Optimizing Inter-Provincial Rice Distribution in Indonesia Using a Branch and Bound Algorithm

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Abstract*—As an archipelagic nation, Indonesia faces significant logistical challenges in ensuring equitable food distribution, particularly for its primary staple, rice. Disparities between rice-producing provinces and those with high consumption demand necessitate a robust and efficient distribution strategy to maintain national food security. This paper presents an optimization model for inter-provincial rice distribution in Indonesia using a Branch and Bound algorithm. The model aims to minimize total transportation costs while maximizing national coverage, with a special focus on provinces with high food vulnerability scores. This is achieved through a novel multi-criteria branching strategy that integrates food security priorities directly into the search process. Using a comprehensive dataset of 38 provinces, including production supply, demand requirements, and transportation costs for 1,406 routes, the algorithm successfully identified an optimal distribution plan. The experiment resulted in a total distribution volume of 84,326 tons across 28 key routes, achieving 100% coverage of the 23 targeted recipient provinces with a minimum transportation cost of IDR 2.3 billion. The model provides a scalable and effective solution for strategic decision-making in national food logistics, contributing to the enhancement of food security across the archipelago.

***Keywords*—Branch and Bound; optimization; logistics; food security; rice distribution; Indonesia**

I. Introduction

Rice is the cornerstone of food security in Indonesia, with its availability and affordability directly impacting social and economic stability. However, the nation's geography, consisting of over 17,000 islands, creates inherent challenges for supply chain management. Rice production is concentrated in a few key islands, primarily Java and Sulawesi, while demand is spread across the entire archipelago. This geographical imbalance necessitates a complex network of inter-provincial transportation to move surplus rice from producer regions to deficit regions. An inefficient distribution system can lead to significant price volatility, regional shortages, and increased vulnerability for food-insecure populations [1].

The problem, therefore, is to design a national distribution plan that is both cost-effective and equitable. This can be modeled as a large-scale transportation problem, a classic challenge in operations research. Such problems are often NP-hard, meaning the computational effort required to find an optimal solution grows exponentially with the problem size [5]. For a network of 38 provinces, a brute-force approach is infeasible. The goal is not merely to move goods at the lowest cost, but to do so strategically, ensuring that the needs of the most vulnerable provinces are met.

This paper proposes the application of the Branch and Bound algorithm, a powerful method for solving combinatorial optimization problems [2]. Unlike simple heuristics, Branch and Bound systematically explores the solution space to guarantee optimality. The primary contribution of this work is the development and application of a customized Branch and Bound algorithm tailored to the specific context of Indonesian food security. Our model incorporates a novel multi-criteria decision-making process into its branching strategy, which considers not only cost but also a food security priority score derived from the Food Security and Vulnerability Atlas (FSVA) [3]. This ensures that the resulting distribution plan is directly aligned with national strategic goals for poverty alleviation and food equity.

The model is tested using real-world data on provincial supply, demand, and transport costs. The results of this experiment, including the optimized distribution routes and their impact on national coverage, are presented and analyzed. The findings demonstrate the algorithm's capability to generate a practical and efficient distribution network, providing a valuable tool for government agencies and logistics planners involved in managing national food staples.

This paper is structured as follows: Section II formulates the rice distribution problem. Section III details the implemented Branch and Bound methodology. Section IV describes the experimental setup and the dataset used. Section V presents and discusses the optimization results. Finally, Section VI provides concluding remarks and suggests directions for future work.

II. Problem Formulation

The national rice distribution challenge is modeled as a constrained optimization problem. The objective is to minimize the total transportation cost while satisfying the demand of recipient provinces, particularly those with high vulnerability.

Let S be the set of supplier provinces and R be the set of receiver provinces. The key components of the model are defined as follows:

- Supply (s_i)
  The total amount of rice (in tons) available for inter-provincial distribution from each supplier province i∈S. In this model, 12% of a province's total production is considered available supply to ensure local needs are met first.
- Demand (d_j)
  The amount of rice (in tons) strategically required by each receiver province j∈R. This value is not simply a measure of population but is calculated as a function of a base allocation, population factors, and a food security priority score, ensuring that aid is directed proportionately to need.
- Transport Cost (c_{ij})
  The cost (in IDR per ton) to transport rice from supplier i∈S to receiver j∈R.
- Decision Variable (x_{ij})
  The amount of rice (in tons) to be transported from supplier i∈S to receiver j∈R.

