurizers for yoghurt production, followed by homogenization and cream separation. Product routing decisions are governed by scenario specific attributes and variable settings, allowing flexible control of yoghurt production ratios, cream recovery levels, and sour milk utilization. In the selected optimized scenario, yogurt allocation is increased to 5% of accepted milk, enabling production frequency of every two days rather than the intermittent schedule observed in the existing system. Sour milk acceptance is increased to 20% of rejected milk, significantly improving raw material utilization for cheese and local cheese production.

Utility and equipment constraints observed in the baseline system are also addressed through targeted upgrades. A screw type air compressor eliminates compressed air related waiting times at milk and yogurt packing stations and other compressed air related packing quality problems, enabling simultaneous operation of multiple packers. The number of milk packers and their planned operating schedules are adjusted to reduce queuing and improve utilization. Preventive maintenance is introduced for selected critical machines, with scenario-specific maintenance frequencies incorporated into the model to reduce breakdown occurrence and repair durations.

The cream processing line is fully refurbished and automated in the selected scenario. Cream extracted during separation is automatically transferred to an upgraded cream pasteurizer, after which 50% is packed directly as bottled or cup cream and the remaining portion is processed into butter. Additional cream recovered from sour milk is integrated into the same processing stream, further enhancing material efficiency. Cheese and local cheese production benefit from automated vacuum packing, replacing manual operations and reducing contamination risk, packing time, and labor dependency.

Packing, storage, and distribution operations are also enhanced. Expanded cold storage capacity and automated conveyor systems improve material flow and product handling consistency. Distribution logistics are modeled using Assign modules that calculate

transportation costs, labor wages, and revenue dynamically based on batch quantities and delivery routes, allowing accurate financial performance estimation.

The selected optimized production line model generally represents the best-performing configuration identified through Arena Process Analyzer. By integrating improved maintenance strategies, optimized resource allocation, enhanced utility reliability, and increased automation, the model demonstrates substantial reductions in downtime and product losses, higher equipment utilization, increased throughput across all product lines, and significantly improved annual profit compared to the existing system. The optimized production line model is illustrated in Figure 4.8.

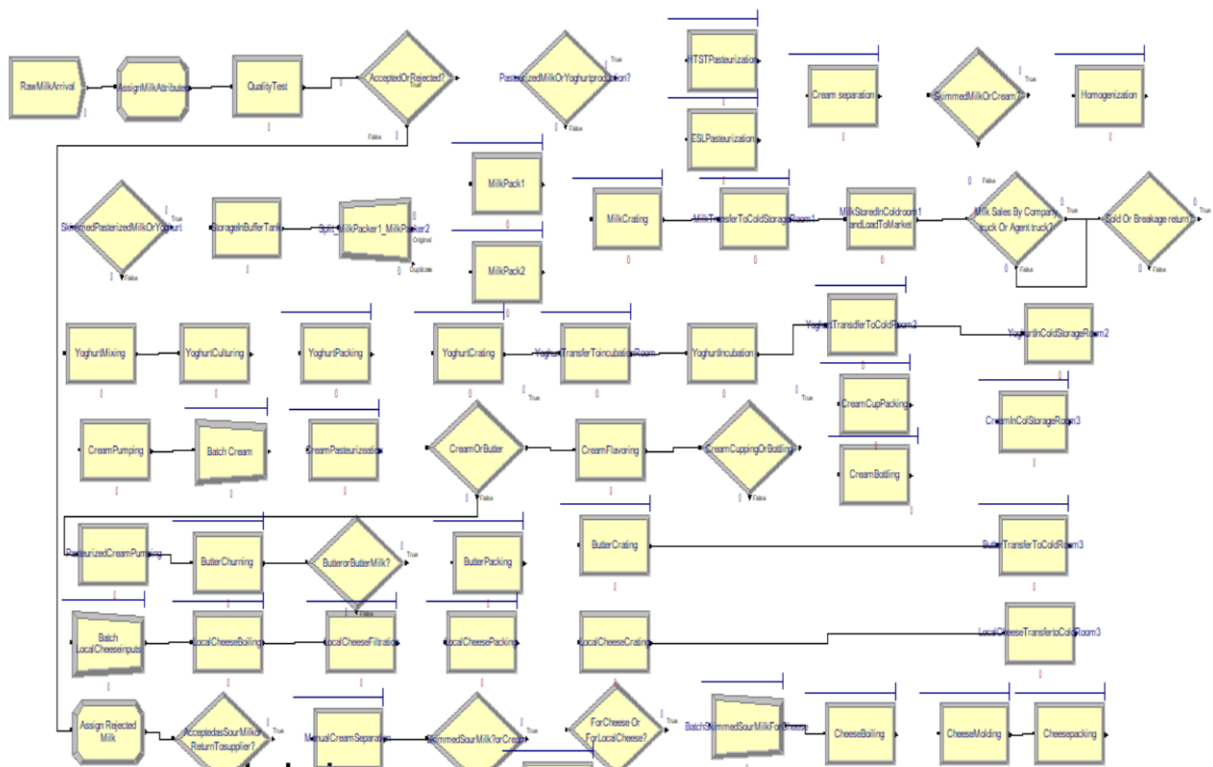


Fig.4. 8 Production Line Model-Optimized Scenario (Image modified to capture screenshot)

4.4.4. Inventory Modeling of Spare Parts and Spare-Part Kits for the Selected Optimized Scenario

In the selected optimized scenario, spare-part inventory management is explicitly modeled in Arena to support both corrective and preventive maintenance activities and to eliminate downtime caused by part unavailability. The inventory system includes individual spare parts such as bearings, seals, sensors, and relays, as well as machine-specific spare-part kits for critical equipment, including the milk packer, yoghurt packer, homogenizer, cream separator,

air compressor, and pasteurizers. This integrated approach reflects realistic maintenance practices in industrial dairy plants, where failures often require replacement of multiple related items rather than isolated parts.

Each spare part and spare part kit is modeled using standard inventory control parameters like stock level, reorder point, order quantity, lead time, and an order flag mechanism. Initial stock levels are assigned based on the requirements of the optimized system, ensuring enough availability for both scheduled preventive maintenance and unexpected corrective repairs. Unlike the existing system, where spare parts are often purchased only after a failure occurs, the optimized scenario assumes that critical components are stocked to support continuous operation.

A reorder point based follow up policy governs inventory behavior in the model. When the stock balance of a part or kit falls to or below its predefined reorder point, a purchase order is automatically triggered. The reorder point is defined to cover expected consumption during supplier lead time, thereby preventing shortages during periods of high maintenance demand. To avoid multiple orders for the same item while a previous order is still pending, an order flag is used. This flag activates when an order is placed and is reset only when the item is received, ensuring controlled and realistic inventory management.

Order quantities are defined to restore inventory to appropriate operating levels without excessive overstocking. This allows the model to balance spare part availability with inventory holding considerations, reflecting practical industrial decision making. Lead time is explicitly included to represent delays between placing an order and receiving spare parts from suppliers. By incorporating lead time into the simulation logic, the model captures the real impact of procurement delays on maintenance execution and machine availability. In the selected optimized scenario, stock levels and reorder points are structured such that available inventory is sufficient to cover demand during lead time, effectively eliminating spare-part-related downtime.

All spare part and spare part kit inventory parameters are implemented in Arena using Variables, enabling continuous tracking of stock levels and seamless integration with breakdown and preventive maintenance modules. When a maintenance event occurs, the required parts or kits are checked for availability, deducted from inventory upon use, and

replenished automatically according to the defined control logic. This structure ensures that both corrective repairs and planned maintenance activities are executed without unnecessary waiting time.

The modeled spare-part inventory system plays a critical role in the performance of the selected optimized scenario. By ensuring timely availability of maintenance components, the system significantly reduces repair delays, supports uninterrupted preventive maintenance execution, and improves the reliability and availability of critical equipment. The spare-part inventory model for the selected optimized scenario is illustrated in Figure 4.9.

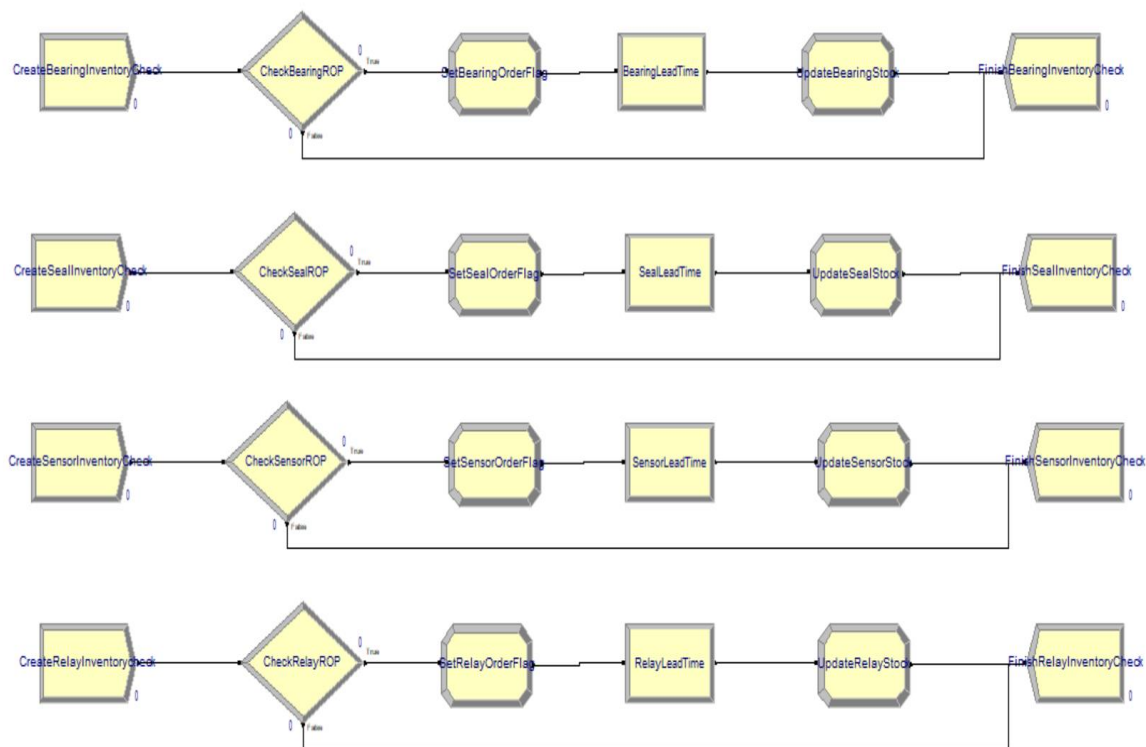


Fig.4. 9 Spare part Inventory Model-Optimized Scenario

4.4.5 Preventive Maintenance, Breakdowns, and Downtime Modeling in the Optimized Scenario

In the optimized scenario, equipment reliability and maintenance behavior were explicitly modeled to reduce unplanned downtime and make production stable. Preventive maintenance and rare breakdowns were added into the Arena model using variable and Arena modules. This approach represents a clear difference from the existing system, where maintenance activities are largely reactive and unplanned.

Preventive maintenance was applied to all critical processing and utility equipment, including milk packers, pasteurizers, homogenizers, cream separators, air compressors, and boiler and chiller. Maintenance activities are triggered either by operating hours or by predefined calendar intervals, depending on the equipment type. During preventive maintenance, machines are temporarily unavailable; however, these planned stoppages significantly reduce the probability of unexpected failures. The model captures both the duration of maintenance tasks and the restoration of equipment reliability following service, allowing machine availability to improve over time despite the introduction of scheduled downtime.

Although the optimized scenario includes preventive maintenance and refurbished machinery, breakdown events were still modeled to reflect unavoidable real world uncertainties. These rare failures are represented using probabilistic distributions, such as exponential or lognormal distributions, based on historical mean time between failures data. Breakdown downtime includes actual repair time, labor requirements and spare-part availability. By modeling these low frequency events, the simulation produces realistic estimates of system robustness and avoids exaggerated optimistic performance predictions.

Total equipment downtime in the optimized scenario therefore consists of scheduled preventive maintenance, rare breakdown repairs, and minor operational stoppages. Downtime is tracked individually for all critical equipment, enabling detailed analysis of utilization, idle time, and throughput impacts. The combined effect of preventive maintenance, improved spare part availability, and upgraded machinery results in higher machine utilization, fewer unexpected stoppages and smoother material flow throughout the plant. Key performance indicators such as equipment downtime, processing time and throughput demonstrate the effectiveness of the optimized maintenance strategy in reducing production losses and enhancing overall system efficiency.

4.4.6 Financial Modeling in the Optimized Scenario

The financial modeling of the optimized scenario follows the same structural logic and calculation methodology as the existing system model. No new financial equations or were introduced. The optimized scenario differs only in the values assigned to variables spreadsheet, such as production volumes, machine availability, maintenance frequency, spare part inventory, and product mix ratio. Consequently, any observed changes in revenue, cost,

or profit are due to operational improvements rather than differences in financial modeling assumptions.

The financial model was included to evaluate the economic effect of the proposed changes, including preventive maintenance planning, utility enhancements, spare part inventory and partial automation of production and material handling activities. The model evaluates revenues, costs, and profits at both product and plant levels, providing a comprehensive assessment of financial performance under new operating conditions.

Revenue is calculated for each product line, including pasteurized milk, yoghurt, butter, cheese, cream, and local cheese. Batch selling prices are multiplied by the simulated annual production batches generated by the Arena model. These production volumes are recorded automatically as entities complete packing and storage processes. Revenue values are stored in Arena variables and updated continuously during simulation. Total plant revenue is obtained by aggregating revenues from all product lines. Compared with the existing system, the optimized scenario achieves higher revenues primarily due to increased throughput, reduced downtime, improved equipment utilization, and the effective utilization of previously underperforming product lines such as cream and cheese products.

Costs are modeled using a combination of variable and fixed components directly linked to operational activities. Batch dependent production costs include raw milk, additives, packaging materials and labor. Transportation costs for company owned trucks are calculated based on fuel consumption, driver wages, and sales personnel expenses. Maintenance costs include preventive, corrective, and emergency maintenance activities. Even though preventive maintenance increases planned maintenance cost relative to the existing system, it significantly reduces unplanned breakdowns, idle time, and production losses, resulting in a better profit. Other operating costs, including depreciation, salaries, and facility related expenses, are treated as fixed costs and held constant across scenarios to maintain analytical fairness.

Profit is computed at both product and system levels. Product level profit is obtained by subtracting production costs from product specific revenues, while total plant profit is calculated by subtracting all operating costs from total revenue. In the optimized scenario, profitability increases significantly due to higher production volumes, reduced machine idle

time, lower breakage returns and improved raw material utilization. All financial calculations are implemented within Arena simulation software using Assign modules and variable spreadsheet, ensuring that revenues, costs, and profits resulted in response to real time system behavior.

4.4.7. Summary of the Selected Optimized Scenario Modeling Framework

The selected optimized scenario represents an integrated improvement across **production line design, maintenance strategy, inventory management, and financial performance**. All of the above are implemented within single Arena simulation Modeled. The production line model incorporates improved milk allocation, enhanced packing capacity, reduced transfer delays, and automation of critical operations. Preventive maintenance schedules and spare-part inventories improves equipment availability and reduce breakdown-related stoppages. Including spare-part stock levels support continuous operation without excessive downtime or congestion.

The financial model of optimized scenario is identical in structure to that of the existing scenario. The values which make differences are filled in variable spreadsheet of Arena. By maintaining consistent financial logic while varying only operational parameters, the model provides a transparent and defensible assessment of the economic benefits of optimization. Collectively, these integrated modeling components demonstrate that coordinated system-level interventions, rather than isolated improvements, are essential for achieving sustainable operational and financial performance gains at Elemtu Milk Industry.

CHAPTER FIVE: SIMULATION RESULTS, OPTIMIZATION, AND PERFORMANCE ANALYSIS

5.1 Introduction

This chapter presents and analyzes the simulation results for both the existing and optimized scenarios of Elemtu Milk Industry. The analysis mainly focuses on evaluating system performance, identifying key bottlenecks, and comparing across scenarios to determine the effectiveness of the suggested optimization. The results provide quantitative evidence for selecting the best-performing system and for estimating improvements in throughput, Downtime, packing quality, resource utilization, and profitability.

Simulation outputs (from exported.dat file) were analyzed using both **graphical and statistical methods**. **Histograms** were used to visualize the distribution, variability, and stability of key performance indicators such as product throughput, machine utilization, down times, and profit. These tools help show differences between the existing and optimized scenarios.

Paired-sample t-test of Arena Output Analyzer was used to compare the two scenarios to enable direct comparison of mean values. The paired-t mean comparison provides statistical evidence of whether observed improvements in the optimized system are significant rather than due to random variation.

In general, the chapter explains how optimization strategies such as the introduction of preventive maintenance, improved spare-part management, increased milk allocation to yoghurt, and some added partial automation cause improvements in product throughputs, resource utilization, Equipment downtimes, and financial performance.

5.2 Histogram Analysis of Individual Scenarios

This section discusses graphical analysis of the simulation outputs for the individual scenarios using histogram plots. The output distributions those resulted in the graph representations are changed into table forms for some KPIs below to make it clear since we are explaining about the output distribution values. For some other KPIs, the histogram graph itself was added as figure. Histogram analysis is employed to examine the distribution,

variability, and stability of key performance indicators such as product throughput, machine utilization, waiting times, and profit. The observations obtained from these distributions provide a foundation for understanding system behavior and support the next statistical comparison of scenarios using paired mean analysis.

5.2.1 Simulation Results of the Existing Scenario Analysis and Identified Bottlenecks

Modeling and simulation of the existing system at Elemtu Milk Processing Plant shows that the production processes are dominated by frequent interruptions, unstable process flows, and underutilization of critical resources. Total throughput at all major product lines is found to be below the plant’s design capacity, due to equipment downtimes caused by unavailability of spare parts. The failure and repair patterns added into the model shows how downtimes in key machines like HTST pasteurizer, ESL Pasteurizer, homogenizer, cream separator, milk packer, and yoghurt packer. Failure and repair model of also Utility machines like boiler, chiller and Air compressors added. These failures caused accumulation of queues, forced operators into long periods of idleness, and resulted in variable daily production rates.

