MODEL OF VEHICLE ROUTING PROBLEM WITH SPLIT DELIVERY MULTI TRIPS, MULTI PRODUCTS AND COMPARTMENTS FOR DETERMINING FUEL DISTRIBUTION ROUTES

Dinda Safitri Ramadhani[1*], Nur Aini Masruroh[2], Joko Waluyo[3]

[1]Master of System Engineering, Universitas Gadjah Mada
[2,3]Department of Mechanical and Industrial Engineering, Universitas Gadjah Mada
*Correspondence: dinda.safitri.r@mail.ugm.ac.id

Abstract

The industrial development in Indonesia encourages companies to have high sensitivity in competing to meet consumer demands promptly by considering minimum distribution costs. One of the factors that can affect distribution costs is route determination. Determining the distribution route is the Vehicle Routing Problem (VRP). The purpose of VRP is to arrange the order of distribution routes to produce a minimum total distance. This study aims to determine the fuel distribution route at TBBM Rewulu in one period to obtain the optimal distribution route and minimize the vehicle mileage. Delivery is carried out using three types of tanker trucks with heterogeneous capacities. This study uses a mathematical model of Mixed Integer Linear Programming (MILP) by considering split delivery, multi trips, multi-products, and compartments.

The branch and bound method in the LINGO solver has been used to solve this problem. This model was tested on a simple case using data of 8 customers with different distances and demand shipped by truck. The results obtained indicate that no boundaries are violated, and all consumers are served. The mathematical model built is still general, so it can solve similar cases. A model can be developed for further research by adding VRP variants such as time windows and adding the product types to represent the entire existing system.

1. Introduction

The increase in Indonesia's population impacts all aspects of people's lives, especially on the consumption of fuel oil (BBM) in the transportation sector. Companies are required to have high competitiveness against changes that occur to survive and compete with other companies. The projected energy demand in the transportation sector has increased from 362 million BOE (barrel oil equivalent) in 2017 to 1,252 million BOE (barrel oil equivalent) in 2050 or with an average growth rate of 3.8% per year (BPPT, 2019).

The distribution system is an important thing that must be considered because it becomes the main supporting factor after the production process. Distribution activities ensure that the product arrives in the hands of consumers on time, following the conditions ordered, with minimal shipping costs (Febriandini et al., 2020). In distribution problems, there is often a delay in receiving goods to consumers, which is the cause of not paying attention to the problem of finding the fastest or shortest path and setting the order of customers to be visited by starting and ending at the central depot.

One of the efforts made by the company to avoid delays in delivery to consumers is to make deliveries quickly, do not cost a lot, and have a minimum distance. This effort can be carried out by considering the configuration of the right distribution route and following the company's characteristics. Given the company has a limited number of vehicles and vehicle capacity. The absence of control over the distribution of products can cause losses for the company (Rofiq et al., 2016).

The problem of determining the route is generally known as the Vehicle Routing Problem (Karim et al., 2017). The Vehicle Routing Problem (VRP) is a problem in finding the optimal route for delivery or collection of goods or services from one or more depots to a number of cities or customers by meeting a number of constraints (Baradaran et al., 2019).

In general, the purpose of VRP is to minimize distribution costs and mileage as well as minimize the number of vehicles used, balance travel routes, and minimize consumer dissatisfaction such as delays in delivery times (Toth and Vigo, 2002).

The vehicle routing problem (VRP) is one of the most important and studied combinatorial optimization problems in distribution, logistics, and transportation (Feng et al., 2017). There are much literature that discusses how to solve this problem. Many studies have developed various variants of the classic VRP model, such as the VRP model with particular characteristics of multiple routes or multiple trips (VRPMT) conducted by Prins (2002), Olivera, and Viera (2007), Mingozzi et al. (2013).

This characteristic illustrates that one vehicle can serve more than one route in one planning horizon. Prins (2002) discusses a real case of a French furniture manufacturer to minimize the total travel time and the number of vehicles needed. Heuristic and Tabu Search methods were applied to this study to provide solutions in real cases with 775 stores for distribution purposes. Olivera and Viera (2007) proposed the Adaptive Memory Programming (AMP) algorithm, while Mingozzi et al. (2013) used an exact method with two-set-partitioning in formulating existing problems. The researcher proposes four Column and Cut Generations and then uses an integer programming solver to reduce the existing problems.

