M – 14

THE CHARACTERISTICS STUDY OF SOLVING VARIANTS OF VEHICLE ROUTING PROBLEM AND ITS APPLICATION ON DISTRIBUTION PROBLEM

Sapti Wahyuningsih [1], Darmawan Satyananda[2]
[1]*Universitas Negeri Malang, sapti.wahyuningsih.fmipa@um.ac.id*
[2]*Universitas Negeri Malang, darmawan.satyananda.fmipa@um.ac.id*

Abstract

Vehicle Routing Problem (VRP) is one of the most challenging problems in combinatorial optimization. Objective of VRP is to find minimum length route starts and ends in a depot. There are some additional constraints such as more than one depot, service time, time window, capacity of vehicle, and many more. These are cause of VRP variants. Vehicle Routing Problem with Time Windows (VRPTW) is a variant of VRP with some additional constrains, that are number of requests may not exceed the vehicle capacity, as well as travel time and service time may not exceed the time window. Multi Depot Vehicle Routing Problem (MDVRP) has number of depots serving all customers, a number of vehicles distributing goods to customers with a minimum distance of distribution route without exceeding the capacity of the vehicle.

Many researches have presented algorithms to solve VRPTW and MDVRP. This article discusses solution characteristics of VRPTW and MDVRP algorithms, and their performance. VRPTW algorithms reviewed are Tabu Search, Clarke and Wright, Nearest Insertion Heuristics, Harmony Search, Simulated Annealing, and Improved Ant Colony System algorithm. Performance of MDVRP algorithms studied are Self-developed Algorithm, Upper Bound, Clarke and Wright, Ant Colony Optimization, and Genetic Algorithm. Each algorithm is studied on its performance, process, advantages, and disadvantages.

This article presents example of distribution problem in VRPTW and MDVRP, based on characteristic of the real problem. A computer program created using Delphi is implemented for VRPTW and MDVRP, to solve distribution problem for any number of vehicles and customer locations.

Keywords: VRPTW, MDVRP, Distribution problem

Introduction

Vehicle Routing Problem (VRP) is a combinatorial problem that combines two problems: Travelling Salesman Problem (TSP) and Bin Packing Problem (BPP). Objective of TSP is finding Hamiltonian cycle, that is a minimum weight closed path. BPP is a problem of determining minimum number of vehicles required to distribute all goods into all customers, in a certain capacity of vehicle. In addition of finding routes with minimum number of vehicle, VRP also has constrains that each customer is served exactly once, the route starts and ends at the same depot, and must not exceed a certain capacity (Yeun, Ismail, Omar, and Zirour, 2008)

In the real-world application, there are several kinds of additional constraints, such as more than one depot (multi-depot), service time of each customer, and time window for all services. These are cause of development of VRP variants. Vehicle Routing Problem with Time Window (VRPTW) for example, is a variant of VRP with some additional constrains, that are number of requests may not exceed the vehicle capacity, as well as travel time and service time may not exceed the time window. Another one, Multiple Depot Vehicle Routing Problem (MDVRP) has number of depots serving all customers, a number of vehicles distributing goods to customers with a minimum distance of distribution route without exceeding the capacity of the vehicle.

Many researches tried to find algorithm used to implements these VRP variants. The algorithm can be exact algorithm or heuristic algorithm. Sandhya (2013) described solution of algorithms for VRP and its variants, as shown in the following figure:

