CAPACITATED VEHICLE ROUTING PROBLEM WITH TIME WINDOWS FOR MILK COLLECTION AT KPBS PANGALENGAN

Tjutju Tarliah Dimyati

Industrial Engineering Department, Pasundan University
tjutjutarliah@gmail.com; tjutju@unpas.ac.id

ABSTRACT

This research aims to solve a real-life problem faced by KPBS, a regional dairy company in Pangalengan Village of West Java that collects raw milk from farmers to the location of Milk Treatment. In the considered problem, a daily plan is needed to determine a heterogeneous fleet of vehicles that depart from a depot (the factory) and must visit a set of farmers for collection operations within given time window. This problem is known as the Capacitated Vehicle Routing Problem with Time Windows (CVRPTW) which is one of the classical areas of study in Operations Research. In this study the problem will be solved using heuristic method.

Key words: Milk collection, CVRPTW, Operations Research, Heuristic

1. INTRODUCTION

The dairy industry in Pangalengan Village of West Java, Indonesia is organized on the basis of regional cooperative dairy company, named KPBS. Milk collected from the client farmers (*suppliers*) is then delivered by several vehicles with a certain capacity to the location of Milk Treatment operated by the company. In order to maintain the standard quality of milk, each vehicle has to arrive at the location of Milk Treatment within three hours since the milk is picked up from the farmers. In this vehicle routing problem, two kinds of constraints are considered: 1) each vehicle has a limited capacity of collecting milk, and 2) there is time window associated with each farmer, during which the collection operation must be done.

In the considered problem, a daily plan is needed to determine a heterogeneous fleet of vehicles that depart from a depot and must visit a set of farmers for collection operations within given time window, where the collected milk is then delivered to the location of milk treatment for further process. A common objective of the company for this operation is the minimization of the collection cost per kilogram or liter of milk, where the cost of each vehicle route is computed through a system of fees depending on the distance traveled.

In order to achieve this objective, it is needed to group all the suppliers into several clusters i.e., a list of suppliers serviced in sequence by one vehicle in a specific order. Each cluster begins at a factory, collects the milk from the suppliers in turn (this is termed *servicing* the supplier), and finally delivers the milk to the factory. The total milk collected in a cluster cannot exceed the known, upper limit (*capacity*) of the vehicle assigned to that cluster.

The objective of this paper is to determine the minimum number of vehicle routes and the sequence of farmers visited by each vehicle, such that all farmers' milk are collected and all constraints imposed by vehicle capacity, service times and time window are satisfied.

The rest of this paper is organized as follows: Section 2 reviews the related past research in this area. Section 3 describes the data of the problem and the heuristic applied to solve it. Computational results are presented in Section 4, followed by the conclusion in section 5.

2. LITERATURE REVIEW

The capacitated vehicle routing problem with time windows (CVRPTW) is an important problem occurring in many distribution systems. Basically, the CVRPTW is an extension of the classical CVRP that each customer is associated with a time interval, called a time window. The problem can be described as the problem of designing least cost routes from one depot to a set of geographically scattered points.

Although it is possible to formulate the CVRPTW with a single objective function, most real-world applications involve multiple objectives. Usually, the primary objective is to find the minimum number of vehicles, and the secondary objective is often to minimize the total distance travelled. Other objectives include the minimization of the total schedule time and the minimization of the total waiting time.

During the past few years, numerous papers have been written on generating good solutions for VRPTW. Solomon (1987) is a landmark paper on the VRPTW and is cited by many papers thereafter. It proposes several construction heuristics and provides an extensive computational study of their performance. Tan et al. (2001) investigates various meta-heuristics to solve the VRPTW. This paper implements simulated annealing, tabu search and genetic algorithms to Solomon instances with 100 customers and provides comprehensive results.

Braysy and Gendreau (2005a) reviews and compares classical heuristic methods (route construction heuristics and improvement heuristics) for VRPTW, meanwhile Braysy and Gendreau (2005b) reviews various meta-heuristic algorithms for VRPTW. Russel and Chiang (2006) have used a scatter search metaheuristics to solve the VRPTW. Both a common arc method and an optimization-based set covering model are used to combine vehicle routing solutions.