Table 5. 1 Histogram Of Packed Milk Batches-Existing

Cell	From (L)	To (L)	Abs. Freq.	Cumulative Freq.	Abs. Rel. Freq.	Cumulative Rel. Freq.
1	-∞	23980	1	1	0.1111	0.1111
2	23980	24000	0	1	0	0.1111
3	24000	24020	0	1	0	0.1111
4	24020	24040	1	2	0.1111	0.2222
5	24040	24060	1	3	0.1111	0.3333
6	24060	24080	1	4	0.1111	0.4444
7	24080	24100	2	6	0.2222	0.6667
8	24100	24120	1	7	0.1111	0.7778
9	24120	24140	0	7	0	0.7778
10	24140	24160	1	8	0.1111	0.8889
11	24160	24180	1	9	0.1111	1
12	24180	24200	0	9	0	1

13	24200	$+\infty$	0	9	0	1
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1.OA Histogram Analysis of Packed Milk Batches-Existing

A good example of the system’s performance limitations is annual packed milk batches. As seen from Output Analyzer histogram for annual packed milk batches, only a narrow variation is achieved across the 10 replications, all far below the theoretical annual capacity. This small output result is driven by two main issues:

1. The plant has only one milk packing machine with a maximum capacity of 2700 L/h, creating a downstream bottleneck regardless of upstream processing capacity.
2. Frequent failures of the packer and other downstream units, combined with long spare-part waiting times, significantly reduce uptime and further depress yearly packed milk production.

The simulation results for the existing scenario were further analyzed using histograms to understand the distribution and variability of packed milk batches and total breakage. Table 5.1 summarizes the packed milk output across ten simulation replications. The highest frequency occurs in the range of 24,080–24,100 liters, indicating the most common batch size produced by the plant. The cumulative relative frequency shows that 66.67 percent of the packed milk batches fall below 24,100 liters. This result emphasizes that the plant operates below its design capacity. The histogram also ensures that bottlenecks at the milk packer caused by spare-part shortages significantly affect throughput.

2. Histogram Analysis of Breakage Returns-Existing

Table 5. 2 Histogram of Breakage Return-Existing

Cell	From (L)	To (L)	Abs. Freq.	Cumulative Freq.	Abs. Rel. Freq.	Cumulative Rel. Freq.
1	$-\infty$	2100	0	0	0	0
2	2100	2120	1	1	0.1111	0.1111
3	2120	2140	0	1	0	0.1111
4	2140	2160	0	1	0	0.1111
5	2160	2180	2	3	0.2222	0.3333
6	2180	2200	0	3	0	0.3333
7	2200	2220	2	5	0.2222	0.5556
8	2220	2240	2	7	0.2222	0.7778
9	2240	2260	0	7	0	0.7778
10	2260	2280	1	8	0.1111	0.8889

11	2280	2300	0	8	0	0.8889
12	2300	2320	0	8	0	0.8889
13	2320	2340	0	8	0	0.8889
14	2340	2360	1	9	0.1111	1
15	2360	+∞	0	9	0	1

Table 5.2 above presents the distribution of annual breakage return across ten replications. Most frequent breakage return values lie between 2,160 and 2,240 liters, with the cumulative relative frequency indicating that 77.78% of breakage returns values fall below 2,240 liters. This shows that breakage is significant operational issue. The observed losses are mainly due to challenges in packaging operations, including worn sealing parts, manual handling, broken crates, and insufficient compressed air. The histogram also confirms that extreme values are rare, as represented by the “-Infinity” and “+Infinity” placeholders, with all actual breakage falling within the meaningful range of 2,100–2,360 liters.

3. Histogram Analysis of Power Outage Downtime-Existing

Utility related problems also had remarkable impact on production stability. Power outages contributed approximately 2,686 minutes of downtime per year, interrupting the operation of boilers, chillers, pasteurizers, homogenizers, and cream separators. These forced interruptions show the extent to which external utility reliability affect plant throughput. Similarly, compressed air limitations created predictable delays in the packing line, particularly when milk and yoghurt packing needed to operate simultaneously. The insufficient air supply prevented simultaneous operation, creating repeated idle periods for the milk packer every time there is yoghurt packing.

Table 5. 3 Histogram of Power Outage Downtime (minutes)-Existing

Cell	From (min)	To (min)	Abs. Freq.	Cumulative Freq.	Abs. Rel. Freq.	Cumulative Rel. Freq.
1	-∞	2686	0	0	0	0
2	2686	2686	0	0	0	0
3	2686	2686	0	0	0	0
4	2686	2686	0	0	0	0
5	2686	2686	0	0	0	0
6	2686	2686	0	0	0	0
7	2686	2686	0	0	0	0
8	2686	2686	0	0	0	0
9	2686	2686	0	0	0	0
10	2686	2686	0	0	0	0
11	2686	2686	9	9	1	1

12	2686	2686	0	9	0	1
13	2686	2686	0	9	0	1
14	2686	2686	0	9	0	1
15	2686	2686	0	9	0	1
16	2686	2686	0	9	0	1
17	2686	2686	0	9	0	1
18	2686	2686	0	9	0	1
19	2686	2686	0	9	0	1
20	2686	2686	0	9	0	1
21	2686	+∞	0	9	0	1

Table 5.3 presents the distribution of annual power outage downtime across ten simulation replications for the existing scenario. The histogram shows a consistent pattern in downtime, with all replications recording exactly 2,686 minutes of outage. This uniformity indicates that the simulated power interruptions are modeled as deterministic events rather than random variations, reflecting the real-world reliability of the external utility supply. Even though power outage actually occurs at random rate and is unpredictable, the input distribution of power outage is modeled by taking constant average value of more than one year power outage data. All the histogram bins are placeholders, with the actual data concentrated entirely in cell 11. The “-Infinity” and “+Infinity” cells, as with previous histograms, serve as formal bounds in Arena’s output and do not correspond to real observations in this case.

Power outage downtime directly affects boilers, chillers, pasteurizers, homogenizers, and cream separators, and contributes to repeated idle periods and bottlenecks throughout the production process. The analysis demonstrates that external utility reliability is a critical constraint on plant performance, reinforcing the need for contingency measures, backup systems, or scheduling adjustments to reduce the operational impact of outages.

4. Histogram Analysis of Total Profit-Existing

The histogram of annual total profit from the simulation shows that the plant’s financial performance is **both low and narrowly distributed**, with actual profits consistently falling between **18.75 and 19.4 million ETB**. The frequency distribution indicates the most common outcomes occur in the **19.2–19.25 million ETB** range and the **19.4+ million ETB** range. Cumulative relative frequencies show that approximately **two-thirds (66.7%) of replications** fall below 19.25 million ETB, demonstrating a persistent trend of constrained profitability.

This tight clustering of profits is reflection of:

- **Bottlenecks at the single milk packer** severely restrict throughput despite the plant’s 5,000 L/h design capacity.
- **Low machine utilization** and frequent breakdowns reduce effective production time.
- **Insufficient spare-part availability** limits maintenance options and prolongs downtime.
- **Losses from product breakages and market returns** further affect profits.
- **Utility related interruptions**, such as power outages, exacerbate production disruptions.

The histogram confirms that while the system behaves predictably under current conditions, it is structurally limited. This prevents the plant from achieving higher financial performance. The narrow profit range indicates that even minor operational interruptions have a significant impact. These results establish a baseline for comparative analysis with optimized scenarios.

Table 5. 4 Histogram of Annual Profit(Million ETB)-Existing

Cell	From (M ETB)	To (M ETB)	Absolute Frequency	Cumulative Abs. Freq.	Relative Frequency	Cumulative Rel. Freq.
1	$-\infty$	18.75	0	0	0	0
2	18.75	18.8	1	1	0.1111	0.1111
3	18.8	18.85	0	1	0	0.1111
4	18.85	18.9	0	1	0	0.1111
5	18.9	18.95	0	1	0	0.1111
6	18.95	19	0	1	0	0.1111
7	19	19.05	0	1	0	0.1111
8	19.05	19.1	1	2	0.1111	0.2222
9	19.1	19.15	1	3	0.1111	0.3333
10	19.15	19.2	1	4	0.1111	0.4444
11	19.2	19.25	2	6	0.2222	0.6667
12	19.25	19.3	1	7	0.1111	0.7778
13	19.3	19.35	0	7	0	0.7778
14	19.35	19.4	0	7	0	0.7778
15	19.4	$+\infty$	2	9	0.2222	1

Similar to the above selected KPIs Analysis, annual resource utilization percentage in the existing system was low across nearly all units. For instance, the yoghurt packer operated at an average of 16.66 percent utilization, reflecting the combined effects of low yoghurt allocation only two percent of accepted milk and frequent downtimes. In practice, this implicates that the entire yoghurt processing line and associated packing machinery remained idle for the majority of the year. Across the plant, almost all resources operated at less than

half of their planned run time. This inefficiency implies the need for increased allocation to yoghurt production, improved coordination between processing and packing activities, and the implementation of preventive maintenance to reduce downtime.

In summary, the simulated results for the existing scenario confirmed that the Elemtu Milk Processing Plant operates far below its design capacity. Low annual batch throughput, high breakage return, insufficient product diversification, and less profit illustrated a system constrained by structural bottlenecks, unreliable equipment, and poor spare-part management. These problems provide a clear justification for implementing comprehensive improvements, including preventive maintenance, reliable spare-part inventories, refurbishment of critical machinery, increased milk supply stability, and partial automation. Establishing these improvements is essential for shifting the existing plant to a stable, capacity-aligned system capable of delivering higher throughput, improved product quality, and enhanced financial performance. These findings naturally motivate the development and simulation of optimized scenarios in the subsequent sections.

5.2.2 Simulation Result Analysis (Histogram) – Optimized Scenario

This section presents the Histogram analysis of key performance indicators (KPIs) obtained from the simulation of the selected best optimized scenario at Elemtu Milk industry. Histograms were generated to visualize the frequency and cumulative behavior of selected KPIs, providing insights into production stability, equipment performance, product quality, and financial outcomes.

Histograms are used because simulation outputs are **stochastic in nature**, meaning that each replication produces slightly different results due to randomness in milk arrivals, processing times, and operational interruptions. Rather than relying only on average values, histograms allow the distribution, spread, and concentration of outcomes across replications to be examined. This makes it possible to assess not only expected performance, but also **variability, consistency, and reliability** of the optimized scenario results.

By presenting results in histogram form, the analysis shows how frequently specific performance levels occur, how quickly cumulative performance is achieved, and whether outcomes are tightly clustered or widely spread. This is essential for evaluating the robustness of the optimized scenario under real operating conditions. The analysis focuses on packed

milk batches, total breakage, power outage downtime, and total annual profit, as these KPIs directly reflect production efficiency, operational losses, system reliability, and economic performance within the simulated plant.

1. Packed Milk Batches Histogram Analysis-Optimized

Table 5. 5 Packed Milk Batches Distribution – Optimized Scenario

Cell	From (L)	To (L)	Abs. Freq.	Cumulative Freq.	Abs. Freq.	Rel. Freq.	Cumulative Freq.	Rel. Freq.
1	-∞	51,760	0	0	0	0	0	0
2	51,760	51,780	1	1	1	0.1111	0.1111	0.1111
3	51,780	51,800	0	1	1	0	0.1111	0.1111
4	51,800	51,820	1	2	2	0.1111	0.2222	0.2222
5	51,820	51,840	0	2	2	0	0.2222	0.2222
6	51,840	51,860	0	2	2	0	0.2222	0.2222
7	51,860	51,880	0	2	2	0	0.2222	0.2222
8	51,880	51,900	2	4	4	0.2222	0.4444	0.4444
9	51,900	51,920	1	5	5	0.1111	0.5556	0.5556
10	51,920	51,940	0	5	5	0	0.5556	0.5556
11	51,940	51,960	0	5	5	0	0.5556	0.5556
12	51,960	51,980	1	6	6	0.1111	0.6667	0.6667
13	51,980	52,000	1	7	7	0.1111	0.7778	0.7778
14	52,000	52,020	1	8	8	0.1111	0.8889	0.8889
15	52,020	52,040	1	9	9	0.1111	1	1
16	52,040	+∞	0	9	9	0	1	1

The histogram distribution table above indicates that the majority of packed milk production lies between 51,880 and 52,040 batches, with the cumulative frequency reaching 100% by the 16th cell. The narrow spread of the distribution confirms low variability and stable production behavior across simulation replications. The highest frequency occurs around the central cells, reflecting consistent annual batch throughput under the optimized operating conditions.

In the simulation model, one batch represents 100 liters of packed milk. That means, an annual production level of approximately 51,980 batches corresponds to 5.198 million liters per year. Although the installed packing capacity of the plant is 5,000 L/h, the system does not operate continuously throughout the year. Effective production time is constrained by planned preventive maintenance and unplanned breakdowns affecting both upstream and downstream equipment, including the HTST pasteurizer, homogenizer, cream separator, buffer tanks, and packing machines.

Because the milk packer is dependent on the availability of upstream processing units, any preventive maintenance or breakdown in these machines interrupts milk flow and reduces effective packing hours. As a result, the plant operates for significantly fewer than 365 days per year, and the achievable annual packed milk output is decided by system wide availability rather than nominal equipment capacity.

The cumulative relative frequency shows that 66.7% of the simulation replications produced up to approximately 51,980 batches per year, indicating that the optimized system delivers this amount of annual output under realistic operating conditions that include maintenance and breakdown days across the full processing line. The resulting production level is therefore consistent with the plant’s design capacity when adjusted for actual system availability.

2. Breakage Return Histogram Analysis-Optimized

Table 5. 6: Breakage Total Distribution – Optimized Scenario

Cell	From (L)	To (L)	Abs. Freq.	Cumulative Freq.	Abs. Rel. Freq.	Cumulative Rel. Freq.
1	-∞	480	1	1	0.1111	0.1111
2	480	485	0	1	0	0.1111
3	485	490	0	1	0	0.1111
4	490	495	1	2	0.1111	0.2222
5	495	500	1	3	0.1111	0.3333
6	500	505	0	3	0	0.3333
7	505	510	1	4	0.1111	0.4444
8	510	515	1	5	0.1111	0.5556
9	515	520	1	6	0.1111	0.6667
10	520	525	0	6	0	0.6667
11	525	530	1	7	0.1111	0.7778
12	530	535	1	8	0.1111	0.8889
13	535	540	0	8	0	0.8889
14	540	545	0	8	0	0.8889
15	545	550	0	8	0	0.8889
16	550	555	0	8	0	0.8889
17	555	560	0	8	0	0.8889
18	560	565	1	9	0.1111	1
19	565	+∞	0	9	0	1

The histogram for total breakage in the optimized scenario shows that annual losses are concentrated between 480 and 565 liters per replication, with the highest frequencies occurring in the 490–520 liter range. The narrow distribution, indicates low variability and

stable performance across all replications. Approximately 66.67% of the replications result in breakage levels below 520 liters, demonstrating that most simulation runs achieve consistently low breakage return.

The observed low breakage return result is due to the cumulative effects of preventive maintenance implementation, improved spare-part availability, partial automation in packing operations, and improved coordination between upstream and downstream processes.

3. Power Outage Downtime Histogram Analysis-Optimized

Table 5. 7:Power Outage Downtime Distribution – Optimized Scenario

Cell	From (min)	To (min)	Abs. Freq.	Cumulative Freq.	Abs. Rel. Freq.	Cumulative Rel. Freq.
1	-∞	-0.1	0	0	0	0
2	-0.1	-0.08	0	0	0	0
3	-0.08	-0.06	0	0	0	0
4	-0.06	-0.04	0	0	0	0
5	-0.04	-0.02	0	0	0	0
6	-0.02	0	0	0	0	0
7	0	0.02	9	9	1	1
8	0.02	0.04	0	9	0	1
9	0.04	0.06	0	9	0	1
10	0.06	0.08	0	9	0	1
11	0.08	0.1	0	9	0	1
12	0.1	+∞	0	9	0	1

The above histogram result distribution table shows that all replications in the selected optimized scenario record effectively zero downtime due to power outages, with values fully concentrated within the 0–0.02 minute range. This indicates that power-related interruptions are negligible across all simulation runs.

This is due to backup power systems, and operational scheduling strategies that prevent production stoppages caused by external utility problems. As a result, critical processing units such as pasteurizers, homogenizers, cream separators, and packing lines are able to operate without power related interruptions throughout the simulated period.

In general, the histogram confirms that power outages do not act as a limiting factor in the optimized scenario, supporting uninterrupted production and stable plant operation.

4. Profit Total Histogram Analysis-Optimized

Table 5. 8 Profit Total Distribution – Optimized Scenario

Cell	From (Million ETB)	To (Million ETB)	Abs. Freq.	Cumulative Abs. Freq.	Rel. Freq.	Cumulative Rel. Freq.
1	$-\infty$	90.8	0	0	0	0
2	90.8	90.9	1	1	0.1111	0.1111
3	90.9	91	2	3	0.2222	0.3333
4	91	91.1	1	4	0.1111	0.4444
5	91.1	91.2	0	4	0	0.4444
6	91.2	91.3	1	5	0.1111	0.5556
7	91.3	91.4	0	5	0	0.5556
8	91.4	91.5	2	7	0.2222	0.7778
9	91.5	91.6	1	8	0.1111	0.8889
10	91.6	91.7	0	8	0	0.8889
11	91.7	91.8	1	9	0.1111	1
12	91.8	$+\infty$	0	9	0	1

The above table is taken from histogram of total annual profit in the selected optimized scenario. It is tightly clustered between 90.8 and 91.8 million ETB across all replications. Approximately 66.67% of the outcomes fall below 91.6 million ETB, while the remaining 33.33% reach slightly higher values. This is reflection of normal stochastic variations in milk arrivals, processing times, and minor operational disturbances within the system.

The narrow fluctuation of the distribution indicates low variability and high financial stability in the optimized operations. This is due to consistent throughput; controlled breakage amounts; effective utilization of pasteurizers, homogenizers, and packing machines, an improved product mix including yoghurt and sour-milk utilization, and reduced downtime achieved through preventive maintenance and improved spare-part availability.

5. Compressed Air Wait Time Histogram Analysis-Optimized

The histograms for compressed-air wait time sit entirely at zero. This indicates that the packing machines do not have to be interrupted due to compressed air shortages. This reflects correct sizing of utility equipment and proper synchronization of demand and supply across the plant. Histograms of Compressed Air Wait Time shown in Fig5.1 visually represent the complete elimination of compressed air wait time.