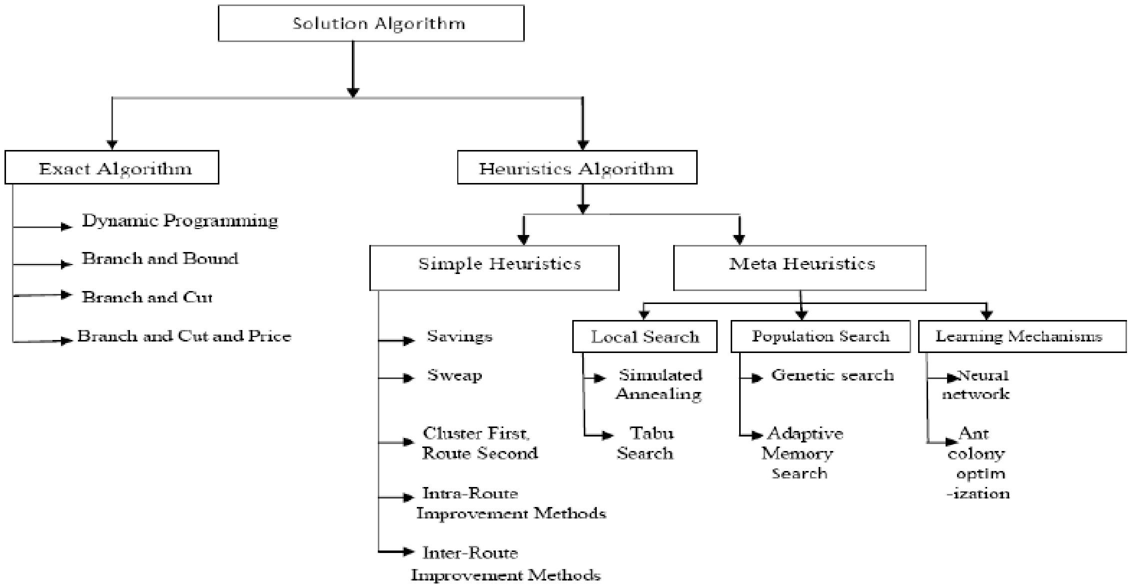

Figure 1. Solution algorithm for VRP variants

Some algorithms can be used for solving problems in VRPTW; among others are Tabu Search algorithm, Clark and Wright algorithm, Nearest Insertion Heuristic algorithm, Harmony Search algorithm, Simulated Anealling, and Ant Colony System algorithm. Characteristics of the solution of these algorithms will be reviewed in this article; about the iterative process as well as both their advantages and disadvantages.

To solve problems in MDVRP, some algorithms used are Self-developed algorithm, Ant Colony Optimization algorithm, Genetic algorithm, Clark & Wright algorithm, and Upper Bound algorithm. In this article, performance of the algorithm will be reviewed based on main principles in MDVRP: grouping, routing, and scheduling.

A tailor-made computer application created by Delphi programming language will be used to implement algorithms in VRPTW and MDVRP.

RESULT AND DISCUSSION

A. VRPTW

The characteristics Study of VRPTW algorithms

This article will assess the performance of several algorithms to find solutions of problems in VRPTW. They are Tabu Search algorithm (TS), Clark & Wright (CW), Nearest Insertion Heuristic algorithm (NIH), Harmony Search algorithm (HS), Simulated Anealing algorithm (SA), and Improved Ant Colony System algorithm (IACS).

Tabu search algorithm for VRPTW has two main stages: initialization stage and development stage. The initialization stage consists of two steps: determine distance between nodes, and determine service time of each node. The second phase also consists of two steps: exchange nodes, and check constraints (Baltzersen, 2010; Bräysy & Gendreau, 2001).

Clark and Wright algorithm for VRPTW has following steps:

1) Calculate saving (S_{ij}) and sort them in ascending order,
2) Build and select the route,

3) Expand route and merge them while not violating capacity constraints and time constraints,
4) The process continues until the number of requests does not exceed the capacity of the vehicle and the total time does not exceed the specified time window. If all S_{ij} values have been selected and there is saving not yet included in the route of step 4), then a new route is formed.
5) The expansion process stops after all of customers are included in the routes formed in step 4 and 5. No customer that has been selected in the previous route should be selected again in the next selection (Sandhya, 2013).

