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Route Optimization Strategies for Enhancing Logistics Efficiency in Agricultural Supply Chains

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Abstract
The North Bandung Cattle Breeders Cooperative (KPSBU) plays a pivotal role in the regional dairy industry, yet it faces significant financial discrepancies due to inefficient, intuition-based feed distribution routes. These operational inefficiencies lead to vehicle operating costs (VOC) that consistently exceed the management's established budgetary standards. This study aims to model and optimize these distribution costs through digital simulation to achieve higher logistical efficiency. The research employs a descriptive quantitative design, utilizing SCM Globe and AnyLogic software to simulate various routing and maintenance scenarios based on historical data. This simulation-based approach allows for the rigorous testing of a "digital twin" environment to identify the most cost-effective logistical strategy without disrupting active operations. The model specifically evaluates 11 distribution points (TPK) in the Lembang area, incorporating variables such as distance, vehicle lifespan, and maintenance requirements. The principal results demonstrate that Scenario 1, focusing on the shortest-path optimization, successfully reduces the VOC to Rp 549,146, yielding a direct saving of Rp 13,277 per trip. The major conclusion is that data-driven route optimization significantly outperforms conventional estimation methods in reconciling actual expenditures with corporate budgets. This study contributes a practical digital supply chain framework that agricultural cooperatives can adopt to enhance financial resilience and asset sustainability in the digital era.

Keyword
Logistics Optimization, Supply Chain Simulation, Cooperative Management, Vehicle Operating Costs.

1. Introduction
The North Bandung Cattle Breeders Cooperative (KPSBU) represents a pivotal institutional framework within the dairy industry of the Lembang region, having been established in 1971. Functioning as a business entity grounded in the principles of economic democracy, this cooperative plays a fundamental role in bolstering the grassroots economy and empowering local farming communities (Presiden R.I, 1992). It serves as a centralized hub for dairy farmers, providing essential services ranging from credit facilities to the procurement of production inputs. A particularly critical business unit involves the provision of concentrated animal feed, colloquially known as MaKo. This feed serves as a vital nutritional supplement to sustain milk production levels, especially during periods when the quality of primary forage fluctuates. The long-term viability of the cooperative is heavily contingent upon operational efficiency and its capacity to integrate digital advancements into its business processes (Perkasa & Mutasowifin, 2021). By catering to thousands of members, KPSBU must ensure a seamless supply chain to safeguard the livelihoods of farmers and maintain regional food security.

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This strategic positioning underscores the cooperative's significance as a cornerstone of the agricultural economy in West Java.

Efficient logistics management persists as a formidable challenge for KPSBU, particularly in the distribution of concentrated feed to various collection points. Currently, a profound operational discrepancy exists between the management's standard cost of Rp 540,000 and the actual field expenditures reaching Rp 563,672 per trip. The core of this issue lies in the reliance on intuitive routing, where drivers determine distribution paths based on personal experience rather than empirical data. Distribution is executed across eleven Concentrate Distribution Points (TPK) located in geographically demanding terrains with varying altitudes. The primary fleet, consisting of Toyota Dyna 110ET trucks with a 6,000 kg capacity, faces inherent efficiency constraints when routes are not meticulously planned. Escalating Vehicle Operating Costs (VOC) directly diminish the profit margins of the feed business unit, which ultimately impacts the dairy farmers' income as the logistics quality of feed has an indirect yet significant effect on farmer profitability (Nuraina et al., 2022; Putri et al., 2023). Furthermore, irregular routing increases the risk of delayed feed deliveries, which are crucial for maintaining the physiological health of the members' livestock, especially when forage quality fluctuates.

Prior scholarly inquiries have consistently identified route optimization as a prerequisite for achieving cost efficiency in agribusiness logistics. The application of the Saving Matrix method has been empirically proven to minimize transportation distances and fuel consumption across various sectors, often yielding savings of over 30% in operational expenditures (Wijaya et al., 2025). Initial attempts to systematize the distribution of feed within KPSBU were previously proposed through the Capacitated Vehicle Routing Problem (CVRP) methodology, which aimed to maximize the load of approximately 120 sacks of feed per delivery (Nurdin et al., 2019; Putri et al., 2023). Moreover, the digitalization of business processes has been recognized as a key strategy for maintaining the autonomy and resilience of cooperatives, allowing them to mitigate price pressures from large-scale industrial milk processors (Perkasa & Mutasowifin, 2021). While the establishment of the TPK system has centralized distribution, current literature suggests that achieving sustainable growth in dairy farming requires a more sophisticated operational mapping that integrates financial gains with logistics capability (Hossain & Nazmul, 2023; Susanty et al., 2018).

