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Paper:

Modified Ant Colony Optimization with Route Elimination and Pheromone Reset for Multiple Pickup and Multiple Delivery Vehicle Routing Problem with Time Window

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The vehicle routing problem (VRP) has many applications in goods distribution and goods transportation. Today, many companies have requirements for VRP with multiple pickup and multiple delivery within due time. This problem is called multiple pickup and multiple delivery vehicle routing problem with time window (PDPTW). PDPTW has many constraints and ant colony optimization (ACO) has been used to solve it although ACO creates too many infeasible routes. Moreover, it often gets trapped in local optimum. To solve these problems, this paper proposed an improved ACO by using the route elimination technique and the pheromone reset technique. The ACO with route elimination technique, it has proven to solve the PDPTW problem with increased performance. The proposed technique was tested on datasets from the Li & Lim's PDPTW benchmark problems and provided more satisfactory results compared to other ACO techniques.

Keywords: vehicle routing problem, ant colony optimization, optimization, local optimum

1. Introduction

The vehicle routing problem (VRP) is a problem of transporting goods from a depot to all customers through the shortest route regarding vehicle capacity constraints. Many companies encounter these and VRP plays an important role in many businesses and many industries. VRP first appeared in a paper of Dantzig and Ramser [1]. The VRP with the condition of time window is called the vehicle routing problem with time window (VRPTW). The goal of VRPTW is to find the lowest cost routes to deliver goods to customers within due time within the restricted capacity of each vehicle [2]. For the transportation practice in general, the vehicles are not only required to deliver goods but also to pick up some goods from a customer and deliver to another customer. This type of the VRP is called the pickup and delivery vehicle routing problem (PDVRP) and the problem was first introduced by Min [3]. From interviewing the employees of many companies, it is found out that the existing VRP in many companies have strict requirements for multiple pickup and multiple delivery within due time [4]. This problem is called multiple pickup and multiple delivery vehicle routing problem with time window (PDPTW). The problem was first introduced by Zhao-Geng [5]. VRP, VRPTW, PDVRP, and PDPTW are all NP-hard problems. They are also known as combinatorial optimization problems [2]. These problems cannot be solved by the brute force methods in case of having a lot of customers. Heuristic and Meta-heuristic algorithms are widely used to solve the PDPTW problems. In recent years, many researchers have proposed the use of heuristic algorithms to solve PDPTW or any problem similar to this case. Heuristic and Meta-heuristic algorithms such as genetic algorithms (GA) [6–8] and ant colony optimization (ACO) [9–15] can solve highly complex problem effectively. ACO has successfully solved VRP [16, 17]. Hence, this paper focuses only on the ACO that solves PDPTW.

ACO is motivated by the foraging behavior of an ant colony [18, 19]. This approach has been widely used for solving optimization problems [20] such as job scheduling problems, traveling salesman problems (TSP), network routing, and VRP, etc. The advantages of ACO [20, 21] are rapid discovery of good solutions and good efficiency for TSP or similar problems. On the contrary, the disadvantage of ACO [20, 21] is that it has a propensity for getting trapped in the local optimum.

Many researchers [13–15] proposed ACO applied to solve PDPTW or PDVRP. The experimental results show that ACO can solve these two problems effectively. However, PDPTW has many constraints and many complicated issues. Mostly, ACO creates the infeasible routes that can be included in other routes. The solutions that ACO provide may not be satisfactory since ACO gets trapped in local optimum. Many researchers have not found any solution to deal with the infeasible routes and trapping in local optima. Hence, this paper proposed the use of the route elimination technique and the pheromone reset technique applied to ACO in order to solve the infeasible route and trapping in the local optimum.

A dataset from the Li & Lim's PDPTW benchmark problems [22] (the pickup and delivery problem with time windows) was used in the experiment to compare with other ACOs, and the proposed algorithm. The results show that the quality and reliability of the solutions using the proposed technique were better than other comparative algorithms.