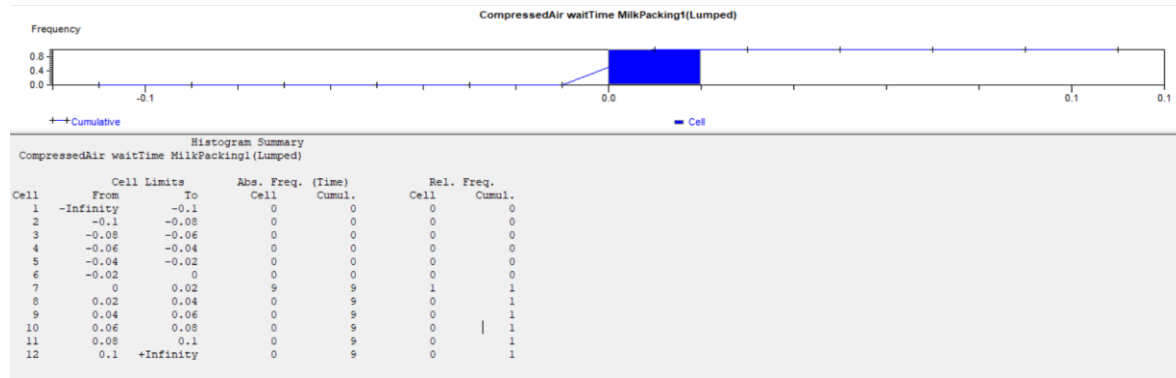
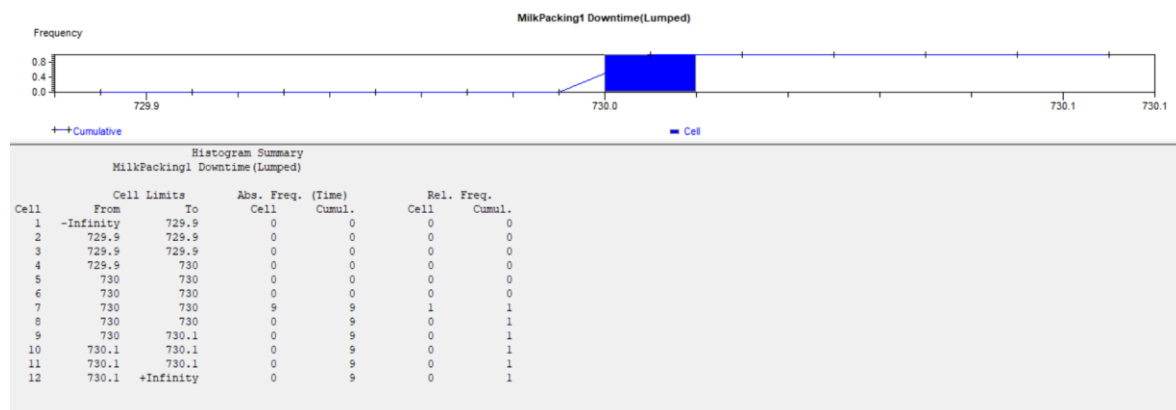


Fig 5. 1 Compressed Air Wait Time-Optimized Scenario;

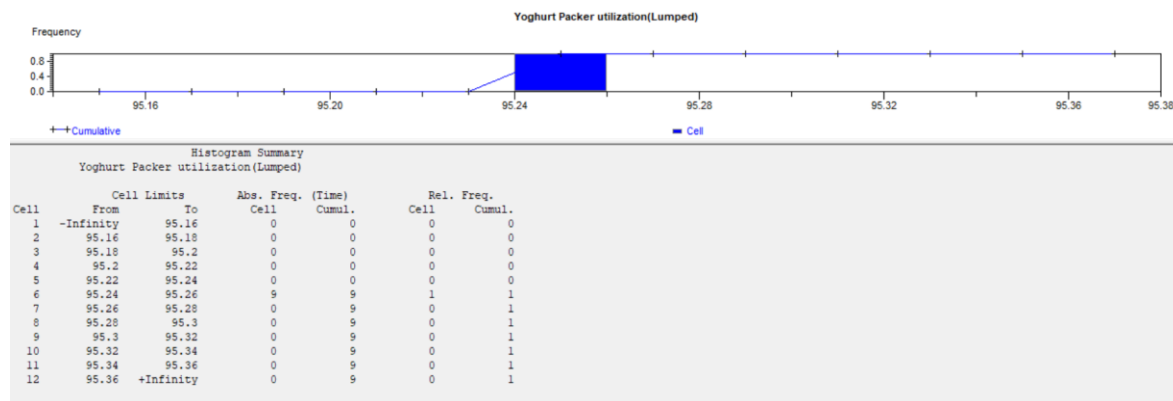
3. Equipment Utilization and Downtime Histogram Analysis-Optimized

The histogram for Milk Packing Machine 1 downtime (Figure 5.2(a)) shows a single consistent value across all replications, corresponding to routine scheduled preventive maintenance. No additional unplanned downtime appears in the distribution, confirming that the optimized maintenance plan and refurbished equipment have eliminated random breakdowns.

Operational efficiency is reflected in equipment utilization as well. The histogram for yoghurt packer utilization (Fig.5.2 (b)), for instance, shows a tight cluster around approximately ninety-five percent. This high, stable utilization indicates that the machine is neither overloaded nor underused, and that upstream processes deliver product at a balanced and predictable rate.



a)



b)

Fig 5. 2 a) Histograms of Milk Packer1 Downtime-Optimized scenario; b) Yoghurt Packer Utilization-Optimized Scenario

5.3 Statistical Comparison of Simulation Results

This section presents a statistical discussion of key performance indicators obtained from Arena Output Analyzer for the existing and optimized scenarios. Mean values from replicated simulation runs were compared using paired-T tests at a 95% confidence level. The paired-T approach ensures that observed differences in system performance are related to operational changes introduced in the optimized scenario rather than stochastic variation. While histograms were used earlier to examine distributional behavior and stability, the paired-T tests provide formal statistical comparison.

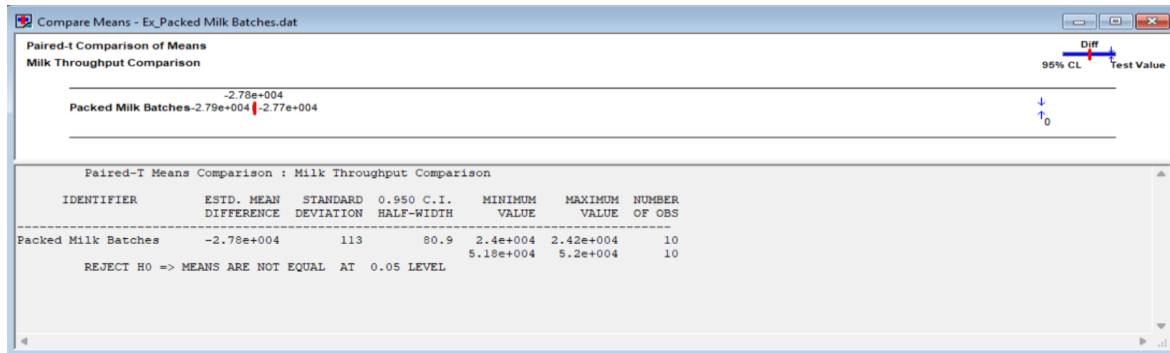
The selected KPIs include annual packed milk batches, milk packer downtime, yoghurt packer utilization, compressed air waiting time, and total annual profit. These selected KPIs capture production capacity, equipment reliability, resource utilization, operational bottlenecks, and financial performance, providing a comprehensive assessment of system behavior.

Across all KPIs, the paired-T results consistently reject the null hypothesis of equal means at the 0.05 significance level. This confirms that the optimized scenario shows statistically significant differences in performance relative to the existing system. The narrow confidence interval half-widths observed for most KPIs further indicate that the estimated means are statistically reliable and that system performance in the optimized scenario is stable across replications.

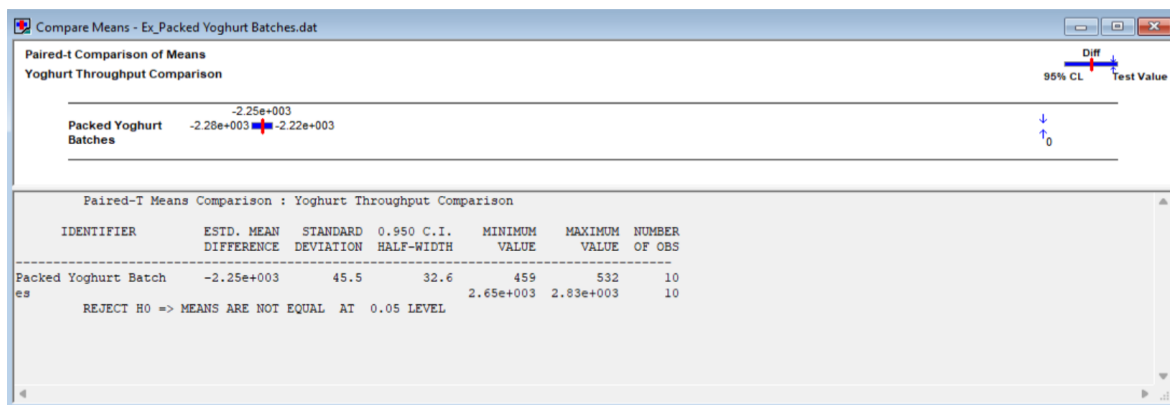
5.3.1 Product Throughput Comparison and Analysis

The Output Analyzer was employed to conduct a statistical comparison of the existing and optimized scenarios for the Elemtu Milk Industry. This tool enabled evaluation of key performance indicators, particularly annual throughput for all major product lines, machine utilization, downtime, and financial outputs. By analyzing ten replications per scenario, the study accounted for stochastic variability in milk arrivals, processing times, and equipment failures, ensuring that observed differences were statistically robust and operationally meaningful.

The comparison shows substantial improvements in annual throughput across all product lines following the implementation of optimization measures. For pasteurized milk, annual production increased from 24,093 batches under the existing scenario to 51,916 batches in the optimized scenario. This increase reflects improved equipment reliability through preventive maintenance, the addition of a refurbished milk packer, and elimination of delays caused by compressed air shortages. Higher milk acceptance rates at reception also ensured a consistent raw material supply, allowing continuous operation and minimizing idle periods across the processing stages. The statistical analysis confirmed that this throughput increase was significant. The Histogram from Arena Output Analyzer from Annual Pasteurized Milk is presented in Figure 5.3(a) below



a)



a)

Fig 5. 3.a) Annual Milk Throughput; b) Annual yoghurt throughput Paired-t Compare means

Paired-T analysis statistically confirms that the implemented optimization interventions have significantly increased the plant's milk processing capacity.

The estimated mean difference of -27822.6 liters indicates a remarkable increase in processed milk under the optimized system. The magnitude of this difference is due to the significant operational gains achieved. These improvements not only support the achievement of production targets but also enhance operational efficiency, throughput consistency, and overall reliability of the milk processing system.

Yoghurt production also achieved a similarly significant improvement. The optimized system increased the annual yoghurt output by approximately 1,560 batches, supported by better utility availability, preventive maintenance, and improved synchronization of pasteurization, incubation, and packing stages. This is also due to the fact that percentage of accepted milk allocation for yoghurt production also increased from 2% to 5%. The observed standard deviation and confidence intervals in Fig 5.3(b) above indicated that these gains were

consistent and reliable. This improvement demonstrates that scheduling and equipment reliability enhancements can substantially increase throughput and operational stability, even for smaller production lines within a multiproduct plant.

For butter production, the optimization measures led to a significant increase in annual batches, with the Paired-T analysis confirming statistical significance. This is due to different factors like Automation of the butter packing line, Automated cream collection, cream separation from sour milk, Automated cream batch pasteurization, reduced manual handling delays and ensured continuous downstream processing. Preventive maintenance further supported consistent operation, resulting in higher throughput and operational reliability.

Cheese throughput also increased significantly under the optimized scenario due to replacement of Manual works with Automation at production stages like cheese Molding and vacuum packing, minimized manual delays; and increased sour milk acceptance percentage. Enhanced equipment reliability through preventive maintenance maintained continuous operation and reduced downtime, contributing to higher annual output and consistent product quality.

Cream production was absent in the existing system and introduced in the optimized scenario. The annual throughput ranged up to 41.9 batches as a result of integrating automated cream collection, pasteurization, and packaging processes. Increased sour-milk utilization and starting cream separation from sour milk further enhanced cream production, highlighting the benefits of process optimization, operator training, and preventive maintenance in activating new product lines.

Local cheese production also experienced a significant increase, with annual throughput rising by approximately 16 batches. Improvements resulted from automatic vacuum packing, more frequent and efficient production scheduling and enhanced process reliability achieved through preventive maintenance and operator training. These interventions reduced idle time, ensured continuous operation, and stabilized product quality.

As summarized in Table 5.9 below, paired-t test comparison confirms that the optimized scenario yield more throughput than the existing system across all product lines. The integration of preventive maintenance, spare part availability, partial automation of key processes, and improved scheduling collectively increased throughput, reduced downtime,

and improved equipment utilization. These results provide clear statistical and operational evidence that optimized scenario implementation can enhance both technical performance and production efficiency in a multiproduct milk processing plant. The OA outputs proves the Process Analyzer findings, validating the effectiveness of the optimized scenario and providing a robust foundation for recommending system-level improvements.

Table 5.9: Annual Throughput Comparison per Product (Batches, Quantity, and Improvement)

Product	Existing Qty.	Optimized Qty.	Improvement Qty.	% Change
Butter (kg)	280	2570	+2290	+817.9%
Cheese (kg)	1010	2540	+1530	+151.5%
Cream (L)	0	4190	+4190	Not defined (baseline is zero)
Local Cheese (kg)	2410	4340	+1930	+80.1%
Milk (L)	2,409,310	5,191,570	+2,782,260	+115.4%
Yoghurt (L)	49,370	274,340	+224,970	+455.6%
Breakage (L)	2,175.3	529.7	-1,645.6	-75.6% reduction

5.3.2. Downtime Comparison and Analysis (OA)

Downtime is defined as all periods during which production equipment is unavailable for operation, including stoppages caused by mechanical failures, utility disruptions, and delays due to spare part shortages. Effective downtime management is essential for maintaining production efficiency, consistent throughput, and optimal resource utilization in the dairy processing plant. The Output Analyzer comparison between the existing and optimized scenarios demonstrates the significant operational improvements achieved through targeted improvements.

In the current existing system, downtime is found to be significant challenge. Utility related problems like insufficient compressed air supply and unstable electricity, caused stoppages in critical operations such as pasteurization, homogenization, and cream separator. The absence of a reliable backup generator increased impact of power outages. Frequent equipment breakdowns occurred because preventive maintenance was not practiced, while delays in waiting spare parts further extended idle periods. These collective factors resulted in

prolonged batch completions, low equipment utilization, and reduced throughput, making production highly unpredictable.

The optimized system resulted in remarkable reduction in downtime, reflecting the effectiveness of several strategic improvements. Implementation of preventive maintenance (PM) programs for all critical machinery including pasteurizers, homogenizers, and packing lines significantly reduced unexpected failures. Introduction of spare part inventory system also allowed quick repairs, while operator and technician training enhanced early fault detection. Utility reliability was improved by installing a high-capacity diesel generator and upgrading Air compressors, ensuring continuous operation even during external power outages or insufficient compressed air supply. These measures collectively minimized interruptions, stabilized batch flow, and improved overall operational efficiency.

Utility and Equipment Downtime Comparisons

Air Compressor Downtime: In the existing system, Air Compressor 1 experienced long downtime due to reactive maintenance and lack of spare parts. This has direct impact on downstream operations, causing delays in pasteurization, homogenization, and packing. After optimization, structured PM schedules, improved spare part stocking, and operator training reduced downtime dramatically. Paired-T analysis shows a statistically significant mean reduction of 20,000 minutes annually, confirming that utility reliability improvements directly contribute to higher plant throughput.

Boiler Downtime: Steam boiler also faced frequent interruptions due to reactive maintenance, spare part shortages, and delayed operator responses, limiting steam availability for heat-dependent processes like pasteurization and cheese boiling. Optimized improvements, including PM, spare part stocking, and operator monitoring, reduced boiler downtime by a mean of 9,040 minutes annually (statistically significant). This ensured continuous steam supply for pasteurization and cream processing, supporting higher production efficiency.

Chiller Downtime: Chillers also experienced extended downtime in the existing scenario simulation due to reactive maintenance and insufficient spare parts. This affects cooling and cold storage operations. After optimization, preventive maintenance, operator training, and

spare part management reduced chiller downtime by 16,900 minutes annually, maintaining product quality, prolonging shelf life, and supporting uninterrupted processing.

Pasteurizer Downtime

Both ESL and HTST pasteurizers resulted in long downtimes due to reactive maintenance, aged equipment, and spare part delays. Optimization through preventive maintenance and spare part management reduced downtime significantly, with mean annual reductions of 5,480 minutes for ESL and 9,080 minutes for HTST pasteurizers. Continuous pasteurizer operation supports uninterrupted milk and yogurt processing, ensuring consistent quality, extended shelf life, and higher throughput.

Homogenizer and Cream Separator Downtime

Homogenizer and cream separator also suffered from reactive maintenance, spare part shortages, and operational errors, leading to frequent interruptions. Optimization plans reduced downtime significantly, with Paired-T mean reductions of 11,400 minutes and 11,300 minutes annually, respectively. These improvements facilitated consistent production flow, improved product quality, and enhanced operational reliability.

Milk and Yoghurt Packers Downtime

Milk Packer 1 and the yoghurt packer were bottlenecks in existing scenario due to frequent breakdowns, utility interruptions, and lack of preventive maintenance. Optimized scenario introduced an additional milk packer, PM schedules, upgraded utilities, and stocked spare parts, leading to smoother operations and significant reductions in downtime. Reliable packing operations ensure continuous throughput, better scheduling, and improved utilization of upstream processes.

Power Outages and Compressed Air Wait Times

Frequent electricity outages and inadequate compressed air supply caused significant production interruptions. Addition of a high capacity backup generator and a new screw compressor eliminated these constraints, reducing annual waiting time for milk packing from 2,430 minutes to zero and ensuring uninterrupted parallel operation of both milk and yoghurt

packing lines. This improvement directly contributed to increased throughput and operational efficiency.

In summary, the Output Analyzer confirms that the combination of preventive maintenance, spare part management, operator training, and utility upgrades has remarkably reduced downtime across all critical equipment. These improvements have transformed previously unpredictable stoppages into manageable and minimal interruptions. This directly enhances production efficiency, throughput consistency, and overall reliability of the milk processing plant. Statistical summary of selected Resources Downtime across replications, including mean values, standard deviations, and confidence intervals is summarized in Table 5.10 below.

Table 5.10: Annual Downtime Comparisons of Main Machines

Equipment	Existing Downtime (min/year)	Optimized Downtime (min/year)	Improvement (%)	Notes on Optimization
Air Compressor 1	20,426	425	97.9%	Preventive maintenance, spare parts stocked
Boiler	9,730	696	92.8%	PM, spare parts ready, serviced
Chiller	17,500	607	96.5%	PM and spare parts replaced
Borehole Pump	8,640	5,900	31.7%	PM; additional borehole recommended for redundancy
ESL Pasteurizer	6,080	608	90.0%	PM and spare parts available
HTST Pasteurizer	9,690	608	93.7%	PM and spare parts available
Homogenizer	12,200	730	94.0%	PM and spare parts replaced
Cream Separator	12,200	850	93.0%	PM and spare parts replaced
Milk Packer 1	12,200	730	94.0%	PM and spare parts ready; additional packer added
Yoghurt Packer	6,080	730	88.0%	PM and spare parts replaced
Power Outage	2,690	0	100%	High-capacity diesel generator installed
Average Downtime	10,611.5	1,080.6	89.8% reduction	—

5.3.3 Product Variety Comparison and Analysis

Product variety in the milk processing plant refers to the number of dairy products produced. Comparing the existing and optimized scenarios highlights the significant impact of process improvements on both product diversity and operational efficiency.