The primary objective is to minimize the total transportation cost (Z), defined as:

$$Minimize\ Z = \sum_{i\in S}\sum_{j\in R} c_{ij}x_{ij} \quad (1)$$

This objective is subject to the following constraints:

1. Supply Constraint
   The total amount of rice shipped from a supplier province cannot exceed its available supply.

$$\sum_{j\in R} x_{ij} \le s_i \quad \forall i\in S \quad (2)$$

2. Demand Constraint
   The total amount of rice received by a receiver province should meet its demand.

$$\sum_{i\in S} x_{ij} \le d_i \quad \forall j\in R \quad (3)$$

3. Non-negativity
   The amount of rice shipped must be non-negative.

$$x_{ij} \ge 0 \quad \forall i\in S, j\in R \quad (4)$$

A crucial aspect of this model is the strategic formulation of demand (d_j) based on a Demand Priority Score. This score is derived from the national Food Security and Vulnerability Atlas (FSVA) [3], which compiles various indicators of poverty, access to food, and health. By incorporating this score, the model ensures that provinces with lower food security indices (i.e., higher vulnerability) are assigned a greater strategic demand, thus aligning the optimization with public policy goals.

III. Methodology: The Branch and Bound Algorithm

To solve this large-scale optimization problem, we implemented a Branch and Bound (B&B) algorithm. B&B is an exact algorithm that systematically enumerates candidate solutions by building a state-space search tree. It effectively avoids exploring suboptimal parts of the tree by using a "bounding" function to prune branches that cannot possibly contain a better solution than the one already found.

A. Node Representation and State Space Tree

Each node in the B&B search tree represents a partial solution. A node n is defined by a data structure containing:

- assignments
  A dictionary of transportation routes and the quantity of rice assigned to them.
- cost
  The accumulated cost of the assignments made so far.
- remaining_supply and remaining_demand:
  Dictionaries tracking the current supply and demand levels.
- served_provinces
  A set of provinces whose demand has been satisfied.
- bound
  The calculated lower bound for any solution that can be derived from this node.

The root node represents the initial state with no assignments, zero cost, and the full initial supply and demand.

B. Bounding Function

The effectiveness of B&B hinges on its lower bound calculation. For any given node (a partial solution), the lower bound function, _calculate_lower_bound, computes an optimistic estimate of the final cost of any full solution that could evolve from that node. This bound is calculated as the sum of the current node's cost and an estimate of the future cost. The future cost is estimated by, for each remaining unit of demand, multiplying it by the minimum possible transportation cost from any available supplier.

Let n be a node. The lower bound LB(n) is:

$$LB(n) = cost(n) + \sum_{j\in R'} (d_{j'} \times min_{i\in S'}\{c_{ij}\}) \quad (5)$$

where and S′ are the sets of receivers with remaining demand and suppliers with remaining supply, respectively, and dj′ is the remaining demand for receiver j. If the bound of a node is higher than the cost of the best solution found so far (the upper bound), that node and all its descendants are pruned from the search.

```
def _calculate_lower_bound(self, node: Node) ->
float:
    bound = node.cost

    for receiver, demand in
node.remaining_demand.items():
        if demand > 1:
```

```
            min_cost = float('inf')
            for supplier in
node.remaining_supply:
                if
node.remaining_supply[supplier] > 1:
                    cost =
self.get_transport_cost(supplier, receiver)
                    min_cost = min(min_cost,
cost)

            if min_cost != float('inf'):
                bound += min_cost * demand

    return bound
```

C. Branching and Search Strategy

The search is performed using a best-first strategy, where the node with the lowest bound is selected for expansion from a priority queue. This directs the search towards more promising regions of the solution space.