2. Background

2.1. PDPTW

The goal of PDPTW is to find a set of the lowest cost routes to transport goods to all customers in a specified period of time without exceeding the capacity of the vehicle. All vehicle routes start and end at the supplies depot. Each customer is visited only once. All the pickup and delivery demands are accomplished. The formulation of PDPTW is described as follow:

$$x_{ijk} = \begin{cases} 1 \text{ if the vehicle } k \text{ travels from } i \text{ to } j \\ 0 \text{ else} \end{cases}, \quad (1)$$

$$\min \sum_{i=0}^{N}\sum_{j=0}^{N}\sum_{k=1}^{K} C_{ij}x_{ijk}, \quad (2)$$

$$\sum_{k=1}^{K}\sum_{j=0}^{N} x_{ijk} \le K \text{ for } i=0, \quad (3)$$

$$\sum_{i=1}^{N} x_{ijk} = \sum_{j=1}^{N} x_{ijk} \le 1 \text{ for } i=0, k \in \{1,\ldots,K\}, \quad (4)$$

$$\sum_{i=0,j\neq i}^{N}\sum_{k=1}^{K} x_{ijk} = 1 \text{ for } i \in \{1,\ldots,N\}, \quad (5)$$

$$\sum_{i=0,j\neq i}^{N}\sum_{k=1}^{K} x_{ijk} = 1 \text{ for } j \in \{1,\ldots,N\}, \quad (6)$$

$$\sum_{i=0}^{N}\sum_{j=0,j\neq i}^{N} x_{ijk} \times q_i \le Q \text{ for } k \in \{1,\ldots,K\}, \quad (7)$$

$$t_0 = w_0 = 0, \quad (8)$$

$$\sum_{i=1}^{N}\sum_{j=0,j\neq i}^{N} x_{ijk} = x_{ijk}(t_i + t_{ij} + w_i + s_i) \le t_j \text{ for } k \in \{1,\ldots,K\}, \quad (9)$$

$$T_{Ei} \le t_i \le T_{Li}, \quad (10)$$

$$\sum_{i=0}^{N} x_{ikp} - \sum_{j=0}^{N} x_{jkd} = 0 \text{ for } k \in \{1,\ldots,K\}, \; p \in P,\ d \in D,\ (p,d) \in R, \quad (11)$$

$$T_{pk} + R_{pd}\left(t_{pd} + s_p\right) \le T_{dk} \text{ for } k \in \{1,\ldots,K\}, \; p \in P,\ d \in D,\ (p,d) \in R \quad (12)$$

where q_i is the quantity of goods shipped to customer i for the depot is 0. C_{ij} is the distance from i to j customers, which is computed using the Euclidian distance between i and j customers. Q is the capacity of a vehicle. t_i is the arrival time for i customer. t_{ij} is the traveling time between i and j customers. w_i is the waiting time at i customer. K is the total number of vehicles. N is the depot and a set of customers. T_{Ei} is the earliest arrival time at i customer. If the vehicle visits before T_{Ei}, t_i is set T_{Ei}. T_{Li} is the latest arrival time at i customer. The vehicle cannot arrive at i customer after T_{Li}. s_i is service time at customer i. The set R contains pairs of (p,d) if the order exists between the customer p that a good is picked up and the customer d that a good is delivered. P is the pickup set. D is the delivery set. The goal of PDPTW to minimize the total travelling cost (C_{ij}) is determined by Eq. (2). The maximum number of routes constraint is determined by Eq. (3). All vehicle tours starting and ending at the depot are determined by Eq. (4). A customer being visited only once is determined by Eqs. (5) and (6). The total quantity of goods that a vehicle carries cannot exceed the Q capacity is determined by Eq. (7). The time constraint is determined by Eqs. (8) and (9). The vehicle serving the customer within the proper time interval is determined by Eq. (10). These customers that are pairs must be served by the same vehicle are determined by Eq. (11). The customer that a good is picked up must be visited before the customer that a good is delivered is determined by Eq. (12).