Pramuditha (2014) conducted a VRP study on drug distribution in pharmaceutical companies with the characteristics of multiple product distribution systems from single distribution centers to multiple buyers using multi-vehicles. Shipments are made to 56 customers for each delivery period. The model is built with the characteristics of integer linear programming, and the solution is searched using LINGO software.

The optimization can reduce distribution costs by 22.97% and save time by 233.88 minutes. Setiawan (2016) developed a variant of the Heterogenous-VRP model by adding multi-trips and multi-products variants. A variation of this VRP is where the company has a heterogeneous fleet in terms of capacity, fixed and variable costs, and speed. The artificial data that has been built is then solved using the exact branch, and bound method and the results are compared with the genetic algorithm.

This research tries to consider other variants of VRP, namely in the conditions of split delivery, multiple trips, multiple products, and compartments. This research was applied to a real case at Pertamina TBBM located in Rewulu, Yogyakarta. So far, the delivery of BBM products has only been based on the driver's experience. This method cannot guarantee that route of each vehicle is optimal route. Therefore, this study will determine the fuel delivery route in one delivery period to obtain the optimal distribution route and reach the vehicle mileage.

2. Methodology

A. System Characteristics

PT. Pertamina TBBM Rewulu is one of the Pertamina companies that acts as a distribution center (DC) for fuel oil. TBBM Rewulu delivered petrol products to several gas stations located in Yogyakarta and parts of Central Java, namely Purworejo, Magelang, Temanggung, and Klaten. The fuel supply is obtained from the Pertamina RU IV Cilacap refinery through a pipeline network and then distributed by TBBM Rewulu to any customers of gas stations. Fuel delivery from the depot uses a tank truck which consists of three types of capacities, namely 16 kiloliters, 24 kiloliters, and 32 kiloliters.

Each tank is divided into compartments with a homogeneous compartment capacity of 8 kiloliters. In general, there are 140 customer gas stations served by TBBM Rewulu. However, in the case of fuel distribution, each gas station is not required to make a request every day, so the number of gas stations served by the depots are various because it depends on whether or not there is a request from the gas station. The products that will be discussed in this research are biodiesel and pertalite with deterministic demand characteristics.

This research will use the exact branch and bound method in the LINGO 18.0 software. The advantage of the branch and bound method lies in its effectiveness in solving problems with accurate results (Lubis and Herliansyah, 2017). The model that will be developed in the fuel distribution has several limitations, namely:

1. Split Delivery
   Products delivered to one customer can be split into one or more vehicles.
2. Multi Trips
   One vehicle can serve customers or routes in one tour products delivery.
3. Multi Products and Compartments
   The vehicle has more than one compartment, and the products being delivered are more than one kind of product.

But, one compartment can only be filled with one kind of product.

B. Distribution Process

To distribute fuel from the depot to the gas station, PT. Pertamina is supported by its subsidiary, PT Patra Niaga, responsible for managing the delivery of fuel using a fleet of tank trucks, most of which are rental cars. Figure 1 describes the distribution process from depot to customers.
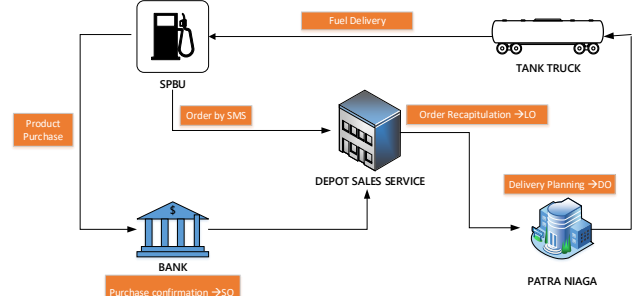

Figure 1. Distribution process of fuel delivery from depot to customers

The distribution flow begins with the gas station reporting the stock demand for fuel via SMS one day before petrol products are sent to the gas station. Then the SMS will be received by the server. The depot sales service will confirm the request whether the quantity and type of BBM ordered is available, and the depot can send BBM on demand. If the depot can make deliveries, the gas station will get a payment code to pay according to the amount ordered. The bank confirms the purchase and then issues an SO (Sales Order).