A reactive tabu search metaheuristic and a tabu search with an advanced recovery feature, together with a set covering procedure are used for solution improvement. Soler et al. (2009) proposed a method to solve, optimally, TDVRP instances that are too small for practical purposes and was likely to experience exponential growth of computational time as a function of problem size. Bettinelli et al. (2011) describes a version where multiple warehouses are considered, using a branch-and-cut-and-price algorithm. These studies clearly demonstrate continuing interest of researchers to solve the problem.

3. PROBLEM STATEMENT

KPBS Pangalengan is a farmer cooperative located in Pangalengan village of Southern Bandung, which is responsible for helping farmers to store and sell milk. Milk collected from the client farmers (suppliers) is then delivered by several vehicles with a certain capacity to the location of Milk Treatment operated by the company.

Because milk is a highly perishable product, the delivery of fresh milk should be sent to the Milk Treatment location within a specific time limit. At the moment, there are 19 registered milk pick-up points (called TPKs) associated with the active member of KPBS Pangalengan, each of which has a certain pick-up demand and time windows as shown in Table 1 below.

Table 1 Data of each pick-up point

Pick-up Point	Pick-up Demand (Liter)	Arrival Time	Departure Time
TPK 1	3.188	05:00	07:30
TPK 2	2.962	05:00	07:00
TPK 3	2.076	05:00	07:30
TPK 4	2.023	05:00	08:00
TPK 5	1.040	05:00	07:30
TPK 6	2.600	05:00	08:00
TPK 7	2.669	05:00	07:00
TPK 8	2.426	05:00	06:30
TPK 9	1.883	05:00	08:00
TPK 10	1.435	06:00	08:30
TPK 11	1.595	05:00	07:30
TPK 12	2.347	05:00	07:30
TPK 13	1.833	05:00	07:30
TPK 14	1.525	05:00	07:00
TPK 15	1.771	05:30	08:30
TPK 16	1.937	05:30	08:00
TPK 17	2.128	05:30	08:30
TPK 18	2.174	05:30	08:30
TPK 19	2.000	05:00	07:00

To conduct the milk collection, the company operates 10 units of vehicle with different capacity, i.e., 2 units of 4.000 liters, 2 units of 4.200 liters, 1 unit of 4.400 liters, 1 unit of 5.400 liters, and 4 units of 6.000 liters. In

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order to maintain the standard quality of milk, the vehicles leave the Milk Treatment location to begin a tour and must end the tour at the same location within 3 hours. The distance and average time needed to travel between the milk treatment and pick-up points is shown in Appendix A.

Considering these situations, the problem to solve can be classified as the capacitated vehicle routing problem with time windows (CVRPTW).

The CVRPTW is defined on a graph (N, A). The node set N consists of the set of customers, denoted by C, and the nodes 0 and n+1, which represent the depot. The number of customers $|C|$ will be denoted n and the customers will be denoted by 1,2,…,n. The arc set A corresponds to possible connections between the nodes. No arc terminates at node 0 and no arc originates at node n+1. All routes start at 0 and end at n+1. A cost Z_{ij} and travel time t_{ij} are associated with each arc $(i, j) \in A$ of the network. The travel time t_{ij} includes a service time at customer i. The set of (identical) vehicles is denoted by V. Each vehicle has a given capacity q and each customer a demand d_i, $i \in C$.

At each customer, the start of the service must be within a given time interval, called a time window, $[a_i, b_i]$, $i \in C$. Vehicles must also leave the depot within the time window $[a_0, b_0]$ and return during the time window $[a_{n+1}, b_{n+1}]$. A vehicle is permitted to arrive before the opening of the time window, and wait at no cost until service becomes possible, but it is not permitted to arrive after the deadline. Since waiting time is permitted at no cost, we may assume without loss of generality that $a_0 = b_0 = 0$; that is, all routes start at time 0.