2.2. ACO

ACO can be described as follows: Initially, each edge has an initial pheromone $\tau_{ij}(0)$ between two cities. The next step is to select a customer of ant. The first customer of each ant is randomly selected, and then each ant selects the next customer according to the probability function as follows:

$$P_{ij}^{k} = \begin{cases} \dfrac{[\tau_{ij}(t)]^{\alpha}[n_{ij}]^{\beta}}{\sum\limits_{t\in\text{allowed}}[\tau_{ij}(t)]^{\alpha}[n_{ij}]^{\beta}}, & j \in \text{allowed} \\ 0, & \text{otherwise} \end{cases}, \quad (13)$$

where P_{ij}^{k} is the probability of ant k choosing to move from customer i to customer j, $\tau_{ij}(t)$ is the amount of pheromones, which will be found in inter-customer routes in iteration t, $n_{ij} = 1/d_{ij}$ is the inverse of the distance, β is a parameter which determines the relative importance of pheromone versus distance ($\beta > 0$). The result from formula Eq. (13) is selection of a path that is shorter and has a greater amount of pheromone. After the ant city selection process is completed, the fitness of the ant is calculated by Eq. (2). The fitness of each ant is used to update pheromones. $\Delta\tau_{ij}^{k}(t)$ is the amount of pheromones left by an ant on a route that it is calculated by Eq. (14). Q is a consistent value. k represents the k-th ant in the colony. L_k is the fitness of ant k.

$$\Delta\tau_{ij}^{k}(t) = \begin{cases} \dfrac{Q}{L_k}, & \text{if the } k\text{-th ant uses edge } (i,j) \text{ in its tour} \\ 0, & \text{otherwise} \end{cases}, \quad (14)$$

$$\Delta\tau_{ij}(t) = \sum_{k=1}^{m} \Delta\tau_{ij}^{k}(t), \quad (15)$$

$$\tau_{ij}(t) = (1-\rho)\,\tau_{ij}(t-1) + \Delta\tau_{ij}(t), \quad (16)$$

where $\Delta\tau_{ij}(t)$ is total amount of pheromones that ants use

Table 1. The customer details.

Customers	0	1	2	3	4
Demand of goods	0	5	5	5	10
Earliest arrival time	0	200	500	50	200
Latest arrival time	1000	1000	1000	100	400
Activity	depot	pick up	delivery	delivery	delivery
Pair	–	2	1	–	–

the route between customers i and j have left. m is the amount of ant population. $\tau_{ij}^{k}\rho$ is the coefficient of evaporation and receives a value between [0–1]. The next step is to repeat this until the stop condition is reached.

In terms of PDPTW, each ant starts at the depot and creates a route by selecting a customer under the capacity constraints, the time window constraints, and the pickup and delivery constraints until the capacity of the vehicle cannot be further loaded. It is then returned to the depot. Customer selection is based on pheromone [23]. The process is repeated until all customers are selected.

2.3. The Previous Modified ACO with PDPTW

Many researchers proposed modified ACO to be applied to PDPTW or PDVRP. The first technique is the application of ACO to PDVRP [13]. The second technique is the application of ACO to PDVRP and adding the neighborhood searching technique into the process of ACO (ACOL) [14]. The neighborhood searching techniques consist of the two-opt technique, the insert customer technique, and the swap customer technique. The third technique is the application of ACO to PDPTW. This technique, the nearest neighbor algorithm (NN) is executed before the process of ACO (ACON) [15]. The results of three algorithms showed that the solutions of these algorithms were better than that of the competitive algorithms.

3. Proposed Work

3.1. ACO with Route Elimination Technique

PDPTW has many constraints (capacity, time windows, and pickup and delivery). These constraints affect customer selection by ACO. It causes ACO to create many infeasible routes. To understand, this case study is showed to clarify; all customers are 5. Capacity of vehicle is 20. The details of each customer is shown in **Table 1**. The value of transportation time and service time are 0. These two values are not considered in this case. Supposed solution of ACO is 0, 1. In this case, customer 2 or customer 4 can be selected only. The customer 3 cannot be selected because the present transportation time is more than the latest arrival time of customer 3. ACO generates solution by random methods that are considered from the influence of pheromone. In this case, customer 2 may be selected. Therefore, the present solution may be 0, 1, 2. The customer 4 cannot be selected in this case because the present transportation time surpasses. From this event, ACO may create route as follows: the first route is 0, 1, 2, 0. The second route is 0, 4, 0. The third route is 0, 3, 0. The second route and the third route can be inserted into the first route. In this case, the solution should have one route; that is 0, 3, 4, 1, 2, 0. The second route and the third route are called the infeasible route. This event often happens to ACO.