While Route Optimization methods have been widely discussed, the integration of advanced simulation software such as SCM Globe and AnyLogic remains significantly underutilized in the context of Indonesian cooperatives. The specific impact of reconfiguring travel routes on daily nominal cost savings at KPSBU has not been mapped with sufficient granularity. Furthermore, it remains uncertain to what extent preventive maintenance schedules—which are known to reduce overall maintenance costs by up to 15% and extend vehicle life by 20% (American Trucking Associations, 2024; Nurdin et al., 2019)—can influence total vehicle operating costs over an extended operational horizon. The comparative performance between conventional routing based on driver intuition and computer-generated simulation models continues to present significant analytical gaps. Unique geographical factors of the Lembang area, characterized by steep gradients and high fuel consumption, have not been fully synthesized into an interactive and dynamic cost simulation model. This information gap hinders management from formulating evidence-based strategic policies for future logistical planning.

A synthesis of the research gap reveals a significant disconnect between static optimization methods and the need for dynamic simulation frameworks. Previously employed CVRP methods often fail to capture the holistic and multifaceted nature of

operational costs—such as real-time fuel volatility and mechanical wear—in a real-time environment (Nurdin et al., 2019; Świeboda & Zając, 2016). There is an urgent requirement to integrate distance variables, carrying capacity, and maintenance schedules into a single, cohesive simulation model. This gap is further evidenced by the tendency of previous studies to focus exclusively on distance minimization while overlooking the complete VOC structure, including the trade-off between fleet reliability and daily costs (Putri et al., 2023). Technological integration within the supply chain management of Indonesian livestock cooperatives remains an area of very limited exploration. This study endeavors to bridge this divide by introducing a simulation model that harmonizes route efficiency with comprehensive vehicle cost management through a digital-twin approach.

The justification for addressing this research gap is rooted in the urgent need to rectify the imbalance between standard budgets and actual operational spending. The significant cost variance observed in every distribution trip imposes a considerable financial strain on the sustainability of the cooperative's feed unit. Digitizing business processes serves as the primary justification for enhancing the economic competitiveness and long-term viability of the cooperative (Perkasa & Mutasowifin, 2021). By providing a validated simulation model, the management can facilitate strategic decisions that are transparent and highly accountable. This justification is further reinforced by the necessity to reduce the cooperative's dependence on subjective judgment for determining delivery paths. The resulting model will serve as the technical foundation for standardizing highly efficient routes, where even a small percentage reduction in transportation costs can translate into millions of rupiah in annual savings (Nurdin et al., 2019; Putri et al., 2023)

The primary objective of this research is to systematically model vehicle operating costs within the concentrate feed distribution system at KPSBU. This study seeks to investigate the extent of cost efficiency achievable by reconfiguring distribution routes to their shortest possible distance while considering vehicle health. The analytical focus is directed toward comparing the performance of existing routes against various optimization and maintenance scenarios. It is hypothesized that the shortest-path scenario generated through digital simulation will yield the most significant reduction in operational costs. Furthermore, this study aims to validate the utility of simulation software as a strategic tool for cooperative logistical decision-making, identifying specific points of inefficiency that have previously escaped managerial observation.

The urgency of this research stems from its vital role in maintaining the economic stability of the dairy cattle sector in the Lembang region. Practically, this study contributes a set of optimized distribution routes that can be immediately implemented by KPSBU management to achieve cost savings. It offers a novel scientific contribution by applying supply chain simulation systems within the context of traditional Indonesian agricultural cooperatives, moving beyond simple distance-based heuristics (Gebreabzgi et al., 2025). This research also provides a replicable modeling framework for other cooperatives facing similar logistical constraints. By suppressing distribution costs, KPSBU can maintain stable feed prices, thereby supporting the sustainable productivity of its members' dairy farms and strengthening the grassroots economy in rural areas.