To solve this real-life milk collection problem, the Solomon's insertion heuristic, called *I1* is implemented. A route is first initialized with a seed customer and the remaining unrouted customers are added into this route until its capacity constraint is violated. If unrouted customers remain, the initializations and insertion procedures are then repeated until all pick-up points are serviced. The seed customers are selected by finding either the geographically farthest unrouted customer in relation to the depot or the unrouted customer with the lowest starting time for service.

After initializing the current route with a seed customer, the method uses two subsequently defined criteria $c_1(i, u, j)$ and $c_2(i, u, j)$ to select customer u for insertion between adjacent customers i and j in the current partial route.

Let $(i_0, i_1, i_2, \ldots, I_m)$ be the current route with i_0 and i_m representing the depot. For each unrouted customer u, we first compute its best feasible insertion cost on the route as

$$c_1(i(u), u, j(u)) = \underset{\rho=1,\ldots,m}{optimum} \quad c_1(i_{\rho-1}, u, i_\rho),$$

Next, the best customer u^* to be inserted in the route is the one for which

$$c_2(i(u^*), u^*, j(u^*)) = \underset{u}{optimum} \quad c_2(i(u), u, j(u)),$$

u unrouted and feasible.

Client u^* is then inserted into the route between $i(u^*)$ and $j(u^*)$. When no more customers with feasible insertions can be found, the method starts a new route, unless it has already routed all customers.

More precisely $c_1(i, u, j)$ is calculated as

$Z_1(i, u, j) = \alpha_1 Z_{11}(i, u, j) + \alpha_2 Z_{12}(i, u, j)$,

where $\alpha_1 + \alpha_2 = 1$, $\alpha_1 \geq 0$, $\alpha_2 \geq 0$,

$Z_{11}(i, u, j) = (d_{iu} + d_{uj} - \mu d_{ij})$; $\mu \geq 0$

$Z_{12}(i, u, j) = b_{ju} - b_j$

or $Z_{12}(i, u, j) = t_{0u} + t_u + t_{ui} - t_{0i}$

t_{0u} , t_{ui} , and t_{0i} are travel time from the depot to customer u, from customer u to customer i and from depot to customer i respectively, while t_u is the service time at customer u.

d_{iu}, d_{uj} and d_{ij} are distances between customers i and u, u and j and i and j respectively. Parameter μ controls the savings in distance and b_{ju} denotes the new time for service to begin at customer j, given that u is inserted on the route and b_j is the beginning of service before insertion.

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The criterion Z_2 (i, u, j) is calculated as
$Z_2 (i, u, j) = \lambda d_{0u} - Z_1 (i,u,j), \lambda \geq 0.$

Parameter λ is used to define how much the best insertion place for an unrouted customer depends on its distance from the depot and on the other hand how much the best place depends on the extra distance and extra time required to visit the customer by the current vehicle.

4. COMPUTATIONAL RESULTS

To solve the problem, the parameters are set arbitrarily as follows, $\mu = 1; \alpha_1 = \alpha_2 = 0.5$; and $\lambda = 1.$
Since pick-up point TPK 8 has the shortest time window (see Table 1), it then chosen to be the seed customer in the first iteration, which result the partial route of {0, 8, 0}. After the value of Z_1 and Z_2 computed, it is found that TPK 14 has the minimum value of Z_1 (see Appendix B). Therefore TPK 14 is chosen to be inserted to the partial route, so that the resulted route is {0, 8, 14, 0} with the total demand of 3.951 liters.

It is important to notice that since 10 units of different capacity vehicle are available to perform the milk collection, inserting a pick-up point to a given partial route has to be done by concerning the capacity constraint of a chosen vehicle. In the first iteration, if the vehicle assigned to the route is the one of 4000 liters capacity then there is no more pick-up point can be inserted to the route. The schedule resulted of this iteration is presented in Table 2

Table 2. Schedule of Iteration 1

Pick-up Point	Arrive	Depart	Cumulative Unit (liter)	Cumulative Distance (km)
MT (Depot)		5:00		
TPK 2	5:10	5:25	2.426	3.2
TPK 7	5:34	5:49	3.951	6.2
MT (Depot)	6:02	6:17		10.6

Since unrouted pick-up points remain, the initializations and insertion procedures are then repeated. In the second iteration TPK 2 is chosen to be the seed, followed by TPK 7. As the total pick-up demand of these two TPKs is 6.000 liters, the insertion is stopped which result the route of {0, 2, 7, 0} and the schedule as shown in Table 3.