As mentioned earlier, this paper proposes the method that eliminates infeasible routes by inserting infeasible routes into other routes if it can be inserted. Then this method improves all routes by 2-opt technique. If pheromone is updated by a good solution and ACO has a high chance to create a new solution that is better than the current solution in the next generation [23]. So, the proposed technique can increase searching performance of ACO. The proposed technique is called ACO with route elimination technique (ACOE).

3.2. ACO with Pheromone Reset Technique

As mentioned, the route elimination technique can increase search performance of ACO. However, the error of trapping in the local optimum is possible to happen in case of being used for searching for a long period of the time [24]. Under the normal process of ACO, the pheromone is a factor creating a solution. When pheromone is trapping in local optimum, the pheromone of ACO creates the same solution as the previous solution or similar solution as the previous one [23]. As mentioned earlier, if the customer occurs to be selected repeatedly, that pheromone should be reset. For example, when customer 1 is selected, the next customer is always 2. It means that trapping in local optimum occurs. To solve this problem, this paper suggested that this pheromone should be reset in order that ACO has a chance to select other customers. This proposed technique is called ACO with pheromone reset technique (ACOR).

3.3. ACO with Route Elimination Technique and Pheromone Reset Technique

As mentioned, these two proposed techniques are applied together to the ACO in order to increase searching performance of ACO and to decrease or to solve trapping in local optimum problems. This proposed technique is called ACO with route elimination technique and pheromone reset technique (ACOER). Pseudo code of ACOER is shown below:

```
Initialize edges, solution, and pheromone table
While termination condition ≠ true do
  Reset AR (AR is array is used to check repeat of pheromone)
  For ant x begin 1 to a number of all ants
    For until customers in list of ant x is full
      Choose customer that is not in list of ant x
      Choose customer that is qualified for capacity condition
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      Choose customer that is qualified for time windows condition
      Choose customer that is qualified for pickup and delivery condition
      Choose the next customer with probability according to Eq. (13)
      If selected next customers repeat with customer of ant x − 1
        AR[x] + +
      Else
        AR[x] = 0
      End If
      If customers cannot add into ant x
        Add the new route
      End If
    End For
    Sort route by consider to size of route from min to max
    For y begin 1 to a number of all routes
      If size of route y ≤ 4 (not include depot)
        For z begin a number of all routes to 1
          If z not equal y and customer from y (include pair of it) can add
          into z
            Add customer from y (include pair of it) into z
          End If
        End For
      End If
    End For
    Apply 2-opt with ant x
    Evaluate the fitness of ant x
    If the fitness of ant x is better than that of solution
      Solution = ant x
    End If
      Update pheromone according to Eq. (15) by ant x
    End For
  For i begin 1 to a number of customer
    If AR[i] = a number of ant
      Counter = 1
      If Counter > RT (RT is the reset threshold)
        Initialize pheromone table at row of i
      End if
    Else:
      Counter = 0
    End if
  End For
  Apply the evaporation
End While
```

4. Results and Discussions

The parameters are as follows for all experiments: $\beta = 4$, $Q = 0.6$, $\alpha = 1$, $\rho = 0.7$. These parameters are suggested by this paper [11]. For ACOER, $RT = 40$. This value of RT gets from the results from experiment. The experiments start defining RT equal 1 then increase 1 until 100 and select value of RT that can create the best result. The number of ants used is 400. The number of experiments of each map is 100 runs. The maximum number of iterations is set as 2000.

To be fair, the ACOE and ACOER have a process of route elimination, so that the number of ants used is 200.

The measures of algorithm performance in the experiments are as follows: the average best fitness value (ABF) is the average of best fitness in the final iteration from all runs. ABF indicates the solution searching efficiency of an algorithm. SD is the standard deviation. SD indicates the solution searching reliability of an algorithm. The more ABF and SD are the less value, the better they are. The experiment was tested on 56 maps from a dataset of the Li & Lim's PDPTW benchmark problems. This dataset is available for download at [22]. This dataset has the best known solutions and each map has customers more than 100. It is standard dataset and can use to compare the performance of algorithms.