In the existing system, only pasteurized milk and yoghurt were produced consistently, while other products such as butter, cheese, local cheese, and cream were minimally produced or entirely absent. Cream production, in particular, was completely omitted. Reliance on manual handling for butter and cheese production created bottlenecks, reduced throughput, increased contamination risk, and led to inconsistent product quality and shorter shelf life. Consequently, the plant operated with limited product diversification and unrealized revenue potential.

In contrast, the optimized scenario demonstrates substantial improvements. All six product lines pasteurized milk, yoghurt, butter; cheese, local cheese, and cream are produced consistently at remarkable scale. Automation of critical stages, including packing, cheese making, and cream processing, improved throughput, quality, and hygiene standards. Enhanced utilities, preventive maintenance programs, and additional milk packers reduced downtime and improved synchronization across the production line. Local cheese throughput is more than doubled due to automated vacuum packing, and cream production was successfully introduced, transforming a previously idle line into a profitable operation.

Generally, the optimization plans not only expanded product variety but also improved production frequency, operational reliability, and hygiene, while reducing manual handling that had previously limited throughput and shelf life. These interventions enable the plant to increase revenue potential, and achieve a more efficient, consistent, and sustainable dairy processing operation.

5.3.4. Breakage Return Comparison and Analysis

Product breakage, the volume of packed milk returned from market due to damage during processing, handling, or transportation, is an indicator of operational efficiency and product quality. In the existing scenario, annual breakage was relatively high, with about 3% of daily

production returned from the market. This was primarily due to aging packing machinery, worn components, the absence of preventive maintenance, and improper handling during packing, storage, and transport. High breakage not only reduced net sales but also negatively impacted customer satisfaction and product reliability.

In the optimized scenario, breakage was reduced to 1% of daily production through targeted interventions like servicing and replacement of worn machine components, implementation of preventive maintenance, operator training in proper handling, and improved utilities such as a consistent compressed air supply. As a result, packing operations became more reliable, production losses decreased, and marketable output increased.

The reduction in breakage shows direct link between machine reliability, operational efficiency, and market performance. By minimizing damage, the plant not only enhances customer trust and product quality but also ensures that resources raw milk, labor, and utilities are fully utilized, maximizing throughput and contributing to a more sustainable and profitable dairy operation.

In the existing scenario, high breakage returns are due to the fact that packing machines were old, spares were worn, preventive maintenance was absent, and handling was improper. Optimized scenario improvements serviced machines, fresh spare parts, Operator training, and proper handling procedures significantly reduce breakage, lowering losses and improving product reliability. This metric reflects both operational efficiency and product quality, linking machine reliability directly to market performance.

5.3.5. Spare Part Inventory Comparison and Analysis

Spare part inventory management plays a crucial role in determining the operational reliability, maintenance responsiveness, and overall production efficiency of a dairy processing plant. The comparison between the existing and optimized scenarios highlights how strategic improvements in spare part planning directly influence machine uptime, downtime reduction, and throughput stability.

In the existing scenario, spare part shortages were critical operational constraint. The plant relied on reactive maintenance, searching for spare parts only after failures occurred. This approach resulted in extended machine downtime, delayed repairs, and interruptions across

processing and packing activities. In addition, spare parts of some critical processing machines are specifically to be ordered and imported from the manufacturer of the machine and not found on local markets. Due to this, critical equipment such as pasteurizers, homogenizers, compressors, and packing machines frequently remained idle for days or weeks until spare parts are imported. Additionally, the absence of a structured inventory system meant that no records of stock levels, lead times, or consumption patterns were maintained, preventing proactive maintenance planning. These shortcomings contributed significantly to the high annual downtime values observed across all major machines.

The optimized scenario demonstrates a systematic and data-driven approach to spare part management. A dedicated spare part inventory system was introduced, covering critical components for utilities, processing equipment, and packing lines. Commonly failing parts such as gaskets, seals, bearings, valves, sensors, and electrical components were stocked in predefined quantities based on failure history and manufacturer recommendations. Lead times were reduced through framework agreements with suppliers, enabling faster replenishment and cost stability. Integration of preventive maintenance schedules with spare part planning ensured that parts required for planned servicing were always available before maintenance activities commenced.

This shift from reactive to proactive maintenance and spare part management contributed to the reduction in annual downtime and improvements in throughput. Machines that previously suffered frequent and long downtime due to part shortages now operated with consistent reliability. The availability of critical spare parts also enhanced maintenance activity, as technicians could complete repairs without delays. Due to this, equipment utilization increased, throughput increased and the plant achieved higher overall production efficiency.

Statistical comparisons showed strong correlations between reduced downtime and increased throughput in pasteurized milk, yoghurt, butter, cheese, cream, and local cheese production. The optimized spare part system showed that maintenance became predictable, timely, and synchronized with operating schedules. This supports continuous processing and reducing variability in production outcomes.

Spare part inventory improvements, in general, formed a foundational improvement of the optimized scenario. By eliminating the uncertainty and delays due to spare part shortages, the

plant was able to achieve better equipment reliability, minimize interruptions, and support the main goals of preventive maintenance, automation, and product line expansion. This optimization strategy enables long term resilience of plant operations and ensures sustained performance improvements beyond the simulation period

5.3.6. Resource Utilization Comparison and Analysis

Resource utilization across the milk processing plant was analyzed to evaluate the effectiveness of the optimized scenario in improving operational efficiency. Paired-T means comparisons for fifteen major machines and utilities shows statistically significant improvements at the 95% confidence level ($p < 0.05$). In the existing scenario, utilization rates were generally below 70%, reflecting inconsistent scheduling, limited utility capacity, and frequent equipment downtime. Critical utilities such as compressed air and chilling systems often operated beyond or below optimal limits, creating bottlenecks and production delays.

The optimized scenario implemented comprehensive process synchronization, preventive maintenance programs, and equipment upgrades including a high-capacity screw compressor, improved boiler and chiller units and structured production scheduling. As a result, most resources achieved utilization levels between 90–96%, indicating coordinated and efficient operation throughout the plant. Critical processing units such as pasteurizers, homogenizers, and cream separators achieved the largest gains. This confirms that balanced material flow and resource allocation directly increase throughput. Packaging equipment, including milk and yoghurt packers, cream cup packers, and vacuum cheese packers, also achieved over 90% utilization due to improved compressed air availability, automation, and better integration with upstream processes.

Utilities also showed significant improvements; with the Air compressor upgraded satisfy to compressed air need of multiple machines, eliminating prior bottlenecks. ESL pasteurizer utilization increased from 17% to 79% following scheduling and increased accepted milk allocated percentage for yoghurt production, while homogenizer and cream separator utilization rose from approximately 69% to over 94%, reflecting steady production flow and reduced idle times. Milk Packer 1 utilization increased from 80% to 92%, Yoghurt Packer from 17% to 95%, and the introduction of Milk Packer 2, automated cream cup packers, and

vacuum cheese packers enabled utilization percentages above 92%, effectively eliminating previous bottlenecks caused by manual handling or missing equipment.

These improvements demonstrate that the optimized scenario remarkably enhanced machine performance, production reliability, and overall plant efficiency. Process synchronization, equipment upgrades, utility stabilization, preventive maintenance and automation collectively transformed the system into a highly coordinated operation, ensuring continuous production, higher throughput, and better resource utilization across all product lines. Table 4.5 presents the statistical summary of selected Resource Utilization across replications, including mean values, standard deviations, and confidence intervals.

Table 5.11: Resource Utilization Comparison

Resource / Machine	Existing (%)	Optimized (%)	Improvement (%)	Key Point
Compressed Air System	>100	<100	–	Prevents air shortage, ensures smooth operation
HTST Pasteurizer	63	92	+29	Continuous milk flow improves utilization
ESL Pasteurizer	17	79	+62	Better synchronization, consistent ESL milk
Homogenizer	69	95	+26	Upstream coordination enhances efficiency
Cream Separator	69	94	+25	Stabilized cream separation performance
Milk Packer 1	80	92	+12	Improved packaging efficiency
Milk Packer 2	—	92.4	+92.4	Balanced workload, increased throughput
Yoghurt Packer	17	95	+78	Enhanced scheduling, air supply
Cream Cup Packer	—	93.9	+93.9	Reduced idle time, automated operations
Vacuum Cheese Packer	—	94.2	+94.2	Consistent packaging, reduced downtime
Boiler	67	93	+26	Steady steam supply
Chiller	58	91	+33	Reliable cooling for pasteurizers & storage
Air Compressor (Combined)	61	96	+35	Balanced air supply to all lines
Average Utilization	46	92	+46	Overall utilization significantly improved

5.3.7. Financial Comparison and Analysis

Financial Comparison and Analysis of Individual Products

The financial performance of the milk processing plant was evaluated by comparing revenues, profits and costs under the existing and optimized scenarios. In the existing scenario, revenue was lower due to limited product variety, low throughput, and high breakage, resulting in poor financial returns. Pasteurized milk generated approximately 270 million ETB annually, yoghurt 6.4 million ETB, butter 0.3 million ETB, cheese 0.8 million ETB, local cheese 0.72 million ETB, and cream production was negligible. The restricted capacity, frequent equipment downtime, and inefficiencies in packing and process coordination limited revenue potential across all product lines.

Revenue:-Following optimization, total annual revenue increased from 278.3 million ETB to 625.3 million ETB, a 59% overall gain. The improvements were driven by higher throughput, expanded product variety, and the refurbishment of previously idle lines such as cream, which contributed 1.89 million ETB. Pasteurized milk revenue more than doubled to 581.9 million ETB, yoghurt increased to 35.7 million ETB, butter rose to 2.83 million ETB, cheese reached 1.78 million ETB, and local cheese increased to 1.3 million ETB. Paired-T tests confirmed that these increases are statistically significant at the 0.05 level, highlighting that revenue gains were directly due to the optimization measures rather than random variation. Comparison of Revenue per each product is presented below in Table 4.6

Table 5.12: Annual Revenue Comparison for each Product between Existing and Optimized Scenarios

Product	Existing Revenue (ETB)	Optimized Revenue (ETB)	Difference (ETB)
Butter	30,8000	2,827,000	2,796,200
Cheese	808,000	1,778,000	970,000
Cream	0	1,885,500	1,885,500
Local Cheese	723,000	1,302,000	579,000
Milk	270.03 million	581.87 million	311.84 million
Yoghurt	6,418,100	35,664,200	29,246,100

The financial growth resulted from several factors like improved equipment reliability through preventive maintenance to reduce downtime across pasteurizers, homogenizers,

separators, and packing lines and improved utility stability. This enabled more consistent production and increased packing capacity due to additional milk packer and automated lines for cream and cheese, facilitated higher throughput. Improved process synchronization allowed all product lines to operate efficiently, while the introduction of new products expanded market coverage and generated additional revenue.

The study demonstrates that operational optimization through improved maintenance, automation, process coordination, and product line activation produces good financial benefits. DES enabled evaluation of economic impact of the applied strategies and guiding evidence-based decisions to enhance the profitability and efficiency of the dairy processing plant.

Profit:-The profitability of the milk processing plant was significantly enhanced under the optimized scenario compared to the existing system. In the existing scenario, profit margins were narrow and sometimes negative due to high downtime, equipment failures, limited product variety, and elevated breakage rates. Pasteurized milk generated approximately 71.9 million ETB, yoghurt 1.49 million ETB, butter 0.31 million ETB, cheese 0.8 million ETB, local cheese 0.46 million ETB, while cream production was negligible. Operational inefficiencies and limited throughput constrained financial performance across all product lines. Summary of Annual Profit per product is resented below in table 5.13

Table 5. 13: Comparison of Product Profits

Product	Existing Profit (ETB)	Optimized Profit (ETB)	Difference (ETB)
Butter	307,105.82	2,812,492.35	2,505,386.53
Cheese	800,460.35	1,757,980.99	957,520.64
Cream	0.00	1,808,843.95	1,808,843.95
Local Cheese	451,674.26	732,468.40	280,794.14
Milk	71,965,255	154,812,106	82,846,851
Yoghurt	1,490,974	8,285,068	6,794,094

After optimization, Pasteurized milk profit more than doubled to 154.8 million ETB, yoghurt profit increased over 318% to 8.28 million ETB, butter profit rose dramatically to 2.81 million ETB due to higher cream utilization, cheese and local cheese profits increased to 1.38 million ETB and 0.65 million ETB, respectively, and cream production, newly implemented, contributed 1.81 million ETB to profit. Paired-T analyses confirmed that all profit

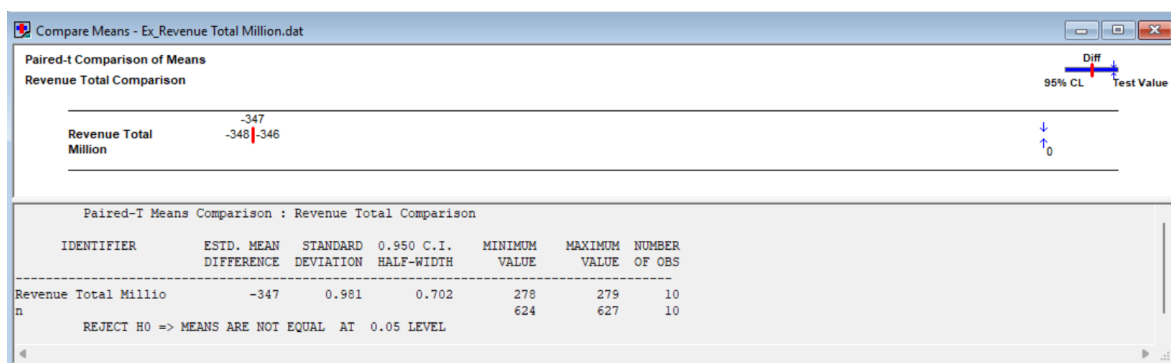
improvements were statistically significant at the 0.05 level, demonstrating that the gains were directly attributable to the optimization measures.

The improvements are due to multiple operational enhancements: preventive maintenance and refurbishment increased machine reliability and reduced downtime; process synchronization and improved scheduling. These ensured smoother production flow; automation in packing and cream handling and increased throughput and consistency. Activation of previously idle product lines, such as cream, created entirely new revenue addition. While total costs rose from 229.0 million ETB to 534.1 million ETB due to higher production volumes, maintenance, and spare parts, the corresponding revenue and throughput gains led to substantial net profit growth.

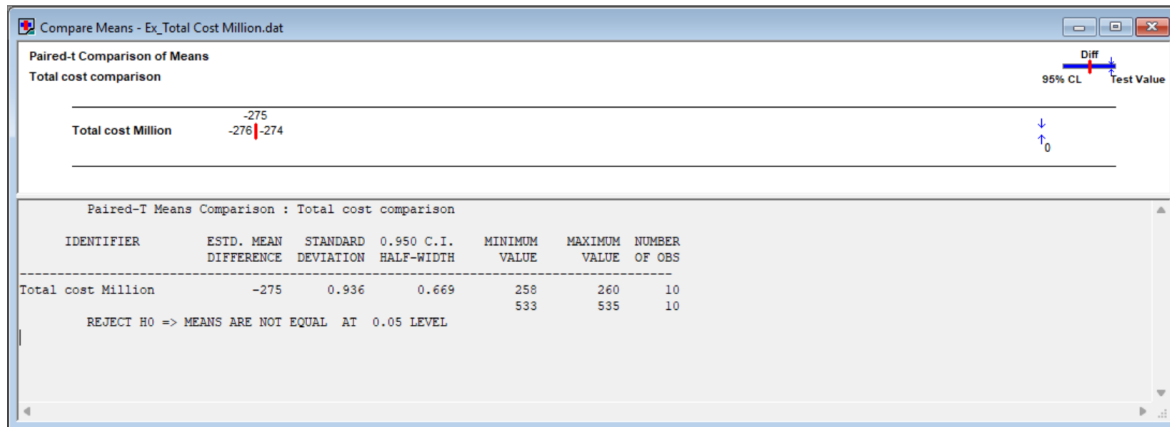
The study, in general, demonstrates that the optimization strategies not only enhanced operational efficiency and product throughput but also results in financial benefits, significantly improving the plant’s profitability and sustainability.

Total Financial Comparison

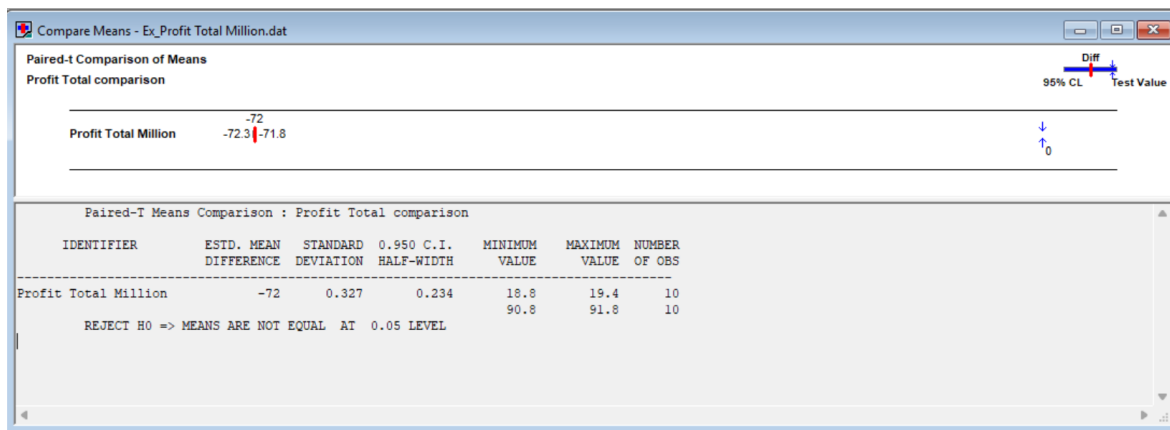
The effect of plant optimization on the total annual financial performance of the dairy plant under the study was evaluated using Arena simulation outputs and the Arena Output Analyzer. The analysis included revenue, costs, and profit, with paired-T tests confirming significant improvements in the optimized scenario. Histograms of Annual Financial Comparison from Arena Output Analyzer are presented below in Fig.5.4.



a)



b)



c)

Fig 5. 4 Histograms of Annual Revenue (a); Cost (b) and Profit(c) Comparison paired-t

Optimized scenario revenue exceeded that of existing scenario in all 10 replications. Estimated mean difference of the total revenues is about 374 million birr. This implies that higher revenue in optimized scenario is gained due to higher product throughput, addition of new production lines, improved machine availability, and introduction of partial automations. The narrow confidence interval and minimal variation across runs also ensure that revenue increase is consistent and statistically significant at 95% confidence level. In all replication, total revenue of the optimized scenario ranged from 624–627 million ETB, compared to 278–279 million ETB in the existing scenario, emphasizing the significance of the optimization benefits.

