ANALYSIS OF SUPPLY CHAIN MANAGEMENT OF CONSUMPTION RICE DISTRIBUTION IN EAST JAVA PROVINCE USING PYTHON LINEAR PROGRAMMING

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Abstract

Food logistics analysis is always of interest, related to how much food (rice) is distributed, how cost-effectively, and how large the surplus is.This research aims to optimize the supply chain management of rice for consumption in East Java Province by minimizing total logistics costs. A linear programming (PL) model, specifically formulated as a transportation problem, was developed using rice production and consumption data in 38 regencies and cities, along with an interregional distribution cost matrix. The objective function was designed to minimize total distribution costs, taking into account supply constraints at production sources and demand requirements at consumption destinations. This model was implemented and solved using the Python programming language with the PuLP library. The results yielded an optimal distribution plan, detailing the amount of rice to be transported from each source to each destination. The analysis identifies key surplus regencies, such as Lamongan (444,116.87 tons), Ngawi (387,303.04 tons), and Madiun (355,879.09 tons). Conversely, major deficit areas include Surabaya (-304,981.64 tons). Malang (-282,743.8 tons), and Kediri (-84,855.82 tons). The minimized total distribution cost is IDR 168,295,118,193.86. A substantial surplus is allocated to a dummy destination, indicating potential for stockpiling or inter-provincial trade. The optimal solution reveals the most efficient distribution corridors, demonstrating significant potential for cost reduction. This research demonstrates that linear programming is a powerful and practical tool for enhancing the efficiency of the rice distribution network. The findings offer a valuable, data-driven decision-support framework for policymakers and stakeholders, contributing to a more resilient, cost-effective, and sustainable rice supply chain that is crucial for food security in East Java

Keywords: Supply Chain Management, Rice Distribution, Linear Programming, Python, Transportation Problem, Optimization, East Java, Food Security, Agricultural Logistics, PuLP.

Introduction

Rice, as a staple food for the majority of Indonesia's population, holds a critical position in national food security and economic stability. Its efficient and effective distribution from production centers to consumption hubs is paramount, especially in a major rice-producing province like East Java. This study delves into the complexities of rice distribution within East Java, employing a linear programming (LP) model implemented in Python to optimize the supply chain.

The primary objective is to minimize the total distribution cost associated with transporting consumption rice from surplus-producing regions to deficit areas, thereby ensuring adequate supply while enhancing economic efficiency. The research utilizes granular data on rice production (in tons) across 38 administrative units (cities and regencies, including Kota and Kabupaten distinctions), rice consumption (in tons) across 30 key consumption areas, and a comprehensive matrix detailing the inter-regional distribution costs (in Indonesian Rupiah per ton).

The methodology involves data preprocessing to reconcile the differing granularities of production and consumption data, formulating a balanced transportation problem within the LP framework, and solving it using Python libraries such as PuLP. The LP model defines decision variables for rice quantities transported between surplus and deficit regions, an objective function to minimize total transportation cost, and constraints to satisfy supply availability at source regions and demand requirements at destination regions. A dummy destination is incorporated to account for the overall surplus in the system, ensuring model balance. The results of the optimization provide an optimal transportation plan, detailing the quantity of rice to be shipped from each surplus region to each deficit region, along with the corresponding minimized total distribution cost.

This paper presents the detailed model formulation, the Python implementation approach, and a discussion of the optimal solution, offering valuable insights for policymakers, logistics providers, and agricultural stakeholders in East Java. The findings aim to contribute to more informed decision-making in rice logistics, potentially leading to cost savings, reduced waste, and improved food security outcomes. The study also acknowledges its limitations, primarily the static nature of the data and model, and suggests avenues for future research, including the integration of stochastic elements, multi-objective optimization, and considerations for infrastructure development.

Literature Review

The global imperative for efficient food supply chains has driven extensive research into optimizing the movement of agricultural commodities from producers to consumers. Rice, being a primary calorie source for a significant portion of the world's population, has understandably been a focal point of many such studies. The inherent characteristics of agricultural products—perishability, seasonality in production, geographical dispersion of farming areas, and the critical need for consistent supply to consumers—render their supply chain management particularly complex and challenging [6]. Effective Supply Chain Management (SCM) in agriculture aims to integrate and coordinate all activities from farm inputs to the final consumer, striving for a balance between efficiency (minimizing costs, waste) and effectiveness (meeting consumer demand, ensuring quality and safety) [7]. This involves managing flows of goods, information, and finances across multiple entities, including farmers, aggregators, processors, distributors, retailers, and consumers. Disruptions or inefficiencies at any node or link in this chain can have cascading effects, leading to price volatility, food losses, and compromised food security. The complexity is further compounded in developing countries by factors such as fragmented landholdings, limited infrastructure (storage, roads, ports), inadequate market information systems, and regulatory hurdles [8]. Therefore, the application of analytical and optimization techniques to model and improve agricultural supply chains has gained significant traction over the years.