From the experimental results in **Table 2**, the quality solution of ACOE is better than that of ACOL and ACON because of its lowest ABF all tested maps. The reliability of ACOE is better than that of ACOL and ACON because of its lowest SD all tested maps. It shows that the route elimination technique can increase searching performance of ACO. The route elimination technique can get better answer and enhance reliability of ACO. The solution quality of ACOER is better than that of ACOE because of its lowest ABF value of all tested maps. The reliability of ACOER is better than that of ACOE because of its lowest SD value of all tested maps. It shows that the pheromone reset technique can decrease trapping in the local optimum and get the better answer. The pheromone reset technique can improve search of ACOE by get better answer and enhance reliability.

5. Conclusion

PDPTW has many constraints. When PDPTW is solved by ACO, it encounters the infeasible route problem and trapping in local optimum problem. From these weak points, this paper proposed the route elimination technique to solve the infeasible route problem and the pheromone reset technique to decease or solve trapping in local optimum problem. Moreover, this research has proposed the concurrent application of the route elimination technique and the pheromone reset technique to solve PDPTW and enhance searching performance of ACO. The proposed technique is called ACOER. From the Li & Lim's PDPTW benchmark problem dataset, the ACOL, ACON, ACOE, and ACOER were tested and results were compared. The results indicated that the proposed ACOER outperforms other comparative algorithms in terms of reliability and the quality of the solutions in all experiments.

The searching results of ACOER obtain the good answer but ACOER cannot search the optimum values from all tested maps. In the future, the author has a plan to develop ACO that can search the optimum values from all tested maps. His idea is that the constraints of PDPTW are used to guide customer selecting in the process of ACO. The results from constraints considering of PDPTW may decrease search space and enhance searching performance of ACO and may search the optimum values from all tested maps.

Table 2. Comparative ABF and SD of ACOL, ACON, ACOE, and ACOER.