Total cost also increased significantly in the optimized scenario as seen in paired-t test comparison. This is due to increase in product throughputs, which highly adds production

costs like cost of raw material, cost of packing material and labor cost which are added in the model. Estimated mean difference is -275 million birr, where the negative sign shows that cost in optimized scenario is higher. Half width at 95% confidence interval is only 0.669 million birr which confirms stability and reliability of the simulation results.

Despite the increase in total cost, the optimized scenario had achieved **lower effective per-unit costs** due to improved equipment reliability, reduced downtime, minimized waste and product returns, and better resource utilization. The existing scenario, on the other hand, characterized by high costs compared to revenue and throughput as a result of frequent breakdowns, inefficiencies, and operational losses. These results show that the optimized scenario is better from **economies performance and process optimization**, achieving higher output and profitability while maintaining improved cost efficiency.

The paired-T means comparison shows that **total profit increased significantly in optimized scenario**. The estimated mean difference in total profit is **-72 million ETB**. Here, the negative sign of Estimated mean difference indicates that total annual profit in optimized scenario is higher than that of the existing system. The paired-T test rejects the null hypothesis of equal mean profits at the **5% significance level**. This also confirms that the improvement in profitability is statistically significant.

Profit results of the existing scenario ranged from 18.8 to 19.4 million ETB, while profit under the optimized scenario ranged from 90.8 to 91.8 million ETB. There is also small standard deviation (0.327) and narrow 95% confidence interval half-width (0.234 million ETB) which indicate high consistency across simulation replications and strong reliable results.

The Significant increase in profit confirms that the additional operational and maintenance costs added in the optimized scenario were compensated by higher revenue generated through increased throughput, expanded product lines, improved equipment reliability, and reduced operational losses. These results ensure the **financial effectiveness of the proposed optimization measures**. This illustrates the adoption of Optimized scenario for economic sustainability. A summary of the annual financial comparison is presented in **Table 5.14**.

Table 5. 14: Comparison – Financial Summary of the Plant

Metric	Existing Scenario (Million ETB)	Optimized Scenario (Million ETB)	Difference (Million ETB)
Total Revenue	278.29	625.33	+347.04
Total Cost	259.11	534.10	+274.99
Total Profit	19.18	91.23	+72.05

The comparison of financial outputs from Arena Category Overview between the existing and optimized scenarios emphasizes that there is significant improvement in the economic performance of Elemtu dairy processing plant. Total revenue increased by **347.04 million ETB (124.7%)**, mainly due to higher throughput, better utilization of processing equipment, and the introduction of additional product lines. This indicates that the optimized system effectively converts available capacity and raw milk into saleable products.

Total operating cost also increased by **274.99 million ETB (106.1%)**, which is expected due to higher production volumes, expanded operations, and additional maintenance activities. However, the proportional increase in cost is **lower than the increase in revenue**, indicating improved cost efficiency at higher production levels.

Total profit rose from **19.18 million ETB to 91.23 million ETB**. This indicates the profit increase of **72.05 million ETB (375.6%)**. This growth in profit confirms that the optimized scenario not only scales production but does so economically.

In general, the results confirm that the optimized scenario significantly enhances the plant's financial performance. DES model also successfully improves the economic benefits of operational improvements and proved to be an effective decision-support tool for evaluating process redesign, maintenance strategies, and capacity expansion in dairy processing plants.

5.4 Evaluation of Technical and Financial Improvements

The combined evaluation of Elemtu milk industry production efficiency parameters using Arena Output Analyzer confirms that the optimized scenario achieves statistically significant

improvements across all evaluated technical and financial key performance indicators. Implementation of preventive maintenance, improved spare-part availability, partial automation, and optimized production scheduling led to increases in product throughput, particularly for milk, yoghurt, cream, butter, and cheese, while simultaneously reducing breakage and product losses due to packing quality problems.

Operational reliability improved as utility-related interruptions, mainly compressed air delays and power outage downtime, were effectively eliminated. This resulted in uninterrupted operation of critical processing and packaging equipment. Reductions in machine downtime were observed for critical machines like air compressor, boiler, homogenizer, and packing machines. This directly improves equipment availability and maintains a stable production flow.

These technical improvements resulted in increase in machine utilization percentages, shifting the system from high underutilization in the existing scenario to highly increased utilization in the optimized scenario. This result indicates improved alignment between installed capacity, material flow, and operational control strategies.

From a financial point of view, the improved operational stability and increased throughput were reflected in significantly higher revenues and a near doubling of annual profit. The narrow mean value ranges observed in the simulation outputs confirms the reliability of the optimized scenario financial performance. In conclusion, the results demonstrate that simulation-driven decision-making provides a good basis for identifying system bottlenecks, evaluating improvement strategies, and recommending practical, evidence-based operational improvements for Elemtu Milk Industry.

CHAPTER SIX: RECOMMENDATIONS AND CONCLUSION

This chapter outlines practical and strategic recommendations based on the simulation results, and conclusions of the research. The discussion focuses on how discrete-event simulation was applied to evaluate and improve the operational performance of the 5000 L/h Elemtu Milk Processing Plant, with particular emphasis on bottlenecks, utility reliability, maintenance practices, and managerial decision making.

6.1 Recommendations

Based on the findings of the simulation analysis, several technical, strategic, and research-oriented recommendations are proposed to support performance improvement at the Elemtu Milk Processing Plant and similar dairy processing facilities.

6.2.1 Technical Recommendations

To improve operational reliability and efficiency, the following technical measures are recommended:

1. Shift from breakdown based maintenance to planned preventive maintenance schedules in order to reduce unplanned downtime and extend equipment life.
2. Establish a structured spare part inventory management system to minimize maintenance delays caused by part unavailability in stock.
3. Upgrade and regularly maintain utility systems to ensure uninterrupted production.
4. Strengthen training programs for operators and maintenance personnel to improve equipment handling and early fault detection.
5. Implement continuous data collection and periodically update the simulation model to support ongoing monitoring and optimization of plant performance.

6.1.2 Strategic Investment Recommendations

Simulation based financial analysis indicates that targeted investments in utilities, maintenance systems, and material handling can generate significant performance and economic benefits. Table 6.1 summarizes the recommended strategic investments and their expected impacts.

Table 6.1 Strategic Investment Recommendations

Investment Item	Estimated Cost (ETB)	Expected Benefit
New air compressor ($\geq 7,000$ L/s)	4,000,000	Eliminate compressed air shortages
Diesel generator (400 kVA)	24,800,000	Eliminate production losses due to power outages
Manual cream separator (sour milk)	100,000	Recover approximately 3.5% cream yield
Conveyor systems (3 units)	100,000	Reduce manual handling and delays
Refurbishment of old machines	5,000,000	Restore full production capability
Preventive maintenance program	3,000,000	Reduce unplanned downtime
Spare-part inventory establishment	8,000,000	Reduce maintenance waiting time
Other	5,000,000	—
Total Investment	50,000,000	Estimated payback < 2 years

The results indicate that these investments are economically justified, as improved operational stability leads to higher throughput, better product quality, and increased profitability.

6.1.3 Further Research Recommendations

Future studies may extend and deepen the findings of this research by:

1. Expanding the simulation model to include raw milk supply, transportation, and distribution logistics.
2. Developing a digital twin of the plant to support real time monitoring and operational decision-making.
3. Integrating predictive maintenance approaches using sensor data and condition-monitoring systems.

4. Optimizing product distribution and supply chain operations beyond the processing plant.
5. Incorporating environmental performance indicators such as energy consumption, water usage and emissions.
6. Conducting comparative simulation studies across multiple dairy processing plants in Ethiopia.

6.2 Conclusion

This study demonstrated the practical application of discrete-event simulation as a decision-making support tool for identifying operational problems and evaluating improvement strategies in a medium-scale dairy processing plant. By modeling the 5000 L/h Elemtu Milk Processing Plant in Arena 14, the research captured the interactions among processing equipment, utilities, maintenance activities, resource utilization and product mix ratios under realistic operating conditions.

The analysis improves that the plant's low throughput, frequent production interruptions, quality losses, and limited product variety were not the result of insufficient installed capacity, but rather of internal operational inefficiencies. Particularly, reliance on corrective maintenance, absence of critical spare part inventories, insufficient compressed air and power supply during power outages from national grid, capacity mismatches in packaging operations, and unbalanced allocation of milk among different dairy product types were identified as the main factors of high downtime, poor resource utilization, and weak financial results.

To address these problems, technical and managerial corrections were evaluated through optimized simulation scenarios. Introduction of **preventive maintenance (PM)** schedules and **inventory management for critical spare parts and spare-part kits**, directly reduced machine downtime and maintenance waiting time. This resulted in equipment availability improved, unplanned stoppages reduced and resource utilization became better across the production system.

Utility related production interruptions were eliminated by improving the reliability of compressed air and power supply. This stabilized continuous operations and reduced idle time in critical processing stages, particularly packaging. Capacity mismatches in milk

packing were corrected by **adding an additional milk packing machine**. This also eliminated bottlenecks at milk packing, reduced overtime work, and improved daily throughput.

Product quality and processing efficiency were also improved by **automating cheese-making and cheese packing operations**. Automation reduced manual handling, shortened processing time, improved hygiene conditions, extended product shelf life and reduced labor requirements. The refurbishment of **vacuum packing for cheese and local cheese products** also improved packaging quality and reduced product quality and demand increase.

In other ways process improvements also achieved by better utilization of raw materials. **Cream separation from sour milk** enabled recovery of cream that was previously underutilized, leading to higher cream and butter throughput and improved overall yield. Adjustments in **yogurt allocation percentage** increased yogurt throughput, allowing the plant to better increase volumes of higher value products without increasing total processing capacity.

Preventive maintenance applied specifically to packaging equipment reduced breakage returns. This is achieved by improving packing quality. In addition, increased and more stable **milk arrival volumes**, evaluated through the simulation model had a strong positive impact on throughput across all product lines and significantly improved overall profitability.

The results of the optimized scenarios clearly showed that these improvements collectively led to more stable production flows, higher equipment and labor utilization, increased throughput for individual products as well as the overall system, expanded product variety and improved financial gain. The important point here is that these gains were achieved without major capacity expansion, emphasizing the value of operational reliability and system balancing over capital intensive solutions.

From a managerial point of view, the findings confirm that investments in preventive maintenance, spare part inventory control, utility reliability, and partial automation at some processing stages resulted in significant economic returns even though there are increases in operating costs. The study highlights that poor maintenance practices and reactive management resulted in hidden losses that accumulate over time, while proactive operational planning significantly enhances sustainability and competitiveness.

To conclude, this research confirms that simulation based optimization provides a robust, data driven framework for improving productivity, quality, and profitability in dairy processing plants operating in developing countries. The approach enables managers to test corrective actions before implementation, reduce operational risk, and prioritize investments based on measurable performance impacts. The findings offer transferable insights for small and medium scale dairy and food processing industries in Ethiopia and similar developing countries seeking sustainable operational improvement.

REFERENCES

- 1) Abebe, M., & Worku, T. (2023). Process optimization of edible oil factories in Ethiopia using discrete-event simulation. *African Journal of Manufacturing and Production*, 11(2), 45–60.
- 2) Aregawi, T., & Melesse, B. (2022). Assessment of production inefficiencies in Ethiopian dairy processing industries. *Journal of Agribusiness and Rural Development*, 4(66), 45–57.
- 3) Banks, J., Carson, J. S., Nelson, B. L., & Nicol, D. M. (2010). *Discrete-event system simulation* (5th ed.). Pearson Education.
- 4) Barbosa-Cánovas, G. V., Tapia, M. S., & Cano, M. P. (2008). *Novel food processing technologies*. CRC Press.
- 5) Birhan, M., Mekuriaw, Y., Tassew, A., & Tegegne, F. (2023). Monitoring dairy farm management determinants in the Amhara region, Ethiopia. *Veterinary Medicine and Science*, 9, 1742–1756. <https://doi.org/10.1002/vms3.1140>
- 6) Bunte, F., van Galen, M., & Kuiper, M. (2011). Improving dairy chain performance through process optimization. *Journal of Dairy Science*, 94(12), 6011–6023. <https://doi.org/10.3168/jds.2011.4503>
- 7) Cavalieri, S., Gaiardelli, P., & Ierace, S. (2020). A simulation-based framework for evaluating maintenance and spare parts policies. *Journal of Manufacturing Systems*, 56, 150–164. <https://doi.org/10.1016/j.jmsy.2020.05.006>
- 8) FAO. (2017). *Maintenance systems for the dairy plant*. Food and Agriculture Organization of the United Nations.
- 9) FAO. (2019). *Dairy development in Ethiopia: Status, constraints, and opportunities*. Food and Agriculture Organization of the United Nations.
- 10) Feleke, S., et al. (2010). Milk marketing and post-harvest loss in Ethiopia. *Journal of Economics and Sustainable Development*.
- 11) Feyisa, B. W., Haji, J., & Mirzabaev, A. (2024). Adoption of milk safety practices: Evidence from dairy farmers in Ethiopia. *Agriculture & Food Security*, 13, 25. <https://doi.org/10.1186/s40066-024-00479-z>
- 12) Frontiers in Animal Science. (2025). precision of dairy farming: Opportunities and challenges for sustainable dairy production in Africa. *Frontiers in Animal Science*. <https://doi.org/10.3389/fanim.2025.1541838>

- 13) Gebremariam, S., & Alemu, D. (2021). Maintenance practices and operational performance of food processing industries in Ethiopia. *Journal of Engineering and Technology Research*, 13(2), 27–36.
- 14) Getabalew, Y., et al. (2021). Integrating dairy value chain perspectives in Ethiopia. *Tropical Animal Health and Production*. <https://doi.org/10.1007/s11250-021-02695-2>
- 15) Haile, M., & Tadesse, F. (2020). Operational efficiency and constraints of medium-scale dairy processing plants in Ethiopia. *Ethiopian Journal of Agricultural Sciences*, 30(2), 89–103.
- 16) Heliyon. (2023). Analysis of collaborative control of dairy supply chain quality: Evolutionary games. *Heliyon*, 9(12), e23024. <https://doi.org/10.1016/j.heliyon.2023.e23024>
- 17) Huijps, K., et al. (2017). Stochastic bio-economic modeling of mastitis in Ethiopian dairy farms. *Livestock Science*.
- 18) ILRI. (2021). *Dairy value chain and productivity in Ethiopia*. International Livestock Research Institute.
- 19) ILRI & Ministry of Livestock. (2017). *Dairy development in Tanzania and quality control strategies*.
- 20) Innocenti, M., Denis, S., & Hirst, L. (2023). Managing stressed employees at milk and dairy suppliers in East Africa. *East African Journal of Business and Economics*, 6(1), 1–10. <https://doi.org/10.37284/eajbe.6.1.1052>
- 21) Jain, S., & Leong, S. (2005). Modeling and analysis of food processing systems using discrete-event simulation. *International Journal of Simulation and Process Modelling*, 1(3), 129–138.
- 22) Ketere, S. K., & Osoro, A. (2023). Supply chain optimization and performance of dairy processing farms in Kiambu County, Kenya. *International Journal of Social Sciences Management and Entrepreneurship*, 7(2), 140–151.
- 23) Kilima, F. T. M., Msalya, G. M., & Omore, A. (2024). Enhancing capacity to comply with sustainability standards in the milk value chain in East Africa. *Sustainability*, 16(18), 8100. <https://doi.org/10.3390/su16188100>
- 24) Kimaro, E. M., Kisawike, B., & Ruoja, C. (2021). Lean supply chain strategy and performance of dairy industry in Iringa Region, Tanzania. *Journal of Procurement & Supply Chain*, 5(2), 21–31.

- 25) Kinyua, R., Mwangi, M., & Kamau, J. (2021). Application of discrete-event simulation in food packaging industries in Kenya. *International Journal of Industrial Engineering*, 28(4), 512–525.
- 26) Kivaisi, A. K., Rubindamayugi, M. S. T., & Mdegela, R. H. (2020). Hygiene and cold chain challenges in dairy processing in East Africa. *African Journal of Food Science*, 14(9), 252–260.
- 27) Kumar, R., Singh, S. P., & Shankar, R. (2021). Simulation-based analysis of dairy supply chain operations. *Journal of Cleaner Production*, 279, 123789. <https://doi.org/10.1016/j.jclepro.2020.123789>
- 28) Law, A. M., & Kelton, W. D. (2015). *Simulation modeling and analysis* (5th ed.). McGraw-Hill Education.
- 29) Lee, J., Bagheri, B., & Kao, H. A. (2017). A cyber-physical systems architecture for Industry 4.0-based manufacturing systems. *Manufacturing Letters*, 3, 18–23.
- 30) Maina, C., Njehia, B. K., & Eric, B. K. (2024). Enhancing organisational performance in the dairy industry: A supply chain management approach. *International Journal of Agriculture*. <https://doi.org/10.47604/ija.1080>
- 31) Materials Today: Proceedings. (2023). Reliability analysis of repairable and replaceable systems: Dairy product industry. *Materials Today: Proceedings*, 77(3), 573–578. <https://doi.org/10.1016/j.matpr.2022.10.074>
- 32) Mobley, R. K. (2002). *An introduction to predictive maintenance*. Butterworth-Heinemann.
- 33) Mugisha, J., Kikulwe, E., & Ochieng, J. (2022). Challenges and performance of dairy processing enterprises in Uganda. *Development in Practice*, 32(6), 812–824.
- 34) Negash, T., & Alemayehu, G. (2022). Spare parts management and maintenance performance in Ethiopian manufacturing firms. *International Journal of Industrial Engineering Research*, 5(1), 41–53.
- 35) Nyokabi, N. S., et al. (2024). Exploring adoption of food safety measures in smallholder dairy systems in Ethiopia. *Food Security*, 16, 423–435. <https://doi.org/10.1007/s12571-024-01439-y>
- 36) Oyango, D., Okello, J. J., & Njuki, J. (2021). Determinants of productivity in medium-scale dairy processing firms in Kenya. *African Journal of Agricultural and Resource Economics*, 16(1), 45–60.
- 37) Rossetti, M. D. (2016). *Simulation modeling and Arena* (2nd ed.). Wiley.