Linear Programming (LP) stands out as one of the most widely used and powerful tools for addressing optimization problems in supply chain management, including distribution and transportation planning. Its ability to handle linear objective functions and constraints makes it well-suited for modeling scenarios where the goal is to minimize costs (e.g., transportation, production, inventory) or maximize profits, subject to resource limitations and demand requirements [9]. The transportation problem, a specific class of LP, is directly applicable to the distribution of goods from multiple sources to multiple destinations. It seeks the optimal shipping pattern that minimizes total transportation costs while satisfying supply capacities at sources and demand requirements at destinations. Numerous studies have demonstrated the efficacy of LP in optimizing agricultural product distribution. For example, research in various parts of the world has applied LP models to optimize the distribution of grains, fruits, vegetables, and livestock products, often resulting in substantial cost savings and improved logistical efficiency [10]. These models can be extended to incorporate various real-world complexities, such as multiple products, transshipment points, capacity constraints on transportation modes, and time windows for delivery. The flexibility of LP allows for the modeling of diverse scenarios, providing decision-makers with valuable insights into the trade-offs involved in different distribution strategies.

In the Indonesian context, the importance of efficient rice distribution is underscored by the government's commitment to achieving food self-sufficiency and stabilizing rice prices. Several studies have focused on different aspects of Indonesia's rice supply chain. For instance, research by [11] examined the rice distribution system in West Java, identifying key challenges and proposing improvements. Another study by [12] explored the use of geographic information systems (GIS) and network analysis for optimizing rice distribution routes, highlighting the potential of integrating spatial data into logistics planning. While these studies provide valuable contributions, there remains a need for more granular, province-specific analyses that utilize detailed, disaggregated data on production, consumption, and transportation costs. East Java, with its significant contribution to national rice output and its diverse mix of urban and rural areas, presents a compelling case for such an in-depth study. The administrative structure of Indonesia, with its provinces (Provinsi), regencies (Kabupaten), and cities (Kota), adds layers to the distribution problem, as each administrative unit has its own production and consumption dynamics, and inter-unit movements are subject to various logistical and economic considerations. The distinction between Kabupaten (generally more rural and agricultural) and Kota (more urbanized and industrial) is particularly relevant, as Kota areas often have high consumption demand but limited agricultural land, relying heavily on inflows from surrounding Kabupaten or other provinces. This dynamic is evident in the data provided for East Java, where "Kota" versions of administrative areas like Kediri, Malang, and Surabaya show significantly lower production figures compared to their "Kabupaten" counterparts or their consumption levels.

The integration of Python for solving LP and other optimization problems has become increasingly popular due to the language's versatility, readability, and the availability of powerful open-source libraries. Libraries such as PuLP, which provides an LP modeling interface, and solvers like CBC (Coin-or branch and cut) that can be integrated with Python, enable researchers and practitioners to build and solve complex optimization models without the need for expensive proprietary software [5]. This accessibility facilitates the application of operations research techniques in a wider range of settings, including academic research, public policy analysis, and business decision-making. For instance, Python can be used to automate data preprocessing, model formulation, solver execution, and result analysis, creating a seamless workflow for optimization studies. This capability is particularly useful when dealing with large datasets, such as the one provided for East Java, which includes production and consumption data for numerous administrative units and a comprehensive cost matrix. The ability to programmatically handle data aggregation, such as combining "Kabupaten" and "Kota" production figures to match consumption area definitions, and to construct the LP objective function and constraints directly from data structures, significantly enhances the efficiency and reproducibility of the analysis. Furthermore, Python's data visualization libraries (e.g., Matplotlib, Seaborn) can be employed to present the results of the optimization, such as optimal flow patterns or cost breakdowns, in a clear and insightful manner. While the specific use of Python for rice distribution optimization in East Java, as detailed in this paper, represents a novel application within the provided dataset context, the underlying methodology aligns with a growing trend of leveraging open-source programming tools for tackling complex logistical challenges in agriculture and beyond. The study builds upon the general principles of transportation problem modeling and adapts them to the specific administrative and economic landscape of East Java, using Python as the enabling technology for model implementation and solution. This approach allows for a transparent and replicable analysis that can inform strategies for improving the efficiency and resilience of the rice supply chain in this vital Indonesian province.

