Optimizing rice distribution routes in Indonesia using a two-step linear programming considering logistics costs

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Abstract. The increase in rice consumption should be balanced with an increase in rice production. However, although the national rice production was declared a surplus, the volume of national rice imports also increased. The imports in 2018 were 2.2 million tons and showed that surplus rice production is not effectively taken as an advantage in overcoming the deficit in some provinces in Indonesia. Some provinces that experiencing surplus should be able to fill the shortage in the other provinces. This paper contributes to determine distribution routes and help the government to fulfill the shortage demand. This study uses the two-steps linear programming method. The first step is performed by the transportation model and followed by the Capacitated Vehicle Routing Problem (CVRP) model in sequence. This two-step linear programming reaches an optimal global solution in distributing goods from oversupply provinces to the over-demand one. The results show cost savings are gained if this strategy is performed to meet the demand, rather than importing the rice.

1. Introduction

Business logistics can also be considered as a transportation problem, which requires optimization techniques to solve[1]. The last mile distribution plays an indispensable role in serving the final customers[2]. Last-mile distribution is the last part of the supply chain logistics process, which involves a set of activities that are necessary for the delivery process from the last transit point to the final drop point[3]. A recent study discussed an innovative last-mile delivery concept in which a truck collaborates with a drone to make deliveries[4]. A study found that performance is affected by the working condition [5] or compensation to the employee[6]. In short, all efforts should be brought in to achieve customer satisfaction[7].

This paper discusses the last mile distribution for rice in Indonesia. It is important to any stakeholder to pay attention to the product availability [8]. The increase in rice consumption should be balanced with an increase in rice production to maintain a balance in the supply chain. The trend of Indonesia’s rice consumption in 2018 has increased according to the population, which is 1.27% from 2017. Production data for 2018 shows rice production in Indonesia has a surplus of 2.85 million tons. Although the national rice production was declared a surplus, the volume of national rice imports also increased. Rice imports during that period were recorded at 2.2 million tons. This number increased rapidly from the January-December 2017 period of 305.75 thousand tons. Besides, there are 22 provinces experiencing rice deficits in fulfilling the demand at the provincial level. This condition
shows that the utilization of rice production surplus is not an effective solution in overcoming the rice deficit at the provincial level in Indonesia.

The distribution of rice at the provincial level is not evenly distributed. On one hand, more than half of the provinces in Indonesia experiencing a deficit. On the other hand, 12 provinces experienced a rice surplus. The condition of rice in surplus provinces should be able to fill the needs of provinces experiencing a deficit. Therefore, equitable distribution can be a solution for the Indonesian government to meet rice needs at the provincial level.

Distribution problems was solved by various methods. Monte Carlo simulation was used to solve the problem of uncertainty in the supply chain manufacturing process [9]. Besides, Monte Carlo simulation is also used to perform the demand forecasting under uncertainty environment [10]. In addition, the genetic algorithm method is used to determine the shortest route with the traveling salesman problem (TSP) [11].

Linear programming can be used to optimize distributions based on decision variables, such as distance and cost. A previous study considered distance traveled and costs as decision variables [12]. The application of the linear programming method can be used to determine a sustainable supply chain network for biomass supply [13]. The fuzzy linear programming method is used in scheduling train stations in China [14].

This study examines the problem of uneven rice distribution at the provincial level using the linear programming method. The linear programming method is expected to be able to provide solutions for distribution between provinces experiencing rice surpluses and provinces experiencing rice deficits so that the fulfillment of rice consumption needs will be evenly distributed when viewed on a provincial scale. Furthermore, the effectiveness and efficiency can be achieved by eliminating waste, such as waste of transportation [15]. Finally, this research is also expected to provide optimal distribution solutions to minimize distribution costs.

Linear programming is a mathematical function used to determine the optimal value of an activity based on decision variables. Linear programming determines the allocation of work activities that are interconnected. This method can be done in three ways, namely algebra, graphics, and simplex [16-17]. Linear programming not only can optimize the rice distribution process but also a solution for the government in regulating the distribution. For the community, this research can meet the needs of rice consumption. For academics, this research can be a reference from the field of supply chain management for rice distribution using the linear programming method. Therefore, this paper contributes to optimizing the distribution of rice in all provinces in Indonesia.