Meanwhile, Nearest Insertion Heuristic Algorithm for VRPTW problem has some steps (Sandhya, 2013):

1) Calculate saving (S_{ij}) and sort them in ascending order,
2) Build a route that begins and ends at the depot to check whether it meets capacity and time constraints.
3) Route expansion: search outlet (customer) with closest distance to the outlet in the route of step 2. The expansion continues until number of requests in one route does not exceed the vehicle capacity, and the total time does not exceed the time limit (time window).
4) If there is outlet that is not included in the route of step 3, then a new route is formed by repeating step 2, until all outlets are served. No outlet that has been selected in the previous route can be selected again in the next selection

Harmony Search algorithm on VRPTW consists of 5 steps;

1) Initialize distance parameter from the depot to the customer or the customer to other customer, service time for each customer, time window, maximum capacity of the vehicle, and the average speed of vehicle.
2). Initialize harmony memory (in other word, determination of route memory), to produce routes that randomized from the clusters route generated at the cluster route generation stage.
3) Improvisation of new harmony, that is improvising a route formed in Harmony Memory (HM), by forming a new route vector memory using Harmony Memory Consideration Rate (HMCR) and Pitch Adjustment Rate (PAR) parameters.
4) Update harmony memory, by calculating objective function value on a new route memory vector. If the result gives better objective function value than the worst value of the route memory vector in HM, the new route memory vector will be inserted into HM to replace the worst one.
5) Check the termination criteria (for example number of iterations), if it has been met the the process stops (Weyland, 2010; Geem, Lee, Park, 2005).

In Simulated Annealing algorithm, steps of solutions are

1) Determine initial solution by using Push-Forward Insertion Heuristic method,
2) Refine the solution by using λ-Interchange Local Search Descent method, and
3) By using global-best selection strategy, define temperature parameter, calculate difference of total distance of new solution with previous solution, determine whether the new solution is acceptable according to acceptance criterion, and decrease the temperature,
4) Repeat the process while stopping criterion has not been met (Thangiah, Osman, Sun, 2012).

The detailed steps Improved Ant Colony Algorithm System for the VRPTW are:

1) Determine the parameters,
2) Generate initial solutions using nearest neighbor heuristic algorithms,
3) Applying local search (using insertion move algorithm) on the initial solution and stored as a first solution.
4) Arrange a solution based on the route construction rule and conduct local pheromone update,
5) Sort the solutions, applying local search (using insertion move algorithm) on the best solution and stored as a solution,
6) Implement the Global Pheromone Update, set the best solution as a first solution on the next generation

7) Repeat the process until termination criterion has been met (Yu, Yang, Yao, 2006; Chen, Ting, 2006).

Route formation process

For tabu search algorithm, a node closest to depot (of course it has shortest travel time) is selected and it must be directly connected to the depot. This process continues until nodes are selected without violating the determined constraints, that is the time window and the maximum capacity of the vehicle. After several routes formed, the next step is to exchange each point on each route in order to find routes with minimum distance and time, as long as not violating constraints specified.

Initial route was selected based on the greatest savings. From the biggest saving, next biggest saving is selected by considering a node that is connected directly to the end point of the previous saving. This is repeated until all nodes contained in the route. This node selection should also consider the time constraints and capacity constraints.

This method has almost the same way as Clarke and Wright algorithm does; it uses the largest savings and starts from the depot. However, the method has difference: after a route is selected from the biggest saving, a node in inserted such that it has minimum distance to the nodes that have been previously selected. This method considering the order to visit the customer. The formation and node insertion to establish a new route may not exceed the time and capacity constraints.

Generation of initial route in Harmony Search algorithm uses saving method of Clark and Wright algorithm. While Simulated Annealing algorithm begins with determining the initial solution using the Push-Forward Insertion Heuristic (PFIH). The determination begins with the selection of a starting point and then does the insertion. The starting point chosen according to the cost (distance) from the depot to the customer. Unselected node is inserted into the route by considering minimum distance. All constraints are examined, the node can be inserted if all constraints are met, otherwise build a new route. The process continues until all the customers are selected.

In Improved algorithm Ant Colony System (IACS), there are three stages: determination of the parameters, initialization of the trail pheromone, and iteration stage. The pheromone initialization uses nearest neighbor heuristic algorithm that puts each ant on a journey that starts from the depot to visit other customers. Each customer is visited only once. At the stage of iteration, any ants build solutions freely with state transition rule and perform local pheromone update, applying local search to improve solutions, and update global pheromone information.