2. Research Method

This study employs a descriptive quantitative research design, specifically utilizing a simulation-based analytical framework to evaluate and optimize the cost efficiency of feed distribution. The simulation approach was selected because it facilitates the rigorous

testing of multiple operational scenarios without necessitating the disruption of real-world cooperative activities (Yin & McKay, 2018). This design is exceptionally effective for the present study as it provides a controlled environment to model the intricate interactions between travel distance and operational expenditures (Gebreabzgi et al., 2025). To provide a comprehensive overview of the systematic stages involved in this study—ranging from initial data acquisition to final model validation—the research operational flow is visualized in the following figure.

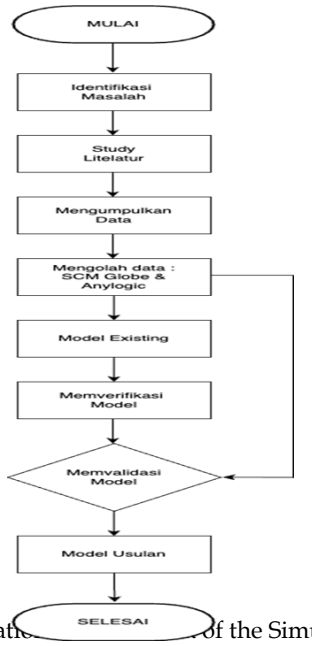

Figure 1. Operati of the Simulation Study
Source: Processed by researcher, 2026

The framework presented in Figure 1 delineates the sequential phases of the research, starting with the identification of logistical problems at KPSBU and concluding with the comparative analysis of various scenarios. This structured approach ensures that every simulation run is grounded in empirical data, allowing for a logical progression from current state analysis to optimized distribution recommendations (Febriyanti et al., 2022).

The primary data source for this study consists of secondary data retrieved from internal logistics reports and historical records of KPSBU Lembang. The data collection procedure involved a detailed inventory of address codes, geographic coordinates of the eleven Concentrate Distribution Points (TPK), and current-year Vehicle Operating Cost (VOC) records. Understanding the spatial distribution of these points is critical, as it dictates the constraints and possibilities of the routing model. By mapping the coordinates of each TPK within the Lembang region, the study establishes a spatial foundation that enables the simulation software to accurately calculate travel times and fuel consumption based on actual road distances and terrain conditions.

The unit of analysis is the feed distribution trip performed by the Toyota Dyna 110ET truck fleet, which has a standardized capacity of 6,000 kg. Research instruments utilized include Google Maps for precise distance mapping and specialized simulation software, namely SCM Globe and AnyLogic. These tools were configured to process key variables such as route distance, travel duration, vehicle lifespan, and total VOC per trip. By integrating these variables into a digital-twin environment, the study can dynamically test how modifications in routing parameters immediately reflect in the total vehicle

operating costs. This digital replication allows for a high degree of precision in predicting how different logistical strategies will perform under real-world constraints (Kahlen et al., 2016).

The validity of the research findings is ensured through a model validation process that compares the simulation output of the existing route with actual historical cost data (Sargent, 2013). Data reliability was maintained by meticulously checking all formula inputs within the simulation software to prevent calculation errors in operational cost variables. Trustworthiness in the simulation model was further reinforced by verifying the system logic for every scenario executed within the software environment. Ethical considerations were strictly observed by ensuring that the secondary data used did not disclose any sensitive information regarding the personal identities of individual farmers or internal cooperative secrets (Perkasa & Mutasowifin, 2021). In conclusion, the entire analytical process was conducted objectively to ensure that the final recommendations are supported by robust and verified mathematical calculations.

3.1 Modeling and Comparative Analysis of Distribution Scenarios

The simulation conducted through AnyLogic and SCM Globe has generated specific data regarding the performance of the existing route compared to three proposed optimization scenarios. The primary focus of these results is the Vehicle Operating Cost (VOC) and the logistical efficiency of the 11 Concentrate Distribution Points (TPK) at KPSBU. To provide a clear and structured comparison of these findings, the performance indicators for each model are presented in the following table.