- 38) Sahoo, S., Singh, R., & Shankar, R. (2018). Simulation-based performance evaluation of food processing systems. *Journal of Manufacturing Systems*, 48, 72–84.
- 39) Seifu, E., & Doluschitz, R. (2014). Analysis of the dairy value chain: Challenges and opportunities for dairy development in Dire Dawa, Ethiopia. *International Journal of Agricultural Policy and Research*.
- 40) Silva, C. L. M., Gibbs, P. A., & Vieira, M. C. (2018). Simulation tools for improving food processing efficiency. *Food Control*, 90, 144–152.
- 41) Tamime, A. Y. (2018). *Dairy processing and quality assurance*. Wiley Blackwell.
- 42) Tegegne, A., Gebremedhin, B., Hoekstra, D., & Belay, B. (2021). Smallholder dairy production systems in Ethiopia: Constraints and opportunities. *African Journal of Agricultural Research*, 16(4), 512–523.
- 43) Van der Vorst, J. G. A. J., Tromp, S. O., & van der Zee, D. J. (2009). Simulation modelling for food supply chain redesign. *International Journal of Production Economics*, 122(1), 71–87. <https://doi.org/10.1016/j.ijpe.2009.05.020>
- 44) Wolkaro, T., Frew, M., & Galmessa, U. (2024). Physicochemical and microbiological evaluation of yoghurt in Addis Ababa. *Dairy Science & Management*, 1, 1–10. <https://doi.org/10.1186/s44363-024-00001-7>
- 45) Yassin, S., et al. (2023). Cow milk production, consumption, marketing, and food safety constraints in Ethiopia: A systematic review. *Animal Frontiers*, 15(5), 20–28.

APPENDIX

APPENDIX-I Variables Used For Modeling

Variable - Basic Process								
	Name	Rows	Columns	Data Type	Clear Option	File Name	Initial Values	Report Statistics
1	MachineStatus			String	System		0 rows	<input type="checkbox"/>
2	v_Homog_LastType			Real	System		0 rows	<input type="checkbox"/>
3	v_Separator_LastType			Real	System		0 rows	<input type="checkbox"/>
4	tFailureStart			Real	System		0 rows	<input type="checkbox"/>
5	vSpareWaitTime			Real	System		0 rows	<input type="checkbox"/>
6	vRepairTime			Real	System		0 rows	<input type="checkbox"/>
7	vMachine_Failed			Real	System		0 rows	<input type="checkbox"/>
8	vDownTime			Real	System		0 rows	<input type="checkbox"/>
9	vPowerDown			Real	System		0 rows	<input type="checkbox"/>
10	pUnitAir			Real	System		1 rows	<input type="checkbox"/>
11	pAC1_Units_Per_Minute			Real	System		1 rows	<input type="checkbox"/>
12	pAC2_Units_PerMinute			Real	System		1 rows	<input type="checkbox"/>
13	bAC1_Up			Real	System		1 rows	<input type="checkbox"/>
14	bAC2_Up			Real	System		1 rows	<input type="checkbox"/>
15	vCA_Capacity_Per_minute			Real	System		1 rows	<input type="checkbox"/>
16	vChillerCap			Real	System		1 rows	<input type="checkbox"/>
17	vWaterCap			Real	System		1 rows	<input type="checkbox"/>
18	vSteamCap			Real	System		1 rows	<input type="checkbox"/>
19	pStandardBatch			Real	System		1 rows	<input type="checkbox"/>
20	pMilkBatch_L			Real	System		1 rows	<input type="checkbox"/>
21	pMilkPackBatch_L			Real	System		1 rows	<input type="checkbox"/>
22	pButterPackBatch_Kg			Real	System		1 rows	<input type="checkbox"/>
23	pCheesePackBatch_Kg			Real	System		1 rows	<input type="checkbox"/>
24	pLocCheesePackBatch_Kg			Real	System		1 rows	<input type="checkbox"/>
25	pYoghurtPackBatch_L			Real	System		1 rows	<input type="checkbox"/>
26	tHTSTPasteurizerPer100L			Real	System		1 rows	<input type="checkbox"/>

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Variable - Basic Process								
	Name	Rows	Columns	Data Type	Clear Option	File Name	Initial Values	Report Statistics
27	tESLPasteurizerPer100L			Real	System		1 rows	<input type="checkbox"/>
28	tHomogenizationPer100L			Real	System		1 rows	<input type="checkbox"/>
29	tCreamSeparationPer100L			Real	System		1 rows	<input type="checkbox"/>
30	tCreamBoilPer100kg			Real	System		1 rows	<input type="checkbox"/>
31	tButterChurnPer100Kg			Real	System		1 rows	<input type="checkbox"/>
32	tCheeseBoilPer100Kg			Real	System		1 rows	<input type="checkbox"/>
33	tMilkPackPer100L			Real	System		1 rows	<input type="checkbox"/>
34	tButterPackper100Kg			Real	System		1 rows	<input type="checkbox"/>
35	tCheesePackPer100Kg			Real	System		1 rows	<input type="checkbox"/>
36	tLocalCheesePackPer100Kg			Real	System		1 rows	<input type="checkbox"/>
37	tMilkCratePer100Kg			Real	System		1 rows	<input type="checkbox"/>
38	tButterCratePer100Kg			Real	System		1 rows	<input type="checkbox"/>
39	tCheeseCratePer100Kg			Real	System		1 rows	<input type="checkbox"/>
40	tLocalCheeseCratePer100Kg			Real	System		1 rows	<input type="checkbox"/>
41	tTransferToColdroom			Real	System		1 rows	<input type="checkbox"/>
42	tMilkStayInColdroom			Real	System		1 rows	<input type="checkbox"/>
43	tYoghurtStayInColdroom			Real	System		1 rows	<input type="checkbox"/>
44	tButterStayInColdroom			Real	System		1 rows	<input type="checkbox"/>
45	tCheeseStayInColdroom			Real	System		1 rows	<input type="checkbox"/>
46	tLocalCheesestayInColdroom			Real	System		1 rows	<input type="checkbox"/>
47	tLocalCheeseFiltration			Real	System		1 rows	<input type="checkbox"/>
48	tLocalCheeseCooling			Real	System		1 rows	<input type="checkbox"/>
49	tYoghurtIncubation			Real	System		1 rows	<input type="checkbox"/>
50	tYoghurtCulturing			Real	System		1 rows	<input type="checkbox"/>
51	tCreamCollectionPer100L			Real	System		1 rows	<input type="checkbox"/>
52	tBreakageCollectionPer100L			Real	System		1 rows	<input type="checkbox"/>

Variable - Basic Process								
	Name	Rows	Columns	Data Type	Clear Option	File Name	Initial Values	Report Statistics
53	tCheeseMoldingPer100Kg			Real	System		1 rows	<input type="checkbox"/>
54	tMilkInColStorageTank			Real	System		1 rows	<input type="checkbox"/>
55	tAddToDumpTankPer100l			Real	System		1 rows	<input type="checkbox"/>
56	tQualityTest			Real	System		1 rows	<input type="checkbox"/>
57	tMilkPumpingPer100L			Real	System		1 rows	<input type="checkbox"/>
58	CompressedAir.Capacity			Real	System		0 rows	<input type="checkbox"/>
59	ResourceStateMilkPackerUp			Real	System		1 rows	<input type="checkbox"/>
60	pAC1_nom_lps			Real	System		1 rows	<input type="checkbox"/>
61	pAC2_nom_lps			Real	System		1 rows	<input type="checkbox"/>
62	pBoilerSteamCap			Real	System		1 rows	<input type="checkbox"/>
63	pChillerCap			Real	System		1 rows	<input type="checkbox"/>
64	pBoreholeWaterCap			Real	System		1 rows	<input type="checkbox"/>
65	pDerate1			Real	System		1 rows	<input type="checkbox"/>
66	pDerate2			Real	System		1 rows	<input type="checkbox"/>
67	pReceptionPump_airneed_lps			Real	System		1 rows	<input type="checkbox"/>
68	pHTST_airneed_lps			Real	System		1 rows	<input type="checkbox"/>
69	pESL_airneed_lps			Real	System		1 rows	<input type="checkbox"/>
70	pHomogenizer_airneed_lps			Real	System		1 rows	<input type="checkbox"/>
71	pMilkPacker1_airneed_lps			Real	System		1 rows	<input type="checkbox"/>
72	pCheeseVaT_airneed_lps			Real	System		1 rows	<input type="checkbox"/>
73	pYoghurtPacker_airneed_lps			Real	System		1 rows	<input type="checkbox"/>
74	vCA_AirCompressor1			Real	System		0 rows	<input type="checkbox"/>
75	vCA_AirCompressor2			Real	System		0 rows	<input type="checkbox"/>
76	pCream_Per100LMilk			Real	System		1 rows	<input type="checkbox"/>
77	pButter_Per100LMilk			Real	System		1 rows	<input type="checkbox"/>
78	pCheese_Per100LMilk			Real	System		1 rows	<input type="checkbox"/>

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Variable - Basic Process								
	Name	Rows	Columns	Data Type	Clear Option	File Name	Initial Values	Report Statistics
79	pLocalCheese_Per100LButterMilk			Real	System		1 rows	<input type="checkbox"/>
80	pButter_Per100LCream			Real	System		1 rows	<input type="checkbox"/>
81	pLocalCheese_Per100LBreakage			Real	System		1 rows	<input type="checkbox"/>
82	pCheese_Per100LSourMilk			Real	System		1 rows	<input type="checkbox"/>
83	pButterMilk_Per100LCream			Real	System		1 rows	<input type="checkbox"/>
84	pCreamFrac_Milk			Real	System		1 rows	<input type="checkbox"/>
85	pButterFrac_FromCream			Real	System		1 rows	<input type="checkbox"/>
86	pBreakage_Frac			Real	System		1 rows	<input type="checkbox"/>
87	PackedMilk_Batches			Real	System		0 rows	<input type="checkbox"/>
88	PackedYoghurt_Batches			Real	System		0 rows	<input type="checkbox"/>
89	PackedButter_Batches			Real	System		0 rows	<input type="checkbox"/>
90	PackedCheese_Batches			Real	System		0 rows	<input type="checkbox"/>
91	PackedLocalCheese_Batches			Real	System		0 rows	<input type="checkbox"/>
92	Revenue_Milk			Real	System		0 rows	<input type="checkbox"/>
93	Revenue_Yoghurt			Real	System		0 rows	<input type="checkbox"/>
94	Revenue_Cream			Real	System		0 rows	<input type="checkbox"/>
95	Revenue_Butter			Real	System		0 rows	<input type="checkbox"/>
96	Revenue_Cheese			Real	System		0 rows	<input type="checkbox"/>
97	Revenue_LocalCheese			Real	System		0 rows	<input type="checkbox"/>
98	Revenue_Total			Real	System		0 rows	<input type="checkbox"/>
99	Profit_Milk			Real	System		0 rows	<input type="checkbox"/>
100	Profit_Yoghurt			Real	System		0 rows	<input type="checkbox"/>
101	Profit_Cream			Real	System		0 rows	<input type="checkbox"/>
102	Profit_Butter			Real	System		0 rows	<input type="checkbox"/>
103	Profit_Cheese			Real	System		0 rows	<input type="checkbox"/>
104	Profit_LocalCheese			Real	System		0 rows	<input type="checkbox"/>

Variable - Basic Process								
	Name	Rows	Columns	Data Type	Clear Option	File Name	Initial Values	Report Statistics
105	Profit_Total			Real	System		0 rows	<input type="checkbox"/>
106	Price_RawMilk_perBatch			Real	System		1 rows	<input type="checkbox"/>
107	PackedCream_Batches			Real	System		0 rows	<input type="checkbox"/>
108	PackCost_Butter_perBatch			Real	System		1 rows	<input type="checkbox"/>
109	PackCost_Cheese_perBatch			Real	System		1 rows	<input type="checkbox"/>
110	PackCost_LocalCheese_perBatch			Real	System		1 rows	<input type="checkbox"/>
111	LaborCost_Yoghurt_perBatch			Real	System		1 rows	<input type="checkbox"/>
112	LaborCost_Butter_perBatch			Real	System		1 rows	<input type="checkbox"/>
113	LaborCost_Cheese_perBatch			Real	System		1 rows	<input type="checkbox"/>
114	LaborCost_LocalCheese_perBatc			Real	System		1 rows	<input type="checkbox"/>
115	Daily_PackedBatches_Total			Real	System		0 rows	<input type="checkbox"/>
116	TransportCost_perBatch			Real	System		0 rows	<input type="checkbox"/>
117	Driver_Hourly_Wage			Real	System		0 rows	<input type="checkbox"/>
118	Fuel_L_Per_trip			Real	System		0 rows	<input type="checkbox"/>
119	Distance_Per_Trip_km			Real	System		1 rows	<input type="checkbox"/>
120	Daily_TransportCost_Fuel			Real	System		0 rows	<input type="checkbox"/>
121	Fuel_Price_Per_L			Real	System		1 rows	<input type="checkbox"/>
122	Trips_Per_Truck			Real	System		1 rows	<input type="checkbox"/>
123	Cost_YoghurtAdditive			Real	System		0 rows	<input type="checkbox"/>
124	Salesperson_WorkingHoursPerDa			Real	System		1 rows	<input type="checkbox"/>
125	SalesPerson_WorkingdaysPerMon			Real	System		1 rows	<input type="checkbox"/>
126	SalesPerson_Hourly_Wage			Real	System		0 rows	<input type="checkbox"/>
127	Daily_TransportCost_SalesPerson			Real	System		0 rows	<input type="checkbox"/>
128	Price_SourMilk_perBatch			Real	System		1 rows	<input type="checkbox"/>
129	Price_YoghurtCulture_perBatch			Real	System		1 rows	<input type="checkbox"/>
130	SalesPrice_LocalCheese_PerBatc			Real	System		1 rows	<input type="checkbox"/>

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Variable - Basic Process								
	Name	Rows	Columns	Data Type	Clear Option	File Name	Initial Values	Report Statistics
131	SalesPrice_Cheese_PerBatch			Real	System		1 rows	<input type="checkbox"/>
132	SalesPrice_Butter_PerBatch			Real	System		1 rows	<input type="checkbox"/>
133	SalesPrice_Yoghurt_PerBatch			Real	System		1 rows	<input type="checkbox"/>
134	Distance_perTrip_km			Real	System		1 rows	<input type="checkbox"/>
135	FuelConsumption_L_perTrip			Real	System		1 rows	<input type="checkbox"/>
136	SalesPerson_Monthly_Salary			Real	System		1 rows	<input type="checkbox"/>
137	Driver_WorkingDaysPerMonth			Real	System		1 rows	<input type="checkbox"/>
138	Driver_WorkingHoursPerDay			Real	System		1 rows	<input type="checkbox"/>
139	Trip_Duration_hours			Real	System		1 rows	<input type="checkbox"/>
140	Num_Trucks_Company			Real	System		1 rows	<input type="checkbox"/>
141	Company_Truck_Capacity_Batch			Real	System		1 rows	<input type="checkbox"/>
142	Driver_Monthly_Salary			Real	System		1 rows	<input type="checkbox"/>
143	Agent_Truck_Capacity_Batch			Real	System		1 rows	<input type="checkbox"/>
144	Num_Trucks_Agent			Real	System		1 rows	<input type="checkbox"/>
145	ReplicationLength			Real	System		1 rows	<input type="checkbox"/>
146	DailyTrips_Company			Real	System		1 rows	<input type="checkbox"/>
147	DailyTrips_Agent			Real	System		1 rows	<input type="checkbox"/>
148	FuelCost_perTrip			Real	System		0 rows	<input type="checkbox"/>
149	Daily_TransportCost_Total			Real	System		0 rows	<input type="checkbox"/>
150	SalesPrice_Milk_PerBatch_Compa			Real	System		1 rows	<input type="checkbox"/>
151	SalesPrice_Milk_PerBatch_Agent			Real	System		1 rows	<input type="checkbox"/>
152	Num_Trips_Day			Real	System		1 rows	<input type="checkbox"/>
153	Cost_Transport			Real	System		0 rows	<input type="checkbox"/>
154	Cost_Packaging			Real	System		0 rows	<input type="checkbox"/>
155	Cost_Maintenance			Real	System		0 rows	<input type="checkbox"/>
156	Total_Cost			Real	System		0 rows	<input type="checkbox"/>

Variable - Basic Process								
	Name	Rows	Columns	Data Type	Clear Option	File Name	Initial Values	Report Statistics
157	MaintenancCost_perDay			Real	System		1 rows	<input type="checkbox"/>
158	TotalBreakage_L			Real	System		0 rows	<input type="checkbox"/>
159	Count_BreakageMilk			Real	System		0 rows	<input type="checkbox"/>
160	BreakagePercent			Real	System		1 rows	<input type="checkbox"/>
161	Revenue_Total_Million			Real	System		0 rows	<input type="checkbox"/>
162	Total_Cost_Million			Real	System		0 rows	<input type="checkbox"/>
163	Profit_Total_Million			Real	System		0 rows	<input type="checkbox"/>
164	DriverCost_perTrip			Real	System		0 rows	<input type="checkbox"/>
165	SalesPersonCost_perTrip			Real	System		0 rows	<input type="checkbox"/>
166	TransportCost_perTrip			Real	System		0 rows	<input type="checkbox"/>
167	OtherEmployees_Salary_Annual			Real	System		1 rows	<input type="checkbox"/>
168	Emergency_MaintenanceCost_An			Real	System		1 rows	<input type="checkbox"/>
169	Min_MechanicalCheeseVat_Capac			Real	System		1 rows	<input type="checkbox"/>
170	SalesPrice_Cream_PerBatch			Real	System		1 rows	<input type="checkbox"/>
171	Raw_Cost_Milk			Real	System		0 rows	<input type="checkbox"/>
172	Pack_Cost_Milk			Real	System		0 rows	<input type="checkbox"/>
173	Labor_Cost_Milk			Real	System		0 rows	<input type="checkbox"/>
174	Batch_Cost_Milk			Real	System		0 rows	<input type="checkbox"/>
175	Raw_Cost_Yoghurt			Real	System		0 rows	<input type="checkbox"/>
176	Pack_Cost_Yoghurr			Real	System		0 rows	<input type="checkbox"/>
177	Labor_Cost_Yoghurt			Real	System		0 rows	<input type="checkbox"/>
178	Batch_Cost_Yoghurt			Real	System		0 rows	<input type="checkbox"/>
179	Raw_Cost_Cheese			Real	System		0 rows	<input type="checkbox"/>
180	Pack_Cost_Cheese			Real	System		0 rows	<input type="checkbox"/>
181	Labor_Cost_Cheese			Real	System		0 rows	<input type="checkbox"/>
182	Batch_Cost_Cheese			Real	System		0 rows	<input type="checkbox"/>