Advantages and disadvantages of the algorithms

Tabu search algorithm has several advantages, among them is the algorithm directly select nodes with minimum time to be the route, hence the nodes chosen have a total minimum time. This algorithm can also find out the total service time for each route so that it can be estimated how much time it takes to serve customers in a service route. Clarke and Wright algorithm or Nearest Insertion Heuristic do not consider total of service time.

Disadvantage of tabu search algorithm is the distance between the last node on the route to the depot is not selected so that most result of the tabu search algorithm results has longer distance back to the depot, compared to Clark and Wright algorithm and Nearest Insertion Heuristic methods as well. However, Clark and Wright algorithm and Nearest Insertion heuristic methods also use the savings that cannot directly determine whether the selected node has the minimum distance.

Nearest Insertion Heuristic algorithm is a systematic method because the method is concerned with the order of the selected point. A node is inserted into the route in the position that brings minimum distance for a whole route.

There is addition of objective function value in Harmony Search algorithm to calculate the total distance as well as a parameter in the process of improvising a new route. In addition to the service time, the algorithm pays attention to the total mileage. Otherwise, in the Tabu Search algorithm no such additions exist, because the orientation of the Tabu Search algorithm is only on the discovery of the minimum service time. Harmony Search algorithm has route memory generation stage, that is rising up some routes by randomizing cluster routes stored in the route memory.

The use of improvised stage algorithm parameters on Harmony Search provides an opportunity to produce a various route compared to the exchange point from one route to another on the taboo stage on tabu search algorithm. The Harmony Search algorithm has a diverse choice of routes solutions compared to Tabu Search.

The fundamental difference between the VRPTW using Simulated Annealing compared to Clark and Wright algorithm and Nearest Insertion Heuristic algorithms is solution improvement. By using Simulated Annealing, the solution obtained will be corrected to to achieve the optimal solution. Clark and Wright and Nearest Insertion Heuristic do not have this repairment.

The parameters used in the algorithm Improved Ant Colony System basically the same as Ant Colony System. In the pheromone initialization phase, IACS and ACS use nearest neighbor heuristic algorithm. The difference in the two algorithms is at the stage of iteration. There are state transition rule and new pheromone updating rule in IACS algorithms. Local search and global pheromone update imposed on forming the best solution.

B. MDVRP

The characteristics Study of VRPTW algorithms

This paper reviewed some algorithms for MDVRP: Self Developed (Ying, Mingyao, Lixin, Guotao, 2015), Upper bound algorithm (Crevier, Cordeau, Laporte, 2007), Clark & Wright algorithm (Yeun, Ismail, Omar, Zirour, 2008), Ant Colony Optimization algorithm/ACO (Wang, 2013; Kaur & Goyal, 2013), and Genetic Algorithm (Surekha & Sumathi, 2011).

There are three steps on solving MDVRP with Self-Developed algorithms, namely:

1). Initialization step,
2). Iteration step by processing saving and combining route in accordance with the order made for each route in each depot, and
3). Pair step, to mate generated route for each depot with existing vehicles.

First stage of Ant Colony Optimization (ACO) for MDVRP is grouping customers into nearest depot. Other steps afterward, namely

1) calculate inverse distance and determine initial pheromone.
2). using probability equations, determine next node in order to arrange route; repeat this process until all nodes selected, and
3). repeat step (2) so that each ant get their route.

In stage of sorting and optimizing route, several steps must be done, among which

1). Determine the pheromone update for each ant by summing the initial pheromone with pheromone changes,
2). Select the largest pheromone as new route,
3). calculate the total length of the tour so we get a minimum track length.

In genetic algorithms, there are several stages of process, namely encoding, define the fitness value, generate initial population, selection, crossover, mutation, and decoding. First, encoding is a process of codification of problem solution, as a string of chromosome representation. Selection process determines which chromosome remained on the next generation. Crossover process will produce a new chromosome as replacement of missing chromosome so that the total chromosome in a generation is fixed. The mutation process may produce unpredictable chromosome. The latter is the decoding process that is taking the meaning of the best chromosome to answer the problem.

