Proceedings of Science and Mathematics
Faculty of Science, Universiti Teknologi Malaysia

Vol. 3, 2021, page 223-231

# Vehicle Routing Problem with Pick Up and Delivery in Courier Service Application

**Umatun Syuhada Tahar [a], Zaitul Marlizawati Zainuddin [b]***
[a,b]Department of Mathematical Sciences, Faculty of Science, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia.
*Corresponding author: zmarlizawati@utm.my,

## Abstract
Due to the large quantity of items that must be delivered to the customers at earliest time, it is critical for all courier service industries to plan their tour that provides the total minimum distance along the trips. In this research, we focus on solving a mathematical model of Vehicle Routing Problem with Pick Up and Delivery (VRPPD) to find the shortest overall distance for pick-up and delivery trips using their respective routes. Pos Laju operation will be used as the case study and the scope of problem is restricted within Johor Bahru. The VRPPD problem then is solved using VRP Spreadsheet Solver, an open source software. To further the study, it is recommended to widen the scope of locations and number of customers to be served.
**Keywords:** Vehicle Routing Problem with Pick Up Delivery, VRPPD, VRP Spreadsheet Solver

## 1 Introduction
Online sales have risen and demand for parcel deliveries has demonstrated an expansion in volume of roughly 35% all through the lockdown due to COVID-19 outbreak, Malaysia's Movement Conditional Order (MCO) period. Pos Malaysia Bhd representative said the demand for parcel deliveries has demonstrated an expansion in volume of roughly 35% all through the MCO period. For Pos Malaysia Berhad, over 700,000 parcels a day are delivered on a regular basis throughout this period and the highest number of parcels received was over 800,000 packages in a day [1]. Due to the large quantity of items that must be delivered to the customers at the earliest time, it is critical for all courier service industries to schedule their tour that provides the total minimum distance along the trips.

In this research, we focus on solving Vehicle Routing Problem with Pick Up and Delivery (VRPPD) mathematical model to determine the shortest overall distance between the pick-up and delivery trips using their respective routes. PosLaju Berhad operation will be used as the case study in this work. The aim of the study is to determine the optimal route in minimizing the overall length of tours in picking up and delivering the parcels from the single depot center and to analyze the effect of the parameter values to the optimal route obtained from the VRP Spreadsheet Solver.

## 2 Literature Review
### *2.1 Vehicle Routing Problem With Pick Up and Delivery (VRPPD)*

In the context of the general pick-up and delivery of goods, a range of routes must be clearly specified to satisfy the demands for transport. The set of fleets is allocated to each route for a particular load size to be transported. Each vehicle has its own specific capacity, predefined origin and destination. Each order shall be indicated by the point of pick-up, the corresponding point of delivery and the request to be passed between those points. The vehicle routing problem with pick-up and delivery (VRPPD) occurs in certain real-life scenarios when the need for pick-up and delivery is to be satisfied by the same vehicle. Generally, the objective function(s) minimizes the operating system costs.

### *2.2 Related Works of VRPPD*

Some related works of VRPPD are an optimal dynamic programming algorithms has been presented by [2] which in this study, the objective function is to minimize the total customer dissatisfaction and they have developed an exact algorithm procedure, to solve the “static” and “dynamic” versions of single-vehicle, many-to-many, immediate request dial-a-ride problem. Besides, [3] proposed a metaheuristic solution method based on the greedy local search algorithm, named as a new hybrid genetic scatter search algorithm (HGSS) for the one commodity pickup and delivery routing problem.

### *2.3 Software For Solving VRP*

Apart from the above-mentioned exact and heuristic methods, there are also some of Vehicle Routing Problem (VRP) software that can be used to handle VRP problem. The software or any open source available varies depending on the type of problem being solved, such as VRPPD, VRPTW, TSP, and others. For examples, VRP *Solver* by Larry Snyder that implements a randomized version of Clarke-Wright Savings algorithm for VRP [4].

Besides, *VRPSolver* also available which is a Branch-Cut-and-Price based exact solver for VRP and some other related problems. *OptaPlanner* is one of the software that utilizing Open Source Java Artificial Intelligent (AI) constraint solver which is flexible enough to handle any VRP variant, including TSP, CVRP and VRPTW [5].

. Last but not least, *ArcGIS Pro* is another VRP Solver that is built-in with Solve Vehicle Routing Problem tool, creates routes for fleets of vehicles that must visit a large number of orders for delivery, pickups, or servicing calls. The programme operates in an asynchronous mode, making it ideal for larger, time-consuming problems [6].