Table 3. Schedule of Iteration 2

Pick-up Point	Arrive	Depart	Cumulative Unit (liter)	Cumulative Distance (km)
MT (Depot)		5:00		
TPK 2	5:12	5:27	2.962	4.0
TPK 7	5:40	5:55	5.631	8.4
MT (Depot)	6:12	6:27		13.9

All of the above process are then repeated until all pick-up points are serviced. The final solution of the considered problem in this study is shown in Table 4.

Table 4. The final solution

Route	Pick-up Points	Travel Distance (Kilometers)	Capacity Used (liters)
1	0 – 8 – 14 – 0	10,6	4000
2	0 – 2 – 7 – 0	13,9	6000
3	0 – 19 – 12 – 11 – 0	16,6	6000
4	0 – 1 – 13 – 0	27,6	5400
5	0 – 5 – 6 – 3 – 0	34,1	6000
6	0 – 16 – 9 – 17 – 0	47,3	6000
7	0 – 4 – 18 – 0	40,6	4200
8	0 –15 – 0	26	4200
9	0 –10 – 0	48,2	4000

As shown in Table 4, there are 9 routes needed to collect milk from 19 farmers (pick-up points) that will be delivered to the milk treatment location of the factory. It means that the factory has a spare vehicle of 4.400 liters capacity.

5. CONCLUSION

In this study a heuristic is implemented to solve a real-life problem of milk collecting from a set of farmers to the location of Milk Treatment. This problem known as the Capacitated Vehicle Routing Problem with Time Windows (CVRPTW) which categorized as NP-hard problem. The computational result shows that the heuristic in this study is a good heuristic for this problem and the other CVRPTW problems, in terms of its simplicity of implementation.

The main weakness in this heuristic is that there are parameters (μ, α_1, α_2 and λ) that have to be determined arbitrarily. Since these parameters will affect the resulted solution, the only way to find the good solution is to run trial and error all of parameters, which might very time consuming.

6. REFERENCES

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Appendix A The distance (below) and average time needed (upper) to travel between the milk treatment and pick-up points