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Variable - Basic Process								
	Name	Rows	Columns	Data Type	Clear Option	File Name	Initial Values	Report Statistics
183	Raw_Cost_Butter			Real	System		0 rows	<input type="checkbox"/>
184	Pack_Cost_Butter			Real	System		0 rows	<input type="checkbox"/>
185	Labor_Cost_Butter			Real	System		0 rows	<input type="checkbox"/>
186	Batch_Cost_Butter			Real	System		0 rows	<input type="checkbox"/>
187	Pack_Cost_LocalCheese			Real	System		0 rows	<input type="checkbox"/>
188	Labor_Cost_LocalCheese			Real	System		0 rows	<input type="checkbox"/>
189	Batch_Cost_LocalCheese			Real	System		0 rows	<input type="checkbox"/>
190	Revenue_Milk_Million			Real	System		0 rows	<input type="checkbox"/>
191	PackCost_Milk_perBatch			Real	System		1 rows	<input type="checkbox"/>
192	LaborCost_MilkperBatch			Real	System		1 rows	<input type="checkbox"/>
193	PackCost_Yoghurt_perBatch			Real	System		1 rows	<input type="checkbox"/>
194	Raw_Cost_LocalCheese			Real	System		0 rows	<input type="checkbox"/>
195	Depriciation Annual			Real	System		1 rows	<input type="checkbox"/>
196	Cost_OtherAnnual			Real	System		1 rows	<input type="checkbox"/>
197	Cost_SpareAnnual			Real	System		1 rows	<input type="checkbox"/>
198	Cost_Depreciation			Real	System		0 rows	<input type="checkbox"/>
199	Cost_OtherEmployees			Real	System		0 rows	<input type="checkbox"/>
200	Cost_Emergency			Real	System		0 rows	<input type="checkbox"/>
201	Cost_Other			Real	System		0 rows	<input type="checkbox"/>
202	Cost_Spare			Real	System		0 rows	<input type="checkbox"/>
203	SalesCost_perTrip			Real	System		0 rows	<input type="checkbox"/>
204	FuelCost_per_trip			Real	System		0 rows	<input type="checkbox"/>
205	DT_Homogenizer			Real	System		0 rows	<input type="checkbox"/>
206	DT_Cream Separator			Real	System		0 rows	<input type="checkbox"/>
207	DT_HTSTPasteurizer			Real	System		0 rows	<input type="checkbox"/>
208	DT_ESLPasteurizer			Real	System		0 rows	<input type="checkbox"/>

Variable - Basic Process								
	Name	Rows	Columns	Data Type	Clear Option	File Name	Initial Values	Report Statistics
209	DT_MilkPacking1			Real	System		0 rows	<input type="checkbox"/>
210	DT_YoghurtPacker			Real	System		0 rows	<input type="checkbox"/>
211	DT_AirCompressor1			Real	System		0 rows	<input type="checkbox"/>
212	DT_AirCompressor2			Real	System		0 rows	<input type="checkbox"/>
213	DT_Boiler			Real	System		0 rows	<input type="checkbox"/>
214	DT_Chiller			Real	System		0 rows	<input type="checkbox"/>
215	DT_BoreholePump			Real	System		0 rows	<input type="checkbox"/>
216	DT_PowerOutage_Total			Real	System		0 rows	<input type="checkbox"/>
217	N_PowerOutages			Real	System		0 rows	<input type="checkbox"/>
218	v_PowerOutage_Interval			Real	System		1 rows	<input type="checkbox"/>
219	v_PowerOutage_Duration			Real	System		1 rows	<input type="checkbox"/>
220	N_Homogenizer_Failure			Real	System		0 rows	<input type="checkbox"/>
221	v_Homogenizer_Uptime			Real	System		1 rows	<input type="checkbox"/>
222	v_Homogenizer_Sparewait			Real	System		1 rows	<input type="checkbox"/>
223	v_Homogenizer_Repair			Real	System		1 rows	<input type="checkbox"/>
224	N_CreamSeparator_Failure			Real	System		0 rows	<input type="checkbox"/>
225	v_CreamSeparator_Uptime			Real	System		1 rows	<input type="checkbox"/>
226	v_CreamSeparator_SpareWait			Real	System		1 rows	<input type="checkbox"/>
227	v_CreamSeparator_Repair			Real	System		1 rows	<input type="checkbox"/>
228	N_MilkPacking1_Failure			Real	System		0 rows	<input type="checkbox"/>
229	v_MilkPacking1_Uptime			Real	System		1 rows	<input type="checkbox"/>
230	v_MilkPacking1_SpareWait			Real	System		1 rows	<input type="checkbox"/>
231	v_MilkPacking1_Repair			Real	System		1 rows	<input type="checkbox"/>
232	N_YoghurtPacker_Failure			Real	System		0 rows	<input type="checkbox"/>
233	v_YoghurtPacker_Uptime			Real	System		1 rows	<input type="checkbox"/>
234	v_YoghurtPacker_SpareWait			Real	System		1 rows	<input type="checkbox"/>

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Variable - Basic Process								
	Name	Rows	Columns	Data Type	Clear Option	File Name	Initial Values	Report Statistics
235	v_YoghurtPacker_Repair			Real	System		1 rows	<input type="checkbox"/>
236	N_Boiler_Failure			Real	System		0 rows	<input type="checkbox"/>
237	v_Boiler_Uptime			Real	System		1 rows	<input type="checkbox"/>
238	v_Boiler_SpareWait			Real	System		1 rows	<input type="checkbox"/>
239	v_Boiler_Repair			Real	System		1 rows	<input type="checkbox"/>
240	N_Chiller_Failure			Real	System		0 rows	<input type="checkbox"/>
241	v_Chiller_Uptime			Real	System		1 rows	<input type="checkbox"/>
242	v_Chiller_SpareWait			Real	System		1 rows	<input type="checkbox"/>
243	v_Chiller_Repair			Real	System		1 rows	<input type="checkbox"/>
244	N_BoreHolePump_Failure			Real	System		0 rows	<input type="checkbox"/>
245	v_BoreHolePump_Uptime			Real	System		1 rows	<input type="checkbox"/>
246	v_BoreHolePump_SpareWait			Real	System		1 rows	<input type="checkbox"/>
247	v_BoreHolePump_Repair			Real	System		1 rows	<input type="checkbox"/>
248	N_AirCompressor1_Failure			Real	System		0 rows	<input type="checkbox"/>
249	v_AirCompressor1_Uptime			Real	System		1 rows	<input type="checkbox"/>
250	v_AirCompressor1_SpareWait			Real	System		1 rows	<input type="checkbox"/>
251	v_AirCompressor1_Repair			Real	System		1 rows	<input type="checkbox"/>
252	N_AirCompressor2_Failure			Real	System		0 rows	<input type="checkbox"/>
253	N_HTST_Failure			Real	System		0 rows	<input type="checkbox"/>
254	v_HTST_Uptime			Real	System		1 rows	<input type="checkbox"/>
255	v_HTST_SpareWait			Real	System		1 rows	<input type="checkbox"/>
256	v_HTST_Repair			Real	System		1 rows	<input type="checkbox"/>
257	N_ESL_Failure			Real	System		0 rows	<input type="checkbox"/>
258	DT_PowerOutage_Percent			Real	System		0 rows	<input type="checkbox"/>
259	DT_BoreHolePump_Percent			Real	System		0 rows	<input type="checkbox"/>
260	DT_HTST_Percent			Real	System		0 rows	<input type="checkbox"/>

Variable - Basic Process								
	Name	Rows	Columns	Data Type	Clear Option	File Name	Initial Values	Report Statistics
261	DT_ESL_Percent			Real	System		0 rows	<input type="checkbox"/>
262	DT_MilkPacking1_Percent			Real	System		0 rows	<input type="checkbox"/>
263	DT_YoghurtPacker_Percent			Real	System		0 rows	<input type="checkbox"/>
264	DT_Homogenizer_Percent			Real	System		0 rows	<input type="checkbox"/>
265	DT_CreamSeparator_Percent			Real	System		0 rows	<input type="checkbox"/>
266	DT_AirCompressor1_Percent			Real	System		0 rows	<input type="checkbox"/>
267	DT_Boiler_Percent			Real	System		0 rows	<input type="checkbox"/>
268	DT_Chiller_Percent			Real	System		0 rows	<input type="checkbox"/>
269	v_BearingStock			Real	System		1 rows	<input type="checkbox"/>
270	v_BearingOrderFlag			Real	System		1 rows	<input type="checkbox"/>
271	v_BearingROP			Real	System		1 rows	<input type="checkbox"/>
272	v_BearingOrderQty			Real	System		1 rows	<input type="checkbox"/>
273	v_SealStock			Real	System		1 rows	<input type="checkbox"/>
274	v_SealOrderFlag			Real	System		1 rows	<input type="checkbox"/>
275	v_SealROP			Real	System		1 rows	<input type="checkbox"/>
276	v_SealOrderQty			Real	System		1 rows	<input type="checkbox"/>
277	v_SensorStock			Real	System		1 rows	<input type="checkbox"/>
278	v_SensorOrderFlag			Real	System		1 rows	<input type="checkbox"/>
279	v_SensorROP			Real	System		1 rows	<input type="checkbox"/>
280	v_SensorOrderQty			Real	System		1 rows	<input type="checkbox"/>
281	v_SensorLeadTime			Real	System		1 rows	<input type="checkbox"/>
282	v_RelayStock			Real	System		1 rows	<input type="checkbox"/>
283	v_RelayOrderFlag			Real	System		1 rows	<input type="checkbox"/>
284	v_RelayROP			Real	System		1 rows	<input type="checkbox"/>
285	v_RelayOrderQty			Real	System		1 rows	<input type="checkbox"/>
286	v_RelayLeadTime			Real	System		1 rows	<input type="checkbox"/>

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Variable - Basic Process								
	Name	Rows	Columns	Data Type	Clear Option	File Name	Initial Values	Report Statistics
287	v_MilkPacking1SpareKitStock			Real	System		1 rows	<input type="checkbox"/>
288	v_MilkPacking1SpareKitOrderFlag			Real	System		1 rows	<input type="checkbox"/>
289	v_MilkPacking1SpareKitROP			Real	System		1 rows	<input type="checkbox"/>
290	v_MilkPacking1SpareKitOrderQty			Real	System		1 rows	<input type="checkbox"/>
291	v_MilkPacking1SpareKitLeadTime			Real	System		1 rows	<input type="checkbox"/>
292	v_YoghurtPackerSpareKitStock			Real	System		1 rows	<input type="checkbox"/>
293	v_YoghurtPackerspareKitOrderFla			Real	System		1 rows	<input type="checkbox"/>
294	v_YoghurtPackerSpareKitROP			Real	System		1 rows	<input type="checkbox"/>
295	v_YoghurtPackerSpareKitOrderQt			Real	System		1 rows	<input type="checkbox"/>
296	v_YoghurtPackerSpareKitLeadTim			Real	System		1 rows	<input type="checkbox"/>
297	v_HomogenizerSpareKitStock			Real	System		1 rows	<input type="checkbox"/>
298	v_HomogenizerSpareKitOrderFlag			Real	System		1 rows	<input type="checkbox"/>
299	v_HomogenizerSpareKitROP			Real	System		1 rows	<input type="checkbox"/>
300	v_HomogenizerSpareKitOrderQty			Real	System		1 rows	<input type="checkbox"/>
301	v_HomogenizerSpareKitLeadTime			Real	System		1 rows	<input type="checkbox"/>
302	v_CreamSeparatorSpareKitStock			Real	System		1 rows	<input type="checkbox"/>
303	v_CreamSeparatorSpareKitOrderF			Real	System		1 rows	<input type="checkbox"/>
304	v_CreamSeparatorspareKitROP			Real	System		1 rows	<input type="checkbox"/>
305	v_CreamSeparatorSpareKitOrder			Real	System		1 rows	<input type="checkbox"/>
306	v_CreamSeparatorSpareKitleadTi			Real	System		1 rows	<input type="checkbox"/>
307	v_AirCompressor1SpareKitStock			Real	System		1 rows	<input type="checkbox"/>
308	v_AirCompressor1SpareKitOrderF			Real	System		1 rows	<input type="checkbox"/>
309	v_BearingLeadTime			Real	System		1 rows	<input type="checkbox"/>
310	v_SealLeadtime			Real	System		1 rows	<input type="checkbox"/>
311	v_AirCompressor1SpareKitROP			Real	System		1 rows	<input type="checkbox"/>
312	v_AirCompressor1SpareKitOrder			Real	System		1 rows	<input type="checkbox"/>

Variable - Basic Process								
	Name	Rows	Columns	Data Type	Clear Option	File Name	Initial Values	Report Statistics
313	v_AirCompressor1SpareKitLeadTi			Real	System		1 rows	<input type="checkbox"/>
314	v_HTSTPasteurizerSpareKitStock			Real	System		1 rows	<input type="checkbox"/>
315	v_HTSTPasteurizerSpareKitOrder			Real	System		1 rows	<input type="checkbox"/>
316	v_HTSTPasteurizerSpareKitROP			Real	System		1 rows	<input type="checkbox"/>
317	v_HTSTPasteurizerSpareKitOrder			Real	System		1 rows	<input type="checkbox"/>
318	v_HTSTPasteurizerSpareKitLeadTi			Real	System		1 rows	<input type="checkbox"/>
319	NDays			Real	System		1 rows	<input type="checkbox"/>
320	PlannedRun_CompressedAir			Real	System		1 rows	<input type="checkbox"/>
321	PlannedRun_HTST			Real	System		1 rows	<input type="checkbox"/>
322	PlannedRun_ESL			Real	System		1 rows	<input type="checkbox"/>
323	PlannedRun_Homogenizer			Real	System		1 rows	<input type="checkbox"/>
324	PlannedRun_MilkPacking1			Real	System		1 rows	<input type="checkbox"/>
325	PlannedRun_Cream Separator			Real	System		1 rows	<input type="checkbox"/>
326	PlannedRun_YoghurtPacker			Real	System		1 rows	<input type="checkbox"/>
327	vBusy_CompressedAir			Real	System		0 rows	<input type="checkbox"/>
328	vBusy_HTST			Real	System		0 rows	<input type="checkbox"/>
329	vBusy_ESL			Real	System		0 rows	<input type="checkbox"/>
330	vBusy_Homogenizer			Real	System		0 rows	<input type="checkbox"/>
331	vBusy_Cream Separator			Real	System		0 rows	<input type="checkbox"/>
332	vBusy_MilkPacking1			Real	System		0 rows	<input type="checkbox"/>
333	vBusy_Yoghurt Packer			Real	System		0 rows	<input type="checkbox"/>
334	vUtil_CompressedAir			Real	System		0 rows	<input type="checkbox"/>
335	vUtil_HTST			Real	System		0 rows	<input type="checkbox"/>
336	vUtil_ESL			Real	System		0 rows	<input type="checkbox"/>
337	vUtil_Homogenizer			Real	System		0 rows	<input type="checkbox"/>
338	vUtil_Cream Separator			Real	System		0 rows	<input type="checkbox"/>

Simulation Based Modeling and Performance Evaluation of a Dairy Processing Plant
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Variable - Basic Process								
	Name	Rows	Columns	Data Type	Clear Option	File Name	Initial Values	Report Statistics
339	vUtil_MilkPacking1			Real	System		0 rows	<input type="checkbox"/>
340	vUtil_Yoghurtpacker			Real	System		0 rows	<input type="checkbox"/>
341	vWait_CompressedAir_MilkPackin			Real	System		0 rows	<input type="checkbox"/>
342	vStartWait_MilkPacking1_Compres			Real	System		1 rows	<input type="checkbox"/>
343	vYoghurtPackeron			Real	System		1 rows	<input type="checkbox"/>
344	vForceMilkPacking1Wait_Compres			Real	System		1 rows	<input type="checkbox"/>
345	v_ESL_Repair			Real	System		1 rows	<input type="checkbox"/>
346	v_ESL_SpareWait			Real	System		1 rows	<input type="checkbox"/>
347	v_ESL_Uptime			Real	System		1 rows	<input type="checkbox"/>
348	vMilkArrivalRate 1Batch			Real	System		1 rows	<input type="checkbox"/>
349	vYoghurt Production %			Real	System		1 rows	<input type="checkbox"/>
350	vMilkPacker Count			Real	System		1 rows	<input type="checkbox"/>
351	vRejected Milk %			Real	System		1 rows	<input type="checkbox"/>
352	vSour Milk Accepted Percent From			Real	System		1 rows	<input type="checkbox"/>
353	vCream Packer Count			Real	System		1 rows	<input type="checkbox"/>
354	vConveyor Count			Real	System		1 rows	<input type="checkbox"/>
355	vVacuum Packer Count			Real	System		1 rows	<input type="checkbox"/>
356	vManual Cream Separator Count			Real	System		1 rows	<input type="checkbox"/>
357	vCompressedAir Available			Real	System		1 rows	<input type="checkbox"/>
358	N_AirCompressor1_PM			Real	System		1 rows	<input type="checkbox"/>
359	N_AirCompressor2_PM			Real	System		1 rows	<input type="checkbox"/>
360	N_Boiler_PM			Real	System		1 rows	<input type="checkbox"/>
361	N_Chiller_PM			Real	System		1 rows	<input type="checkbox"/>
362	N_HTST_PM			Real	System		1 rows	<input type="checkbox"/>
363	N_ESL_PM			Real	System		1 rows	<input type="checkbox"/>
364	N_Homogenizer_PM			Real	System		1 rows	<input type="checkbox"/>

APPENDIX-II: Selected Simulation Model Output from Arena

8:11:21PM

Category Overview

November 25, 2025

Values Across All Replications

Optimized Model Elemtu Milk Industry By

Replications: 10 Time Units: Minutes

Key Performance Indicators

System

Number Out

Average

58,352

8:11:21PM

Category Overview

November 25, 2025

Values Across All Replications

Optimized Model Elemtu Milk Industry By

Replications: 10 Time Units: Minutes

User Specified

Output

Output	Average	Half Width	Minimum Average	Maximum Average
AirCompressor SpareKit Stock	15.7000	3.27	7.0000	25.0000
AirCompressor1 Downtime	425.83	0.00	425.83	425.83
AirCompressor2 Downtime	425.83	0.00	425.83	425.83
Bearing Stock	800.00	0.00	800.00	800.00
Boiler Downtime	696.91	0.00	696.91	696.91
BoreHolePump Downtime	5900.00	0.00	5900.00	5900.00
Breakage Total	511.50	17.64	478.00	563.00
Chiller Downtime	608.33	0.00	608.33	608.33
CompressedAir Utilization	95.9066	0.00	95.9066	95.9066
CompressedAir waitTime	0.00	0.00	0.00	0.00
MilkPacking1				
Cream Cup Packer utilization	93.9352	0.00	93.9352	93.9352
Cream Separator SpareKit Stock	8.2000	1.84	4.0000	14.0000