## 3 Research Methodology

### *3.1 Description of VRPPD Problem*

The logistic process in PosLaju started with parcels collection at any PosLaju office all around Malaysia, then all of them will be transported by lorries to the International Parcel Centers (IPC) in Shah Alam. Then, all the parcels will be transferred to its mail centre according to their destination. The parcels will be sorted out according to the customers’ addresses.

In this case study, Johor Bahru Main PosLaju office will represent the central depot with a certain number of transport vehicles, which is responsible for the delivery demand of customers and each vehicle needs to complete the delivery service when it arrives at the location of each customer. The locations of the depot and each customer is known as well as the demands of each customer. Each vehicle will return to the depot after the pick up and delivery task has been completed. Noted that there is no requirement of time windows, thus there will be no certain penalty applied if the vehicle reach the destination early or late.

In short, the main purpose is to determine the optimal route in order to minimize the total distance travelled by vehicles in VRPPD, considering the fixed costs of vehicles and transportation costs. As mentioned before, the scope of locations will be restricted to Johor Bahru district only and focusing on the three main cities, which are Johor Bahru City, Bandar Baru Uda and Kempas.

### *3.2 Problem Formulation*

The VRPPD model used for this case study is from [7]. The mathematical model and notations used in the problem are presented as follows:

Input variables

| | |
|---|---|
| $c_{ij}$ | The distance between nodes $i$ and $j$ |
| $d_i$ | The delivery demand of customer $i$ |
| $p_i$ | The pick up demand of customer $i$ |
| $Q$ | The vehicle capacity |

Decision variables

| | |
|---|---|
| $x_{ij}$ | $\begin{cases} 1 & \text{if vehicle travelling from node } i \text{ to node } j \\ 0 & \text{otherwise} \end{cases}$ |
| $R_{ij}$ | The total of delivery goods on arc $ij$ |
| $P_{ij}$ | The total of pick up goods on arc $ij$ |
| $N$ | Collection of nodes including the depot (N0, N1,N2,…) |
| $n_c$ | Collection of nodes excluding the depot (N1,N2,…) |

$$\text{Min } \sum_{i=0}^{n} \sum_{j=0}^{n} c_{ij} x_{ij} \tag{1}$$

subject to

$$\sum_{i=0}^{n} x_{ij} = 1 \qquad \forall j \in \{1, \dots, n_c\} \tag{2}$$

$$\sum_{i=0}^{n} x_{ji} = 1 \qquad \forall j \in \{1, \dots, n_c\} \tag{3}$$

$$\sum_{i=0}^{n} R_{ij} - d_j = \sum_{i=0}^{n} R_{ji} \qquad \forall j \in \{1, \dots, n_c\} \tag{4}$$

$$\sum_{i=0}^{n} P_{ij} + p_j = \sum_{i=0}^{n} P_{ji} \qquad \forall j \in \{1, \dots, n_c\} \tag{5}$$

$$\sum_{i=0}^{n} P_{i0} = 0 \tag{6}$$

$$\sum_{i=0}^{n} R_{0i} = 0 \tag{7}$$

$$R_{ij} + P_{ij} \leq Q \sum x_{ij} \qquad \forall i \in \{0, \dots, N\}, \quad \forall j \in \{0, \dots, N\} \tag{8}$$

$$R_{ij} \geq 0 \qquad \forall i \in \{0, \dots, N\}, \quad \forall j \in \{0, \dots, N\} \tag{9}$$

$$P_{ij} \geq 0 \qquad \forall i \in \{0, \dots, N\}, \quad \forall j \in \{0, \dots, N\} \tag{10}$$

$$x_{ij} \in \{0,1\} \qquad \forall i \in \{0, \dots, N\}, \quad \forall j \in \{0, \dots, N\} \tag{11}$$

The linear objective function (1) minimizes the total travel costs which depends on the parameter to be minimized, (i.e., total distance travelled, cost operation) or others. Constraints (2) and (3) specify that each request (i.e., the pickup and delivery nodes) is served exactly once and by the same vehicle. Constraints (4) and (5) describe the flow conversation constraints which are to eliminate the subtours. Next, constraints (6) and (7) implies the vehicle start with zero pick up and finish with zero delivery load. (8) express the maximum capacity constraint where the total of loads both for pick up and delivery must not exceed the vehicle capacity. While (9)–(10) implied the demand for pickup and delivery nodes must be greater than 0. Finally, (11) expressed the binary requirements for the vehicle.