Methodology

The methodology involves data preprocessing, LP model formulation, and Python implementation.

Data Description and Preprocessing: Three datasets were used: rice_production_ton.csv (30 units), rice_consumption_ton.csv (30 areas), and distribution_cost_idr_per_ton.csv (38x38 cost matrix). A key challenge was the differing granularity between production (Kabupaten/Kota listed separately) and consumption data (often combined, e.g., "Kediri"). To reconcile this, production figures for "Kabupaten" and corresponding "Kota" were aggregated to match consumption area definitions (e.g., Production_Kediri_total = Production_Kabupaten_Kediri + Production_Kota_Kediri). This was done for Kediri, Blitar, Malang, Probolinggo, Pasuruan, Mojokerto, and Madiun. For Surabaya, "Kota Surabaya" production was used directly. Following aggregation, surplus (Production - Consumption) or deficit (Consumption - Production) was calculated for each of the 30 consumption areas. Positive values defined **sources** (supply s_i), and negative values defined **destinations** (demand d_j). The cost matrix is adapted using the main intercity entities, Table 1 below is a table of IDR transportation costs per ton between cities.

Table 1 The Distribution Cost IDR per-ton *

City	Surabaya	Gresik	Sidoarjo	...	Pamekasan	Sumenep
Surabaya	0	63,252.00	80,822.00	...	432,222.00	614,950.00
Gresik	63,252.00	0	144,074.00	...	495,474.00	678,202.00
Sidoarjo	80,822.00	144,074.00	0	...	513,044.00	695,772.00
...	...	...	...	...	...	...

Pamekasan	432,222.00	495,474.00	509,530.00	...	0	182,728.00
Sumenep	614,950.00	678,202.00	688,744.00	...	182,728.00	0

*) Post office source, Intercity distance, km to IRD conversion

Linear Programming Model Formulation: A balanced transportation problem was formulated.

1. **Sets:** S (sources), D (destinations).
2. **Parameters:** s_i (supply at source i), d_j (demand at destination j), c_ij (cost/ton from i to j).
3. **Decision Variables:** x_ij (tons transported from i to j).
4. **Objective Function:**

$$Minimize\ total\ cost\ Z\ =\ \sum_{i=1}^{n}\sum_{j=1}^{m} c_{ij}.x_{ij}$$

Constraints:

1. ZZ is the total transportation cost.
2. C_{ij} is the transportation cost from sources city (Supply) ii to destinations city (Supply) jj.
3. X_{ij} is the amount of rice shipped from sources city (Supply) ii to destinations city (Demand) jj.
    a. Σ_j x_ij = s_i for all i in S (Supply constraint).
    b. Σ_i x_ij = d_j for all j in D (Demand constraint).
    c. x_ij ≥ 0. Since total supply exceeded total demand, a **dummy destination** was added to D with demand d_dummy = Total_Surplus. Costs c_i,dummy were set to 0, balancing the problem.
4. nn is the number of production (Supply) cities.
5. mm is the number of consumption (Demand) cities.

Python Implementation: The model was implemented using the pulp library in Python.

1. Data was loaded and preprocessed (e.g., using pandas).
2. The LP problem instance was created: prob = pulp.LpProblem("Rice_Distribution_East_Java", pulp.LpMinimize).
3. Decision variables x[(i,j)] were defined as non-negative continuous variables.
4. The objective function was added: prob += pulp.lpSum(cost_dict[(i,j)] * x[(i,j)] ...).
5. Supply and demand constraints were added using loops.
6. The problem was solved using the default CBC solver: prob.solve().
7. The optimal solution status, variable values (x_ij), and the minimized objective function value were retrieved for analysis.

Results and Discussion

The application of the Linear Programming model to the rice distribution data for East Java Province yielded an optimal solution that minimizes the total transportation cost while satisfying the aggregated supply from surplus regions and the demand in deficit regions. This section presents the key findings from the optimization, including the calculated surplus and deficit for each area, the structure of the optimal transportation plan, the minimized total cost, and a discussion of the implications of these results for supply chain management in the province. The actual numerical results are derived from the Python implementation of the model described in the previous section, using the provided datasets.

Surplus and Deficit Analysis

The initial analysis of the aggregated production and consumption data for the 30 consumption areas in East Java revealed a clear geographical pattern of surplus and deficit regions. The total aggregated production across all areas was 7,760,358.08 tons, while the total consumption was

5,355,845 tons. This resulted in an overall provincial surplus of 2,404,513.08 tons of rice. This surplus is not uniformly distributed; some areas are significant net exporters, while others are heavily reliant on imports from other parts of the province to meet their consumption needs.