2. Literature review
Supply chain management is a network involving distributors who work together to distribute products to consumers. The supply chain covers raw materials (upstream) to retail stores and into the hands of consumers (downstream) [18]. The movement in the distribution of the supply chain must be arranged to keep it running in an orderly manner. The shorter the supply chain will affect the price of the product that is distributed.

The transportation model is part of linear programming which functions to distribute goods from producers to consumers. The transportation method deals specifically with the transportation of materials (commodities) so that a certain transportation pattern is formed [16].

Another paper applied a route-first cluster second approach to minimize production and distribution of a perishable product [19]. This paper tries to apply the converse methodology, cluster-first route-second. A previous paper discussed a cluster-first route-second method using K-Means, K-Medoids and random clustering at the first stage and using a branch and bound algorithm at the second stage [20-21]. The first stage is to cluster and the second stage is to optimize the job dispatching using is a mixed integer linear program (MILP) [21]. The paper was aimed to maximize the picked-up loads and minimize the repair time of the damaged components considering resource, traveling time, repair time, and skill set [21]. When it comes to increasing the effectiveness, another paper proposed a total productive maintenance while achieving sustainability [22].
Similar to the previous study, this paper also aims to determine the number of vehicles and their routes to minimize the total cost of distribution[19]. A fixed cost is assumed as each vehicle hired that is paid once during the planning horizon and a variable cost is assumed as per unit distance traveled[19]. The fixed cost is significantly higher than the variable cost[19].

2.1. Clustering analysis
Clustering method varies according to data type and purpose of the study[20]. The clustering procedure is necessary to be performed prior to the initial route construction procedure[24]. This procedure increases the likelihood that the solution will converge to an optimal value[24]. The clustering stage also reduces the scale of CVRP and convert it to VRP due to control the capacity[20]. The flight trajectories are clustered based on spatial and dynamic similarity measures[25]. Passengers are clustered based on the same region with a similar walking distance from passengers’ origins to each boarding location[26]. This paper use assignment method in the clustering stage. Assignment decisions determine a particular vehicle serve particular customers, and routing decisions determine the sequence of the customers according to each vehicle assignment[4]. Highlighting the customers perspective is very important because it is the key factor to the customer’s satisfaction[27]. Previous study proposed the transportation model to assign the customer at the cluster stage, but followed by heuristics at the routing stage [28].

2.2. Capacitated vehicle routing problem (CVRP)
CVRP is one of the most important problems of optimization of distribution network and the most common type of VRP[20]. The logistic problems concerning medical device distribution and pharmacological waste collection has been discussed as a the rich vehicle routing problem (RVRP)[1]. The RVRP had been modeled as a clustered vehicle routing problem with pickups and deliveries, asymmetric variable costs, forbidden roads and cost constraints[1]. Previous paper discussed the route-first cluster-second heuristics to solve green vehicle routing problem (Green VRP)[29]. In the Green VRP the objective is to find a set of routes of minimum total distance such that each customer is visited exactly once[29]. A multi-depot two-echelon vehicle routing problem with delivery options had been discussed using a hybrid multi-population genetic algorithm to minimize the total distribution cost[2].

Another branch of VRP is bus route clustering problem (BRCP) which concerns the assignment of bus routes to different boarding locations of a bus station[26]. An efficient transport system is determined by many factors, including fleet size, routes, timetables, and frequencies[26]. A recent study proposed the genetic algorithm to solve the vehicle routing problem with time windows (VRPTW) considering the quality of perishable products[3]. A previous paper approximated the distribution cost by stochastic travel time [30]. Unlike the previous work, this paper applies a symmetric variable cost to minimize the total shipping costs served by the third party logistics.