### *3.3 Description of VRP Spreadsheet Solver*

VRP Spreadsheet Solver is an open source software built by [8] using Visual Basic for Applications, a Microsoft programming language (VBA). The author introduced this solver as a based tool for solving many variants of Vehicle Routing Problem (VRP). The worksheets consisted of six main sheets which are *VRP Solver Console* as the main sheet, *Locations, Distances, Vehicles, Solution* and lastly *Visualization.*

*VRP Solver Console* sheet is the core section of the spreadsheet where we select the value of parameters we wish to utilize according to the purposed problem. Next, customers' addresses will be listed in the *Locations* sheet, and their latitude and longitude are generated by the Solver which is linked by *Bing Maps*. Besides, the *Distances* sheet is where the distances between the points/locations are computed. The tabular distance result obtained must then be transformed into a distance matrix in order to be used in further computations. There will be a square $n \times n$ distance matrix that includes all locations, including the depot.

There are three parameters that need to be specified for this case study in *Vehicles* sheet, which are the vehicle capacity, the distance limit, and the number of vehicles. There are more settings that are not applicable, therefore they are set to default. Next, *Solution* sheet will displayed the routes generated for each vehicle, together with respective pick up and delivery demands to be served and the distance travelled for each locations. Last but not least, to display the visualization of all routes obtained by the Solver, the *Visualization* sheet is linked to a *Solution* sheet. Using the drop-down menu, we can choose whether to display each route individually or all of them together.

## 4 Result and Discussion

### *4.1 Visualization of Locations for Depot and Nodes*

Table 1 shows the list of customers' addresses for 20 customers with their respective pick up and delivery demands.

Table 1 : List of Nodes with respective demands

| Depot/Customers | Customers' Addresses | Pick Up Demands | Delivery Demands |
|---|---|---|---|
| Depot | Pos Malaysia Berhad Johor Bahru | 0 | 0 |
| Customer 1 | Horizon Hills, Nusajaya Johor | 27 | 126 |
| Customer 2 | Majlis Sukan Negeri Johor | 25 | 48 |
| Customer 3 | Kompleks Tun Abdul Razak (KOMTAR) Johor | 42 | 33 |
| Customer 4 | Indah Samudera Condominium Johor | 16 | 64 |
| Customer 5 | Kampung Stulang Darat Johor | 13 | 126 |
| Customer 6 | Country Garden Danga Bay Johor | 17 | 45 |
| Customer 7 | Taman Tasek Utara Johor | 24 | 93 |

| | | | |
|---|---|---|---|
| Customer 8 | Indera Putra Kondo Johor | 45 | 113 |
| Customer 9 | Kompleks Kastam Tanjung Petri Johor | 36 | 121 |
| Customer 10 | Kawasan Perindustrian Dato Onn Johor | 11 | 93 |
| Customer 11 | Taman Tebrau Jaya Johor | 47 | 131 |
| Customer 12 | Hospital Sultanah Aminah Johor | 29 | 60 |
| Customer 13 | Bandar Kulai Johor | 21 | 92 |
| Customer 14 | Kulai Johor | 47 | 59 |
| Customer 15 | Jalan Mustika Johor | 34 | 31 |
| Customer 16 | Kampung Melayu Pandan Johor | 24 | 100 |
| Customer 17 | Taman Austin Height Johor | 24 | 78 |
| Customer 18 | Bandar Baru Uda Johor | 32 | 93 |
| Customer 19 | Kempas Johor | 36 | 143 |
| Customer 20 | Bandar Baru Kangkar Pulai Johor | 44 | 197 |

Figure 1 demonstrated the visualization of all locations including depot, which was marked with black square. Figure 2 shows the Visualization of all routes as the final output for the case study while Figure 3 - Figure 5 below demonstrated the close up of the routes, Route 1 – Route 10.