The list of buyers will be collected by the sales service in the form of LO (Loading Order) then a distribution plan will be made. The fuel delivery plan that the depot sales service has prepared is submitted to Patra Niaga as the tank truck's steward for further delivery to the gas station. Patra Niaga usually makes deliveries based on previous experience because there is no optimization of shipping routes. Generally, gas stations located close to the depot will be supplied first and then to gas station locations that are far away.

Fuel delivery using tank trucks with different capacities. These tank trucks are compartmentalized and do not have flow meter. This implies that the contents of a compartment cannot be used to replenish more than one underground reservoir. Consequently, each compartment of the delivery vehicle must be filled with one of the products to be delivered on its route. Each compartment has a capacity of 8 kiloliters. So, consumers who want to order petrol products must order with multiple capacities of 8 kiloliters.

3. Results and Discussion

A. Mathematic Formulation

The mathematical model used in this study refers to Normasari and Warangga (2019) research with modifications model according to the specified system characteristics. The mathematical model consists of several sets, index, parameters, and variable.

1. Index :

V = (0, 1, 2, …, n)	: Set stations and depot
E = {(i,j)|i,j∈V, i<j }	: Set of undirected edges
K	: Set of vehicles (k = 1, …, K)
P	: Set of products (p = 1, …, P)
T	: Set of trips (t = 1, …, T)

2. Parameter

z_k : number of a compartment in vehicle k

Cap_k : capacity of a single compartment of vehicle k

C_{ij} : distance from i to j

d_{jp} : demand of stations j for product p

h : dummy variable for synchronize origin and destination

3. Decision Variables :

x_{ijkt} : 1, if vehicle k trip t is traveling from i to j;
0, otherwise

y_{jt} : 1, if node j visited on trip t;
0, if otherwise

u_{jtp} : number of products p delivered during trip t
to customer j

This mathematical model is made in the form of Mixed Integer Linear Programming (MILP) with the notations described previously. The objective function and constraints of the mathematical model are shown below:

Objective Function:

$$minimize \sum_i \sum_j \sum_k \sum_t C_{ij} x_{ijkt} \qquad (1)$$

Subject to :

$$\sum_{j \in V \setminus \{1\}} x_{ijkt} \le 1 \qquad \forall t, k, i = 1 \qquad (2)$$

$$\sum_i x_{ihkt} - \sum_j x_{hjkt} \le 1 \qquad \forall k, t, h \qquad (3)$$

$$\sum_i x_{ihkt} - \sum_j x_{hjkt} = 0 \qquad \forall k, t, h \qquad (4)$$

$$x_{ijkt} + x_{jikt} \le 1 \qquad \forall i, j, k, t \qquad (5)$$

$$\sum_i \sum_k \sum_t x_{ijkt} \ge 1 \qquad \forall j \qquad (6)$$

$$\sum_t u_{jtp} \ge d_{jp} \qquad \forall j \in V, p \qquad (7)$$

$$\sum_{j \in V \setminus \{0\}} u_{jtp} \le z_k Cap_k \qquad \forall k, t, p \qquad (8)$$

$$x_{ijkt} \in \{0,1\} \qquad \forall (i,j) \in E, k, t \qquad (9)$$

$$y_{jt} \in \{0,1\} \qquad \forall i \in V \setminus \{0\}, k, t \qquad (10)$$

The objective function in formula (1) is to minimize the total distance of vehicle. Constraint (2) ensures that the vehicle can be used more than once. Constraint (3) ensures the continuity of the routing process, ensuring that vehicles leaving the depot will return to the depot. Constraint (4) ensures a vehicle of various origins to h must exit the h to wherever the next destination, except h = depot. Constraint (5) states that there are no vehicles that return to the previous point that has been visited.

