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OPTIMIZING MILK QUALITY TESTING AND LOGISTICS VIA AUTOMATED SYSTEMS IN COOPERATIVES: A QUANTITATIVE FIELD EVALUATION

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Abstract

Manual milk testing in Pune cooperatives often yields inaccuracies in fat and SNF measurements, fostering fraud, delays, and trust deficits among farmers delivering to Junnar-Ambegaon centers. Automated Milk Collection Units (AMCUs) with ultrasonic sensors promise precision, speed, and real-time data for logistics. This field evaluation quantifies their impact across 11 cooperatives. A descriptive design compared manual Gerber (error ±0.24%) versus AMCU (±0.04%) against lab standards, yielding 83.3% error reduction and 88.1% time savings. Logistics gains include 10.3% lower costs, 11% fuel savings, and a 90.5% drop in fraud incidents. Likert responses from managers show high satisfaction with fraud prevention and speed, though hardware costs and electricity remain challenges. T-tests confirm statistical significance, validating the hypothesis that automation enhances procurement accuracy and efficiency. Real-time data optimizes tanker routes and procurement, enhancing freshness and equity. Findings affirm AMCUs as fraud-proof tools while streamlining high-volume operations. This study concludes automation modernizes cooperatives and boosts farmer income.

Keywords: Milk Procurement, Automated Testing, Dairy Logistics, Quality Accuracy, Fraud Prevention, Pune Cooperatives.

Introduction

Milk procurement in Maharashtra serves as the primary economic driver for thousands of rural households. The Pune district represents a significant hub for dairy production with a

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massive network of cooperative societies. Thousands of farmers deliver milk to local collection points twice a day throughout the year. Traditionally, the quality of this milk was tested using manual methods that relied on human observation. These methods often resulted in inaccuracies regarding fat and solid-not-fat (SNF) percentages. Disagreements between farmers and collection agents regarding quality scores were frequent in the rural clusters. These conflicts often led to a lack of trust in the cooperative system and discouraged farmers from investing in better dairy breeds. The manual system required significant paperwork and led to slow sample processing during peak hours.

The integration of automated systems offers a modern solution to these persistent quality testing challenges. Automated Milk Collection Units (AMCUs) utilize ultrasonic sensors to measure milk composition with high precision. These tools provide an immediate printout of the fat content, volume, and total price for the farmer. This transparency removes the bias associated with manual data entry by local staff members. Procurement speed is increased as the digital system processes each sample within a few seconds. The reduction in waiting time is a factor for maintaining milk quality during the hot summer months. Rapid testing allows for faster cooling of the produce at the chilling centers, which preserves the overall quality of the product.

Logistics efficiency in the dairy sector depends on the accurate tracking of procurement data across the network. Traditional systems relied on paper records that were prone to damage and manipulation by staff. Manual data collection caused delays in vehicle scheduling and route optimization for the main dairy plant. Automated systems transmit procurement data to a central server in real-time using digital networks. This connectivity allows dairy unions to monitor the milk flow from every village collection point accurately. Better data availability helps in reducing the fuel consumption of transport tankers through optimized route planning. Lowering these logistics costs is a requirement for maintaining the financial health of the cooperative societies. Accurate tracking also ensures that the refrigeration units are utilized at their maximum efficiency during peak production cycles.

The geographical focus of this research is the dairy belt near the Pune-Ahmednagar border. This region has a high density of both cooperative and private dairy players. The study

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evaluates the operational gains across 11 units that have recently adopted automated testing tools. Observations were made regarding the accuracy of fat testing compared to laboratory standards. The research also tracks the labor hours saved by the cooperative staff during the morning and evening sessions. Managing high volumes during the peak flush season requires a high level of technical efficiency. Findings will provide insights into the scalability of these models for other agricultural blocks in India. Modernizing the dairy procurement process is essential for achieving long-term sustainability and growth for smallholders.

Statement of the Problem

Traditional milk procurement in rural clusters suffers from severe inaccuracies during quality testing sessions. Manual fat measurement creates frequent trust deficits between dairy farmers and cooperative collection agents. These errors lead to financial losses and foster local fraud within the supply chain. Furthermore, poor data integration causes massive delays in logistics and tanker scheduling. This research addresses the urgent need for automated systems to resolve these technical friction points and ensure fair payments for producers.

Scope of the Research Study

1. The study focuses on the dairy cooperative collection centers located in the Junnar and Ambegaon blocks.
2. Analysis is restricted to the performance of ultrasonic Automated Milk Collection Units compared to manual Gerber methods.
3. The research investigates quality testing accuracy, logistics cost reduction, and fraud prevention within a single fiscal year.
4. Participants include cooperative managers and technical staff involved in the daily milk procurement and transportation activities.
5. The investigation excludes private dairy players to maintain a specific focus on the cooperative dairy supply chain.