3. Methodology
The stages of this research begin with collecting data from the observations, consist of the amount of rice surplus from each province, the amount of rice deficit from each province, the mode of transportation for distribution, shipping costs based on the mode of transportation, and the capacity of each mode of transportation. Furthermore, the determination of each mode of transportation is used for each distribution between provinces experiencing a rice surplus to provinces experiencing rice shortages. The calculation of the transportation capacity in each mode of transportation is used after adjusting the demand for rice deficit provinces. It is assumed that rice delivery for provinces experiencing deficit is carried out every week by dividing the total deficit by 52 weeks (number of weeks in a year). The shipping costs for each mode of transportation are used for both transportation and CVRP model respectively. Distribution visualization is carried out to make it easier for readers to understand the rice distribution routes for each province. Furthermore, the calculation of the total distribution cost is carried out after knowing the optimal distribution route.
The aim of this research is to optimize the even distribution of rice on a provincial scale in Indonesia. Secondary data collection is carried out by finding the required capacity and cost of the transportation modes through the land, sea, and air (airplane), as shown in Figure 1. For each consecutive subsequence the procedure is to select the lowest shipping cost as shown in equation (1) where $C_{ij}$ denotes the shipping cost from $i$ to $j$.

$$C_{ij} := \min_{k=1}^{j-1} C(i, j, k)$$  \hspace{1cm} (1)

Quantitative analysis is carried out on data in the form of numbers. There are several variables that determine the linear programming method. These variables serve as constraints that need to be known to solve distribution problems, namely [16]:

- Variables that change the decision, namely the amount of rice surplus from each province and the amount of rice deficit from each province.
- Constraint factors, namely the capacity of transport in each mode of transportation and the cost of delivery that must be incurred for the distribution of rice to each province with a rice deficit.
- The transportation model is a method for regulating the distribution of goods/services from distribution sources to places where goods/services are needed optimally.
- Determination of capacity, which is used to determine the number of modes of transportation for transporting rice according to the mode of transportation used.
- The objective function, namely the goal to be achieved, that is, maximized or minimized. In this study, the objective function is intended to determine the most optimal distribution channel and minimize distribution costs.

**Figure 1.** Design of cluster-first route-second methodology

4. Results and discussion

Each province with a surplus will become a Distribution Centers (DCs) to distribute rice to provinces experiencing a deficit. Table 1 presents the rice surplus data for twelve provinces. It is known that the total surplus rice was 12,498,945 tons, with details of the surplus in each province. The rice deficit calculation is obtained based on data from the Central Statistics Agency for each province in Indonesia. Each province with a deficit will be the destination of rice distribution. Table 2 presents the rice deficit data in twenty-two provinces in Indonesia. The total deficit of rice was 5,176,423 tons with the largest value was experienced by Jakarta, namely 1,230,000 tons.
Table 1. Supply and demand for rice

| Sources | Destinations |
|---------|--------------|
| Code    | Province     | Rice (Tons) | Code | Province | Rice (Tons) |
| DC1     | South Sulawesi | 2,310,000 | 1   | Jakarta  | 1,230,000 |
| DC2     | East Java     | 1,750,000 | 2   | West Java| 770,000  |
| DC3     | Central Java  | 1,720,000 | 3   | North Sumatera | 564,000 |
| DC4     | South Sumatera| 2,300,000 | 4   | Riau     | 425,000  |
| DC5     | Lampung       | 300,000   | 5   | Banten   | 411,000  |
| DC6     | Aceh          | 306,070   | 6   | Riau Islands | 194,798 |
| DC7     | West Sumatera | 210,390   | 7   | East Kalimantan | 187,900 |
| DC8     | South Kalimantan | 2,850,000 | 8   | East Nusa Tenggara | 178,030 |
| DC9     | Central Sulawesi | 282,141   | 9   | Bali     | 150,276  |
| DC10    | Central Kalimantan | 275,308   | 10  | Papua    | 147,949  |
| DC11    | West Nusa Tenggara | 180,000   | 11  | Maluku   | 142,280  |
| DC12    | West Sulawesi | 15,037    | 12  | Yogyakarta| 142,000  |
|         |              |          | 13  | Bangka Belitung Islands | 111,042 |
|         |              |          | 14  | West Kalimantan | 122,586 |
|         |              |          | 15  | North Maluku | 88,780  |
|         |              |          | 16  | West Papua | 63,085  |
|         |              |          | 17  | North Sulawesi | 50,004  |
|         |              |          | 18  | Bengkulu   | 53,848  |
|         |              |          | 19  | Jambi      | 97,240  |
|         |              |          | 20  | North Kalimantan | 36,720  |
|         |              |          | 21  | Southeast Sulawesi | 9,289   |
|         |              |          | 22  | Gorontalo  | 596     |