Constraint (6) ensures that each customer can be visited by several vehicles. Constraint (7) ensures that d_{jp} dan u_{jtp} Synchronize. The maximum amount of fuel a vehicle can deliver during a single trip is bounded by the number of compartments dedicated to this type of fuel, multiplied by the compartment capacity (Constraint 8). Constraint (9) and (10) define a binary variable.

B. Model Verification

The model that has been built is then verified with a simple case using the exact branch and bound method through the LINGO 18.0. Model verification is carried out to ensure that the model created is running according to the expected logic, namely following the behavior of the system. The problems for the following simple case are using one depot and 8 customers with two types of products sent in biodiesel and pertalite. The vehicles used are 3 tank trucks with a capacity of 16 kL, 24 kL dan 32 kL. Each customer has their code to describe the petrol station. There are:

Table 1. List of customers

No	Code	Address
1	Depot	Jl. Wates Km 10, Argomulyo, Bantul
2	4155101	Jl. KOmpol Suprapto, Lempuyangan
3	4155201	Jl. Laksda Adisucipto
4	4155202	Jl. HOS Cokroaminoto, Tegalrejo
5	4355218	Jl. Ring road utara, Mlati, Sleman
6	4355715	Jl. Samas No. 2, Palbapang, Bantul

Table 1. List of Customers (Continue)

No	Code	Address
7	4355810	Jl. Dharmakusuma, Selang, Wonosari
8	4454101	Jl. Kledung Kradenan, Banyuurip
9	4454102	Jl. Raya Butuh-kutoarjo Km.4

The following table is consumer demand data, distance matrix from depot to the costumer and between costumers can be seen in the Table 2.

Table 2. Customer's demand (Kiloliters)

No.	Code of Petrol Station	Biosolar	Pertalite
1.	DEPOT	0	0
2.	4155101	0	8
3.	4155201	0	16
4,	4155202	8	16
5.	4355218	8	8
6.	4355715	0	8
7.	4355810	0	16
8.	4454101	8	16
9.	4454102	0	8

Table 3. Distance matrix for each depot and customer (Kilometers)

	1	2	3	4	5	6	7	8	9
1	0	13	16,8	10,5	15,7	18,6	54,1	50,1	69,2
2	13	0	4,4	4,5	9,1	17	39,4	62	77,2
3	16,8	4,4	0	8,9	11,4	22	37,8	65,8	82,5
4	10,5	4,5	8,9	0	6,1	15,6	45	59,5	76,2
5	15,7	9,1	11,4	6,1	0	25	48	64,7	81,4
6	18,6	17	22	15,6	25	0	40,5	52,4	68,3
7	54,1	39,4	37,8	45	48	40,5	0	91,3	107
8	50,8	62	65,8	59,5	64,7	52,4	91,3	0	15,3
9	66	77,2	82,5	76,2	81,4	68,3	107	15,3	0

Table 3 is a matrix of the distance from the depot to the consumer and the distance between consumers in kilometers. Distance data is obtained from the real distance by google maps. The mathematical model was successfully tested using the branch and bound method on LINGO 18.0 with the simple case above, so the results of delivery routes are:
vehicle 1 route 1 serving consumers $1 - 3 - 5 - 1$
vehicle 2 route 1 serving consumers $1 - 4 - 1$
vehicle 2 route 2 serving consumers $1 - 4 - 1$
vehicle 3 route 1 serving consumers $1 - 8 - 9 - 1$
vehicle 4 route 1 serving consumers $1 - 2 - 7 - 6 - 1$

After knowing the results of the LINGO solver, then in table 4 it will be shown verification of the output obtained to find out if there are any violated in the mathematical model.

Table 4. Output verification in LINGO 18.0.

Vehicle	Route	Capacity (kiloliters)	Load (kiloliters)
1	1	32	32
2	1	16	16
2	2	16	8
3	1	32	32
4	1	24	24

Based on the table above, it can be seen that the output of the optimization results meets the limits specified in the model, namely the output of the vehicle can-make more than one trip in a distribution period, no load that exceeds the capacity of the vehicle in one route, and all consumers are served. From the optimization results above, it can be said that the model output does not violate the limits, so the LINGO output has been verified.