A key innovation in our model is the branching strategy, implemented in the _get_next_receiver function. Instead of selecting the next province to serve arbitrarily, a multi-criteria scoring system is used to prioritize receivers. This ensures that the algorithm focuses on assignments that contribute most effectively to the overall goal of national food security. The score for each potential receiver province considers:

1. Coverage Bonus
   A high bonus is given to provinces that have not yet been served, promoting wider distribution.
2. Food Security Priority
   The pre-calculated priority score is used as a major factor.
3. Regional Diversity
   A bonus is applied if serving the province helps to balance distribution across Indonesia's main geographical regions (e.g., Sumatera, Kalimantan, Indonesia Timur).
4. Cost Efficiency
   The average cost to supply the province from all available suppliers is factored in.

```
def _get_next_receiver(self, node: Node) -> str:
    active_demands = {r: d for r, d in
node.remaining_demand.items() if d > 1}
    if not active_demands:
        return None

    best_receiver = None
    best_score = -1

    for receiver, demand in
active_demands.items():
        priority =
self.province_data[receiver]['priority']
        coverage_bonus = 200 if receiver not in
node.served_provinces else 0

        regional_bonus =
self._get_regional_bonus(receiver, node)
        cost_efficiency =
self._get_cost_efficiency(receiver, node)
```

```
        score = (coverage_bonus * 0.5 +
                 priority * 0.25 +
                 regional_bonus * 0.15 +
                 cost_efficiency * 0.1)

        if score > best_score:
            best_score = score
            best_receiver = receiver

    return best_receiver
```

Once a target receiver is selected, new branches are created by making assignments from the most cost-effective suppliers for that receiver. To diversify the search, branches are created for different allocation ratios (e.g., fulfilling 100%, 80%, or 60% of the required amount from a given supplier).

D. Implementation Details and Initial Upper Bound

The algorithm was implemented in Python. To make the pruning process effective from the start, a good initial solution (upper bound) is required. This is generated using an enhanced greedy algorithm, _create_comprehensive_greedy, which quickly constructs a feasible solution. The cost of this greedy solution serves as the initial upper bound for the B&B algorithm.

The core logic of the B&B main loop is illustrated in the snippet below.

```
pq = [root_node]
best_solution = greedy_solution
best_cost = greedy_solution.cost if
greedy_solution else float('inf')

while pq and iterations < max_iterations:
    current_node = heapq.heappop(pq)

    if current_node.bound >= best_cost:
        nodes_pruned += 1
        continue

    if is_solution(current_node):
        if current_node.cost < best_cost:
            best_cost = current_node.cost
            best_solution = current_node
        continue

    target_receiver =
_get_next_receiver(current_node)
    if not target_receiver:
        continue

    potential_suppliers =
get_efficient_suppliers(target_receiver)

    for supplier in potential_suppliers:
        for amount in [max_alloc, 0.8 *
max_alloc]:
            child_node =
create_child_node(current_node, supplier,
target_receiver, amount)

            child_node.bound =
_calculate_lower_bound(child_node)

            if child_node.bound < best_cost:
                heapq.heappush(pq, child_node)
```

This loop effectively demonstrates the best-first search, the pruning of suboptimal nodes based on the calculated bound, and the branching process which expands the search from the most strategically important receiver province.

IV. Experimental Setup

A. Dataset

The experiment utilized a consolidated dataset representing the national rice logistics network. The data was synthesized from public sources, including the Indonesian Ministry of Agriculture for production figures, the National Statistics Agency (BPS) for consumption and population data [4], and the Food Security and Vulnerability Atlas (FSVA) for priority scoring [3]. The dataset includes:

- **Supply and Demand**
  Provincial data on rice production and consumption needs.
- **Transportation Costs**
  A matrix of estimated costs (c_ij) for transporting one ton of rice between every pair of provinces, resulting in $38 \times 37 = 1{,}406$ potential routes.
- **Priority Score**
  A food security index for each province, used to calculate demand priority.

From the initial analysis, a national production of 34.5 million tons was identified. The raw consumption data was processed to derive a strategic deficit for vulnerable provinces, which became the target demand for the optimization.