Total 12,498,945 5,176,423

The coordinates of warehouse or DCs are obtained through Google Maps. This paper uses the minimum shipping costs per kilogram by a private company. This transportation model is used as the clustering stage to deliver the rice. Table 2 presents the number of shipments (kg) and the minimum cost per unit. There are eight transmissions from DC1, DC2, DC3, DC4, DC6, DC7, DC10, and DC11. Because the surplus amount exceeds the total demand, there are DCs that don’t need to send rice, namely DC5, DC8, DC9, and DC12. Each DC represents each cluster and it can have 1 or more trips subject to the capacity of transportation mode. The visualization of sources, destinations, and routes are shown in Figure 2.

Table 2. Routing decisions and related costs (1 x 10^3)

| Cluster | Route | Shipping Cost (IDR/kg) | Demand (kg) | Total Cost (IDR) |
|---------|-------|------------------------|-------------|-----------------|
| 1       | DC1 – 20 – 15 – 21 – 16 – 10 – 22 – DC1 | 291.5 | 6,662 | 1,941,973,000 |
| 2       | DC2 – 5 – DC2 | 14 | 7,904 | 110,656,000 |
|         | DC2 – 7 – 14 – 1 – 11 – DC2 | 101 | 16,822 | 1,699,022,000 |
|         | DC2 – 13 – DC2 | 46 | 2,135 | 98,210,000 |
| 3       | DC3 – 1 – DC3 | 14 | 15,538 | 217,532,000 |
|         | DC3 – 12 – 2 – DC3 | 19 | 17,538 | 333,222,000 |
The highest shipping cost is found in DC1, which is also cluster 1, namely IDR 291,500/kg. Meanwhile, the lowest shipping cost is in DC11 which is also a cluster 8, which is IDR 10,000/kg. The demand in Table 2 has been converted from tons to kg so that the resulting total costs are the total cost per trip. The trip with the highest cost is in cluster 1 which happens to only have 1 trip, which is IDR \(1.94 \times 10^{11}\). The total cost of all trips is IDR \(5.26 \times 10^{11}\) per week or IDR \(2.73 \times 10^{14}\) per annum.

It is important to enrich the clustering process by identifying and labeling outliers[25]. The increasing traffic congestion, environment issues, and small truckloads may be considered as a unique characteristics[2]. Any trade-off should be balanced and assessed using feasibility study [31].

5. Conclusion
Based on the results of the transportation model, it shows that the delivery assignment with the minimum cost from each DC to the destinations. Distribution route processing is carried out using the CVRP model. The results of the CVRP model show the most efficient distribution route for each DC based on predetermined loading. In 2018, there were 2.2 million tons imported rice with a total expenditure of USD 1.02 billion or equal to IDR \(1,416.02 \times 10^{14}\). This means, by utilizing the potential of regions that have a surplus the government can save \(1,413.29 \times 10^{14}\).

The policy of utilizing surplus areas does have several challenges and limitations. By implementing this policy, it means that local governments that are surplus send all excess stock without paying attention to meeting needs in the following year. The government’s import policy has strong reasons for securing stocks in the regions for a certain period so that if there is a disruption in the supply line, the community will not experience shortages of stock. For this reason, further research can use the safety stock policy as a factor that can affect the amount of supply from DC, because each DC also needs to pay attention to stock safety in the next few months.
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