Figure 1 : Locations for Depot and Nodes


Figure 2 : Visualization of all routes as the final output

Figure 3 : Visualization of Route 1 (on top left) – Route 4 (on bottom right)

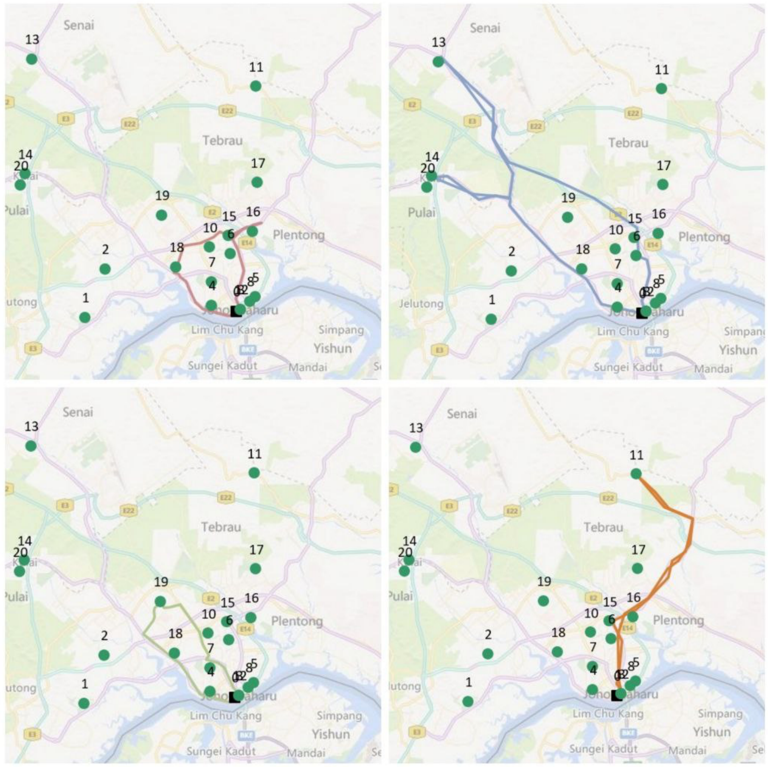


Figure 4 : Visualization of Route 5 (on top left) – Route 8 (on bottom right)

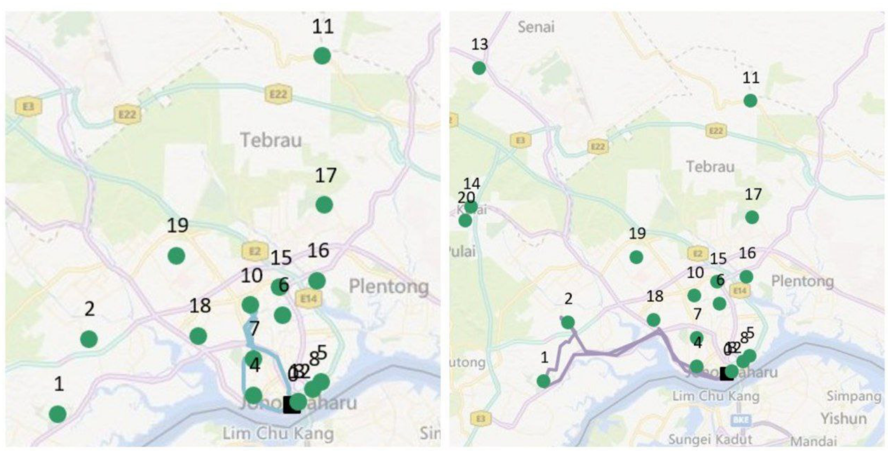


Figure 5 : Visualization of Route 9 (left) – Route 10 (right)

The trips for all routes are summarized in the Table 2 as follows and the total distance for the all routes is 744.02 km, with total demands throughout the trips of 871 units by 10 vehicles.

## *4.2 Analysis of Result*

Table 2 : Summary of routes obtained from VRP Spreadsheet Solver

| Vehicles | Route | Distance | Total Load (Pick-Up & Delivery) |
|---|---|---|---|
| Vehicle 1 | [0-20-0] | 76.83 | 44 |
| Vehicle 2 | [0-9-12-0] | 16.09 | 101 |
| Vehicle 3 | [0-17-8-0] | 79.49 | 93 |
| Vehicle 4 | [0-5-4-0] | 34.16 | 42 |
| Vehicle 5 | [0-11-15-0] | 128.07 | 128 |
| Vehicle 6 | [0-6-13-14-0] | 181.65 | 140 |
| Vehicle 7 | [0-16-18-0] | 65.41 | 80 |
| Vehicle 8 | [0-3-19-0] | 42.49 | 120 |
| Vehicle 9 | [0-2-1-0] | 80.70 | 77 |
| Vehicle 10 | [0-10-7-0] | 39.13 | 46 |