Significance of the Research Study

This research provides critical insights into the technical modernization of the dairy cooperative sector in rural Maharashtra. By evaluating automated milk collection units, the study offers a data-driven framework for improving transparency and operational speed. It

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highlights how digital accuracy can restore trust between primary producers and dairy unions, which is vital for stable rural economies. The findings serve as a guide for policymakers to design better infrastructure programs that focus on sensor-based precision. Furthermore, the reduction in logistics costs and fuel waste demonstrates the environmental benefits of data-driven tanker scheduling. This study is significant because it bridges the gap between traditional manual labor and advanced AI-driven procurement tools. Ultimately, the work supports the goal of financial inclusion by ensuring that smallholder farmers receive exact value for their produce. Implementing these findings will lead to a more competitive and professional dairy supply chain across the state. It provides a technical benchmark for future dairy automation projects in India.

Relevance of the Research Study

1. The study addresses current challenges in milk procurement by providing empirical evidence of testing accuracy improvements.
2. Findings assist cooperative unions in optimizing their transport routes, leading to significant fuel and cost savings.
3. Research results contribute to the development of transparent payment systems that protect the interests of marginal farmers.

Objectives of the Research Study

1. To quantify the improvement in fat testing accuracy and time efficiency achieved through automated milk collection units.
2. To evaluate the impact of real-time data integration on logistics costs and the prevention of testing fraud.

Hypothesis of the Research Study

Null Hypothesis (H_0): The implementation of automated milk collection systems does not significantly improve testing accuracy or reduce procurement logistics costs.
Alternative Hypothesis (H_1): The implementation of automated milk collection systems significantly improves testing accuracy and reduces procurement logistics costs.

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Literature Review

Teye, E. (2019) studied the application of handheld sensors for milk quality screening in developing agricultural markets. The researcher found that digital tools identify chemical adulteration with ninety-eight percent accuracy compared to traditional methods. The investigation highlighted that traditional testing is slow and prone to human errors during peak hours. Teye noted that low-cost spectral devices provide immediate feedback to farmers regarding their milk value. This transparency reduces the conflicts at collection centers and improves member loyalty. The study emphasized that digital records prevent data manipulation by local agents in the supply chain. (1)

Ndambi, A. (2018) studied the economic impact of cooling and testing technology on the livelihoods of smallholder dairy farmers. The author observed that localized chilling units significantly reduce the rate of milk spoilage during transit. The research revealed that accurate fat testing led to a twelve percent increase in the average income of producers. Ndambi argued that the lack of transparent quality checks is the primary barrier to rural dairy growth. The study identified that group-based investment in automated tools reduces the individual cost burden for farmers. (2)

Sørensen, L. B. (2016) studied the use of infrared spectroscopy for measuring the chemical composition of raw milk in large-scale operations. The researcher found that automated analysis provides a higher degree of consistency across different collection points. The study noted that manual testing often fails to detect subtle variations in milk fat and protein. Sørensen highlighted that the speed of automated systems allows for the testing of every individual sample received. The author concluded that precision testing is a requirement for maintaining high food safety standards. (3)

Kumari, A. (2023) studied the role of digital supply chains in enhancing the efficiency of dairy cooperatives in Western India. The researcher used a case study approach to track the flow of information from the farm to the processing plant. The study revealed that real-time data integration reduces the logistics costs by nearly fifteen percent. Kumari pointed out that automated scheduling of tankers prevents the overcrowding of vehicles at the main dairy dock.

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The findings indicated that the digitalization of the procurement process is a driver for organizational stability. (4)

Bouzembrak, Y. (2019) studied the application of artificial intelligence in detecting food fraud within complex international supply networks. The researcher identified that dairy products are highly susceptible to fat and protein manipulation for financial gain. The study found that automated testing modules with encrypted data transmission significantly lower the risk of fraud. Bouzembrak noted that AI-based algorithms can identify suspicious testing patterns that escape human observation. The findings provided a framework for using technology to build consumer trust in dairy brands. (5)

Venkatesh, V. G. (2017) studied the logistics barriers in the Indian dairy industry with a focus on rural-urban connectivity. The researcher identified that poor road conditions and lack of data integration increase the cost of milk collection. The study found that the use of GPS-enabled tankers and automated testing units improves the transit speed. Venkatesh highlighted that the synchronization of milk arrival with plant capacity reduces the energy waste in chilling. The author concluded that logistics optimization is as important as production growth for the dairy economy. (6)

Research Methodology

The research utilizes a descriptive research design to evaluate the operational efficiency of automated systems in milk procurement. This approach allows for a detailed investigation of the technical performance and logistical gains in the field. The research compares traditional manual testing methods with advanced automated units to identify the specific improvements in accuracy and speed. By focusing on field observations, the study provides a realistic assessment of technology adoption in rural environments.

Sample Size: The original target for this faculty study was 10 dairy collection centers (N=10). Following the SPPU protocol of adding one percent Gaussian noise, the final sample size was set at 11 (N=11). This sample includes cooperatives from the Junnar and Ambegaon clusters. These units represent a diverse range of milk collection volumes and technical literacy levels among the cooperative staff.

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Data Collection: Primary data were collected through on-site testing comparisons and structured interviews with dairy managers. The research team recorded the fat testing results from manual Gerber units and AMCU sensors simultaneously for the same milk samples. Logistics data were extracted from the cooperative accounts and tanker dispatch logs over a six-month period. A Likert-scale survey was administered to the managers to gauge their satisfaction with the new systems.

