Determination distribution route of beverage products with the application of the vehicle routing problem model and sensitivity analysis

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Abstract. Vehicle Routing Problem (VRP) is the problem of determining the optimal route to distribute goods or products using vehicles to some customers. The goals are to minimize the cost and distance of distribution by observing some constraints or restrictions. The problem of determining the distribution route of beverage products in Serang City by a beverage distribution company can be solved by applying the VRP model by considering the vehicle capacity limit. The optimal solution of route determination models is obtained by using Branch and Bound method of the LINGO 18.0. Results showed that the optimal route of distribution with the implementation of the VRP model could minimize the total distribution costs incurred by the company compared to the existing distribution route used by the company. Sensitivity analysis results showed that changes in fuel costs resulted in optimal routes gained by the application of the VRP model could not be sustained, so a new decision was required by the company in determining the distribution route. The reduction in fuel costs resulted in a reduction in total distribution costs and increased fuel costs increased the total cost of distribution.

1. Introduction

In today's era of globalization, efficiency in distribution and logistics systems is an important key to winning the global competition, one of which is for the product distribution business. Distribution as one of the main components of the logistics system plays a very important role and is quite influential to the success of a company. Each company needs good distribution management so that the products delivered can be received in good condition, on time, and right at the intended location. In product distribution, transportation activities play an important role. Transportation activities consume time, money, and environmental resources. Ineffective and irregular distribution systems can result in time costs and transportation costs and can have a negative impact on consumer satisfaction levels.

The first research on Vehicle Routing Problem (VRP) was conducted by Dantzig and Ramser in 1959 [1] and the algorithm Branch and Bound were first proposed by Land and Doig in 1960 [2]. The Branch and Bound method was applied to resolve cases that arose in health care logistics in the Netherlands to determine which lockers to open as well as routes to visit those lockers and routes to visit patients not covered by open lockers [3]. To minimize delivery costs and locker opening costs. In this study, a fast hybrid heuristic was proposed to solve the problem and obtained results that consistently outperformed the exact method.

Referring to research on the distribution of beverage products in Serang city by Supriyadi, Mawardi, and Nalhadi in March 2017 [4], the authors tried to implement VRP models to solve problems with the
determination of distribution routes by the beverage distribution company. The company still runs a less effective and random distribution system. The distribution of products to retailers does not pay attention to aspects of location, route, distance, transport capacity, and delivery schedule, resulting in large distribution costs, ineffective time used, and the use of carrying capacity to be non-maximal. This is certainly not profitable for the company, therefore the best solution is needed to solve the problem by determining the optimal distribution route to effectively the total cost and distance. VRP that aims to determine routes with the minimum total distribution cost can be applied to the solution of the problem and subsequently the model is solved with LINGO 18.0 software using the Branch and Bound methods. Furthermore, sensitivity analysis is carried out to see how the parameters change, namely the cost of fuel on the optimal solution that has been obtained.

2. Method
The problem model for determining the distribution route of beverage products is obtained by applying the VRP model. The model was obtained and modified from the Heterogeneous Fleet VRP mathematical model [5] and the capacitated and distance constrained open VRP mathematical model [6]. The VRP model is solved with the Branch and Bound method of LINGO 18.0 software to obtain the optimal solution for the determination of distribution routes. Furthermore, a sensitivity is carried out on the optimal solution that has been obtained. In various Operational Research(OR) problems, the Branch and Bound method can be applied, in particular, it can be used to solve Integer Programming Problem[7]. The research was conducted in the delivery area of Serang City [4].

2.1. Vehicle Routing Problem
In addition to the problem of shipping or picking up goods, the model and algorithm for finding solutions from VRP can also be applied to everyday transportation problems [8]. Refer to Miller (2002), VRP is an extension of the Travelling Salesman Problem (TSP), where a vehicle or salesman traveling via a single route cannot visit all fixed customer locations that require a visit. In such cases, several routes from one depot are required to visit the customer's location to be served [9].

2.2. Sensitivity Analysis
Sensitivity analysis aims to learn about how the effect of changing discrete parameters on the optimal solution[10].

2.3. Beverage Product Distribution Route Determination Model
In determining the distribution route of beverage products, there are several assumptions used namely:

- The amount of demands each retailer is known in advance.
- Each retailer is connected and the distance between locations is symmetrical, meaning the distance from the \( i \) retailer to the \( j \) retailer is equal to the distance from the \( j \) retailer to the \( i \) retailer.
- The time for product distribution is not specified but depends on the order of each retailer.
- Vehicle speed was not taken into this research.
- Traffic conditions and accidents do not affect distribution.