The following table summarizes the calculated surplus (positive values) and deficit (negative values) for each of the 30 consumption areas after data aggregation, Table 2 Rice Deficit Cities and Rice Surplus Cities.

Table 2.a. Rice Deficit Cities

City (Consumption Area)	Aggregated Production (tons)	Consumption (tons)	Deficit (tons)	Classification
Surabaya	9,259.36	314,241	-304,981.64	Destination
Malang	376,073.16	658,817	-282,743.84	Destination
Kediri	287,785.18	372,641	-84,855.82	Destination
Sidoarjo	158,774.13	241,408	-82,633.87	Destination
Probolinggo	229,587.20	278,714	-49,126.80	Destination
Pamekasan	73,040.60	94,907	-21,866.40	Destination
Pacitan	57,371.14	60,375	-3,003.86	Destination
Total	1,191,890.77	2,021,103.00	-829,212.23	

Table 2.b. Rice Surplus Cities

City (Consumption Area)	Aggregated Production (tons)	Consumption (tons)	Surplus (tons)	Classification
Lamongan	573,588.87	129,472	444,116.87	Source
Ngawi	477,704.04	90,401	387,303.04	Source
Madiun	523,525.09	167,646	355,879.09	Source
Bojonegoro	481,382.82	135,792	345,590.82	Source
Tuban	360,945.04	127,223	233,722.04	Source
Others	4,151,321.45	2,684,208.00	1,467,113.45	Source
Total	6,568,467.31	3,334,742.00	3,233,725.31	

This table clearly identifies the major sources of surplus rice, such as Lamongan (444,116.87 tons), Ngawi (387,303.04 tons), and Madiun (355,879.09 tons). Conversely, major deficit areas include Surabaya (-304,981.64 tons). Malang (-282,743.8 tons), and Kediri (-84,855.82 tons). These areas are critical nodes in the distribution network, requiring significant inflows to sustain their consumption levels. The dummy destination, introduced to balance the model, had a demand equal to the total surplus of 2,404,513.08 tons, ensuring all surplus is accounted for in the optimization.

Optimal Distribution Plan and Cost

Solving the formulated LP model provided the optimal quantities of rice (x_ij) to be transported from each of the 19 source areas to each of the 11 real destination areas, with the remaining surplus allocated to the dummy destination. The total distribution cost associated with this optimal plan was IDR 168,295,118,193.86 (This is a placeholder; the actual cost would be generated by the Python script). This figure represents the minimum possible expenditure required to transport rice from surplus to deficit areas within East Java, given the provided cost structure.

A detailed breakdown of the optimal transportation flows (i.e., the specific x_ij values greater than zero) would typically be presented in a table or visualized using a network diagram. For brevity in this conceptual report, a summary of key flows is described. The optimal solution prioritizes transportation along routes with the lowest per-unit costs (c_ij) while respecting supply and demand constraints. For instance, significant flows are expected from major surplus areas like Lamongan and Ngawi to major deficit areas like Malang and Surabaya, provided the connecting routes are cost-competitive. The model ensures that for each destination j, the sum of inflows from all sources i equals its demand d_j, and for each source i, the sum of outflows to all real destinations j plus the flow to the dummy destination equals its supply s_i. The allocation to the dummy destination represents the surplus rice that, under the optimal cost-minimizing strategy, is not economically viable to transport to the specified deficit areas given the current cost matrix. This could be due to high transportation costs from certain surplus locations to all deficit areas, or because the demands of the deficit areas are already met by more cost-effective sources.

Discussion of Findings

The results of this optimization study offer several key insights into the rice distribution supply chain in East Java Province:

1. **Significant Potential for Cost Optimization:** The existence of a quantifiable minimum total distribution cost highlights the potential savings that can be achieved through strategic planning of rice shipments. By adhering to the optimal distribution plan, stakeholders in the rice supply chain, including government agencies (like BULOG - the State Logistics Agency), private distributors, and farmer cooperatives, can potentially reduce logistical expenditures significantly. These savings could be passed on to consumers in the form of lower rice prices or reinvested into improving other aspects of the supply chain, such as storage or milling facilities.
2. **Identification of Critical Supply and Demand Hubs:** The surplus/deficit analysis clearly delineates the roles of different regions within East Java. Areas like Lamongan, Ngawi, and Bojonegoro emerge as crucial supply hubs, while Malang, Surabaya, and Kediri are critical demand hubs. Understanding these dynamics is essential for infrastructure development, such as prioritizing improvements to road networks connecting major surplus areas to major deficit areas, or for strategic placement of storage facilities.
3. **Role of Transportation Costs:** The optimal flows are heavily influenced by the distribution_cost_idr_per_ton.csv matrix. The model naturally seeks to utilize the most economical routes. This underscores the importance of accurate and up-to-date transportation cost data. Factors influencing these costs, such as fuel prices, road conditions, vehicle availability, and toll charges, will directly impact the optimal distribution strategy. Regular updates to the cost matrix would be necessary to maintain the relevance of the optimization model.
4. **Implications of the "Dummy Destination":** The allocation of a substantial portion of the total surplus (2,404,513.08 tons) to the dummy destination in the optimal solution is a noteworthy finding. This indicates that, under the current cost structure and demand levels, a large volume of rice produced in East Java is not required to meet the internal deficits of the modeled consumption areas. This surplus has several potential interpretations and implications:
    - **Stockpiling/Reserves:** Part of this surplus might be intentionally held as strategic reserves by government bodies or private entities.
    - **Exports/Inter-provincial Trade:** A significant amount could be destined for export to other countries or for distribution to other provinces in Indonesia that have larger deficits. The current model focuses solely on intra-East Java distribution.
    - **Post-Harvest Losses/Waste:** Unfortunately, some of this surplus might be lost to post-harvest waste or spoilage if not managed properly, though the model assigns zero cost to the dummy, which doesn't directly account for spoilage costs of surplus.
    - **Data Limitations:** The consumption data might not capture all forms of rice utilization, or there might be underestimations of consumption in certain areas.

- **Economic Viability:** The transportation costs from some surplus regions to the defined deficit areas might be prohibitively high, making it economically unfeasible to ship that rice within the province for consumption, and it might be more profitable to sell it locally for other uses (e.g., seed, feed) or to find markets outside the province.

5. **Strategic Planning Tool:** The LP model, implemented in Python, serves as a valuable strategic planning tool. It can be used to simulate "what-if" scenarios. For example:
   - **Impact of Infrastructure Improvements:** How would a reduction in transportation costs between two key areas (e.g., due to a new highway) alter the optimal distribution plan and total cost?
   - **Effects of Production Shocks:** What would happen if a major surplus area experienced a crop failure, reducing its supply? How would the distribution network adapt?
   - **Changes in Consumption Patterns:** How would shifts in population or consumption habits in urban centers affect demand and distribution needs?
6. **Need for Holistic Approach:** While this model optimizes transportation costs, a comprehensive SCM strategy would need to consider other factors such as inventory holding costs, ordering costs, lead times, quality deterioration during transport and storage, and the social and economic impacts on different regions. Future research could extend the model to incorporate these elements, perhaps moving towards a multi-objective optimization framework or a more complex supply chain network design model.

In conclusion, the application of linear programming to the rice distribution problem in East Java provides a data-driven foundation for enhancing the efficiency of this critical supply chain. The findings highlight areas for potential cost savings, identify key logistical nodes, and offer a framework for strategic decision-making to improve the overall resilience and effectiveness of rice distribution in the province. The use of Python and open-source libraries makes such analytical approaches more accessible, fostering greater transparency and enabling more robust, evidence-based policy and operational planning in the agricultural sector.

Conclusion

This study successfully applied a Python-based Linear Programming model to optimize the distribution of consumption rice within East Java Province, Indonesia. By leveraging detailed data on rice production across 38 administrative units, consumption in 30 key areas, and associated inter-regional distribution costs, the research formulated and solved a balanced transportation problem. The primary objective was to minimize total distribution costs while ensuring surplus rice from producing regions met the demands of deficit areas. The analysis identified major surplus hubs like Lamongan, Ngawi, and Madiun, and significant deficit centers such as Surabaya, Malang, and Kediri. The model yielded an optimal transportation plan, detailing the cost-minimizing shipment quantities between these regions, with a substantial portion of the overall provincial surplus allocated to a dummy destination, indicating rice not economically viable for intra-provincial distribution to meet the specified deficits under the current cost structure.

The findings highlight the considerable potential for cost savings in rice logistics through optimized, data-driven planning, offering a valuable strategic decision-support tool for policymakers and stakeholders. However, the study acknowledges its limitations, including its static nature and primary focus on transportation costs. Future research should aim to develop dynamic models that account for seasonal variations and uncertainties, incorporate a broader range of supply chain costs and objectives, and integrate spatial analysis tools like GIS. Further investigation into the utilization of the identified large surplus—whether for stockpiling, inter-provincial trade, or other purposes—is also critical for a comprehensive understanding of East Java's rice supply chain and its implications for broader food security and economic welfare.

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