Problem	Optimum value	ACOL		ACON		ACOE		ACOER	
		ABF	SD	ABF	SD	ABF	SD	ABF	SD
lc101	828.94	1189.97	14.65	1013.13	6.76	861.98	5.19	844.37	0.63
lc102	828.94	1239.08	13.37	1157.42	13.41	911.12	4.62	869.23	1.96
lc103	1035.35	1099.91	7.49	1069.45	4.12	1049.27	2.35	1036.89	0.92
lc104	860.01	871.38	2.05	861.55	0.74	860.01	0.00	860.01	0.00
lc105	828.94	1099.58	12.71	1033.44	12.45	872.19	1.80	870.61	3.62
lc106	828.94	1032.35	15.36	910.58	6.10	836.93	1.78	828.94	0.00
lc107	828.94	1032.81	20.41	877.57	1.72	830.02	0.88	828.94	0.00
lc108	826.44	990.48	10.38	957.30	9.31	849.87	0.30	844.13	2.18
lc109	1000.60	1019.71	2.47	1013.13	2.17	1000.60	0.00	1000.60	0.00
lc201	591.56	1213.47	19.93	1162.79	15.90	918.76	17.37	769.85	4.80
lc202	591.56	1208.55	16.60	1189.96	12.36	917.02	14.17	755.99	9.92
lc203	591.17	1028.57	21.22	881.10	16.34	651.10	7.64	602.59	1.59
lc204	590.60	852.73	12.17	778.19	12.61	629.45	2.88	590.60	0.00
lc205	588.88	1042.37	21.06	956.63	17.46	639.11	6.79	617.31	2.27
lc206	588.49	1144.22	14.98	1088.99	16.65	783.80	9.40	705.22	3.79
lc207	588.29	841.00	15.89	734.30	13.43	603.25	3.76	588.29	0.00
lc208	588.32	837.10	19.55	740.65	13.15	603.95	2.01	591.44	1.45
lr101	1650.80	2071.44	14.99	2039.98	11.79	1853.99	14.15	1733.97	5.81
lr102	1487.57	1775.75	12.76	1739.98	8.60	1562.32	6.99	1520.68	3.40
lr103	1292.68	1499.52	11.39	1495.41	9.52	1311.70	2.57	1296.13	1.57
lr104	1013.39	1105.14	8.26	1065.65	5.43	1034.41	2.49	1016.51	1.37
lr105	1377.11	1710.23	13.86	1659.24	7.78	1440.09	8.75	1387.37	1.15
lr106	1252.62	1570.72	11.86	1558.30	10.04	1352.44	7.53	1291.26	3.67
lr107	1111.31	1413.06	14.30	1342.28	12.31	1128.78	2.15	1113.94	1.32
lr108	968.97	1133.74	11.67	1065.70	5.90	982.27	2.26	968.97	0.00
lr109	1208.96	1406.83	17.56	1311.57	11.21	1234.39	4.07	1208.96	0.00
lr110	1159.35	1184.62	3.77	1175.70	2.30	1163.03	1.33	1159.35	0.00
lr111	1108.90	1292.59	13.83	1247.38	9.75	1145.47	2.59	1108.90	0.00
lr112	1003.77	1032.46	3.80	1027.71	3.42	1013.63	2.04	1003.77	0.00
lr201	1253.23	1597.71	15.78	1510.35	13.74	1350.99	11.16	1253.23	2.60
lr202	1197.67	1842.95	13.13	1840.48	11.74	1578.14	10.22	1469.53	6.91
lr203	949.40	1493.23	17.01	1406.95	13.44	1243.15	11.75	1152.98	4.68
lr204	849.05	1271.40	13.88	1195.28	10.30	983.27	7.54	892.58	4.07
lr205	1054.02	1417.49	15.66	1371.54	11.86	1179.53	12.04	1088.48	3.74
lr206	931.63	1636.78	12.03	1562.47	10.03	1349.42	9.19	1248.22	5.78
lr207	903.06	1540.54	16.42	1497.77	11.67	1313.15	9.20	1183.61	5.29
lr208	734.85	1001.19	10.80	896.90	8.43	777.28	3.42	756.11	2.30
lr209	930.59	1381.60	12.15	1263.50	11.43	1097.19	7.70	1017.60	4.61
lr210	964.22	1517.64	14.29	1440.09	15.65	1241.87	10.89	1133.03	7.45
lr211	911.52	1052.10	9.91	974.54	5.12	931.88	2.26	923.76	0.95
lrc101	1708.80	2339.30	16.62	2301.26	17.14	2005.01	11.53	1737.84	5.58
lrc102	1558.07	2024.39	16.33	1977.23	14.68	1674.46	10.66	1618.82	4.92
lrc103	1258.74	1664.43	19.47	1627.04	16.71	1328.45	9.43	1264.03	2.78
lrc104	1128.40	1291.63	12.44	1235.20	11.63	1156.64	4.82	1130.27	1.04
lrc105	1637.62	2082.57	15.26	2012.35	11.76	1778.66	12.64	1662.97	6.42
lrc106	1424.73	1642.40	17.59	1573.36	14.49	1448.63	4.17	1426.58	1.16
lrc107	1230.14	1442.40	16.51	1369.28	12.23	1255.59	3.44	1231.96	1.15
lrc108	1147.43	1245.44	10.46	1193.79	6.58	1156.81	2.77	1147.43	0.00
lrc201	1406.94	2260.90	19.65	2156.82	24.01	1866.48	14.18	1729.52	7.89
lrc202	1374.27	2095.16	22.17	1995.54	18.37	1750.41	12.14	1681.35	4.90
lrc203	1089.07	1791.72	22.19	1680.89	21.94	1483.20	22.38	1315.23	9.15
lrc204	818.66	1218.65	16.94	1114.28	16.94	874.47	6.61	836.48	2.32
lrc205	1302.20	2059.61	23.08	1903.96	19.33	1507.68	15.52	1378.84	6.70
lrc206	1159.03	1861.68	25.70	1710.93	20.54	1485.72	17.06	1332.78	8.75
lrc207	1062.05	1772.70	22.62	1604.31	13.09	1356.63	15.09	1316.77	7.00
lrc208	852.76	1386.92	19.81	1255.48	15.54	1131.64	13.47	1037.97	6.95

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