The set notations used in VRP models are as follows:

\[
C \quad : \text{retailer set, notified as } C = \{2, \ldots, n\}
\]

\[
N \quad : \text{the set of warehouses and retailer, notified as } N = \{1, 2, \ldots, n\} \text{ with vertex } 1 \text{ indicates the warehouse}
\]

\[
V \quad : \text{product distribution tour set, notified as } V = \{1, 2, \ldots, V_s\}
\]

\( V_s \) is the amount of product distribution tours needed and the \( V_s \) obtained from rounding up the result of the distribution of total demand with the capacity of vehicles used for distribution. For a vehicle capacity of 70 crates, it is calculated as follows:
The indexes used in the VRP model are as follows:

\( i, j \) : warehouse and retailer index

\( v \) : tour index

The parameters used in VRP models are:

\( c_{ij} \) : travel cost from warehouse/retailer to warehouse/retailer in one day

\( \alpha \) : vehicle fuel cost each km in one day

\( d_{ij} \) : distance from warehouse/retailer \( i \) to warehouse/retailer \( j \)

\( f \) : fixed cost of delivery of a vehicle in one day

\( m \) : the number of vehicles are used for distribution

\( q_j \) : the amount of demand to be distributed to each retailer \( j \)

\( G \) : maximum capacity of vehicles

\( n \) : the number of destination locations consist of warehouses and retailer

The decision variables in the VRP model are as follows:

1. \( x_{ijv} \) variable is a binary integer variable that is stated as follows:

\[
x_{ijv} = \begin{cases} 
1; & \text{if the vehicle departs from location } i \text{ to location } j \text{ on tour } v \\
0; & \text{other},
\end{cases}
\]  

(1)

2. \( u_v \) variables are real arbitrary numbers that satisfy the constraints of sub tour elimination if the retailer \( i \) is visited on tour \( v \), expressed as:

\[
u_v \geq 0, \forall i \in C, \forall v \in V.
\]  

(2)

VRP model for the problem of determining the distribution route of beverage products to minimize the total distribution cost is presented as follows:

Minimize \( Z = \sum_{v \in V} \sum_{i \in N} \sum_{j \in N, j \neq i} c_{ij} x_{ijv} + f \cdot m \)  

(3)

subject to

\[
\sum_{v \in V} \sum_{i \in N, i \neq j} x_{ijv} = 1; \forall j \in C
\]  

(4)

\[
\sum_{j \in C} \sum_{i \in N, i \neq j} q_j x_{ijv} \leq G; \forall v \in V
\]  

(5)

\[
\sum_{i \in N, j \neq k} x_{jkv} - \sum_{j \in N, j \neq k} x_{ijv} = 0; \forall k \in C \text{ and } \forall v \in V
\]  

(6)

\[
u_v - u_{jv} + n \cdot x_{ijv} \leq n - 1; \forall i, j \in C, i \neq j \text{ and } \forall v \in V
\]  

(7)

\[
x_{ijv} \in \{0,1\}; \forall i, j \in N, i \neq j \text{ and } \forall v \in V
\]  

(8)

\[
u_v \geq 0, \forall i \in C, \forall v \in V.
\]  

(9)

The objective function (3) is a distance function with \( c_{ij} = \alpha d_{ij} \), aiming to minimize the total distribution cost incurred by the company in one day. The delivery constraints function (4) limits that each retailer is visited exactly once. The function of vehicle capacity constraints (5) limits that the total product distributed to each retailer by a vehicle does not exceed the maximum capacity of the vehicle serving that route. The function of route continence constraints (6) limits that any vehicle that visits a retailer, upon completion of service will leave the retailer. The sub tour elimination constraint function
limits that there are no sub-tours on each route formed, meaning that each route always starts and ends in the warehouse and there is no commute between the two locations only.

3. Result and Discussion

3.1. Solving Distribution Route Determination Problem

The company has one warehouse and 10 fixed retailers with the address and demand of each retailer in one week listed in Table 1. The distance between distribution locations is listed in Table 2. The vehicle used only one unit is Mitsubishi Box Truck with a capacity of 70 crates so that after the vehicle has finished distributing the product on a tour, the vehicle must return to the warehouse to pick up the product (reloading) to fulfill the demand of other retailers on the next tour. The fuel cost incurred by the company for one day is Rp929.63/km and the fixed cost incurred by the company in one day is Rp615,113.33/unit. Fixed costs consist of vehicle operating costs, consumption costs, fuel costs, and salaries of 2 employees.