TPK	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0	0	23.1	12	33.6	41.1	32.7	40.2	16.5	9.6	44.7	72.3	23.7	18.3	30.3	13.2	39	55.5	53.1	35.4	14.4
1	7.7	0	13.2	33	40.5	32.1	39.6	21	24.3	49.2	49.2	28.2	31.8	29.4	15.3	43.5	60	57.6	39.9	27.9
2	4	4.4	0	26.4	34.2	25.8	33	13.2	16.8	41.4	62.4	20.4	23.7	23.1	8.1	35.7	52.2	49.5	31.8	19.8
3	11.2	11	8.8	0	11.1	21.6	28.8	26.1	29.4	46.8	82.2	30	33.3	18.9	20.4	41.4	57.6	55.2	37.5	33
4	13.7	13.5	11.4	3.7	0	28.5	31.2	33.6	37.2	54.6	89.7	37.8	40.8	26.4	27.9	45.6	65.4	63	45.3	40.5
5	10.9	10.7	8.6	7.2	9.5	0	7.2	25.5	28.8	46.2	81.3	29.4	34.5	18	19.8	22.8	57	54.6	20.7	32.1
6	13.4	13.2	11	9.6	10.4	2.4	0	32.7	36	41.7	88.8	26.1	31.5	15.3	27	15.6	52.5	50.1	13.2	39.6
7	5.5	7	4.4	8.7	11.2	8.5	10.9	0	9.9	29.4	70.2	8.4	12	11.1	5.7	23.7	40.2	37.8	20.1	9.3
8	3.2	8.1	5.6	9.8	12.4	9.6	12	3.3	0	38.1	73.5	17.1	12.6	19.8	9	32.7	48.9	46.5	28.8	8.7
9	14.9	16.4	13.8	15.6	18.2	15.4	13.9	9.8	12.7	0	98.4	22.5	27.9	28.5	33.9	32.1	19.8	13.5	28.2	32.1
10	24.1	16.4	20.8	27.4	29.9	27.1	29.6	23.4	24.5	32.8	0	77.4	81	78.6	64.5	92.7	109.2	106.8	89.1	77.1
11	7.9	9.4	6.8	10	12.6	9.8	8.7	2.8	5.7	7.5	25.8	0	6.3	11.7	12.9	6.3	6.3	6.3	6.3	6.3
12	6.1	10.6	7.9	11.1	13.6	11.5	10.5	4	4.2	9.3	27	2.1	0	17.1	16.5	22.2	38.7	36.3	18.6	5.4
13	10.1	9.8	7.7	6.3	8.8	6	5.1	3.7	6.6	9.5	26.2	3.9	5.7	0	17.1	22.8	39.3	36.9	19.2	21
14	4.4	5.1	2.7	6.8	9.3	6.6	9	1.9	3	11.3	21.5	4.3	5.5	5.7	0	28.2	44.7	42.3	24.6	12.6
15	13	14.5	11.9	13.8	15.2	7.6	5.2	7.9	10.9	10.7	30.9	5.7	7.4	7.6	9.4	0	42.9	40.5	3.6	26.4
16	18.5	20	17.4	19.2	21.8	19	17.5	13.4	16.3	6.6	36.4	11.1	12.9	13.1	14.9	14.3	0	26.7	39	42.9
17	17.7	19.2	16.5	18.4	21	18.2	16.7	12.6	15.5	4.5	35.6	10.3	12.1	12.3	14.1	13.5	8.9	0	36.6	40.5
18	11.8	13.3	10.6	12.5	15.1	6.9	4.4	6.7	9.6	9.4	29.7	4.4	6.2	6.4	8.2	1.2	13	12.2	0	22.8
19	4.8	9.3	6.6	11	13.5	10.7	13.2	3.1	2.9	10.7	25.7	3.5	1.8	7	4.2	8.8	14.3	13.5	7.6	0

Appendix B The value of Z_1 and Z_2 of iteration 1

i	u	d(i,u)	d(u,0)	d(i,0)	Z11	t(0,u)	t(u,i)	t(0,i)	Z12	Z1	Z2
8	1	8,1	7,7	3,2	12,6	23	24	10	52	32,3	-24,6
	2	5,6	4,0	3,2	6,4	12	17	10	34	20,3	-16,3
	3	9,8	11,2	3,2	17,8	34	29	10	68	43,1	-31,9
	4	12,4	13,7	3,2	22,9	41	37	10	84	53,3	-39,6
	5	9,6	10,9	3,2	17,3	33	29	10	67	42,1	-31,2
	6	12,0	13,4	3,2	22,2	40	36	10	82	51,9	-38,5
	7	3,3	5,5	3,2	5,6	17	10	10	32	18,7	-13,2
	9	12,7	14,9	3,2	24,4	45	13	10	63	43,6	-28,7
	10	24,5	24,1	3,2	45,4	72	25	10	102	73,8	-49,7
	11	5,7	7,9	3,2	10,4	24	6	10	35	22,6	-14,7
	12	4,2	6,1	3,2	7,1	18	4	10	28	17,5	-11,4
	13	6,6	10,1	3,2	13,5	30	7	10	42	27,9	-17,8
	14	3,0	4,4	3,2	4,2	13	3	10	22	12,9	-8,5
	15	10,9	13,0	3,2	20,7	39	11	10	55	38	-25
	16	16,3	18,5	3,2	31,6	56	16	10	77	54,4	-35,9
	17	15,5	17,7	3,2	30,0	53	16	10	74	52	-34,3
	18	9,6	11,8	3,2	18,2	35	10	10	50	34,3	-22,5
	19	2,9	4,8	3,2	4,5	14	3	10	23	13,6	-8,8