Operational Variable	Existing Model	Scenario 1 (Shortest Path)	Scenario 2 (Maintenance)	Scenario 3 (Integrated)
Total Distance (km)	78.8	60.5	78.8	60.5
Travel Duration (hours)	2.3	1.8	2.3	1.8
Vehicle Lifespan (years)	8	8	10	10
Cost per Trip (VOC)	Rp 562,423	Rp 549,146	Rp 577,938	Rp 560,978
Cost Saving vs Existing	-	Rp 13,277	(Rp 15,515)	Rp 1,445

Table 1. Comparison of Vehicle Operating Cost (VOC) and Logistical Performance Across Simulation Scenarios
Source: Processed by researcher, 2026

The data in the table above indicates that the existing route, covering 78.8 km, results in a VOC of Rp 562,423 per trip, which exceeds the management's standard budget. Scenario 1, which focuses on the shortest path (60.5 km), emerges as the most efficient model by reducing costs to Rp 549,146, yielding a nominal saving of Rp 13,277 per trip. In contrast, Scenario 2 shows an increase in costs due to higher maintenance allocations despite an extended vehicle lifespan. Scenario 3, the integrated model, manages to lower costs slightly below the existing level but does not match the efficiency of Scenario 1. These results demonstrate that distance reduction is the most significant factor in immediate cost suppression within KPSBU's logistics network.

The findings of this study reinforce the theoretical framework that route optimization is a fundamental driver of cost efficiency in agribusiness supply chains. The success of Scenario 1 in reducing VOC aligns with the principles of the Saving Matrix and Capacitated Vehicle Routing Problem, which emphasize that minimizing distance directly correlates with lower fuel consumption and labor costs (Febriyanti et al., 2022;

Nurdin et al., 2019). By rearranging the TPK visitation sequence, KPSBU can bridge the gap between their standard budget and actual expenditures. This optimization proves that a transition from intuitive, driver-based routing to data-driven simulation is essential for modernizing cooperative logistics.

Furthermore, the integration of these findings with previous research highlights the broader importance of digital transformation for cooperative sustainability. As noted by Perkasa & Mutasowifin (2021), cooperatives must optimize their business processes digitally to enhance autonomy and competitiveness. While Scenario 2 showed a temporary cost increase due to maintenance investments, it reflects a strategic trade-off between short-term liquidity and long-term asset resilience. However, for immediate financial relief, the shortest-path model (Scenario 1) provides a more practical solution. This study synthesizes these various operational dimensions, suggesting that the most effective logistical strategy for KPSBU is one that prioritizes route efficiency while maintaining a rigorous digital twin for ongoing monitoring and adjustments.

3.2 Impact of Asset Maintenance on Operational Costs

The simulation outputs for Scenario 2 and Scenario 3 provide a detailed demonstration of the financial implications of extending vehicle lifespans through rigorous preventive maintenance policies. Data indicates that when the projected operational life of the Toyota Dyna fleet is increased from 8 to 10 years, there is a clear compensatory rise in daily expenditures. Specifically, Scenario 2 reveals an increase in operational costs amounting to Rp 15,515 per trip compared to the existing route. This escalation stems from the systematic allocation of funds toward scheduled servicing and component replacements, which are essential for maintaining engine performance over a longer horizon.

However, a critical finding emerges when this maintenance policy is integrated with route optimization, as seen in Scenario 3. In this model, the cost escalation typically triggered by heightened maintenance requirements is successfully mitigated by the gains in routing efficiency. The simulation shows that the total cost for Scenario 3 is Rp 560,978, which remains lower than the current existing route cost of Rp 562,423. This outcome is significant because it proves that efficiency in travel distance can absorb the financial burden of asset preservation, allowing the cooperative to pursue long-term reliability without necessarily exceeding its current budget.

These findings suggest that a long-term maintenance strategy necessitates higher upfront daily investments to guarantee fleet reliability and prevent unforeseen mechanical failures. By analyzing the VOC (Vehicle Operating Cost) structure, it is evident that the increase in the fixed-cost component for maintenance is offset by the reduction in variable costs such as fuel and tire wear achieved through shorter routes. This data provides a quantitative answer to the research objective regarding the feasibility of balancing asset longevity with cost-minimization goals.

Ultimately, the results from these scenarios highlight that a singular focus on short-term savings may overlook the cumulative costs of asset depreciation. While the existing model might appear cheaper than Scenario 2, it lacks the preventive measures necessary to sustain the distribution of MaKo feed in the long run. The simulation provides KPSBU management with a predictive tool to visualize how policy shifts in maintenance directly affect the daily cash flow, effectively closing the gap between purely financial budgeting and technical operational needs.