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Cream Separator utilization	94.7656	0.00	94.7656	94.7656
ESL Downtime	608.15	0.00	608.15	608.15
ESL Utilization	80.9638	0.00	80.9638	80.9638
Homogenizer Downtime	730.00	0.00	730.00	730.00
Homogenizer SpareKit Stock	7.6000	0.90	6.0000	10.0000
Homogenizer Utilization	95.0764	0.00	95.0764	95.0764
HTST Downtime	608.33	0.00	608.33	608.33
HTST Utilization	93.0630	0.00	93.0630	93.0630
Milk Packing2 Utilization	0.00	0.00	0.00	0.00
MilkPacking1 Downtime	730.00	0.00	730.00	730.00
MilkPacking1 SpareKit Stock	16.0000	2.86	10.0000	22.0000
MilkPacking1 Utilization	92.5769	0.00	92.5769	92.5769
Packed Butter Batches	25.7000	2.13	21.0000	30.0000
Packed cheese Batches	25.4000	0.69	24.0000	27.0000
Packed Cream Batches	41.9000	1.95	38.0000	47.0000
Packed LocalCheese Batches	43.4000	1.02	41.0000	45.0000
Packed Milk Batches	51915.70	60.61	51766.00	52035.00
Packed Yoghurt Batches	2743.40	36.43	2653.00	2832.00
Pasteurizer SpareKit Stock	21.4000	3.00	16.0000	28.0000
PowerOutage Downtime	0.00	0.00	0.00	0.00
Profit Butter	2812492.35	233,531.69	2298145.50	3283065.00
Profit Cheese	1757980.99	47,829.02	1661084.40	1868719.95
Profit Cream	1808843.95	84,192.13	1640479.00	2029013.50
Profit LocalCheese	732468.40	22,518.95	693041.32	785629.27

Model Filename: C:\My Files\Desktop\Documents\Final Model\Ideal(Optimized)\Ideal(Optimized)Model Page 36 of 37

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8:11:21PM

Category Overview

November 25, 2025

Values Across All Replications

Optimized Model Elemtu Milk Industry By

Replications: 10 Time Units: Minutes

User Specified

Output

Output	Average	Half Width	Minimum Average	Maximum Average
Profit Milk	154812106	180,740.66	154365697	155167807
Profit Total Million	91.2276	0.23	90.8132	91.7842
Profit Yoghurt	8285068.00	110,014.78	8012060.00	8552640.00
Relay Stock	865.00	156.99	355.00	1120.00
Revenue Butter	2827000.00	234,736.32	2310000.00	3300000.00
Revenue Cheese	1778000.00	48,373.67	1680000.00	1890000.00
Revenue Cream	1885500.00	87,760.06	1710000.00	2115000.00
Revenue LocalCheese	1302000.00	30,683.26	1230000.00	1350000.00
Revenue Milk Million	581.87	0.68	580.19	583.21
Revenue Total Million	625.33	0.56	624.06	626.66
Revenue yoghurt	35664200	473,573.56	34489000	36816000
Seal Stock	1545.00	196.22	1050.00	1950.00
Sensor Stock	402.00	58.48	250.00	530.00

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9:09:13PM **Category Overview** November 26, 2025

Values Across All Replications

Existing Model Elemtu Milk Industry By

Replications: 10 Time Units: Minutes

Key Performance Indicators

System
Number Out Average
26,613

9:09:13PM **Category Overview** November 26, 2025

Values Across All Replications

Existing Model Elemtu Milk Industry By

Replications: 10 Time Units: Minutes

User Specified

Output

Output	Average	Half Width	Minimum Average	Maximum Average
AirCompressor1 Downtime	20440.00	0.00	20440.00	20440.00
AirCompressor1 SpareKit Stock	0.00	0.00	0.00	0.00
AirCompressor2 Downtime	20440.00	0.00	20440.00	20440.00
Bearing Stock	0.00	0.00	0.00	0.00
Boiler Downtime	9733.33	0.00	9733.33	9733.33
BoreHolePump Downtime	8640.00	0.00	8640.00	8640.00
Breakage Total	2206.80	51.55	2106.00	2352.00
Chiller Downtime	17520.00	0.00	17520.00	17520.00
CompressedAir Utilization	100.00	0.00	100.00	100.00
CompressedAir WaitTime	2433.33	0.00	2433.33	2433.33
MilkPacking1				
Cream Cup Packer Utilization	0.00	0.00	0.00	0.00
Cream Separator Downtime	12166.67	0.00	12166.67	12166.67
Cream Separator Utilization	69.2227	0.00	69.2227	69.2227

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Simulation Based Modeling and Performance Evaluation of a Dairy Processing Plant
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CreamSeparator SpareKit Stock	0.00	0.00	0.00	0.00
ESL Downtime	6083.33	0.00	6083.33	6083.33
ESL Utilization	16.6667	0.00	16.6667	16.6667
Homogenizer Downtime	12166.67	0.00	12166.67	12166.67
Homogenizer SpareKit Stock	0.00	0.00	0.00	0.00
Homogenizer Utilization	69.2227	0.00	69.2227	69.2227
HTST Downtime	9691.91	0.00	9691.91	9691.91
HTST Utilization	63.2636	0.00	63.2636	63.2636
HTSTPasteurizer SpareKit Stock	0.00	0.00	0.00	0.00
Milkpacking1 Downtime	11923.33	0.00	11923.33	11923.33
MilkPacking1 SpareKit Stock	0.00	0.00	0.00	0.00
MilkPacking1 Utilization	79.8148	0.00	79.8148	79.8148
MilkPacking2 Utilization	0.00	0.00	0.00	0.00
Packed Butter Batches	2.8000	0.66	1.0000	4.0000
Packed Cheese Batches	10.1000	1.86	6.0000	14.0000
Packed Cream Batches	0.00	0.00	0.00	0.00
Packed LocalCheese Batches	24.1000	0.63	23.0000	26.0000
Packed Milk Batches	24093.10	50.22	23973.00	24205.00
Packed Yoghurt Batches	493.70	14.93	459.00	532.00
PowerOutage Downtime	2686.40	0.00	2686.40	2686.40
Profit Butter	307105.82	72,095.50	109680.65	438722.60
Profit Cheese	800460.35	147,468.22	475521.00	1109549.00
Profit Cream	0.00	0.00	0.00	0.00

Model Filename: C:\My Files\Desktop\Documents\Final Model\Real Model\FINAL REAL(EXISTING) MC Page 37 of 38

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Appendix III: Power Interruption Data

Power Interruption 1 year Data(26/09/2016-26/09/2017)					
S/N	Date	Power Interrupted	Power Released	No Power Duration	Data Source
1	26/9/16	1:45	3:00	1:15	Generator Run Hour record Book
2	27/9/16	4:10	6:00	1:50	Generator Run Hour record Book
3	7/10/2016	11:10	12:00	50	Generator Run Hour record Book
4	9/10/2016	10:30	11:45	1:15	Generator Run Hour record Book
5	10/10/2016	5:15	5:45	30	Generator Run Hour record Book
6	10/10/2016	6:30	6:40	10	Generator Run Hour record Book
7	11/10/2016	9:38	11:00	2:22	Generator Run Hour record Book
8	15/10/16	9:30	9:55	25	Generator Run Hour record Book
9	20/10/16	5:00	6:15	1:15	Generator Run Hour record Book
10	21/10/16	4:45	5:15	30	Generator Run Hour record Book
11	21/10/16	5:40	6:05	25	Generator Run Hour record Book
12	25/10/16	3:10	3:40	30	Generator Run Hour record Book
13	28/10/16	3:50	6:30	1:40	Generator Run Hour record Book
14	30/10/16	3:05	3:15	10	Generator Run Hour record Book
15	1/11/2016	4:10	4:40	30	Generator Run Hour record Book
16	1/11/2016	12:20	12:40	20	Generator Run Hour record Book
17	3/11/2016	5:40	6:50	1:10	Generator Run Hour record Book
18	4/11/2016	6:00	6:50	0:50	Generator Run Hour record Book
19	15/11/2016	8:20	10:20	2:00	Generator Run Hour record Book
20	27/11/16	3:50	4:27	1:37	Generator Run Hour record Book

Appendix IV: Yoghurt Percentage Data

Date	Total Milk Arrived	Pasteurizeed Milk	Yoghurt	%Yoghurt
1/2/2016	23141	23141	0	0
2	31640	31640	0	0
3	24567	24567	0	0
4	21209	21209	0	0
5	23362	23362	0	0
6	25618	25618	0	0
7	22238	22238	0	0
8	26526	26526	0	0
9	20726	20726	0	0
10	19187	19187	0	0
11	24024	24024	0	0
12	25172	25172	0	0
13	22564	22564	0	0
14	18637	18637	0	0
15	23533	23533	0	0
16	19994	19994	0	0
17	18267	18267	0	0
18	14912	14912	0	0
19	15133	15133	0	0
20	15965	15965	0	0

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	11	10340	8403	0	0
	12	9639	8993	0	0
	13	8833	8833	0	0
	14	8791	8604	0	0
	15	13831	12967	0	0
	16	17900	17900	0	0
	17	21720	21179	0	0
	18	19854	19854	0	0
	19	20275	20275	0	0
	20	20591	20591	0	0
	21	20619	20619	0	0
	22	21549	21549	0	0
	23	15311	14998	0	0
	24	21901	21790	0	0
	25	15991	15991	0	0
	26	20168	20168	0	0
	27	17063	17063	0	0
	28	22962	22962	0	0
	29	15601	15601	0	0
	30	15781	15781	0	0
Average		4963126.7	4843952.067	88380	1.780732295

Appendix V: Breakage Return Data

Date	Total Return (ltr)	Machine problem(ltr)	Percentage of Breakage due to machine problem	Total Pasteurized Milk
1/6/2017	100.5	46.5	46.26865672	9389
1/7/2017	136	58.5	43.01470588	8172
1/8/2017	146.5	68.5	46.75767918	8108
1/9/2017	123.5	61	49.39271255	8198
1/10/2017	126	71	56.34920635	4231
1/11/2017	160	86	53.75	6332
1/12/2017	136	54	39.70588235	8696
1/13/2017	159	86	54.08805031	6293
1/14/2017	112	51.5	45.98214286	18452
1/15/2017	169.5	77.5	45.72271386	9079
1/16/2017	188.5	109.5	58.09018568	7722
1/17/2017	158.5	113.5	71.60883281	8148
1/18/2017	115	63	54.7826087	8300
1/19/2017	240	130	54.16666667	8796
1/20/2017	293	160	54.60750853	12381
1/21/2017	208	98	47.11538462	14522
1/22/2017	226	129	57.07964602	5808
1/23/2017	233.5	155	66.38115632	5619
1/24/2017	178	121.5	68.25842697	13757
1/25/2017	93	53.5	57.52688172	6771

6/2/2017	178.5	91.5	51.2605042	7912
6/3/2017	164	112	68.29268293	5904
6/4/2017	492.5	176.5	35.83756345	7462
6/5/2017	288.5	255	88.3882149	4828
6/6/2017	316	190.5	60.28481013	7634
6/7/2017	359	238	66.29526462	11773
6/8/2017	239	164.5	68.82845188	8341
6/9/2017	277	173	62.45487365	6228
6/10/2017	330	213	64.54545455	5087
6/11/2017	291	186	63.91752577	7945
6/12/2017	325	204.5	3/2/1900	8962
6/13/2017	325	224.5	69.07692308	4743
6/14/2017	311	213	68.48874598	7193
6/15/2017	303.5	192	63.26194399	9393
6/16/2017	332.5	204	61.35338346	6857
6/17/2017	432	272.5	63.0787037	6355
6/18/2017	303	172	56.76567657	7941
6/19/2017	81	72.5	89.50617284	5245
6/20/2017	58	46.5	80.17241379	0
Average	34962.5	142.85375	65.22984255	1133127

Appendix VI: Daily (Hourly) Milk Arrival Data

Date	Milk Arrived per Day	Milk Arrived per Hour	100Batch	Inter arrival time(Min)
1/1/2017	7965	995.625	9.95625	6.026365348
2/1/2017	6469	808.625	8.08625	7.420003092
3/1/2017	8795	1099.375	10.99375	5.45764639
4/1/2017	8589	1073.625	10.73625	5.588543486
5/1/2017	7707	963.375	9.63375	6.228104321
6/1/2017	9389	1173.625	11.73625	5.112365534
7/1/2017	8172	1021.5	10.215	5.873715125
8/1/2017	8108	1013.5	10.135	5.920078934
9/1/2017	8198	1024.75	10.2475	5.855086606
10/1/2017	8631	1078.875	10.78875	5.561348627
11/1/2017	6332	791.5	7.915	7.580543272
12/1/2017	8696	1087	10.87	5.519779209
13/1/2017	6293	786.625	7.86625	7.627522644
14/1/2017	18452	2306.5	23.065	2.601344028
15/1/2017	9079	1134.875	11.34875	5.286925873
16/1/2017	7722	1287	12.87	4.662004662
17/1/2017	8148	1358	13.58	4.41826215
18/1/2017	8300	1037.5	10.375	5.78313253
19/1/2017	8796	1099.5	10.995	5.457025921
20/1/2017	12381	1547.625	15.47625	3.876908166
21/1/2017	14922	1865.25	18.6525	3.21672698
9/12/2017	6449	806.125	8.06125	7.443014421
10/12/2017	5544	693	6.93	8.658008658
11/12/2017	7179	897.375	8.97375	6.68616799
12/12/2017	6597	824.625	8.24625	7.276034561
13/12/2018	6648	831	8.31	7.220216606
14/12/2018	7965	995.625	9.95625	6.026365348
15/12/2019	6469	808.625	8.08625	7.420003092
16/12/2019	8795	1099.375	10.99375	5.45764639
17/12/2020	8589	1073.625	10.73625	5.588543486
18/12/2020	7707	963.375	9.63375	6.228104321
19/12/2021	9389	1173.625	11.73625	5.112365534
20/12/2021	8172	1021.5	10.215	5.873715125
21/12/2022	8108	1013.5	10.135	5.920078934
22/12/2022	6284	785.5	7.855	7.638446849
23/12/2023	8564	1070.5	10.705	5.604857543
24/12/2023	7282	910.25	9.1025	6.591595715
25/12/2024	7155	894.375	8.94375	6.708595388
26/12/2025	6898	862.25	8.6225	6.958538707
27/12/2026	7057	882.125	8.82125	6.801757121
28/12/2027	8138	1017.25	10.1725	5.8982551
28/12/2028	3544	443	4.43	13.54401806
29/12/2029	3886	485.75	4.8575	12.35203294
	7274.286533	911.1805158	9.111805158	8.13857292

Appendix VII: Annual Production



ELEMTU INTEGRATED MILK INDUSTRY S.CO
2015 E.C PRODUCED PRODUCTS ANNUAL PRODUCTION REPORT

Item	Month												Annual	
	July	Aug.	September	October	November	December	January	February	March	April	May	Jun		
Pasteurized milk	149045.5	340473	62926.5	394452	349635	519411.5	524398.5	490972	396739.5	328533.5	136947	454393	136947	4284874
250ml yoghurt	543	737	347.25	159	492.75	134.75	254.25	17.75	0	1024.5	0	339	0	4049.25
500ml yoghurt	0	8693.5	4737.5	15104	17149.5	16051	18753.5	10971.5	3287	12207.5	7853	49210	7853	171871
vanilla yoghurt	0	0	0	0	0	0	0	802	0	0	0	0	0	802
sterawberry yoghurt	0	0	0	0	0	0	0	1534	317	0	0	380	0	2231
T.Butter	0	0	1	0	0	0	0	1	0	0	1510.75	0	0	1512.75
C.Butter	408.75	1522.8	381	689	1258	1926	3394.25	2220	580.5	987	0	2729	1510.75	17607
Local Ayib	1356	1353	402.5	903	1486	792	1881.5	364.5	990.5	1101.5	2296.5	3594	2296.5	18817.5
Mozzarella cheese	0	0	0	0	0	0	0	0	54.5	607	0	0	0	661.5




ELEMTU INTEGRATED MILK INDUSTRY S.CO

2016 E.C ANNUAL PRODUCED PRODUCT SUMMERY REPORT

S.N	PRODUCT TYPE	JULY	AUGUST	SEPTEMBER	OCT	NOV	DECE	JANU	FEB	MARCH	APRIL	MAY	JUN	TOTAL	
1	P/MILK	275615	487958	170698	746117	637526.5	489463.5	385853	467641.5	131104.5	245487	245694.5	308225.5	226853.5	4818238
2	400ML YOGHURT	10347.5	0	0	0	3127	2988	4590	12125.5	4087.5	11865.5	5437.5	18419	9655.5	82643
3	250ML YOGHURT	0	0	0	0	13	115	0	0	72.25	20	136.25	117	152.25	625.75
4	MOZZARELLA	236	1010.4	0	0	0	13.5	233	114	0	198	284	76	0	2164.9
5	CREAM	2987	777	0	0	265	100	0	99	76	1266	1836	1072	941	9419
6	BUTTER	1832.5	485.7	66	0	146	165.4	0	64.5	48	624	1041	661.9	655.2	5790.2
7	AYIBE	240.5	351	0	79.5	151.5	420.5	345.5	491	626.5	241.5	270.5	62.5	0	3280.5

Appendix VIII: Milk Packer and Other Critical Machines' Capacity IDENTIFICATION

MANUFACTURER	Thimonnier
Address	11, Avenue de la Paix 69650 S ^T GERMAIN AU M ^T D'OR FRANCE
- Telephone: Thimonnier s.a. - Telephone: After-Sales Service	33 (0)4 72 08 19 19 33 (0)4 72 08 19 02
- Fax:	33 (0)4 72 08 19 00
- e-mail: Thimonnier s.a. - e-mail: After-Sales Service - Web site:	info@thimonnier.fr sav@thimonnier.fr www.thimonnier.fr
TYPE	M2500 / M2500 ESL
Specification	Pillow pouch liquid (milk) packaging machine
Reference: (Please specify in all correspondence)	- 527 A 138 093 - NIKOS HRANENGINEERING
Year of manufacture	2012

 2.1 esl pasteurizer 5000	10/19/2025 9:19 PM	File folder
 2.2 htst pasteurizer 5000	10/19/2025 9:19 PM	File folder
 2.3 cream separator 5000	10/19/2025 9:19 PM	File folder
 2.4 homogenizer 5000	10/19/2025 9:19 PM	File folder