Clark and Wright algorithm to solve MDVRP is as follows:

1). Counting saving for each pair of node,

2) Ordering saving in descending order,
3) Build and select the route,
4) Expand the route, by merging route that is not violating capacity constraints,
5) The expansion process is stopped after all the customer contained in one of routes. No customer that has been selected previously, should be selected again in the next route.

Upper bound algorithm for MDVRP started by formed set of nodes. From depot, a node closest to the depot is to be linked into a cycle in clockwise order. Next step is to find the customer with the shortest distance from customers and depots that are not on the cycle. New selected customers will be inserted in the cycle if it meets the vehicle capacity constraints. Customers who have not been selected will be formed as a new cycle with the same depot. After all customers is contained in the cycle, the process stops.

Route formation process

There are three main steps in MDVRP: grouping, routing, and scheduling. In the self-developed algorithm, the grouping step is to group customers based on distance to one of the nearest depot. Routing stage is to search route for each depot using saving method. There are two steps in routing stage: initialization and iteration step. Self-Developed algorithm is modification of saving algorithm. It calculates savings in final time table so that the resulting route may indicate the time required for each route as well as the distance and demand. Furthermore, these routes are processed at the scheduling stage to build route at each depot.

Ant Colony Optimization algorithms tailored to the three main steps of MDVRP, ie the state transition rules, the pheromone trail updating stage, local trail updates and a list of candidates for the new route. Before entering a transition phase state, some customers are grouped based on the nearest depot. State transition rules and updating the pheromone trail included in the routing stage. At the updating stage, the order of delivery selected by using the local trail update and final route calculation. This process produces route started and ended on each depot. On scheduling stage, delivery is scheduled based on the pheromone update on sequencing phase in order to obtain route that has minimum total distance and meets the capacity constraints.

Genetic Algorithm adjusted into three steps of MDVRP. In grouping stage, customers are grouped into the nearest depot. Encoding of individual uses permutation encoding technique. On permutation encoding, chromosomes is a collection of a number representing the position of the customer or depot on a route. Formation of the population can use Josephus' permutation. Based on the choromosomes, each route (individual) has their fitness. Later in the scheduling phase, selection using wheel roulette method used, crossovers using Order Crossover (OX), and mutation using inversion mutation.

Clark and Wright algorithm is also adapted into three steps of MDVRP. Calculating savings and sorting in descending order are in grouping stage. Selection and expansion included in the routing stage. Merging routes (without violatng capacity contraints) is in scheduling phase. This expansion process is stopped after all the customer service is included in all of the routes formed.

Adaptation to MDVRP is also for upper bound algorithm. Upper bound algorithm for TSP is modified by adding capacity constraints that applicable for MDVRP problem. In grouping step, customers are grouped to the nearest depot. In the routing phase, the formation is carried out separately based on the grouping. In the scheduling phase formed routes are sorted by closest distance to obtain the optimal solution.

C. Application

Computer application for VRP variants was previously developed in research grant competition (Wahyuningsih & Satyananda, 2014). In the application, inputs required to complete VRPTW are depot and number of customers, distance between the location, number of requests of each customer, maximum capacity of the vehicle, service time of each demand, and time limit of servicing customers (time window).