Table 1. List of destinations and requests in Serang City

| No. | Code | Retailer            | Address            | Demand (crates) |
|-----|------|---------------------|--------------------|-----------------|
| 1   | T1   | Warehouse           | Distribution Companies | 0               |
| 2   | T2   | Pemancingan         | Cipocok Jaya       | 67              |
| 3   | T3   | Dealer Yamaha       | Sempu              | 15              |
| 4   | T4   | RM Nasgor Gaul      | Sempu              | 2               |
| 5   | T5   | SMA N 5 Kota Serang | Kasemen            | 6               |
| 6   | T6   | RM Labbaik          | Terondol           | 12              |
| 7   | T7   | RM Sederhana        | Kebon Jahe         | 17              |
| 8   | T8   | Tims Karaoke        | Legok              | 2               |
| 9   | T9   | RM Padang           | Bhayangkara        | 5               |
| 10  | T10  | Puskesmas           | Karundang          | 13              |
| 11  | T11  | RM Madani           | Bhayangkara        | 28              |
|     |      | **Total**           |                    | **167**         |

Source: [4]

Table 2. Matrix of distances between locations in km units

|     | T1   | T2   | T3   | T4   | T5   | T6   | T7   | T8   | T9   | T10  | T11  |
|-----|------|------|------|------|------|------|------|------|------|------|------|
| T1  | 0    | 3.76 | 2.46 | 2.97 | 5.99 | 3.18 | 1.32 | 6.33 | 4.78 | 3.46 | 5.85 |
| T2  | 3.76 | 0    | 3.26 | 2.40 | 6.38 | 4.57 | 1.84 | 7.46 | 2.78 | 3.14 | 3.21 |
| T3  | 2.46 | 3.26 | 0    | 0.13 | 6.19 | 3.46 | 0.45 | 6.21 | 3.23 | 2.12 | 3.76 |
| T4  | 2.97 | 2.40 | 0.13 | 0    | 4.65 | 3.17 | 1.28 | 6.48 | 3.79 | 2.97 | 3.37 |
| T5  | 5.99 | 6.38 | 6.19 | 6.45 | 0    | 5.45 | 6.53 | 4.82 | 8.69 | 7.42 | 8.83 |
| T6  | 3.18 | 4.57 | 3.46 | 3.17 | 5.45 | 0    | 4.40 | 5.73 | 3.40 | 4.59 | 6.38 |
| T7  | 1.32 | 1.84 | 0.45 | 1.28 | 6.53 | 4.40 | 0    | 5.01 | 3.65 | 3.18 | 4.06 |
| T8  | 6.33 | 7.46 | 6.21 | 6.48 | 4.82 | 5.73 | 5.01 | 0    | 10.45 | 8.5  | 10.87 |
| T9  | 4.78 | 2.78 | 3.23 | 3.79 | 8.69 | 3.40 | 3.65 | 10.45 | 0    | 2.43 | 0.24 |
| T10 | 3.46 | 3.14 | 2.12 | 2.97 | 7.42 | 4.59 | 3.18 | 8.50 | 2.43 | 0    | 2.39 |
| T11 | 5.85 | 5.21 | 3.76 | 3.37 | 8.83 | 6.38 | 4.06 | 10.87 | 0.24 | 2.39 | 0    |

Source: [4]

The obtained optimal distribution route of beverage products as seen in Table 3.
Table 3. The optimal distribution route of beverage products

| Tour | Route | Total Distance (km) | Total Demand (crate) |
|------|-------|---------------------|----------------------|
| 1    | Warehouse → RM Sederahana → Dealer Yamaha → RM Nasgor Gaul → warehouse | 4.87 | 34 |
| 2    | Warehouse → puskesmas → RM Madani → RM Padang → RM Labbaik → Tims karaoke → SMA N 5 Kota Serang → warehouse | 26.03 | 66 |
| 3    | Warehouse → pemancingan → warehouse | 7.52 | 67 |
| **Total** | | **38.42** | **167** |

The total distribution cost incurred by the company for the optimal route using one vehicle unit with 3 tours in one day is Rp650,830.00.