4. Conclusion

This research was conducted by building a mathematical model on the VRP split delivery, multi-trips, and multi-product problems using the exact branch and bound method to minimize vehicle mileage. The results indicate that no boundaries are violated, and all consumers are served. The mathematical model built is still general to solve similar cases. For further research, a model can be

developed by adding VRP variants such as time windows and adding product types to represent the entire existing system.

References

Baradaran, V., Shafaei, A., and Hosseinian, A. H. (2019). Stochastic vehicle routing problem with heterogeneous vehicles and multiple prioritized time windows: Mathematical modeling and solution approach. *Computers and Industrial Engineering*, *131*, 187–199. https://doi.org/10.1016/j.cie.2019.03.047

BPPT. (2019). *Outlook Energi Indonesia 2019 Dampak Peningkatan Pemanfaatan Energi Baru Terbarukan Terhadap Perekonomian Nasional* (Issue December).

Febriandini, I. F., Yuniaristanto, and Sutopo, W. (2020). Multi-Compartment Vehicle Routing Problem to Find the Alternative Distribution Route of Petroleum Product Delivery. *IOP Conference Series: Materials Science and Engineering*, *943*(1), 0–8. https://doi.org/10.1088/1757-899X/943/1/012039

Feng, Y., Zhang, R. Q., and Jia, G. (2017). Vehicle Routing Problems with Fuel Consumption and Stochastic Travel Speeds. *Mathematical Problems in Engineering*. https://doi.org/10.1155/2017/6329203

Karim, M. K., Setiawan, B. D., and Adikara, P. P. (2017). Optimasi Vehicle Routing Problem With Time Windows (VRPTW) Pada Rute Mobile Grapari (MOGI) Telkomsel Cabang Malang Menggunakan Algoritme Genetika. *Jurnal Pengembangan Teknologi Informasi Dan Ilmu Komputer (J-PTIIK) Universitas Brawijaya*, *2*(8), 2702–2709.

Lubis, F. S., and Herliansyah, M. K. (2017). Vehicle Routing Problem with SImultaneous Delivery and Pick-up Services (VRPSDP) pada Distribusi Tabung Gas LPG 3 Kg. *Seminar Nasional Teknik Industri Universitas Gadjah Mada*.

Mingozzi, A., Roberti, R., and Toth, P. (2013). An exact algorithm for the multitrip vehicle routing problem. *INFORMS Journal on Computing*, *25*(2), 193–207.

Normasari, N. M., and Warangga, A. (2019). Mathematical Model of Vehicle Routing Problem with Compartment, Split Delivery, Multi Product, and Time Windows. *Jurnal Ilmiah Bidang Teknologi, ANGKASA*, 25–34.

Olivera, A., and Viera, O. (2007). Adaptive memory programming for the vehicle routing problem with multiple trips. *Computers and Operations Research*, *34*(1), 28–47.

Pramuditha, Z. I. (2014). *Optimasi Distribusi Multiple Products pada Multiple Buyers Menggunakan Multi-Vehicle pada Capacitated Vehicle Routing Problem*. Universitas Gadjah Mada.

Prins, C. (2002). Efficient Heuristics for the Heterogeneous Fleet Multitrip VRP with Application to a Large-Scale Real Case. *Journal of Mathematical Modelling and Algorithms*, *1*(2), 135–150.

Rofiq, A. M., Bambang, E., and Pudjo, D. (2016). Optimalisasi Distribusi LPG 3 kg Menggunakan Metode Linear Programming Pada PT Suka Damai Abadi Jember. *Artikel Ilmiah*.

Seixas, M. P., and Mendes, A. B. (2013). Column generation for a multitrip vehicle routing problem with time windows, driver work hours, and heterogeneous fleet. *Mathematical Problems in Engineering*.

Setiawan, F. (2016). *Mathematical Modelling of Heterogeneous Vehicle Routing Problem with Multi-Trips and Multi-Products*. Universitas Gadjah Mada.

Toth, P., and Vigo, D. (2002). *The Vehicle Routing Problem*. Society for Industrial and Applied Mathematics.