We only evaluated 20 customers for this case study, despite the fact that the VRP Spreadsheet Solver can handle the problem for up to 200 customers. This is because, although the Solver generates distance values automatically, there is inconsistency in the values generated, and the values are also not symmetric. Furthermore, it is not in the form of a matrix, therefore prior manual computation to construct a distance matrix is required. The distance matrix, as we all know, is a symmetric quadratic matrix of size $n \times n$ with all zeroes along the main diagonal (the distance back and forth location of the same location is zero). If there are $N$ elements, this matrix will be of size $N \times N$. Having 20 customers into consideration implies we will have 20 × 20 elements, which makes manual distance matrix computation time-consuming. The accuracy of each element is crucial throughout the operation so that the routes produced later as the solution are compatible with the scope of locations studied.

Aside from that, in order to serve 20 customers in 20 distinct destinations, we decided to begin with 20 vehicles as a run test. The routes for the pick-up and delivery trips were then generated using Solver. The procedure remains the same and the distance values pre-populated must be double-checked. The Solver generates a total of 12 routes for 12 vehicles. Since the 12 vehicles were sufficient to serve all 20 customers, thus the remaining 8 vehicles were not used. The overall distance travelled remained the same, at 744.02 kilometres, but the destinations generated for each route were different.

We then lowered the number of vehicles to 15 after that. However, it is apparent that not all of the cars are used, with only ten vehicles serving all customers on all routes. In each pick-up and delivery trip, all 20 customers must be served, and the capacity limit must be met. Because of the capacity constraints, the total demand for pick-up and delivery in each trip must not exceed 200 items, since this will affect the populated routes. We are unable to decrease the total number of vehicles provided to less than ten. Otherwise, all of the customers' demands will not be met, and the total distance travelled will be incompatible since the entire scope of the studied locations will not be covered. As a result, the number of vehicles is reduced to ten as the final parameter value, given that all vehicles are fully utilised and that all customers are served. There are no detours in any of the trips, and all constraints have been met.

## 5 Conclusion

In conclusion, we are able to determine the optimal route for the VRPPD problem. The objective of this problem is to minimize the total distance travelled during the trips restricted to Johor Bahru only. It would be great if any researchers could solve the model using real-world data instead of randomly generated data to get more accurate results, particularly in terms of estimating overall distance travelled during visits. Ultimately, the recommended routes might be considered by the courier company as an alternative to reduce the total distance covered, therefore lowering their costs and improving their service performance while servicing all customers in the region.

For future work it is suggested to propose a model or modified the existing model to solve other field of application, for example the newspaper distribution, food delivery in rural areas or in any transportation field to explore the insight of the problem and what can be improve to enhance their service efficiency.

### References

[1] S. Birruntha, “Delivery firms focus on efficient operations,” *TMR Media Sdn Bhd*, Jun. 09, 2020.

[2] H. N. Psaraftis, “Dynamic Vehicle Routing Problems,” *Veh. Routing Methods Stud.*, pp. 223–248, 1988.

[3] J. Euchi, “Genetic scatter search algorithm to solve 1-commodity Pickup and Delivery Vehicle Routing problem,” vol. 12, no. 1, 2017, doi: doi.org/10.1016/0305-0548(95)O0026-P.

[4] Snyder, L. (2021, September 12). *Software - VRP Solver*. Retrieved from Larry Synder Website: https://coral.ise.lehigh.edu/larry/software/vrp-solver/

[5] *OptaPlanner*. (2021, September 12). Retrieved from https://www.optaplanner.org/learn/useCases/vehicleRoutingProblem.html

[6] *ArcGIS Pro*. (2021, September 12). Retrieved from ArcGIS: https://pro.arcgis.com/en/pro-app/latest/tool-reference/ready-to-use/itemdesc-solvevehicleroutingproblem.htm

[7] N. Wassan and G. Nagy, “Vehicle Routing Problem with Deliveries and Pickups: Modelling Issues and Meta-heuristics Solution Approaches,” *Int. J. Transp.*, vol. 2, no. 1, pp. 95–110, 2014, doi: 10.14257/ijt.2014.2.1.06.

[8] G. Erdoğan, “An open source Spreadsheet Solver for Vehicle Routing Problems,” *Comput. Oper. Res.*, vol. 84, pp. 62–72, 2017, doi: 10.1016/j.cor.2017.02.022.