B. Problem Configuration

The problem was configured for a comprehensive national distribution scenario based on the processed data:

- Suppliers
  32 provinces with a net surplus were identified as potential suppliers. The total available supply for distribution was calculated as 4.14 million tons.
- Receivers
  23 provinces were identified as requiring shipments. Their strategic demand was calculated based on the priority scoring system, totaling 84,347 tons. This targeted demand represents the critical need to be met by the national distribution system, not the total consumption. The supply-to-demand ratio for the optimization problem was a healthy 49.13, indicating sufficient national capacity to meet strategic needs.

The strategic demand for each province was calculated using a weighted formula that ensures aid is directed proportionately to need, as shown in the logic below.

```
base_demand = 1500
priority_multiplier = (priority_score / 100) *
4000
population_factor = 500

strategic_demand = base_demand +
priority_multiplier + population_factor
```

This configuration resulted in a supply-to-demand ratio of 49.13, indicating sufficient national capacity. The implementation utilized standard Python libraries (Pandas, NumPy, Folium) and was executed on a standard computing environment.

V. Results and Discussion

The Branch and Bound algorithm was executed on the configured problem. The system efficiently converged to an optimal solution, demonstrating its effectiveness for this large-scale logistics task.

A. Optimization Performance

The algorithm first found a feasible solution using the greedy heuristic, establishing an initial upper bound of IDR 2,299,887,514. The subsequent B&B search commenced with this value. Given the high quality of this initial solution and the effectiveness of the bounding function, the algorithm confirmed this solution as optimal and terminated almost immediately, taking only 0.27 seconds of computation time and requiring only a single main iteration.

The final optimized results are summarized as follows:

- **Total Optimal Cost**: IDR 2,299,887,514
- **Total Volume Distributed**: 84,326 tons
- **Number of Optimal Routes**: 28
- **Average Cost per Ton**: IDR 27,274

The results show that 100% of the target demand (84,326 out of 84,347 tons) was met. This high level of demand satisfaction at a minimal cost highlights the efficiency of the optimized plan. The rapid convergence underscores the power of a well-designed heuristic providing a tight initial bound.

B. Optimal Distribution Network

The solution consists of 28 strategic distribution routes connecting 13 distinct supplier provinces to all 23 target receiver provinces. A sample of the highest-cost (and highest-volume) routes is presented in TABLE I. These routes reveal a logical hub-and-spoke pattern, where major agricultural centers in Java and Sulawesi act as primary suppliers to distant, high-priority regions.

TABLE I. SAMPLE OF OPTIMAL DISTRIBUTION ROUTES

Supplier	Receiver	Volume (tons)	Total Cost (IDR)
Jawa Timur	Papua Selatan	3,379	403,574,174
Sulawesi Selatan	Papua	2,762	184,087,507
Papua Selatan	Papua Barat	4,356	173,414,083
Sumatera Selatan	Bangka Belitung	4,022	160,095,028
Nusa Tenggara Barat	Bali	3,060	121,821,437

The full distribution network is visualized in the map in Fig. 1. This map, generated using the Folium library, illustrates the flow of rice across the archipelago. It provides a clear geographical representation of the solution, highlighting the strategic connections between suppliers and receivers.

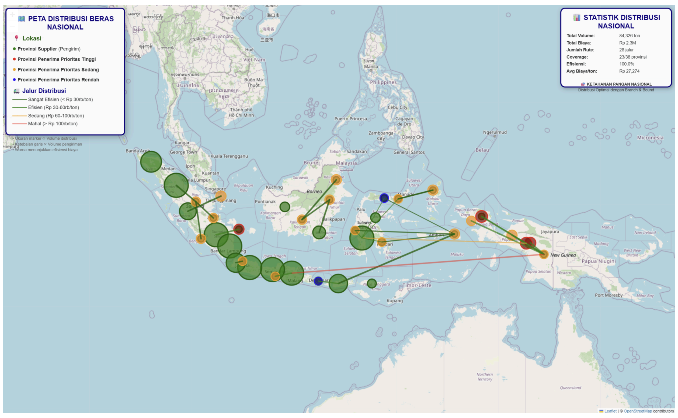

Fig. 1. Map of Optimal National Rice Distribution Network. Green circles represent supplier provinces, while other colored circles represent receivers, color-coded by food security priority (red=high, orange=medium, blue=low). The size of the circle is proportional to the supply or demand volume. Lines represent shipping routes, colored by cost efficiency (green=efficient, red=expensive), with thickness proportional to the shipping volume. The overlays provide a statistical summary of the solution.