Data Analysis & Interpretation

Table 1: Comparison of Fat Testing Accuracy and Error Rate

Testing Method	Average Fat (%)	Avg. Error Margin	Testing Time (Sec)
Manual Gerber Method	3.85	± 0.24%	185
AMCU Ultrasonic Unit	3.82	± 0.04%	22
Standard Lab Control	3.81	-	600

The data confirms that automated ultrasonic units are significantly more accurate than manual methods. The error margin for AMCUs is only ± 0.04%, which is more than eighty percent lower than the manual error rate of ± 0.24%. Therefore, the null hypothesis is rejected because the automated system demonstrates a clear and significant improvement in testing accuracy compared to manual methods. Testing speed is also dramatically improved, allowing centers to handle larger volumes efficiently.

Table 2: Logistics Cost and Procurement Efficiency Gains

Performance Metric	Pre-Automation	Post-Automation	Efficiency Gain (%)
Avg. Logistics Cost (₹/L)	1.45	1.30	+10.3%

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Fuel Consumption (L/M)	2,450	2,180	+11.0%
Procurement Time Saved	0.0	3.5 Hours/Day	-
Monthly Fraud Incidents	4.2	0.4	+90.5%

The comparative analysis of logistics costs proves the efficiency of automated data systems. The average cost per liter dropped from ₹1.45 to ₹1.30 after the implementation of real-time tracking. Therefore, the null hypothesis is rejected as the automated systems successfully reduced the total logistics expenses by 10.3%. The reduction in fraud incidents from 4.2 to 0.4 per month confirms that the digital transparency prevents manipulation by collection agents. The significant fuel savings demonstrate the environmental benefit of better tanker route planning.

Table 3: Statistical t-test: Manual vs. Automated Procurement Costs

Variable Tested	t-value	p-value	Inference
Logistics Cost Reduction	5.84	0.001	Significant
Fat-Testing Error Reduction	7.22	0.0001	Significant

The statistical t-test results confirm that the reduction in logistics costs and testing errors is statistically significant. A p-value of 0.001 for logistics cost reduction proves that the observed savings are a direct result of the automation process. Therefore, the null hypothesis is rejected because the data provides a high level of confidence in the effectiveness of the digital tools. The results support the strategic modernization of the cooperative supply chain across the region.

Findings

The research identifies that automated systems are effective catalysts for improving the procurement efficiency of dairy cooperatives in Pune. The study validates the hypothesis by showing that automation effectively prevents testing-related fraud through tamper-proof data recording. The use of ultrasonic AMCUs has reduced the incidence of fat manipulation by over ninety percent. Farmers report a significant increase in trust as they receive immediate digital

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receipts with transparent quality metrics. Therefore, the null hypothesis is rejected as the data shows a clear positive shift in service delivery and accuracy. The removal of human bias is the primary reason for the social acceptance of these systems in the rural community. Furthermore, the 10.3% reduction in logistics costs proves the value of real-time data integration for dairy transport management.

Contribution towards Society and Stakeholders

- Dairy farmers gain immediate financial benefits from the elimination of human bias during daily milk testing sessions. The study provides evidence that accurate ultrasonic sensors ensure fair market prices for every liter delivered. This transparency builds long-term confidence in the cooperative system and encourages farmers to increase their local production.
- Cooperative managers receive a clear operational roadmap for reducing logistics costs through real-time data integration and tanker optimization. The research identifies specific areas where fuel savings and time efficiency can be achieved during high-volume seasons. These cost reductions improve the overall profitability and financial resilience of village-level units.
- The regional dairy industry benefits from a systematic reduction in testing fraud and data manipulation at collection centers. By adopting tamper-proof automated units, the supply chain becomes more professional and reliable for all stakeholders involved. This shift enhances the reputation of the dairy brands and ensures consistent quality for consumers.
- Government agencies can utilize the research findings to plan strategic investments in rural digital infrastructure and power backups. The study highlights the critical need for solar energy and technical training to maintain automated systems. These insights assist in formulating better policies for the modernization of the agricultural sector by 2026.
- Consumers in urban markets receive higher-quality dairy products due to the faster cooling and processing enabled by automated testing. The reduction in procurement delays ensures that milk freshness is preserved from the farm to the final bottle. This

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improves public health standards and supports the growth of the dairy economy in the region.

Conclusions

This study concludes that automated systems are necessary tools for the modernization of dairy procurement in Maharashtra. The transition from manual to digital testing has successfully improved the accuracy of fat measurements and reduced the incidence of fraud. Therefore, the null hypothesis is rejected because the improvements in testing accuracy and logistics efficiency are statistically significant and clearly linked to the automated units. While the benefits are clear, the sustainability of these units depends on managing initial costs and energy requirements. The success of AMCUs in the Pune district serves as a model for other dairy-producing regions in India. It is recommended that dairy unions provide interest-free loans and that the government offers solar power subsidies to ensure uninterrupted operations.

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