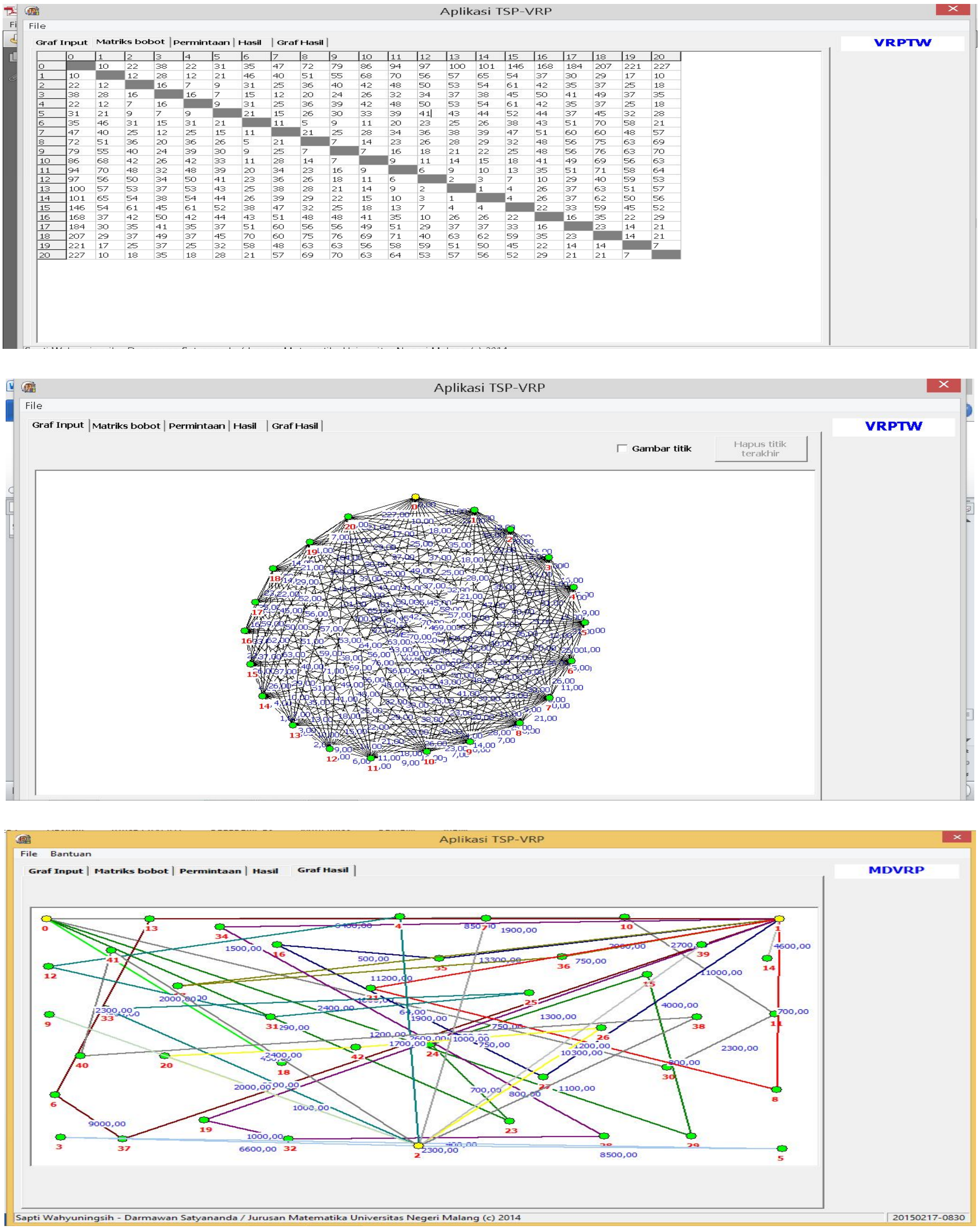

Figure 2. Screenshoot of the application

As example, company A will deliver goods to 20 outlets. Service time is from 09.00 to 15.00 (6 hours), capacity of each vehicle is 70 box, average speed of vehicle is 60 km/hour, and service time for each demand unit is 5 minutes. Problem of VRPTW is how to design optimal route such that total demand per route does not exceed total capacity of vehicle, and total time (travel time and service time) does not exceed time window.

Case for MDVRP, can be as follow. A company will deliver goods to 40 customers in various regions. The company has three depots. The capacity of each vehicle is 400. Problem of MDVRP is how to determine the optimal route for the delivery order of each depot, without violating capacity constraints, and the route has minimum length (which in turn gives minimum travel time).