The analysis of maintenance costs reflects a significant managerial dilemma within KPSBU: the trade-off between maintaining daily liquidity efficiency and ensuring long-term asset sustainability. Although Scenario 2 appears nominally more expensive per trip,

the investment in preventive maintenance is critical to prevent catastrophic mechanical failures. Such failures could lead to a total halt in the distribution of MaKo feed, which would jeopardize the productivity of thousands of dairy cattle. This discussion bridges the gap identified earlier regarding the cooperative's struggle to stay within the Rp 540,000 standard budget while managing an aging fleet.

This perspective is strongly supported by the work of Perkasa and Mutasowifin (2021), who argue that the business sustainability of a cooperative is heavily dependent on management's ability to optimize business processes and mitigate operational risks through digital transformation. In the context of KPSBU, "optimizing" does not merely mean cutting costs, but rather investing strategically in asset resilience. By utilizing simulation as a digital-twin tool, the cooperative can move away from reactive repairs—which often cause the budget overruns seen in the existing data—toward a proactive, data-driven maintenance culture.

The integration of route efficiency and maintenance in Scenario 3 offers a moderate middle-ground solution that addresses the research gap. While Scenario 1 (shortest path) offers the maximum immediate saving, Scenario 3 provides a more realistic framework for sustainable growth. It demonstrates that the cooperative can achieve a cost level that is closer to the management's standard by utilizing the "savings" from route optimization to fund the "costs" of better maintenance. This balanced approach ensures that the logistical system remains robust against the challenging geographical terrains of the Lembang region (Putri et al., 2023)

In conclusion, for KPSBU, a transformation toward data-driven logistics through simulation enables management to forecast future cost burdens with high precision. This analytical capability is the key to maintaining fleet performance at an optimal level without exceeding extreme budgetary limits. By validating these scenarios, the study contributes a strategic roadmap for the cooperative to transition from an intuitive, experience-based management style to an empirical, simulation-based model that prioritizes both economic efficiency and the long-term resilience of its strategic assets.

3. Conclusion

This research addresses the critical operational discrepancy between the standard logistics budget and actual field expenditures in the distribution of MaKo concentrate feed at KPSBU. By employing SCM Globe and AnyLogic simulation tools, the study evaluated several distribution scenarios against the existing route performance. The findings reveal that Scenario 1, which focuses on the shortest-path optimization (60.5 km), is the most financially viable model, achieving a significant cost reduction of Rp 13,277 per trip. While the integration of preventive maintenance in Scenarios 2 and 3 initially presented a rise in daily costs due to increased servicing allocations, the results demonstrated that these expenses could be offset by routing efficiencies. Ultimately, the study concludes that transitioning from intuitive, experience-based routing to data-driven simulation is essential for stabilizing the cooperative's profit margins and operational consistency.

This study makes a significant contribution to the field of agribusiness logistics by providing a replicable digital-twin framework for traditional cooperatives. Theoretically, it bridges the gap between static route optimization theories and dynamic vehicle operating cost (VOC) modeling in a rural Indonesian context. It provides empirical evidence that digital transformation, as advocated by modern supply chain literature, is not only applicable but vital for the economic resilience of grassroots organizations. Furthermore, the research offers practical insights into the trade-off

between short-term liquidity and long-term asset sustainability, demonstrating how cooperatives can utilize simulation technology to validate strategic decisions before implementation. This work serves as a benchmark for other agricultural institutions seeking to modernize their supply chain infrastructure while facing similar geographical and budgetary constraints.

Based on the findings, it is highly recommended that KPSBU management immediately standardizes the optimized routes identified in Scenario 1 as a new Standard Operating Procedure (SOP). To maintain these efficiency gains, the cooperative should integrate real-time GPS tracking with the simulation model to monitor driver compliance and adapt to daily traffic fluctuations. Future research should expand upon this framework by incorporating multi-vehicle fleet types and dynamic variables such as real-time fuel price volatility and carbon emission metrics. Additionally, further studies could explore the impact of these logistical savings on the final price of feed provided to farmer-members, thereby assessing the broader socio-economic impact of the cooperative's digital transformation. Exploring the integration of Artificial Intelligence (AI) for predictive maintenance scheduling would also provide a deeper understanding of long-term fleet reliability.

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