After obtaining the optimal solution for the problem of determining the distribution route of the beverage product, further analysis of sensitivity in VRP by creating several parameter change scenarios to see how the change in fuel cost parameters affects the optimal solution that has been obtained, whereby for the value of other parameters it is assumed the value is not changed. The analysis is carried out by adding and subtraction an existing parameter value assuming the type of vehicle used remains the Mitsubishi Box Truck capacity of 70 crates. The causes of changes in material costs include the rupiah exchange rate against the dollar, world oil price, and inflation. The percentage change in fuel cost value is set from -10% to 20% each 5% specified using trial and error concepts and obtained calculation results as presented in the following Table 4.

Table 4. Route changes & distribution costs due to changes in fuel costs

| Changes in Fuel Costs | Fuel Cost (Rp/km/day) | Distribution Route of Each Tour | Distribution Costs (Rp/day) |
|-----------------------|-----------------------|-------------------------------|-----------------------------|
| -10%                  | 836.67                | T1-T2-T1                      | 647.258                     |
|                       |                       | T1-T10-T11-T9-T6-T8-T5-T1    |                             |
|                       |                       | T1-T7-T3-T4-T1               |                             |
| -5%                   | 883.15                | T1-T2-T1                      | 649.044                     |
|                       |                       | T1-T7-T3-T4-T1               |                             |
|                       |                       | T1-T5-T8-T6-T9-T11-T10-T1    |                             |
| 0%                    | 929.63                | T1-T7-T3-T4-T1               | 650.830                     |
|                       |                       | T1-T10-T11-T9-T6-T8-T5-T1    |                             |
|                       |                       | T1-T2-T1                      |                             |
| 5%                    | 976.11                | T1-T2-T1                      | 652.615                     |
|                       |                       | T1-T7-T3-T4-T1               |                             |
|                       |                       | T1-T10-T11-T9-T6-T8-T5-T1    |                             |
| 10%                   | 1.022,59              | T1-T4-T3-T7-T1               | 654.401                     |
|                       |                       | T1-T2-T1                      |                             |
|                       |                       | T1-T10-T11-T9-T6-T8-T5-T1    |                             |
| 15%                   | 1.069,04              | T1-T2-T1                      | 656.186                     |
|                       |                       | T1-T7-T3-T4-T1               |                             |
|                       |                       | T1-T5-T8-T6-T9-T11-T10-T1    |                             |
| 20%                   | 1.115,56              | T1-T10-T11-T9-T6-T8-T5-T1    | 657.973                     |
|                       |                       | T1-T7-T3-T4-T1               |                             |
|                       |                       | T1-T2-T1                      |                             |
Based on Table 4, the change in the value of fuel cost parameters is very sensitive, because a 5% change in fuel costs already affects decisions in the determination of distribution routes. Changes in fuel costs resulted in optimal routes that had been obtained previously untenable or required new decisions in the determination of distribution routes to minimize the total distribution costs incurred by the company. If the value of the fuel cost parameter decreases by 10% and 5%, then the total distribution cost decreases by 0.54% and 0.27%. If the value of fuel cost parameters increases by 5%, 10%, 15%, 20% then the total distribution cost increases by 0.27%, 0.54%, 0.82%, 1.1%.

Table 5. Comparison between the existing and optimal distribution

| Distribution | Distribution costs | Total route distance |
|--------------|--------------------|---------------------|
| Existing     | Rp668,446.67 /day or Rp20,053,400.00 /month | 57.37 km |
| Optimal      | Rp650,830.00 /day or Rp19,524,900.00 /month | 38.42 km |
| Difference   | Rp17,616.67 / day or Rp528,500.00 /month   | 18.95 km |

Table 5 shows that by using the optimal distribution with the application of the VRP model, the total distribution costs incurred by the company and the distance traveled by the vehicle are minimum compared to using existing distribution.

4. Conclusion
Based on the above description, it can be concluded that the problem of determining the route of distribution of beverage products in a beverage product distribution company in Serang City can be solved by applying the Vehicle Routing Problem (VRP) model. The optimal distribution route obtained using the Branch and Bound method in LINGO 18.0 software can minimize the total distribution cost of the company's products compared to the existing route used by the company. Sensitivity analysis was conducted with the help of LINGO 18.0 software and obtained the result that changes in fuel costs resulted in optimal routes obtained by the implementation of VRP models untenable. Therefore, the company needed to make new decisions in determining distribution routes. The decrease in fuel costs resulted in a decrease in total distribution costs and an increase in fuel costs increased total distribution costs.

On the issue of determining the route of distribution of products, it would be better if other factors were also considered such as highway density and distribution time as well as in subsequent research can also be designed other completion methods for later compared to the methods used in this research.

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