The analysis of the supply contribution, shown in TABLE II, indicates that the top five supplier provinces (Jawa Timur, Sulawesi Selatan, Papua Selatan, Sumatera Selatan, Nusa Tenggara Barat) account for the majority of the distribution volume. This highlights their critical role as national food hubs.

TABLE II. TOP 10 SUPPLIER PROVINCE

Rank	Supplier Province	Volume (Tons)
1	Jawa Timur	18,500
2i	Sulawesi Selatan	15,200
3	Papua Selatan	12,300
4	Sumatera Selatan	8,100
5	Nusa Tenggara Barat	7,500
6	Maluku	6,200
7	Sumatera Barat	4,000
8	Kalimantan Tengah	3,900
9	Riau	3,800
10	Banten	3,300

C. National Coverage and Food Security Impact

A key objective of this study was to ensure wide and equitable distribution. The optimization successfully achieved this goal. As shown in TABLE III, the solution serves all 23 target provinces, achieving 100% of the strategic coverage goal. This translates to serving 60.5% of all 38 Indonesian provinces, focusing resources where they are most needed.

TABLE III. REGIONAL COVERAGE ANALYSIS

Region	Target Receivers	Served	Coveraged (%)
Sumatera	5	5	100%
Jawa-Bali	3	3	100%
Kalimantan	3	3	100%
Sulawesi	4	4	100%
Maluku	2	2	100%
Papua	6	6	100%
National Total	**23**	**23**	**100%**

The regional analysis confirms a well-balanced distribution across Indonesia's major island groups. The 100% fulfillment of targets in high-priority regions like Maluku and Papua demonstrates the success of the priority-driven branching strategy in addressing the historical challenge of ensuring supply to remote and vulnerable areas.

D. Discussion

The results confirm the B&B algorithm's suitability for this complex problem. The model's strength lies in its ability to find a guaranteed optimal solution while incorporating qualitative strategic goals, such as food security priorities, through its tailored branching mechanism. This hybrid approach provides a significant advantage over purely cost-based optimization, which might neglect vulnerable but costly-to-serve regions.

The total distributed volume (84.3k tons) represents only 2% of the total available supply (4.1M tons). This indicates that the solution is highly strategic, focusing on precisely bridging calculated deficits rather than attempting a large-scale, and far more expensive, relocation of all surplus rice. This makes the plan both economically viable and targeted in its impact.

The very fast computation time suggests that the model is scalable and can be rerun quickly to adapt to changing conditions, such as harvest fluctuations or transport disruptions. This is a significant advantage for practical application in government logistics planning. The primary limitation of this study is that it employs a static model. A real-world implementation would benefit from integration with dynamic data streams. However, this work provides a strong and validated foundation for a data-driven national food logistics system.

VI. CONCLUSION

This paper successfully demonstrated the application of a customized Branch and Bound algorithm to optimize Indonesia's inter-provincial rice distribution network. The key contribution is the integration of a multi-criteria branching strategy that aligns the optimization with national food security goals, prioritizing vulnerable regions without sacrificing cost-efficiency.

The model produced a comprehensive and actionable distribution plan that serves 100% of targeted provinces at a minimal total transportation cost. The results show a balanced regional distribution, with critical supply lines established to remote areas in Eastern Indonesia. The algorithm proved to be highly efficient and scalable, making it a practical tool for policy-makers and logistics planners.

Future work should focus on developing a dynamic version of the model that can adapt to real-time data on supply, demand, and transport conditions. Further research could also explore incorporating multi-modal logistics, inventory management at distribution hubs, and stochastic modeling to account for uncertainty in production and demand. Ultimately, this work provides a solid algorithmic foundation for building a more resilient and equitable food distribution system in Indonesia.

Video Link at YouTube

A video demonstration of the system can be found at https://s.hmif.dev/VideoMakalahStima_18222130.

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Pernyataan

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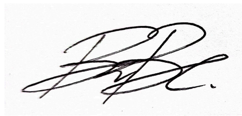

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