D. Closing

This article discusses the characteristics study of solving VRPTW and MDVRP as variants of VRP and its application on distribution problem. Other variants can be assessed for example Vehicle Routing Problem with Backhauls (VRPB) which can service a number of requests of delivery or pickup of goods and for each vehicle, pickup is done after all the goods are delivered to customer, Capacitated Vehicle Routing Problem (CVRP) which has a limitation that each vehicle has equal capacity equal and only loading one commodity, and Vehicle Routing Problem with Simultaneous Deliveries and Pick-ups (VRPSDP) with the addition of freight capacity constraints and returns of defective goods. The characteristics study of solving VRP variants can be examined more.

References

Baltzersen, J. (2010). *Tabu Search Heuristic for Minimizing the Number of Vehicles in VRPTW*. Master thesis, Department of Mathematical Sciences, University of Copenhagen. Retrieved from http://baltzersen.info/files/vrp.

Bräysy, O., & Gendreau, M. (2001). *Tabu Search Heuristics for the Vehicle Routing Problem with Time Windows.* SINTEF Applied Mathematics, Research Council of Norway. Retrieved from http://www.researchgate.net/profile/Olli_Braeysy2/publication/24065418_Tabu_Search_heuristics_for_the_Vehicle_Routing_Problem_with_Time_Windows

Chen, C.H., Ting, C.J. (2006). An Improved Ant Colony Systems Algorithm for The Vehicle Routing Problem. *Journal of the Chinese Institute of Industrial Engineers,* 23 (2), 115-126

Crevier, B., Cordeau,J.F., & Laporte, G. (2007). The Multi-Depot Vehicle Routing Problem with Inter-depot routes. *European Journal of Operational Research,* 176, 756-773

Geem, W.Z., Lee, K. S, Park, Y. (2005). Application of Harmony Search to Vehicle Routing. *American Journal of Applied Sciences,* 2 (12),1552-1557

Kaur, M, Goyal, S. (2013). Application of ACO to Disentangle Max-Min MDVRP Using Clustering Technique. *International Journal of Scientific and Research Publications*, 3(2), 1-6

Sandhya, V.K. (2013). Issues in Solving Vehicle Routing Problem with Time Window and its Variants using Meta heuristics - A Survey. *International Journal of Engineering and Technology*, Volume 3 No. 6, 668-672.

Surekha, P., Sumathi, S., (2011). Solution To Multi-Depot Vehicle Routing Problem Using Genetic Algorithms.*World Applied Programming*, 1(3) : 118-131.

Thangiah, S.R., Osman, I. H., Sun, T. (2012). *Hybrid Genetic Algorithm, Simulated Annealing and Tabu Search Methods for Vehicle Routing Problems with Time Windows.* Retrieved from http://neo.lcc.uma.es/radi-aeb/WebVRP/data/articles/vrptw4.pdf

Wahyuningsih, S. & Satyananda, D. (2014). *Pengembangan modul penerapan teori graph berbasis ICT sebagai pedoman PKL mahasiswa jurusan Matematika di industri*. Laporan Penelitian Hibah Bersaing. Malang: Universitas Negeri Malang.

Wang,Y. (2013). Research of Multi-Depot Vehicle Routing Problem by Cellular Ant Algorithm. *Journal of Computers*, 8(7), 1722-1727

Weyland, D. (2010). *A Rigorous Analysis of the Harmony Search Algorithm: How the Research Community can be Misled by a "Novel" Methodology.* International Journal of Applied Metaheuristic Computing, 1(2), 50-60

Yeun, L. C., Ismail, W. R., Omar, K., & Zirour. (2008). Vehicle Routing Problem: Models and Solutions. *Journal of Quality Measurement and Analysis*, 4(1) 2008, 205-218.

Ying, Z., Mingyao, Q., Lixin, M, and Guotao, W. (2015). *A generalized multi-depot vehicle routing problem with replenishment based on Local Solver.* International Journal of Industrial Engineering Computations, 6, 81–98

Yu, B., Yang, Z. Z., Yao, B.Z. (2006). An Improved Ant Colony Optimization for Vehicle Routing Problem. *European Journal of Operational Research*, 196, 171-176